Radioactive Waste Management

NDA/RWM/167

Geological Disposal

Science and Technology Plan 2020

October 2020

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Abstract

This Science and Technology Plan presents an analysis of the nature and timing of RWM's future technical development activities. The document is primarily an internal document, however publication of this document will provide opportunities for dialogue and involvement of interested parties in the development of our knowledge base for the safe geological disposal of radioactive waste. Feedback is welcomed, particularly in relation to innovative approaches which may address the identified research needs and objectives.

This is a third issue of the Science and Technology Plan, containing a number of enhancements from the previous issue.

Executive Summary

Radioactive Waste Management Limited (RWM) is the UK Government's nominated implementer for delivering a geological disposal facility for the UK's higher activity radioactive wastes. The purpose of this document, the 'Science and Technology Plan', is to provide details of the nature and timing of our planned technical development activities. It is intended that publication of this document will provide opportunities for dialogue and involvement of interested parties in the development of our knowledge base for the safe geological disposal of radioactive waste. We welcome feedback, particularly in relation to innovative solutions to our identified research needs and objectives.

In September 2014, we published our first Science and Technology (S&T) Plan. This was followed by a light update and re-publication in 2016. This document provides a more significant update incorporating improvements resulting from:

- learning and feedback from internal and external stakeholders;
- feedback from our Regulators;
- alignment with the Geological Disposal Technical Programme (which replaces the S&T Programme document);
- an updated 'change control' appendix, identifying and justifying changes to the previously published plan, and providing an audit trail for completed tasks;
- new tasks, recognising the iterative development of the GDF project and out-year planning; and
- a new numbering system for task identification with improved longevity and traceability.

This document comprises a short discussion of the context within which this plan has been developed and the methodology which we have used to develop the detailed analysis, together with the detailed plan contained in the appendices to this document:

- Appendix A is a breakdown of all the topics within RWM's technical programme which require research and development in this generic phase of our programme.
- Appendix B comprises a set of task sheets describing the specific research requirements in a structured manner which provides stakeholders with clarity of the specific research drivers, objectives and suggested scope of every task we currently foresee to be required to appropriately address RWM's generic knowledge gaps.
- Appendix C documents changes to the plan between version 2 and version 3.
- Appendix D is a simple long-range graphic showing the phasing of the generic research and development activities detailed in Appendix B, the individual tasks identified in this graphic are hyperlinked to the relevant task sheets.

RWM is currently engaged with the process of identifying potentially suitable sites for a GDF and willing communities. The time horizon for this S&T Plan is a decade. During this time we will continue to transition from a generic programme to a programme of technical work necessary to develop a GDF at a site-specific level. Throughout our analysis of knowledge gaps and their proposed closure we have utilised Scientific Readiness Levels (SRLs™), developed by the National Nuclear Laboratory along with Technology Readiness Levels (TRLs) which are widely used across the NDA estate, as tools to consider the maturity of the knowledge base as it evolves, and to consider the level of maturity required to support each stage of the Technical Programme.

We have prioritised the schedule in line with the projected budget underpinning RWM's technical programme, utilising a series of prioritisation questions and recognised drivers for research and development.

Having undertaken three decades of research into the geological disposal of UK wastes, significant progress has been made. Challenges to the viability of geological disposal concepts have been overcome (although implementation may be subject to site-specific challenges) and the remaining key uncertainties are currently subject to large focused research projects. Once potential candidate sites have been identified, a programme of site investigation will be undertaken in order to reflect the real environment in the safety case, together with research, development and demonstration studies associated with the optimisation of the disposal system to the local geological environment. Such tasks are identified in the Science and Technology Plan, together with the body of technical development work required to address knowledge gaps associated with the Disposal System Safety Case, disposal concept development and disposal system design.

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List of Abbreviations

ACSIS Atmospheric Corrosion of Stainless Steel in Interim Stores

AGR Advance Gas-Cooled Reactor

ALARP As Low As Reasonably Practicable

ANDRA Agence Nationale pour la gestion des Déchets Radioactifs (French national radioactive waste management agency)

ARFAC Activity Release in Fire Accident Conditions

BEPO British Experimental Pile

BFS Blast Furnace Slag

BIOMASS BIOsphere Modelling and ASSessment

BWR Boiling Water Reactor

CAAS Criticality Accident Alarm System

CAE Claims, Arguments, Evidence

CAST Carbon-14 Source Term

CDP Cellulose Degradation Products

CIDS Criticality Incident Detection System

CR Concentration Ratio

CSA Criticality Safety Assessment

CSSP Construction Site Security Plan

DBE Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe (German company for the construction and operation of repositories for waste)

DCIC Ductile Cast Iron Container

DCO Development Consent Order

DCTC Disposal Container Transport Container

DECOVALEX Development of Coupled Models and their Validation Against Experiments

DNLEU Depleted, Natural and Low-Enriched Uranium

DRZ Disturbed Rock Zone

DSSC Disposal System Safety Case

EA Environment Agency

EBS Engineered Barrier System

EC European Commission

EDZ Excavation Disturbed Zone

EIA Environmental Impact Assessment

ESC Environmental Safety Case

FE Finite Element

FGR Fission Gas Release

FISST Full-Scale In-Situ System Test

FORGE Fate of Repository Gases

GBI Geosphere-Biosphere Interface

GDF Geological Disposal Facility

gDSSC generic Disposal System Safety Case

GGBS Ground Granulated Blast-Furnace Slag

gOESA generic Operational Environmental Safety Assessment

GRA Guidance on Requirements for Authorisation

GRAAL Glass Reactivity with Allowance for the Alteration Layer

GWPS Generic Waste Package Specification

GWTF Groundwater Task Force

HALES Highly Active Liquor Storage and Evaporation

HAW Higher Activity Waste

HEU Highly Enriched Uranium

HHGW High Heat Generating Waste

HHIPT High Heat Generating Waste Integrated Project Team

HLW High Level Waste

HMG Her Majesty's Government

HSR Higher Strength Rock

IAEA International Atomic Energy Agency

ICRP International Commission on Radiological Protection

IGD-TP Implementing Geological Disposal of Radioactive Waste Technology Platform

ILW Intermediate Level Waste

INS International Nuclear Services

IPT Integrated Project Team

IRF Instant Release Fraction

ISE Initial Site Evaluation

ISG International Standard Glass

ISO International Organisation for Standardisation

LASGIT Large Scale Gas Injection Test

LHGW Low Heat Generating Waste

LLW Low Level Waste

LoC Letter of Compliance

LSSR Lower Strength Sedimentary Rock

LWR Light Water Reactor

MBGWS Miscellaneous Beta Gamma Waste Store

MIP Mercury Intrusion Porosimetry

MoD Ministry of Defence

MODARIA Modelling and Data for Radiological Impact Assessments

MOX SF Mixed Oxide Spent Fuel

Nagra Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (Swiss national cooperative for the disposal of radioactive waste)

NIRAB Nuclear Innovation Research Advisory Board

NNL National Nuclear Laboratory

NRVB Nirex Reference Vault Backfill

NSSP Nuclear Site Security Plan

NWMO Nuclear Waste Management Organisation (of Canada)

OESA Operational Environmental Safety Assessment

ONR Office of Nuclear Regulation

OPC Ordinary Portland Cement

OSC Operational Safety Case

PCCCA Post-Closure Criticality Consequences Assessment

PCSA Post-Closure Safety Assessment

PDF Probability Density Function

PFA Pulverised Fuel Ash

PGRC Phased Geological Repository Concept

PIE Post-Irradiation Examination

POCO Post-Operational Clean Out

PWR Pressurised Water Reactor

R&D Research and Development

RAP Reference Animals and Plants

RF Release Fraction

RI Regulatory Issue

RSBTC Robust Shielded Box Transport Container

RSC Robust Shielded Container

SCC Stress Corrosion Cracking

SILW Shielded Intermediate Level Waste

SKB Svensk Kärnbränslehantering AB(Swedish nuclear fuel and waste management company)

SL Sellafield Limited

SLC Site Licence Company

SMOGG Simplified Model of Gas Generation

SRL Scientific Readiness Level

SSB Self-Shielding Box

STFC Science and Technology Facilities Council

SWTC Standard Waste Transport Container

TDB Thermodynamic Database

TDT Thermal Dimensioning Tool

TEM Transmission Electron Microscopy

TENORM Technologically Enhanced Naturally Occurring Radioactive Material

THMC Thermal-Hydraulic-Mechanical-Chemical coupled processes

TRL Technology Readiness Level

TRS Technical Reports Series

TRU Transuranic Waste

TSC Transport Safety Case

UILW Unshielded Intermediate Level Waste

UKRWI UK Radioactive Waste Inventory

URL Underground Rock Laboratory

WAGR Windscale Advanced Gas-cooled Reactor

WBS Work Breakdown Structure

WIPP Waste Isolation Pilot Plant

WMO Waste Management Organisation

WPAP Waste Package Accident Performance

WPSGD Waste Package Specification and Guidance Documentation

WVP Waste Vitrification Plant

XRD X-ray Diffraction

Glossary

backfill Material used to refill excavated portions of a disposal facility after waste has been emplaced.
Backfill is a component of the engineered barrier system. Three specific types of backfill are recognised:
- Local backfill, which is emplaced in disposal vaults to fill the free space between and around waste packages. Depending on the host rock there may be a requirement on the local backfill to provide a certain ratio of backfill material to the conditioned waste volume of a waste package.
- Peripheral backfill, which is the material emplaced in the disposal vaults between local backfill, and the rock or structure of access ways.
- Mass backfill, which is the bulk material used to backfill the areas of a GDF that are not used for disposal of wastes.

bentonite A clay material that swells when saturated with water which is used as a backfill and buffer material in some disposal concepts.

biosphere That part of the environment normally inhabited by living organisms. In practice, the biosphere is generally taken to include the atmosphere and the Earth's surface, including the soil and surface water bodies, seas and oceans and their sediments. There is no generally accepted definition of the depth below the surface at which soil or sediment ceases to be part of the biosphere, but this might typically be taken to be the depth affected by basic human actions, in particular farming.

buffer An engineered barrier that protects the waste package and limits the migration of radionuclides following their release from a waste package. See also backfill.

colloid A state of subdivision of matter in which the particle size varies from that of true 'molecular' solutions to that of a coarse suspension. The diameters of the particles range between 1 and 1000 nm and the particles are dispersed in a liquid phase and do not sediment out.

criticality A state in which a quantity of fissile material can maintain a self-sustaining neutron chain reaction. Criticality requires that a sufficiently large quantity of fissile material (a critical mass) be assembled into a geometry that can sustain a chain reaction; unless both of these requirements are met, no chain reaction can take place and the system is said to be sub-critical.

criticality safety Criticality safety is defined as protection against the consequences of an inadvertent nuclear chain reaction, preferably by prevention of the chain reaction

disposability The ability of a waste package to satisfy the defined requirement for disposal.

disposability assessment The process by which proposals for the production of waste packages are analysed for compatibility with all stages of waste management. The outcome of a disposability assessment is an Assessment Report, detailing the results of the analysis and providing advice on the proposals. Where possible, the outcome includes endorsement by issue of a Letter of Compliance.
Disposability assessments are undertaken by RWM to determine compliance with the safety cases for disposal, currently described in the generic DSSC, and with RWM packaging standards, as captured in Waste Package Specifications.

disposal concept A high level description of the engineered and natural barriers required to ensure that the radioactivity in the wastes is sufficiently contained so that it will not be released back to the surface in unacceptable amounts that may cause harm to people and the environment.

disposal system specification (DSS) A document produced by RWM to set out the high-level and technical requirements on the RWM's organisational management, site selection and evaluation and GDF design, construction, operation and closure, so that the disposal system can meet its fundamental need.

dose A measure of the energy deposited by radiation in a target.

environmental safety The safety of people and the environment both at the time of disposal and in the future.

evaporite One of three generic host rock types considered by RWM. Evaporites are rocks that have formed as ancient seas and lakes evaporated. They often contain bodies of halite that are potential host rocks for a GDF because they provide a suitably dry environment and are weak and creep easily so that open cracks cannot be sustained.

fissile material Material which is capable of undergoing fission by interaction with slow neutrons, specifically U-233, U-235, Pu-239, Pu-241 or any combination of these radionuclides.

geological barrier In the context of geological disposal this comprises the host rock in which a disposal facility is constructed, and the surrounding rocks.

geological disposal A long-term management option involving the emplacement of radioactive waste in an engineered underground geological disposal facility or repository, where the geology (rock structure) provides a barrier against the escape of radioactivity and there is no intention to retrieve the waste once the facility is closed.

geological disposal facility (GDF) A long-term management option involving the emplacement of radioactive waste in an engineered underground geological disposal facility or repository, where the geology (rock structure) provides a barrier against the escape of radioactivity and there is no intention to retrieve the waste once the facility is closed.

geosphere The rock surrounding a GDF that is located below the depth affected by normal human activities and is therefore not considered to be part of the biosphere.
See also geological environment.

groundwater All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

groundwater flow Groundwater flows when there is a difference in hydraulic head across the rock body in which it sits. The amount of groundwater flow (known as the flux) is normally described by Darcy's Law which relates it to the differences in the imposed hydraulic head (the hydraulic gradient), the properties of the rock (permeability) and the properties of the groundwater (which may vary according to its composition). Groundwater may flow though pores in the rock matrix, through discrete fractures cutting the rock, or through a combination of both. Also see "permeability", "hydraulic head".

high heat generating waste (HHGW) A term developed by RWM to describe all the materials in the inventory for disposal where heat has to be taken into account in the design of storage and disposal facilities. HHGW comprises spent fuel from existing and future power stations, and High Level Waste from spent fuel reprocessing

high level waste (HLW) Waste in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities. HLW is produced as a by-product from reprocessing spent fuel from nuclear reactors. HLW typically occurs in liquid form and a process called 'vitrification' converts the liquid HLW into a solid product.

higher activity waste (HAW) Includes the following categories of radioactive waste: high level waste, intermediate level waste, a small fraction of low level waste with a concentration of specific radionuclides sufficient
to prevent its disposal as low level waste.

higher strength rock (HSR) One of three generic host rock types considered by RWM. Higher strength rocks, which may be igneous, metamorphic or older sedimentary rocks, have a low matrix porosity and low permeability, with the majority of any groundwater movement confined to fractures within the rock mass.
Typically crystalline igneous and metamorphic rocks or geologically older sedimentary rocks where any fluid movement is predominantly through discontinuities.

highly enriched uranium (HEU) Uranium containing 20\% or more by mass of the isotope U-235.

host rock The rock in which a disposal facility is located.

intermediate level waste (ILW) Wastes exceeding the upper boundaries for LLW, but which do not need heat to be taken into account in the design of storage or disposal facilities.

low heat generating waste (LHGW) A term developed by RWM to describe materials in the inventory for disposal which do not generate sufficient heat for this to be taken into account in the design of storage and disposal facilities. LHGW comprises intermediate Level Waste arising from operating and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium.

Low Level Waste Repository (LLWR) The UK national facility for the near surface disposal of solid LLW, located near to the village of Drigg in Cumbria.

lower strength sedimentary rock (LSSR) One of three generic host rock types considered by RWM. Lower strength sedimentary rocks are fine-grained, sedimentary rocks with a high content of clay minerals that provides their low permeability and are mechanically weak, so that open fractures cannot be sustained. They will be interlayered with other sedimentary rock types. Also see "mudrocks: clays and mudstones".

Natura 2000 An ecological network of protected areas within the European Union. The network consists of Special Protection Areas (SPAs) and Special Areas of Conservation (SACs).

Nirex (United Kingdom Nirex Limited) Nirex was a United Kingdom body set up in 1982 by the UK nuclear industry to examine safe, environmental and economic aspects of deep geological disposal of intermediate-level and low-level radioactive waste. Originally known as the Nuclear Industry Radioactive Waste Executive, it became incorporated as United Kingdom Nirex Limited on 2nd July 1985. The ownership of Nirex was transferred from the nuclear industry to the UK Government departments DEFRA and DTI in April 2005, and then to the UK's Nuclear Decommissioning Authority (NDA) in November 2006. Nirex's staff and functions were integrated into the NDA in April 2007, at which point Nirex ceased trading as a separate entity. Nirex's role continued through the activities of the Radioactive Waste Management Directorate of the NDA.

Office for Nuclear Regulation (ONR) ONR is a Public Corporation. It maintains and improves safety standards for work with ionising radiation at licensed nuclear installations in the UK. It sets national regulatory standards and helps develop international nuclear safety standards. Through its licensing powers it assesses safety cases and inspects sites for licence compliance. ONR sets out in conditions attached to a nuclear site licence the general safety requirements to deal with the risks on a nuclear site.

operational period (of a disposal facility) The period during which a disposal facility is used for its intended purpose, up until closure.

Performance Assessment (PA) Assessment of the performance of a system or sub-system and its implications for protection and safety at an authorised facility.

post-closure period (of a disposal facility) The period following sealing and closure of a facility.

radioactive waste A substance or article will be a waste if it falls within the definition of "waste" in Schedule 23 to The Environmental Permitting (England and Wales) Regulations 2010 in England or Wales, or section 47 of the Radioactive Substances Act 1993 in Northern Ireland.

retrievability Retrievability is the ability in principle to recover waste or entire waste packages once they have been emplaced in a repository; retrieval is the concrete action of removal of the waste. Retrievability implies making provisions in order to allow retrieval should it be required.

safety case A collection of arguments and evidence in support of the safety of a facility or activity. This will normally include the findings of a safety assessment and a statement of confidence in these findings. For a GDF, there will be a number of safety cases required covering nuclear safety, environmental safety, and transport. A safety case may also relate to a given stage of development (e.g. site investigations, commissioning, operations, closure, post-closure, etc.).

spent fuel (SF) Nuclear fuel removed from a reactor following irradiation that is no longer usable in its present form because of depletion of fissile material, poison build-up or radiation damage.

stakeholders People or organisations, having a particular knowledge of, interest in, or who are affected by, radioactive waste, examples being the waste producers and owners, waste regulators, non-Governmental organisations and local communities and authorities.

total system model A model that captures all significant aspects of a geological disposal system, including representing the uncertainties, in order to calculate overall system performance

transport container A reusable container into which waste packages are placed for transport, the whole assembly then being referred to as a transport package.

transport regulations The IAEA Regulations for the Safe Transport of Radioactive Material and/or those regulations as transposed into an EU Directive, and in turn into regulations that apply within the UK. The generic term 'Transport Regulations' can refer to any or all of these, since the essential wording is identical in all cases.

UK Radioactive Waste Inventory (UKRWI) A compilation of data on UK radioactive waste holdings, produced about every three years. It is sponsored by the Department for Business, Energy and Industrial Strategy and the Nuclear Decommissioning Authority.

Waste Acceptance Criteria (WAC) Quantitative and/or qualitative criteria, specified by the operator of a disposal facility and approved by the regulator, for solid radioactive waste to be accepted for disposal.

waste container The vessel into which a wasteform manufactured from certain waste types (i.e. LHGW) is placed to form a waste package suitable for handling, transport, storage and disposal.

waste package The product of waste conditioning that includes the wasteform and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and/or disposal.

See ”Waste Packages” section for individual waste packages.

wasteform The waste in the physical and chemical form in which it will be disposed of, including any conditioning media and container furniture (i.e. in-drum mixing devices, dewatering tubes etc) but not including the waste container itself or any added inactive capping material.

1 Introduction

1.1 Background

Radioactive Waste Management (RWM) is responsible for implementing geological disposal for the long-term management of higher activity radioactive waste. This policy is set out in *Implementing Geological Disposal - Working with Communities* [1], in England and *Geological Disposal of Higher Activity Radioactive Waste: Working with Communities* [2], in Wales[1,2]

As the delivery organisation for a GDF, RWM is responsible for planning and carrying out an appropriate programme of research and development in order to address safety-related knowledge gaps, progress design development and build technical capability to de-risk future activities. In September 2014, we published our first Science and Technology (S&T) Plan. This was followed by a light update and re-publication in 2016. This document provides a more significant update incorporating:

- Learning and feedback from internal and external stakeholders;
- Feedback from our regulators;
- Alignment with the Geological Disposal Technical Programme (which supersedes the S&T Programme document [3]);
- A 'change log', Appendix C, identifying and justifying changes to the previously published plan and providing an audit trail for completed tasks;
- New tasks, recognising the iterative development of the GDF project, together with early site-specific research and development activities and associated capability building;
- A new numbering system for task identification to improve longevity and traceability;
- Integration with RWM's improved programme planning framework.

The S&T Plan is structured as follows:

Section 1: This introduction, setting the context of the S&T Plan.

Section 2: A statement of the purpose of this document and identification of how it is intended to enable our stakeholders to better understand our Science and Technology research and development needs.

Section 3: A review of the current status of our knowledge base, including its key documents, and the mechanisms for identifying the needs for, and mechanisms for delivery of, work which enhances our knowledge base.

Section 4: An explanation of the approach evaluation of the scientific maturity of our understanding now and at key points in the future using Scientific Readiness Levels (SRLs™)[3].

Section 5: A description of the two key components of the S&T Plan, presented as appendices to this document: Appendix B contains task sheets formatted in a consistent and user-friendly manner and Appendix C summarises the scheduling of these tasks in a long-range graphic.

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1 Scottish Government policy is that the long-term management of higher activity radioactive waste should be in near-surface facilities. Facilities should be located as near to the sites where the waste is produced as possible.

2 Future policy decisions in relation to geological disposal in Northern Ireland are a matter for the Northern Ireland Executive.

3 SRL is a registered trademark of the National Nuclear Laboratory Ltd.

Section 6: An initial consideration of how the generic work presented in this document will interface with site-specific research and development activities once a potential candidate site has been identified.

Section 7: A short summary of the process used to develop and review the S&T Plan.

Section 8: An invitation to readers to provide feedback on this document.

This is a periodic review the S&T Plan and changes to our previous plans have been made transparent in the 'change log', Appendix C.

At the time of publication RWM is involved in informal discussions with a number of potentially interested parties as set out in the '*Working with Communities*' policy frameworks. In planning we have needed to make a series of assumptions about the timing of the formation of Community Partnerships, progression of non-intrusive (seismic reflection and geophysical) surveys and intrusive borehole investigations. In this early stage of planning our development of the S&T Plan has been informed 'top-down' by our understanding of when research needs, technical development and capability building need to have been completed in order to deliver the programme. Understanding of these drivers has been combined with our understanding of existing knowledge gaps in the generic (non-site-specific) safety case, which was based on a series of illustrative designs developed from existing overseas GDF designs, and our understanding of possible alternative disposal concepts that could be implemented dependent upon the geological environments available to RWM. On this basis, our technical experts have started to identify the research and development activities required to deliver RWM's high level objectives. These are the activities identified in this Science & Technology Plan.

This Science & Technology Plan therefore comprises a mixture of generic activities required to close out previously identified generic knowledge gaps, together with our initial understanding of initial activities that will be required once specific locations are being investigated. In transitioning to a site-specific programme it is useful to consider the broad host-rock definitions adopted by RWM: HSR, LSSR or Evaporite Rock (EVR) – specifically in the UK GDF context, halite. These host rock environments may be accompanied by a range of cover rocks which can also provide effective barriers to the migration of radionuclides and other contaminants.

It should be emphasised that our detailed plans will develop as GDF siting progresses, it is however considered valuable to share our understanding of research and development needs at this time with our regulators, industry, academia, international sister organisations and other interested parties. The various work areas presented have been developed by the individual subject matter experts in RWM in discussion with colleagues and stakeholders.

Figure 1 is a summary of the various planning levels RWM is currently developing and integrating; these range from the Board-level strategic plans at Level 1 through to the detailed tactical plans at Level 5. This S&T Plan provides our current best understanding of those research and development activities required at Level 5 of this hierarchy over the forthcoming decade. We recognise this picture is incomplete and a number of review activities are scheduled in the future, when we aim to have less uncertainty in the geological environment, in order to improve our Level 5 plans. Additionally, each task identified in Appendix B includes a field which states which of our generic geological environments the task is applicable to (Higher Strength Rock, Lower Strength Sedimentary Rock and Evaporite Rock). Hence, as the GDF Siting process progresses the site-specific geology will significantly influence the forward direction of research and development, enabling RWM to de-prioritise activities which are no longer relevant to our programme and address new knowledge gaps as they are identified.

Figure 1 Planning Levels in RWM

Level 1 - Sponsor level: Comprises high-level milestones spanning all parts of the entire programme (many years / decades). The purpose is to provide a very high, long-term and strategic summary view of the GDF Programme to enable strategic decision making. Circa 20-50 activities / milestones:

- Recommendations to Government
- Decisions by Government
- Granting of permissions and consents

Level 2 - Executive Control level: Provides medium to long-term summary view to enable Executives to control the direction of the programme to make strategic and tactical decisions. Circa 100-200 activities / milestones:

- Start of intrusive site investigations / submission of permit applications
- End of site characterisation cycle - i.e. Site Descriptive Model available
- Start of design and safety case iteration - i.e. System Requirements available
- Start of construction

Level 3 - Programme level: Supports Programme Board decision making. L3 milestones should be able to tell the Company what to do - and will drive lower level milestones. It answers the 'What and Why' questions. Circa 2,000 activities / milestones - Updated monthly:

- Key contract milestones as defined by value / complexity
- Delivery of safety cases at various levels of maturity
- Input of inventory updates to system requirements

Level 4 - Coordination level: Overview of the schedules which will be placed at Sub-programme level. The purpose is to provide detailed planning. It answers the 'How' questions. Circa 5,000 activities / milestones - Reviewed monthly. Typically covers around 5-10 years.

- Key contract milestones
- High-profile events
- Key interdependent activities

Level 5 - Project Execution level: Key working level. Planning detail for all of project or part of project depending on complexity, enabling effective management of the project. Large volume (Circa 20,000 or more) of activities / milestones which are underpinned by the contractor / supplier schedule.

- Sufficiently detailed as to identify interfaces between tasks
- Contractors' schedules will feed Into this level

A0001-01-RWM

2 Purpose of this Document

This document has been developed in order to present RWM's current understanding of the nature and timing of future research and development activities. It is primarily an internal document used to plan and agree our work priorities. It is however intended that publication of the 2020 Science & Technology Plan will continue to provide opportunities for dialogue and involvement of dialogue and involvement of those with an interest in the development of our knowledge base for the safe geological disposal of radioactive waste.

The uses of the S&T Plan are many; in the following list, in no particular order, the benefits are listed by stakeholder:

- **RWM**. The benefits to RWM are:
    - Improved linkages between the need for underpinning research and technical capability development, and the scope of work being carried out, will drive improved clarity of the end-users' requirements and hence deliver improved value for money. In developing detailed plans to deliver the GDF, the detail contained herein will improve the clarity of what needs to be done and why.
    - Improved clarity in RWM's research and development needs is likely to lead to further economic efficiencies in the tendering of work (e.g. by tendering a bundle of related activities under a solution-based contract) and will also assist in internal technical resource planning.
    - Improved clarity of the specific research needs and objectives of each project in a more structured manner will not only foster better targeted activities, but it will better enable improved knowledge capture via our internal processes following the completion of research. In a multi-generation project such effective knowledge capture is vital and is undertaken via RWM's knowledge base 'change control' process which provides a highly structured approach to the capture of data and understanding of features, events and processes of relevance to our environmental safety case. Research needs in our Operational Safety Case are captured via Forward Action Plans.
    - The high degree of definition in this document will also provide improved clarity in the scheduling of particular activities, including the rationale for the deferral of specific tasks, should prioritisation be required.
    - Improved transparency and facilitation of dialogue with all stakeholders (see below) is of great value in providing confidence in the robustness of our plans.
- **Academia.** RWM operates a needs-driven technical research and development programme in that we commission work targeted at specific needs through our supply chain, where appropriate including academic input. We have previously collaborated with UK Research and Innovation (and its predecessors) and directly with academic institutions in order to build UK skills and capability in this area of strategic national importance. RWM's remit includes supporting the development of the UK's geological disposal skills base; while we are already supporting many PhD students, Post-Doctoral Research Assistants (PDRAs) and young academics; we believe the better engagement that will be facilitated through greater clarity of our research needs will enhance this capability. Our recently launched Research Support Office, based at the University of Manchester, and in collaboration with the University of Sheffield, will benefit from the enhanced clarity of RWM's research needs. While the industrial supply chain will always play an important role in the development of our technical development skills base, we recognise there are many areas where universities, often utilising the UK's world-leading facilities, can support our programme. The Research Support Office will support the coordination of academic R&D to foster greater engagement and collaboration between academic

institutions and RWM. It is intended that RWM's engagement with the academic community in this way will lead to improved focus, better use of national (tax-payer) funding, opportunities for co-funded research and more opportunities for cutting-edge technical input to our programme. The universities should benefit by developing research proposals focussed on our broad needs and objectives, with a higher likelihood of making a significant impact on the national challenge of radioactive waste disposal. As such, they are more likely to attract UK Research and Innovation and/or RWM funding.

- **Potential host communities and other interested parties.** As the GDF siting process develops RWM will seek to engage with Interested Parties, Working Groups and Community Partnerships. Under this engagement we will listen to concerns and where specific scientific and technical concerns are apparent this document may support discussions. Anybody is able to raise issues with us via our website www.nda.gov.uk/RWM . A number of issues have already been raised in relation to the science and technology of geological disposal and have been addressed through our technical work programme. The detailed description of our research needs, objectives and potential scope in the S&T Plan supports the facilitation of dialogue with issue raisers.
- **Regulators.** Our regulators, the ONR, the EA and Natural Resources Wales (Cyfoeth Naturiol Cymru), require appropriate safety-related research activities to be undertaken in support of our evolving safety case. Improved clarity of our longer-term plans for enlarging our knowledge base, particularly as the GDF siting process progresses, will enable early discussion with our regulators and improved focus in any areas of potential concern to them.
- **International Waste Management Organisations (WMOs).** Sharing our previous Science and Technology Plans has facilitated co-funding and collaboration with our 'sister' WMOs. We will continue to seek such collaborative opportunities.
- **Supply chain**. Visibility of our longer term research and development activities will provide our supply chain with improved visibility of our market and hence will enable them to recruit and resource plan more effectively.
- **NDA and the Committee on Radioactive Waste Management (CoRWM).** It is intended that by increasing the clarity of our planned research and development through this document we will provide reassurance and facilitate dialogue with the Government's Committee on Radioactive Waste Management, who provide independent scrutiny.
- **Nuclear Innovation Research Advisory Board (NIRAB).** By identifying clear research needs and objectives we will support NIRAB's objective of fostering greater cooperation and coordination across the nuclear landscape.

2.1 How to Use this Document

From our experience of using this document within RWM, it is recommended that the long-range graphic contained in Appendix D is used as the entry point to the programme. It contains concise, but self-explanatory, task titles and is structured by technical work area. Having identified tasks of interest in the graphic (and their task number) further details can be obtained by identifying the corresponding task sheet, using its unique number, in Appendix B.

The electronic version of this report contains hyperlinks from each task sheet to the relevant long-range graphic, and from each line on the graphic to the specific task sheet, to facilitate ease of use.

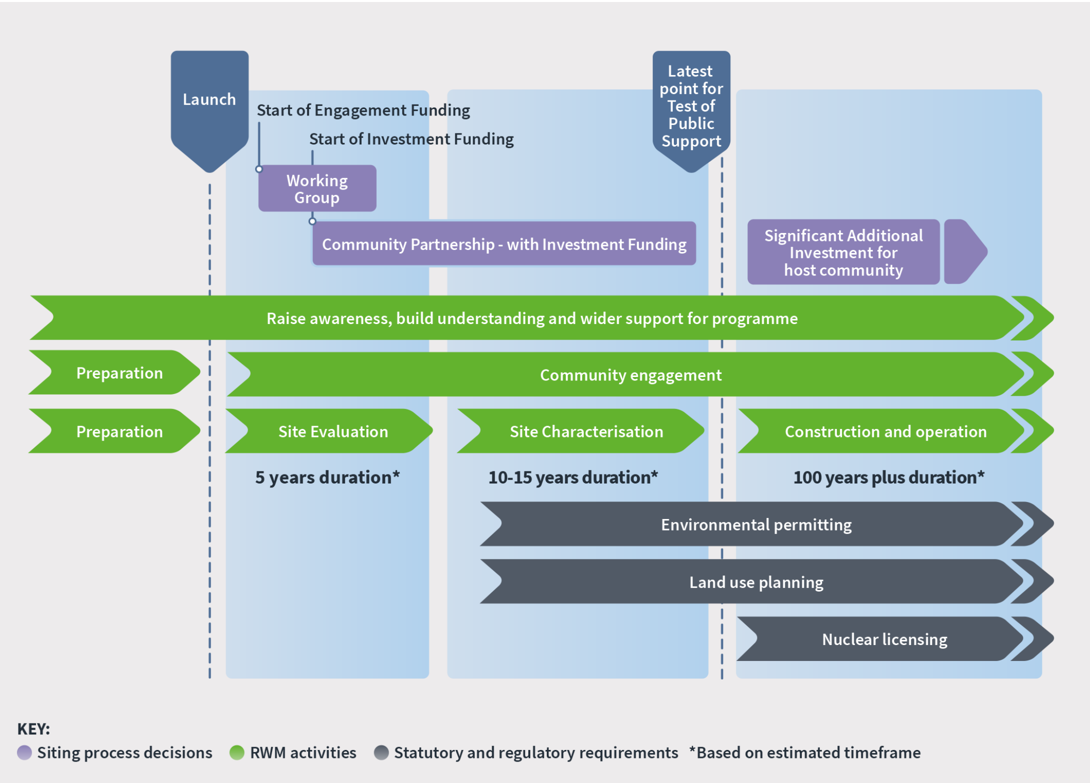
3 Development of Our Knowledge Base

3.1 The GDF Programme

RWM is currently engaged with the process of identifying potentially suitable sites for a GDF and willing communities. The time horizon for this S&T Plan is a decade. During this time we will continue to transition from a generic programme to a programme of technical work necessary to develop a GDF at a site-specific level. This will include the technical work required to support GDF design development and to gain the required permissions.

The implementation timescale of the GDF programme is dependent partly on the consent-based approach to siting, but also the need to undertake comprehensive technical investigations and obtain relevant permissions. Indicative timescales for planning purposes of the key activities in the GDF programme are shown in Figure 2.

Figure 2 GDF Development Programme - Key Activities



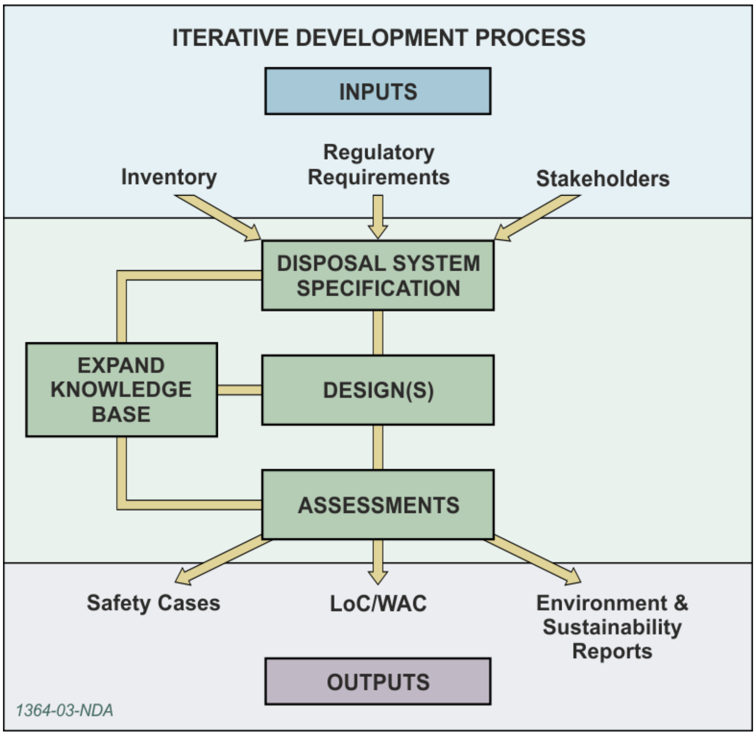
3.2 Geological Disposal Technical Programme

Underpinning the GDF Technical Programme is one of the main workstreams which underpin GDF delivery.

Delivery of the Technical Programme is a requirements-driven process and research needs are identified through iterations of RWM's specification, design, assessments and R&D work. This 'iterative development process' is illustrated in Figure 3. Broadly speaking, these requirements can be grouped into three types of inputs:

- The waste and waste packages that require disposal, i.e. the 'inventory' [4].
- Applicable regulatory requirements and permissions.
- Stakeholder requirements.

Figure 3 RWM's Iterative Development Process for the Development of the Disposal System



The Technical Programme is divided into 'Tranches' that are aligned to key step changes in the siting process for the GDF.

Tranches 1 and 2 align with the early stages of the GDF siting process, where discussions will take place with communities on the potential locations for siting a GDF in their area. For planning purposes, it is assumed that there will be several communities in discussions with RWM, but without a clearly defined site at this stage.

For planning purposes it is assumed that the transition from Tranche 2 to Tranche 3 is marked by a down-selection to two sites that are agreed by Government for borehole investigations. Information gathering in Tranches 1 and 2 is initially limited to information that is already available, for example from RWM's National Geological Screening Guidance [5]. Surface-based geophysical investigations towards the end of Tranche 2 could provide more information on thicknesses, depth and structure of the rocks at the proposed sites, dependent on the geology of the specific sites.

In addition, to support provision of advice to RWM's stakeholders (e.g. NDA Strategy and Government) and to underpin the provision of waste packaging advice to waste producers, it is assumed that the generic safety case is maintained until the agreement of the final site for the GDF.

Contactors are used to support project delivery via either task based[4], solution based[5] or integrated project based[6] contracts. Recognising the cross-cutting nature of many of the knowledge gaps, and the associated requirement for horizontal integration across the organisation and our contractors, we have established a series of 'integrated project teams' (IPTs). Previous IPTs (now complete) have included:

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4 Addressing a specific knowledge gap.

5 Addressing a broader challenge to our understanding.

6 A larger, collaborative team approach; pooling the capabilities of our supply chain and internal experts.

- The influence of heat generated from certain radioactive wastes and materials on engineered barrier systems for the range of generic disposal concepts being considered by RWM, and the development of packaging solutions for these wastes / materials that take account of any thermal constraints (the 'high-heat generating wastes IPT').
- A holistic approach to management of the UK's carbon-14 containing wastes (the 'carbon-14 IPT').
- The disposability and associated full lifecycle implications of managing the UK inventory of DNLEU through geological disposal (the 'uranium IPT').
- The development of disposal concept options to support decisions on concept selection, and identification of associated information needs (the 'concept development IPT').

Existing and planned IPTs include:

- An integrated project to develop backfill materials for the range of geological environments (the 'Backfill IPT' [6]). This project aims to develop backfill solutions as part of the engineered barrier system for each of the geological environments to an appropriate level to support decision making as part of GDF development at each stage of the siting process.
- Development of safety case claims, arguments and evidence for non-radiological pollutants related to the UKRWI[7] and the UK GDF. This IPT will bring together ongoing and preceding work within an overall framework, identify knowledge gaps in the current programme of work, and undertake and deliver studies to ensure RWM's position on non-radiological pollutants meets regulatory requirements. IPT partners will work together to integrate evolving understanding from current and pre-existing projects to develop a holistic approach to the management of non-radiological pollutants in the disposal system.
- An integrated project comprising desk and laboratory studies which will enable confirmation (or otherwise) of the disposability of proposed wasteforms for plutonium residues, should this be required.
- An integrated project to develop plugs and seals for disposal vaults, tunnels and shafts. This project aims to develop plug/sealing solutions for candidate geological environments.

3.3 Current Position

3.3.1 Status of Current Technical Programme Activities

Having undertaken over three decades of research into the geological disposal radioactive wastes, there is strong international consensus that geological disposal is the appropriate route for long term management. The Organisation for Economic Co-operation and Development: Nuclear Energy Agency (OECD NEA) state that 'Geological disposal is technically feasible; it can be made safe for current and future generations; there are no credible alternatives to geological disposal; and, whatever further technical advances may be gained, the need for geological disposal of some classes of waste will persist' [7].

There is a good understanding of the features, events and processes impacting on the safety functions of the GDF. Once potential candidate sites have been identified a

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7 The UKRWI details the wastes destined for the UK GDF – it includes radiological and non-radiological waste components, including container material, encapsulants, metals, organic materials, polymers, etc. – some of these components are also non-radiological pollutants, or form non-radiological pollutants on degradation.

programme of site investigation will be undertaken to ensure that the sites' characteristics are within the bounding assumptions underpinned by the generic research programme, together with research and development studies associated with the development and optimisation of the disposal system to the local geological environment.

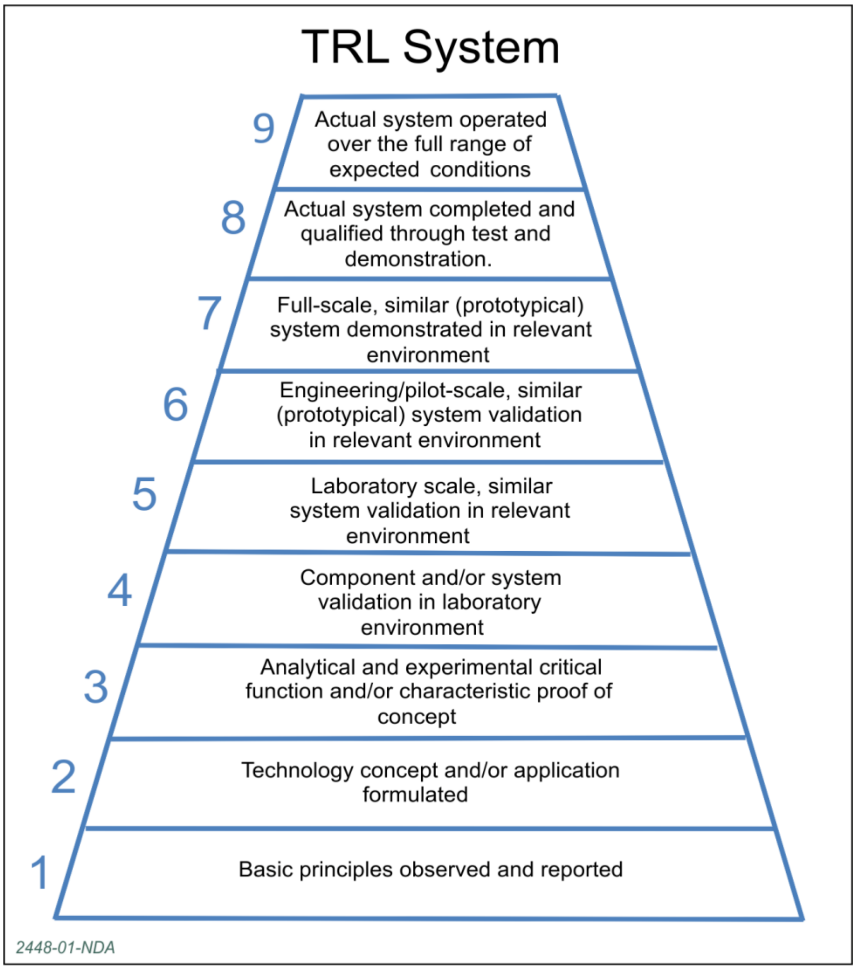
RWM currently deploys a balanced programme of activities including laboratory-based studies, modelling at the process and component level[8], natural / archaeological analogue studies and larger scale experiments and demonstration studies, including those deployed in overseas Underground Research Laboratories. This enables us to undertake a comprehensive technical development programme which explores the mechanistic understanding of physical, chemical and biological processes governing the performance of the future GDF, together with activities that investigate whether this understanding can be up-scaled to the real environment. Work is also undertaken to investigate the social science aspects of planning and implementing effective public engagement, so as to build confidence in RWM's capabilities to deliver a safe long-term solution to the management and disposal of higher activity radioactive wastes.

8 Process model: This type of model is typically very detailed and potentially very complex. It is focused on a specific technical area to provide underlying calculations or arguments that will support the component or total system model or the safety arguments directly. A bottom-up approach is taken to its development. Uncertainty is addressed by considering alternative assumptions.
Component model: This is a collection of process models that uses multidisciplinary information to calculate particular parameters that are used in the Total System Model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development. Some representation of uncertainty is usually required.

4 Assessment and Comparison of Scientific Maturity

The concept of Technology Readiness Levels (TRLs) is widely used across the NDA estate [8] and elsewhere [9], [10] , and has been successfully applied to process wiring diagrams in the NDA estate.

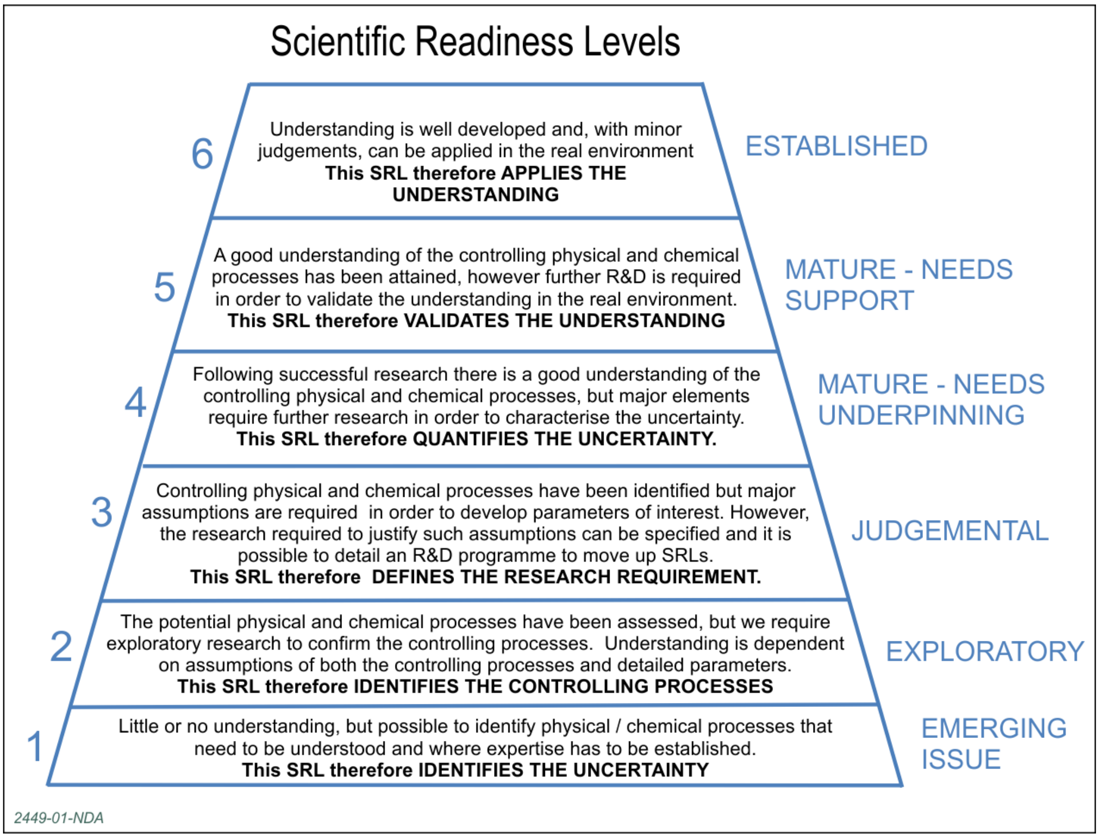
Figure 4 Schematic Representation of the TRL Scale



TRLs have proven useful in evaluating GDF design activities. However, for the purposes of calibrating the scientific maturity of underpinning science TRLs have proven intractable. A survey of possible alternatives was undertaken in support of RWM's 2014 S&T Plan, together with consideration of a novel system and modification of the TRL scale. However, the most promising tool identified was developed by the UK National Nuclear Laboratory (NNL) and utilises SRLs™; the definitions are shown in Figure 5. It should be noted that the term 'SRL' has also been used to denote System Readiness Levels, however, since the term 'SRL™' has been registered as a trademark; RWM will continue to use this terminology.

SRLs™ are similar in organisation to the TRLs and complement their assessment of the 'deployability' of technology with their assessment of the scientific robustness of understanding of the underlying science [11]. In the case of TRLs a successful implementation of a new technology needs a high TRL. However, SRLs™ are an indication of basic mechanistic understanding, and the SRL™ required is a function of the specific need; it is therefore not necessary to achieve an SRL™ of 6 for all applications. A low

Figure 5 Schematic Representation of the Scientific Readiness Level (SRL™) Scale



SRL™ may be an appropriate end-point where a parameter can be shown at to be of low consequence for safety and that no ‘cliff-edges’ exist in its importance.

NNL developed Scientific Readiness Levels™ as a means of identifying and illustrating the value associated with scientific / technical debate and they have been utilised by RWM in this spirit; as a tool to prompt internal discussion over the current maturity of specific areas of underpinning science and of the likely scientific maturity that would result from planned research activities. The definitions of the SRLs™ that have been developed by NNL have broad applicability. The levels represent a logical progression through different stages of the maturity of the scientific / technical arguments that underpin system performance or prediction of complex technological phenomena. The value of utilising SRLs™ is threefold:

- In the consistent assessment of scientific maturity and in the consistent comparison of maturity between different areas within our technical programme. In this way appropriate effort can be channelled to the development of the science underpinning less mature alternative disposal concepts to bring them to an appropriate scientific readiness to facilitate future concept selection, i.e. to close the gap between the current SRL™ and that required to make a decision.
- In providing a structure to enable the planned systematic development of understanding, coupled with the reduction in uncertainty in our knowledge base where it is leading to unhelpful over-conservatisms.

While the concept of a stepwise increase in SRL™ could portray an idealistic scenario we do recognise that science and technology development does not always progress in a stepwise manner. Therefore it is likely, considering the breadth of our research activities, that progress will not be as anticipated in all areas. Nevertheless, the use of SRLs™ is enabling us to calibrate progress in a critical and structured manner.

Robustness and Monitoring of SRL™ Development SRL™ attribution: Following the identification of a research need, end-user agreement is sought in order to provide a first level of governance in that the end-user supports the deployment of effort and funding to address the task. New tasks are periodically compiled into a revised S&T Plan; during its development the Head of Environment and Sustainability reviews every task sheet for SRL™ consistency.

5 Description of Science and Technology Plan Contents

5.1 Task Descriptions and the Long-range Graphic

The Technical Programme is organised according to RWM's Technical WBS. The WBS has been used to structure the tasks within this S&T Plan. The WBS is shown schematically in Appendix A. Under each WBS element we have developed the knowledge gaps into specific tasks and have used a structured approach to clarify the specific research needs and objectives associated with each task, together with other parameters useful in scheduling the task. The following headings, utilised on the task sheets, are annotated here:

Task number

A unique identifier has been attributed to each task, enabling the cross-walk between the task sheets shown in Appendix B and the long-range graphic shown in Appendix D.

WBS descriptors

As shown in Appendix A.

Short Title

A brief description of the scope which is also used in the long-range graphic (Appendix D).

Background (How important or significant is this topic area? How urgent is the task?)

A brief summary of background information is presented in the task sheets in Appendix B in order to provide the context for the task. Note that in successive tasks in the same WBS element some of this text is repeated, however the concept of self-contained task sheets was considered beneficial to end-users and stakeholders.

Research Driver (What is our 'knowledge gap? What is the driver for the R&D?)

This provides a clear link from the knowledge gap to the RWM strategic business case based on, e.g. design concept development, disposal system specification, or assessments (the safety case, waste package disposability or environment & sustainability assessments).

Research Objective (What do we need to know?)

A clear statement of the required outcome(s) from the task which will increase our knowledge with respect to the specific research need.

Scope (What do we need to do to fill the knowledge gap?)

Where appropriate, a scope has been developed although, since a primary objective of the plan is to encourage innovation and dialogue with academia and our supply chain, in many cases the scope has been left deliberately brief.

SRL™/TRL at Task Start and SRL™/TRL at Task End

See Section 4 for a discussion of SRLs™ and TRLs.

A Target SRL™ has also been included where possible in order to convey our current understanding of the level of understanding likely to be required.

Output

The nature of the output of a task, whether a report, model, etc.

Geology application

The applicability of the activity with respect to the three illustrative geological environments: Higher Strength Rock, Lower Strength Sedimentary Rock and Evaporite Rock.

Further Information

Any other relevant text, references or suggestions for collaboration.

Addressing the question of **How long will it take?** is dealt with in the long-range graphic (Appendix D), together with the question of what the linkage is between related tasks. The graphic shows the estimated time needed to complete the work and shows linkages between the tasks.

Based on Figure 6, an estimate of the relative cost is also presented.

Table 1: Parametric cost estimation matrix (redacted) used to develop a crude cost profile for internal use.

Scope	Complexity		
	Simple	Moderate	Challenging
Archiving /storage	A1	A2	A3
Desk study / review	B1	B2	B3
Computational study	C1	C2	C3
Inactive laboratory based research / analogue study	D1	D2	D3
Active laboratory based research	E1	E2	E3
Hot-cell based research	F1	F2	F3
Large scale / URL experimental project	G1	G2	G3

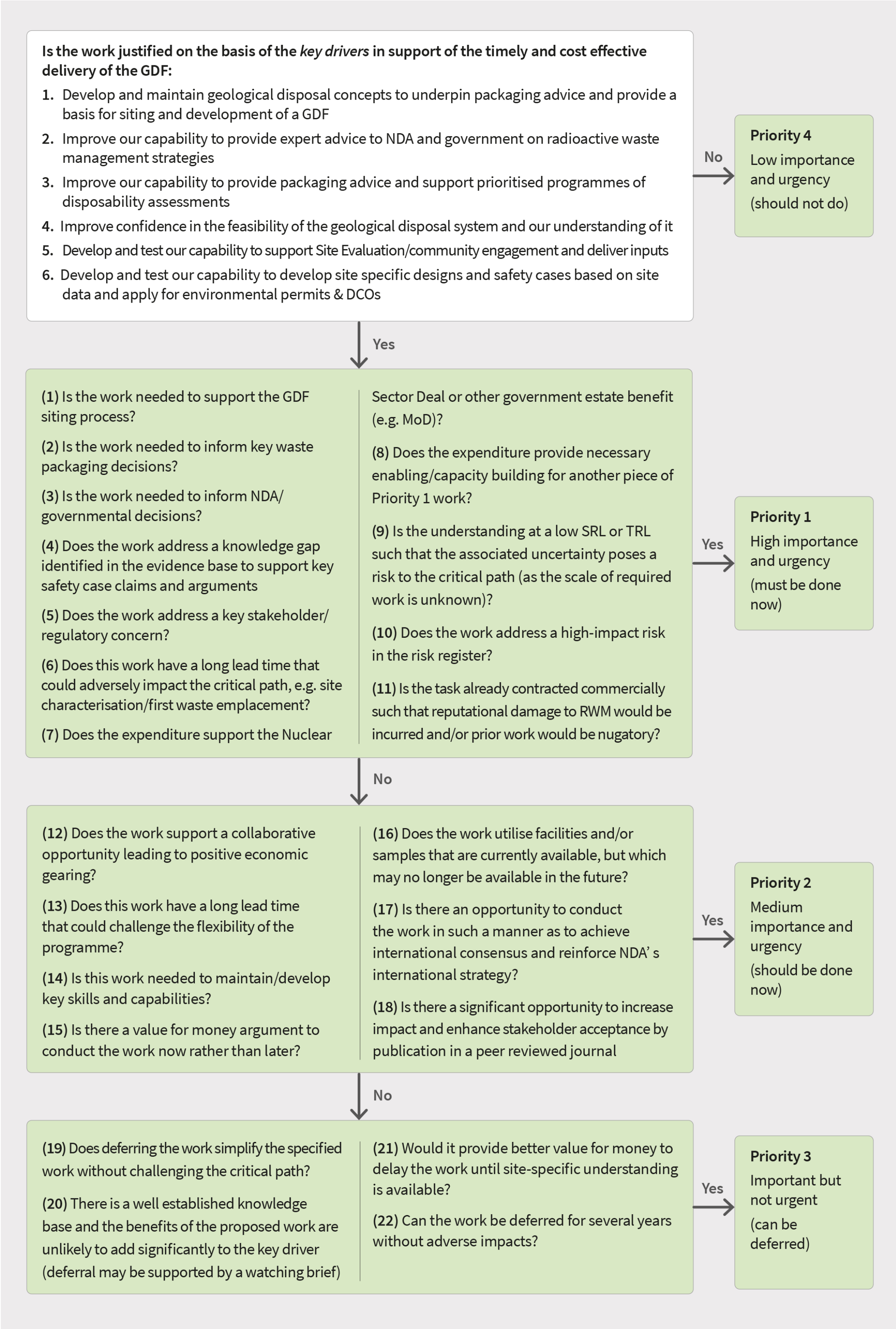
5.2 Planning and Prioritisation of the Technical Programme

There are six key drivers that underpin the Technical Programme. These are:

1. Develop and maintain geological disposal concepts to underpin packaging advice and provide a basis for siting and development of a GDF.
2. Improve our capability to provide expert advice to NDA and Government on radioactive waste management strategies.
3. Improve our capability to provide packaging advice and support the prioritised programme of disposability assessments.
4. Improve confidence in the feasibility of the geological disposal system and our understanding of it.
5. Develop and test our capability to support site evaluation/community engagement and deliver inputs.
6. Develop and test our capability to develop site specific designs and safety cases based on site data and apply for environmental permits and DCOs.

In developing the overall Technical Programme, the high level activities required during each 'Tranche' for each element of the WBS were defined. Further detail was then developed to understand the near-term activities that the Technical Programme would deliver within the Tranche. Finally, to support business planning and the scheduling of work at a greater level of granularity, a set of questions are used to assign priority to individual tasks. This process supports project planning and provides a structured approach to decision making in the event of constrained funding and the need to defer work. A flow diagram to illustrate this structured approach is shown in Figure 6.

Figure 6 Structured approach to prioritisation of the Technical Programme.



6 Transitioning from Generic with Site Specific Research

To date the work programme has carried out only generic activities, i.e. those that can be undertaken in advance of any site-specific geological understanding. As the siting process progresses, our R&D work will change in three ways:

- The emphasis of our research will focus on developing the underpinning science of concepts, designs and safety / environmental assessments specific to the site or sites in question.
- Where appropriate, the scope of those research activities currently identified in the generic programme will be tailored to the site or sites in question. For example, where water-rock interactions are being investigated the programme will transition from using a range of simulated groundwaters relevant to the range of generic concepts, to real samples of groundwater or rock cores extracted from the geological formation(s) in question.

A range of site-specific research tasks will be developed, aimed at:

- Optimisation of the disposal concept and designs against the host geology;
- Reflecting the real environment in the DSSC. Some parameters will be assessed *in situ*, via the site characterisation programme, while others will be more research-focussed and will utilise a range of laboratory-based techniques.

The transition to site-specific activities provides the opportunity to pull together several strands of our research and development work relating to sustainability. The generic environmental assessment and sustainable design work undertaken by RWM over the last few years has highlighted several areas of concept and design development where there will be significant opportunities to reduce the environmental footprint of a GDF. For example, recent work on the sustainability of construction and backfill materials is highlighting areas where we may be able to significantly reduce our carbon footprint and contribute to both NDA and Government Net Zero carbon targets.

Site-specific activities will also allow us to apply the learning gained from our generic research into the societal aspects of geological disposal and sustainable community development. This work will be influenced by the community visioning carried out by Community Partnerships - which may also highlight future research needs in social science. The social science topic area established by RWM's Research Support Office will provide a useful focus for this work.

7 Review and Scrutiny

In developing this S&T Plan we have consulted widely within RWM, in particular with end-users of the research programme (Safety Assessments, Concepts, Engineering, Disposal System Specification and Waste Management Directorate). Furthermore, to support its development as a competent delivery organisation that will be subject to formal regulation, RWM has agreements with the regulators to allow “voluntary scrutiny” of key activities. As part of the scrutiny programme regulators have reviewed versions 1 and 2 of the Science and Technology Plan. They went on to identify 6 recommendations on the basis of version 2 and a number of detailed comments. Our intent in producing this S&T Plan, in addition to updating the schedule and incorporating new tasks, was to address these recommendations.

8 Feedback

In this document we have presented our current understanding of our detailed science and technology requirements in support of the HAW disposal programme, together with an indicative schedule. We have identified over 300 individual tasks scheduled over a period of up to ten years.

We would welcome your comments on our S&T Plan. Specifically, we would ask you to consider the appendices to this document and answer the following questions:

- Are there areas to which you consider that we are giving an inappropriate emphasis?
- Are there areas where you consider the proposed R&D to be inappropriate or inadequate?
- Would you like to suggest any innovative approaches to addressing the research needs and objectives detailed in the appendices?

In each case please tell us your reasons for making the comment and if there are additional sources of information that you would like to bring to our attention that would be very helpful. Comments should be provided to RWM Feedback, using the address identified inside the front cover of this document.

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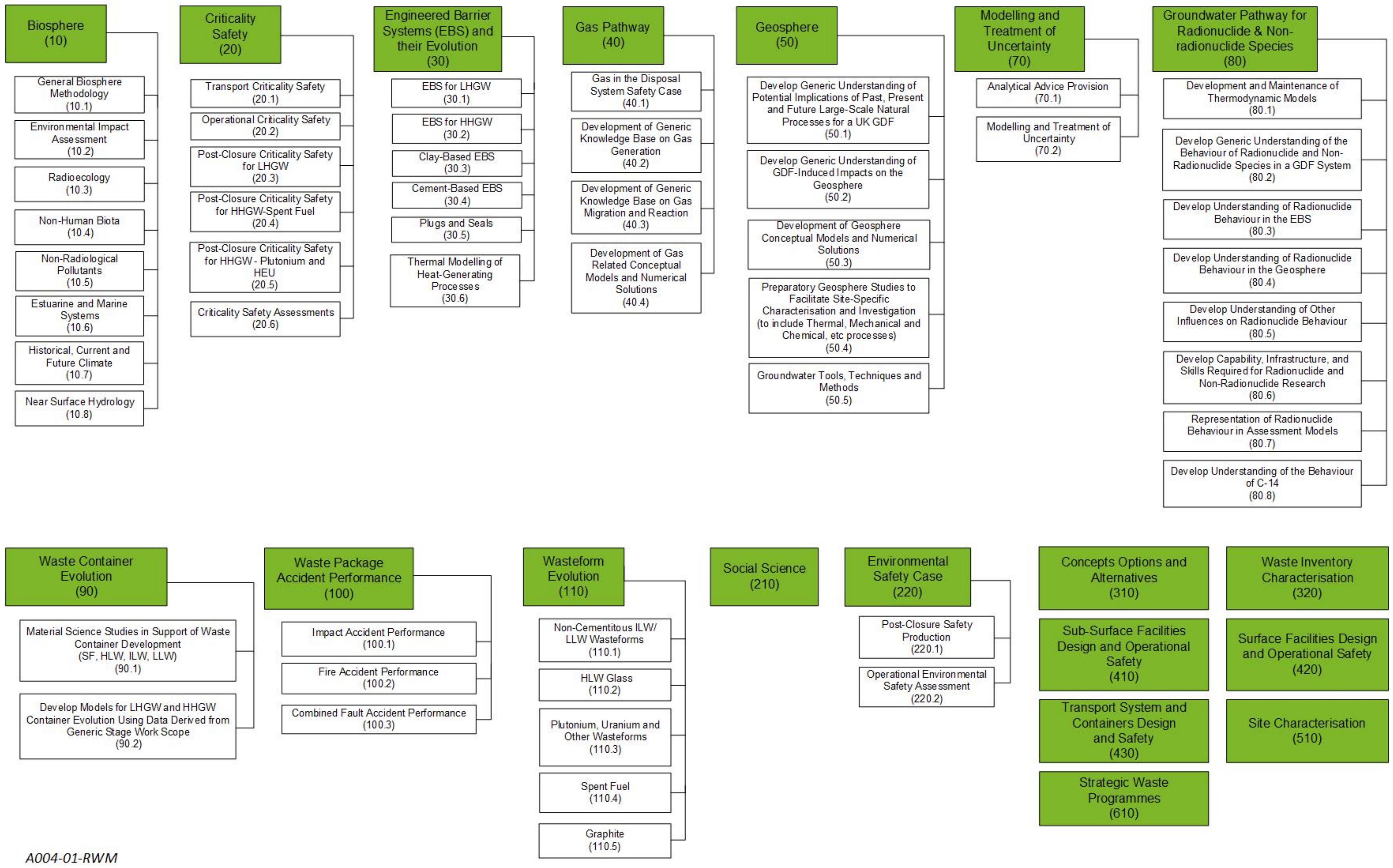
11 *Sustaining Expertise in Specific Aspects of Nuclear Technology*. 2013.

Appendix A Product Breakdown Structure

RWM has recently made significant progress in developing as an implementer of a nationally significant major infrastructure project. This has included improvements in programme definition, including improved clarity of the programme delivery work breakdown structure (WBS). The 2020 Science and Technology Plan has therefore been aligned with this improved WBS, as shown in Appendix A.

Figure A1 Work Breakdown Structure for Tasks in this Plan



Appendix B Task Sheets

B1 WBS 10 - Biosphere

The generic research activities to be concluded before the site-specific stage commences can summarised in the following work areas:

- General biosphere methodology (**WBS 10.1**)
- Environmental impact assessment (**WBS 10.2**)
- Radioecology (**WBS 10.3**)
- Non-human biota (**WBS 10.4**)
- Non-radiological pollutants (**WBS 10.5**)
- Estuarine and marine systems (**WBS 10.6**)
- Historic, current and future climate (**WBS 10.7**)

The biosphere work area will continue to be informed by approaches identified as international best practice and pioneered by overseas waste management organisations, the work planned within the next decade will ensure that the treatment of the biosphere in the early part of the period of the period covered by the post-closure safety case is consistent with that described by the EIA work (Task 10.2.001), and to ensure that data used in human and wildlife impact assessments are consistent with the IAEA recommendations (Task 10.3.001). Further international collaboration is planned through the IAEA's MODARIA programme (Task 10.4.001, Task 10.4.002 and Task 10.7.001) and BIOPROTA (Task 10.1.001 and Task 10.8.001). In order to phase into the next stage of the programme, a roadmap for Tranche 3 (Task 10.1.003) is planned in order to provide the capability for site-specific modelling, the outcomes of the roadmap will lead on to Task 10.1.004 in which the site-specific research and development associated with the biosphere will be identified as a result of initial understanding of potential GDF sites.

Once one or more sites are under consideration, site-specific biosphere models will be produced, using the approach developed through generic research studies. The catchment model is an important component of the biosphere model. It describes the near-surface hydrology and 'points of contact' in the biosphere. It interfaces with the geosphere model, which contains the description of the groundwater environment, via the biosphere – geosphere interface. Currently, this model is generic; it will be developed to represent the site once this is known. Ongoing development of the catchment model will continue during site characterisation as geosphere understanding improves.

RWM has already produced terrestrial models for glacial, tropical, temperate, boreal and glacial climate states. Climate predictions in a European context will be down-sized to regional, and ultimately, the local scale once one or more sites are under consideration. Since climate change science is evolving rapidly, RWM will continue to undertake generic research in this area through international collaborations.

There are other topics where site-specific biosphere research may be required. For example, RWM's non-human biota model (ERICA) is currently supported by a generic database. A site-specific ERICA database may be required in the future. RWM may also study the behaviour of some key radioelements (for example, iodine, technetium, uranium, selenium and radon) in site-specific soils and vegetation. This may be undertaken through field-scale lysimeter experiments similar to those previously undertaken in the generic research programme.

B1.1 WBS 10.1 - General biosphere methodology

B1.1.1 BIOPROTA: Update of BIOMASS (BIOsphere Modelling and ASSessment) Methodology

<table>
<tr><td colspan="2">Task Number</td><td>10.1.001</td><td>Status</td><td colspan="2">Completed, undergoing review</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Biosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">General Biosphere Methodology</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM's approach to representing the biosphere in long-term performance studies aligns with international guidance, notably the BIOMASS methodology developed within the context of an IAEA programme. The BIOMASS methodology sets out a structured approach based on good practice in defining biosphere systems that appropriately reflect the context for the assessment and that can then be used as a basis for quantitative calculations. This methodology was developed in 2003 and needs to be reviewed as a result of the findings of the MODARIA project and other developments in the biosphere area since 2003. The IAEA is considering a project to update the BIOMASS methodology as part of a MODARIA II programme.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To ensure that the treatment of the biosphere in the post-closure safety assessment takes account of improvements in methodology and understanding of various biosphere processes that have occurred since publication of the IAEA BIOMASS methodology in 2003.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To ensure that RWM's approach to representation of the biosphere in the post-closure safety case is consistent with current international guidance and practice.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Particular topics envisaged for the update to the BIOMASS methodology include the following:
• Practical experience of its application.
• Capturing experience in site characterisation and assessment.
• Addressing radionuclide behaviour in the transition zone from the geosphere to the biosphere.
• Conceptual models for key radionuclides (e.g. C-14, Se-79 etc.).
• Current approaches to treatment of non-human biota.
• Enhancements to the methodology to specifically address impacts on the environment and non-radiological impacts linked to radioactive waste disposal.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">IAEA published report on updated BIOMASS methodology.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
Relevant further information can be found in a 2003 BIOMASS report [1].

1 International Atomic Energy Agency, *Reference Biospheres for solid radioactive waste disposal: Report of BIOMASS Theme 1 of the BIOsphere Modelling and ASSessment (biomass) programme*, IAEA Report IAEA-BIOMASS-6, 2003. [Online]. Available: https://www-pub.iaea.org/MTCD/Publications/PDF/Biomass6%5C_web.pdf.

B1.1.2 Consistency of Biosphere with Other Technical Areas within RWM

Task Number	10.1.002	**Status**	Start date in FY2020/21
WBS Level 4	Biosphere		
WBS Level 5	General Biosphere Methodology		

Background

RWM has recently carried out a project to identify the overlaps and interfaces in the representation of the biosphere between different parts of RWM's programme [1]. At present, different modelling approaches are used between the OSC, OESA and PCSA for the same radiation exposure pathways to humans. The biosphere calculations undertaken to support the OSC and for the OESA need to be based on updated models and, particularly, on internationally recommended databases of environmental parameters that have become available in recent years. The same modelling approaches should be adopted where the same exposure pathways are addressed. One way of achieving this would to be to use the current RWM biosphere model to calculate the dose pathways required in the OSC and OESA. This would ensure consistency for both the operational and post-closure safety assessments and would have the additional benefit that both models could directly use site-specific biosphere models once they have been developed.

In future assessments, RWM will be required to include non-human biota dose assessments in both operational and post-closure assessments. RWM has supported much recent development in the science and data sets available in this technical area. A review of the use of the ERICA tool in the OSC and PCSA is required to help ensure consistency in both areas of the programme. It is likely that the OSC and PCSA radionuclide transport models will have to be adapted to output concentrations in the various media as required by ERICA, the review will identify the required additional outputs from the OSC and PCSA codes.

The work outlined below is aimed at resolving the issues identified and to help address the regulatory observations against the OESA, OSC and PCSA.

Research Driver

- There are currently several approaches used to assess biosphere exposure pathways across RWM.
- There are inconsistencies in the methodology to calculate radioactive doses to humans from aerial deposition pathways in the OESA and OSC.
- There is the need for consistency in approach to calculate doses to non-human biota in the OESA and PCSA.

Research Objective

The objective of this work is to:

- have an overall traceable methodology to calculate radioactive doses to humans from aerial deposition pathways in the OESA and OSC; and
- have a standardised approach to dose assessment pathways for humans and non-human biota in RWM.

Scope

The following scope will be undertaken:

- For both the routine and accident off-site release methodologies in the OESA, for both their respective radionuclide gases of interest, use the ADMS code for generic site atmospheric conditions to calculate atmospheric transport of radioactive gases. The OESA covers gaseous releases of H-3, C-14 and Rn-222 during normal operations. The OSC covers gaseous releases of up to 112 radionuclides from an accidental release scenario.
- Review the outputs from the ADMS code to produce the activity concentrations in the various media required by the current RWM biosphere model.
- At present, different modelling approaches are used between the OESA, OSC and PCSA for the same exposure pathways. Review the use of the current RWM biosphere model to model biosphere-related exposure pathways.
- Similar age groups and the same generalised habit data should be used throughout the different types of assessment.
- Consider radionuclides required for the OSC (may be a different list from that in biosphere model).
- Note that other pathways such as exposure to a radioactive plume (inhalation, skin dose, shine) should be consistent throughout and consistent with the pathways in the RWM biosphere code.
- Where the same sorts of modelling approaches are used, covering the same periods of time and/or interfacing in time, the same data should be used in assessments.

Non-human biota dose assessments will be included in both operational and post-closure assessments. RWM has supported much recent development in the science and data sets available on this topic. Review of the use of the ERICA tool in both areas of the programme to help ensure consistency in reference organism assumptions and required outputs will be undertaken in terms of activity concentrations in various terrestrial and water bodies which are required for the aerial releases in the OESA and OSC and for the groundwater release in the PCSA.

Geology Application

HSR, LSSR, Evaporite

Output of Task

- A suite of consistent assessment models for the OESA, OSC and PCSA.
- A contractor report.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information

1 Nucleus, *Review of consistency of biosphere programme with other technical areas*, QRS-1958A-1, 2019.

B1.1.3 Develop Roadmap for Site-specific Modelling and Assessment of Biosphere

Task Number	10.1.003	**Status**	Start date in FY2020/21
WBS Level 4	Biosphere		
WBS Level 5	General Biosphere Methodology		
Background			
Biosphere characterisation is an integral part of the overall process of site characterisation [1]. It facilitates the biosphere aspect of a Performance Assessment from studies of geology, hydrology, climate, human populations, distribution and abundance of animal and plant species, and aspects of sociological and demographic studies. It can also provide inputs to an EIA, which may be required for the construction of a facility, and may prevent the need to undertake the same characterisation activities twice. Biosphere characterisation for a geological disposal programme is not a new discipline and substantial amounts of work have already been undertaken in several international programmes. Therefore, a review of previous approaches to characterisation and those currently being developed affords an opportunity to learn from this experience. RWM's current technical programme has the site evaluation framework for down-selecting from five to two sites for intrusive investigations concluding in 2024 (end of Tranche 2 of the near-term work plan). RWM will then be required to produce site descriptive models, both to provide for the internal information requirements of the GDF development and to communicate understanding of the sites to external stakeholders to gain permits to continue investigations and to build confidence in the reliability of site evaluations. The work in this task outlines the basis for biosphere characterisation noting the progression from reliance on generic or regional data to the need to derive and use site-specific data as the GDF development progresses.			
Research Driver			
During site characterisation, RWM will need to investigate the exact nature of the biosphere at a given site(s) for site selection and input to the ESC; this task aims to provide the methods and capability to do this.			
Research Objective			
A roadmap is required which identifies a process map for the site investigations required to develop the site descriptive model for the two selected sites and recommendations for developing the site-specific biosphere conceptual model using site-specific biosphere data collected during site investigations at the two potential sites into site-specific biosphere models describing flow and transport of contaminants among terrestrial and marine ecosystems.			
Scope			
The scope of work could include, but should not necessarily be limited to, the following: • A review of other international site characterisation programmes relating to deep geological disposal of radioactive waste to identify interpretation and modelling activities relating to the biosphere, together with associated information on resource requirements and availability. The review will focus on biosphere information required for two potential sites. • A description of requirements for characterising the biosphere at a site before site selection (may be for two potential sites), after site selection and throughout the construction, operation, closure and post-closure administrative control periods.			

• Describe the protocols required for research, site characterisation and monitoring, this includes classifying the various types of experimental and monitoring studies that may be undertaken for each area and identifying areas of overlap. • Lead a workshop with the aim of recommending a strategic approach for processing, interpreting and modelling biosphere site characterisation data, including consideration of site-specific factors. A briefing note defining the processes and tools identified, together with associated resource implications, will be prepared as input to the workshop. • Experience of interactions with stakeholders who will have a legitimate interest in how site characterisation is conducted and how the results will be used.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task • Contract-led workshop • Contractor report presenting the findings of project • Learning will be captured in the detailed plans for the GDF programme					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					
1 M. C. Thorne, L. M. C. Limer, and G. M. Smith, *NDA RWMD biosphere assessment studies FY2009-2010: Review of biosphere site characterisation*, RWMD QRS-1378W-3, 2011.					

B1.1.4 Site-Specific Research Needs Identification: Biosphere

<table>
<tr><td>Task Number</td><td colspan="2">10.1.004</td><td colspan="2">Status</td><td>Start date in FY2024/25</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Biosphere</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">General Biosphere Methodology</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In December 2018 RWM launched its siting programme and we are engaging with communities that have an interest in hosting a GDF [1]. As the siting process moves forward, site characterisation will progress through surface-based and intrusive (borehole) investigations. While waste packaging proposals from waste owners will continue to draw upon the generic safety case and its underpinning, many of the more generic research activities will be concluded, while site-specific research and development activities will take place for an assumed two potential candidate host sites, driving our understanding and data maturity towards that required for GDF permissions. Monitoring that was used for site characterisation and data gathering purposes will continue through the operational period and beyond, and may be used for regulatory compliance purposes to assess the consequences of any off-site discharges from operations.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To identify future site-specific research and development associated with this work area as a result of initial understanding of potential GDF sites.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To further develop the Science and Technology Plan to identify site-specific research and development needs.</td></tr>
<tr><td colspan="6">Scope
• To identify site-specific knowledge gaps and key uncertainties requiring further research and development.
• To assess and review the resourcing and capability for the requirements of site-specific activities based on the outcome of the conclusion of generic activities.
• To assess the applicability of generic work to the site(s) taken forward for site characterisation.
• To develop supply chain capability where necessary to transition into Tranche 3.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">Site specific – To be confirmed.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">An understanding of the site-specific knowledge gaps for an assumed two sites and the programme of work required to close them.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>N/A</td><td>SRL/TRL at Task End</td><td>N/A</td><td>Target SRL/TRL</td><td>N/A</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">1 BEIS, Implementing geological disposal - working with communities, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766643/Implementing_Geological_Disposal_-_Working_with_Communities.pdf.</td></tr>
</table>

B1.2 WBS 10.2 - Environmental impact assessment

B1.2.1 Interface of Biosphere Programme with Environmental Impact Assessment (EIA)

Task Number	10.2.001	**Status**	Start date in FY2022/23
WBS Level 4	Biosphere		
WBS Level 5	Environmental Impact Assessment		
Background			
EIAs will be carried out to support Development Consent applications for both deep boreholes and the GDF. The EIAs will include consideration of the environmental, socio-economic and health and well-being effects associated with implementing geological disposal. The focus of the assessments for the GDF will be the operational and short-term post-closure phases – extending to several hundred years. Research is also being carried out to determine how the biosphere should be represented in the DSSC. The timescales considered by this work extend to hundreds of thousands of years. At least 12 months of baseline monitoring and survey work will be carried out at candidate sites to inform the EIAs. This work will help to define a baseline (the situation in the absence of geological disposal, at any defined point in time) which will provide a yardstick against which the predicted effects of the GDF can be compared. Defining the baseline involves collecting information about the current environment and predicting how it might change in the future. The baseline definition used for the EIAs needs to be consistent with the scenarios for long-term environmental change and biosphere development used in the safety case. A review of the approach to climate change between the biosphere research programme and the preparatory EIA work has been carried out. The review shows that over the timescale of common interest, which is the period spanning the short-term (period of authorisation) and long-term (post-closure) assessment (300-1,000 years), both programmes use the UKCP09 data projections (the MODARIA work uses these as lower boundary conditions for long-term climate projections) and hence are consistent.			
Research Driver			
To ensure consistency in the baseline definition used in EIA work and the scenarios for environmental change developed by the biosphere research programme for use in post-closure safety assessments.			
Research Objective			
To ensure that treatment of the biosphere in the early part of the period covered by the post-closure safety case is consistent with that described by the EIA work.			
Scope			
To review and compare specific areas in the biosphere and EIA work programmes and identify where significant differences in approaches and methodology exist. The review should map out a programme of future work to address any discrepancies. Areas that might be covered in a review include climate change, as described above, and related issues such as biodiversity and landscape evolution, population and demographic change, land-use and environmental monitoring. Specific topics to consider might include the following: 1. Habitats, Sites of Special Scientific Interest and Natura 2000 sites (which are internationally-designated nature conservation sites). These are relevant to the terrestrial biosphere model, land use and non-human biota considerations.			

2. Biodiversity, flora and fauna - all individual species (e.g. plants, animals), their habitats and the interactions amongst them, particularly in terms of ecosystem function. Ecosystems are linked communities of organisms together with non-living components of their environment (such as air, water and soil). These are relevant to the biosphere work on non-human biota.
3. Human health, people and communities who could be affected by the effects from developing and operating a GDF, specifically as relates to their health and well-being. These are relevant to the biosphere Potentially Exposed Groups.
4. Population and economic projections and projected demographic changes (e.g. urban and rural population densities). These are relevant to the biosphere Potentially Exposed Groups, land use, habits and predictions of behaviour over long timescales.
5. Geology and soils: quantity and distribution of different soil types. These are relevant to the terrestrial biosphere model.
6. Water quality and resources: size, capacity, shape and location of a water body in relation to its users. Includes flood risk: the likelihood of a flood happening, plus the consequences that will result if the flood occurs. These are relevant to the terrestrial and freshwater biosphere model.
7. Hydromorphology/geomorphology: the relationship between landforms and water bodies, combined with the process of sediment transfer (erosion, transport and deposition). These are relevant to the terrestrial and freshwater biosphere model.
8. Climate change - climate emissions: the greenhouse gases which are emitted as a result of (in general) the use of natural resources; climate adaptation; the measures taken in order to help society and nature adapt to future changes in our climate. These are relevant to MODARIA work on the effects of climate change.

Geology Application

HSR, LSSR, Evaporite

Output of Task

The output of the task will result in a contractor approved report.

SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 6

Further Information

There will be some information from the biosphere site characterisation project ending in November 2020. There are other publications relevant to this task [1]–[3].

1 Nuclear Decommissioning Authority, *Geological Disposal: Geological Disposal and Climate Change*, NDA Report NDA/RWMD/110, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-and-climate-change-ndarwmd110/.

2 International Atomic Energy Agency, *Development of a common framework for addressing climate and environmental change in post-closure radiological assessment of solid radioactive waste disposal*, IAEA-TECDOC-1904, 2020. [Online]. Available: https://www.iaea.org/publications/13642/development-of-a-common-framework-for-addressing-climate-and-environmental-change-in-post-closure-radiological-assessment-of-solid-radioactive-waste-disposal.

3 *Modaria - modelling and data for radiological impact assessments web-site*. [Online]. Available: http://www-ns.iaea.org/projects/modaria/default.asp?l=116.

B1.3 WBS 10.3 - Radioecology

B1.3.1 MODARIA: Review and Update of Radioecological Data

Task Number	10.3.001	**Status**	Start date in FY2021/22
WBS Level 4	Biosphere		
WBS Level 5	Radioecology		
Background			
We are keeping a watching brief on work being undertaken by international bodies to review the approaches adopted to represent the biosphere during future climate change. This includes developing our understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota). International guidance recognises the importance of establishing the context and requirements for representing the biosphere. RWM contributes to collaborative work with sister WMOs, including the IAEA MODARIA programme. The assessment of exposures in planned, existing and emergency exposure situations requires situation-specific models supported by appropriate datasets and input parameters. There are several recent IAEA TRS publications which contain basic data about the human food chain and radionuclide transfer in the terrestrial environment. There is also an earlier TRS report containing data on marine systems. There are, however, many data gaps in the three IAEA TRS publications, as well as considerable variation in many of the parameter values. This task comprises a review of these new publications and their significance to the GDF programme. Findings of the review will be incorporated into an update of the biosphere assessment model currently used by RWM. The model update will enable new sources of information to be taken into account, along with updated guidance on the representation of potentially exposed groups and wildlife.			
Research Driver			
To support the ESC and its underpinning numerical performance assessment by analysing recent IAEA TRS publications to identify key radionuclides and to collate those parameter values which are required for RWM assessments of both human and wildlife exposure.			
Research Objective			
To identify the most important pathways and parameter values for different radionuclide source terms and exposure situations (human and wildlife) using the IAEA TRS publications. To identify key radionuclides so as to allow a process-based modelling approach to be developed which will enable the identification of the most radiologically sensitive species of wildlife and therefore to enable remedial actions, addressing those most vulnerable species, to be considered if required.			
Scope			
The scope comprises a critical evaluation of the TRS publications to identify which data gaps may be important in certain types of assessments (and which are not). The parameter value evaluations will be conducted using either: (a) widely available tools for humans and for wildlife; or (b) MODARIA participants' own models using a specific set of criteria for evaluating the importance of parameter values for humans and wildlife. The analysis of the relative importance of different parameter values for different radionuclides will enable the identification and prioritisation of key radionuclides for which a future process-based approach to modelling may be justified, as opposed to a simple empirical approach.			
Geology Application			
N/A			
Output of Task			

The output of the task will result in a contractor approved report.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					

There are other publications relevant to this task [1]–[4].

1 International Atomic Energy Agency, *Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments*, IAEA Report 472, 2010. [Online]. Available: http://www.iaea.org/publications/8201/handbook-of-parameter-values-for-the-prediction-of-radionuclide-transfer-in-terrestrial-and-freshwater-environments.

2 International Atomic Energy Agency, *Handbook of parameter values for the prediction of radionuclide transfer to wildlife*, IAEA Report 479, 2014. [Online]. Available: http://www.iaea.org/publications/10514/handbook-of-parameter-values-for-the-prediction-of-radionuclide-transfer-to-wildlife.

3 International Atomic Energy Agency, *Sediment distribution coefficients and concentration factors for biota in the marine environment*, IAEA Report 422, 2004. [Online]. Available: https://www.iaea.org/publications/6855/sediment-distribution-coefficients-and-concentration-factors-for-biota-in-the-marine-environment.

4 *Modaria - modelling and data for radiological impact assessments web-site*. [Online]. Available: http://www-ns.iaea.org/projects/modaria/default.asp?l=116.

B1.4 WBS 10.4 - Non-human biota

B1.4.1 MODARIA: Biota Modelling and Parameter Update

Task Number	10.4.001	**Status**	Start date in FY2021/22
WBS Level 4	Biosphere		
WBS Level 5	Non-human biota		
Background			
We are keeping a watching brief on work being undertaken by international bodies to review the approach adopted in representing the biosphere and its subsequent documentation. This includes developing understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota). RWM contributes to the International Atomic Energy Agency's MODARIA programme. The general aim of the MODARIA programme is to improve capabilities in the field of environmental radiation dose assessment by means of acquisition of improved data for model testing and comparison, reaching consensus on modelling philosophies, approaches and parameter values, development of improved methods and exchange of information. Most modelling approaches for the distribution of radioactivity in non-human biota assume heterogeneity of radioactivity in the body, which may not be appropriate. In addition, the concentration ratio (equilibrium) approach is used in most radioecological models and assumes the activity concentrations in the body of a selected plant or animal are in equilibrium with the surrounding medium; such an approach is used in the ERICA tool. However, there can be various physical, chemical and other environmental factors that affect equilibrium, as well as seasonal effects on biota such as changes in diet. In addition, equilibrium approaches have limited applicability in situations where environmental concentrations are changing rapidly with time and space, for example in accident scenarios. Predictions using the CR versus site-specific measurements can therefore vary by orders of magnitude. It is more appropriate to model the activity concentrations in selected biota using dynamic models. This task reviews the state-of-the-art on dynamic modelling.			
Research Driver			
To support the ESC by developing improved environmental dose assessment capabilities for biota exposures which have not yet been considered and to improve dynamic modelling approaches to incorporate adequate assessment of site heterogeneity and improved dosimetry.			
Research Objective			
To produce a guidance handbook for biota dose assessments which will: • Provide a more realistic representation of the exposure of organisms by representing radionuclide behaviour in the body; • Develop approaches for biota spatial modelling as an alternative to the typical assessment approach, focusing upon the maximum exposed individual or the average exposed individual; and • Develop a dynamic biota model assessment approach as an alternative to the CR (equilibrium) approach which can be utilised for non-equilibrium situations such as accident scenarios.			
Scope			
The scope comprises the development of a guidance handbook, its content covering the following:			

- Model applications: scenarios will be carefully selected for model comparison purposes, such as emergency exposure situations, technologically enhanced naturally occurring radioactive material releases, tropical and permafrost environments.
- Improved modelling tasks: dealing with non-equilibrium situations (such as those resulting from accidents); guidance for assessments for heterogeneous distribution of radionuclides in environmental media; improved dosimetry (in close coordination with the ICRP); and the spatial and temporal scale of biota assessment.

Geology Application					
N/A					
Output of Task					
The output of the task will result in a handbook published by the IAEA.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					

To be continued into possible MODARIA III project. There are other publications relevant to this task [1], [2].

1 UNSCEAR, *Annex A, levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-japan earthquake and tsunami, Appendix F (assessment of doses and effects for non-human biota)*, 2013. [Online]. Available: https://www.researchgate.net/publication/265253466_UNSCEAR_2013_Report_Volume_I_Report_to_the_General_Assembly_Annex_A_Levels_and_effects_of_radiation_exposure_due_to_the_nuclear_accident_after_the_2011_great_east-Japan_earthquake_and_tsunami.

2 *Modaria - modelling and data for radiological impact assessments web-site*. [Online]. Available: http://www-ns.iaea.org/projects/modaria/default.asp?l=116.

B1.4.2 MODARIA: Effects of Acute and Chronic Exposure on Wildlife

Task Number	10.4.002	**Status**	Start date in FY2021/22
WBS Level 4	Biosphere		
WBS Level 5	Non-human Biota		
Background			
We are keeping a watching brief on work being undertaken by international bodies to review the approach adopted in representing the biosphere and its subsequent documentation. This includes developing understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota). RWM contributes to the International Atomic Energy Agency's MODARIA programme. The general aim of the MODARIA programme is to improve capabilities in the field of environmental radiation dose assessment by means of acquisition of improved data for model testing and comparison, reaching consensus on modelling philosophies, approaches and parameter values, development of improved methods and exchange of information. Models should only be applied to representative wildlife species to assess population effects. Whilst there has been some work on defining RAP, there is still a need to reach consensus on a definition of a population (e.g. a sub-population) that is both scientifically relevant and appropriate from the viewpoint of radiological protection. This requires that exposure conditions, dose-response relationships for relevant life-history traits and life-history characteristics of the species over their entire life cycles are described and combined into population dynamics. In assessing the effects of radiation on non-human biota there is a need for a conceptual model which considers data from both acute and chronic radiation exposures (instead of using acute effect data to predict chronic situations). Ideally, a conceptual model would take account of both acute and chronic exposure situations (in order to make the best use of all available data). There is also a need for relevant chronic experimental and field data to calibrate such models so they are applicable to low dose exposure situations as well as to 'middle range' doses. This task, under the MODARIA project, focuses on improving the methodology for wildlife population dose assessment.			
Research Driver			
To support the ESC by improving our understanding of radiological consequences on populations of wildlife species, considering: exposure conditions; the total, and time dependent, absorbed dose; and dose response relationships (for relevant assessment endpoints).			
Research Objective			
To determine whether numeric criteria derived for individuals are representative of populations and to investigate whether the models that consider effects on populations, often based on acute effects data, are also applicable to chronic effects.			

Scope					
The scope comprises the development of a methodology for population modelling, incorporating estimation of radiation effects at the population level and including comparison and analysis of radiation dose effect models for different taxonomic groups (including terrestrial and aquatic invertebrates, fish and mammals). Also included is consideration of the modelling of acute versus chronic effects. It is important to distinguish between the two as one is significantly more likely to lead to permanent irradiation damage than the other. An initial approach was developed using an index of the ratio between effects and exposure time over lifespan. Acute dose is largely delivered over a timescale and level where recovery is not possible, whereas chronic exposure relates more to a time and intensity where recovery processes are possible. A simple logistic population model has now been developed based on a single age category which allows consideration of chronic or acute exposure. For acute exposure, the healthy group reduce exponentially whilst the unhealthy group initially increase before succumbing to mortality, whereas for chronic exposure, both repair and fecundity functions work to maintain the population.					
Geology Application					
N/A					
Output of Task					
Appropriately updated methodology captured in an IAEA document.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
To be continued into possible MODARIA III project.. Scope will be refined through the MODARIA project. Relevant further information can be found on the MODARIA website [1]. Related to Task 10.4.005 and Task 10.5.001. 1 *Modaria - modelling and data for radiological impact assessments web-site*. [Online]. Available: http://www-ns.iaea.org/projects/modaria/default.asp?l=116.					

B1.4.3 Further International Collaboration on Effects of Radiation on Non-human Biota

<table>
<tr><td colspan="2">Task Number</td><td>10.4.003</td><td>Status</td><td colspan="2">Start date in FY2021/22</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Biosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Non-human Biota</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">We are contributing to work with international bodies to review the approach adopted in representing the biosphere and its subsequent documentation. This includes developing understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota). RWM contributes to the International Atomic Energy Agency's MODARIA programme. The general aim of the MODARIA programme is to improve capabilities in the field of environmental radiation dose assessment. One of the outcomes of the MODARIA programme will be to establish an agreed international approach on non-human biota by: collating existing datasets; defining populations; developing conceptual models which take account of both acute and chronic exposure situations; and, considering non-heterogeneous distributions of radioactivity in the body. Such information will help in estimating the exposure of non-human biota to ionising radiation. There will be further interest in using such information to develop guidelines for the protection of non-human biota at national and international levels which may require further work. This task addresses such future development.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the ESC by providing an internationally agreed basis for the estimation of chronic radiological consequences on non-human biota.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop models, laboratory techniques and field studies further to increase our knowledge of the effects of radiation on non-human biota.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To revisit the effect of exposures to non-human biota when new data become available and models undergo significant development.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Appropriately updated methodology captured in an IAEA document.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">Current work in this area is being undertaken through the MODARIA and BIOPROTA international collaborations. This task may be continued into possible MODARIA III project. These collaborative programmes are highly cost-effective in sharing the financial burden of large studies and in developing international consensus in a potentially contentious area. It is assumed that this rationale will continue and will support this task. There are other publications relevant to this task [1], [2].Related to Task 10.4.005 and Task 10.5.001.

1 Modaria - modelling and data for radiological impact assessments web-site. [Online]. Available: http://www-ns.iaea.org/projects/modaria/default.asp?l=116.
2 Bioprota web-site. [Online]. Available: http://www.bioprota.org/.</td></tr>
</table>

B1.4.4 Consideration of Non-human Biota in Deep Groundwater

<table>
<tr><td>Task Number</td><td>10.4.004</td><td>Status</td><td>Start date in FY2021/22</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Biosphere</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Non-human Biota</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Subterranean ecosystems have long been considered as extreme environments inhabited by only a few specialised species. This assumption is now being revised, as many studies show that this environment harbours diverse animal communities (mainly invertebrates) across different space and time scales [1]. Biodiversity patterns of subterranean terrestrial and aquatic ecosystems may differ from other environments due to the different features of the subsurface environment (absence of light, limited variations in temperature, paucity of food, high physical fragmentation). These differences and influences need to be explored.

Terrestrial subterranean habitats encompass the whole unsaturated zone (vadose zone) of underground, most evident in karstic areas (caves, fissures, cracks, etc.). Because they develop in rocks or sediments that protect them against surface environmental changes, these subterranean ecosystems, in contrast to most surface ecosystems which are short-lived (rivers, wetlands, or forests), may persist relatively unchanged for millions of years.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">RWM has considered microbial activity close to a GDF in the wastes and materials used to construct certain engineered barriers and during operations. Our work on microbial activity in the geosphere is summarised in the Geosphere Status Report [2]. However:

• there is currently no work in RWM to assess the impact of radioactivity or non-radiological pollutants on subterranean environments;
• there is a need for consistency in approach to the assessment of the impact of radioactive and non-radioactive contaminants on non-human biota in the surface environment; and
• the EA has identified this as a gap in RWM’s knowledge base.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">The purpose of this research is to understand the patterns, processes, and determinants of subterranean biodiversity.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">Only by understanding the known characteristics of such systems can we begin to scope out how to assess the effect on these systems of different pollutants from the GDF. The fundamental questions to be asked at such an early stage of study include the following:

• What are the characteristics of subterranean (aquatic and terrestrial) biodiversity?
• Why do subterranean patterns of biodiversity differ markedly from those of surface habitats?
• What can we learn about the origin and causes of biodiversity of subterranean ecosystems?</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
</table>

A contractor report summarising the current knowledge of the topic.					
SRL/TRL at Task Start	SRL 1	**SRL/TRL at Task End**	SRL 2	**Target SRL/TRL**	SRL 2
Further Information					

1 J. Gibert and L. Deharveng, *Subterranean ecosystems: A truncated functional biodiversity*. BioScience, vol. 52, pp. 473–481, Issue 6 2002. [Online]. Available: https://academic.oup.com/bioscience/article/52/6/473/240329#:~:text=Subterranean%20Ecosystems%3A%20A%20Truncated%20Functional%20Biodiversity%3A%20This%20article,this%20truncation%20both%20from%20functional%20and%20evolutionary%20perspectives.

2 Radioactive Waste Management, *Geological disposal: Criticality safety status report*, RWM Report DSSC/458/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-criticality-safety-status-report/.

B1.4.5 A Review of the Knowledge Base of the Effect of Non-radiological Pollutants on Non-human Biota

Task Number	10.4.005	**Status**	Start date in FY2021/22
WBS Level 4	Biosphere		
WBS Level 5	Non-human Biota		

Background

The need for an improved understanding of the impacts of non-radiological pollutants on non-human biota falls under the general heading of ecotoxicology and, as such, faces many of the same challenges related to ecotoxicology.

Ecotoxicology is the study of how chemicals interact with organisms in the environment. Environments that are potentially at risk vary greatly and include marine and freshwater environments, terrestrial environments and even the air, in which respiratory exposures and foliar uptake by plants can occur. Organisms at risk from chemical exposures include plants, fungi, and algae (primary producers); invertebrates (such as worms, bugs, beetles, and molluscs); fish; amphibians; reptiles; birds; and mammals.

Given this wide range of biodiversity, it is impossible to know everything about the potential ecotoxicological effects of chemicals [1]. Instead, ecotoxicologists rely on a small set of indicator organisms and an understanding of how the physiochemical properties of compounds cause them to partition in the environment and organisms.

Ecotoxicological research has tended to focus principally on the development of practical techniques to evaluate the potential toxicity of chemicals in the environment and the likelihood that organisms will be exposed to dangerous concentrations *in situ*. In particular, a great deal of effort has been put into developing toxicity test procedures that not only use mortality as an endpoint, but also consider sub-lethal effects on growth, reproduction and viability of offspring. Similarly, attention has been paid to the chemical speciation, persistence and fate of contaminants in diverse environmental media, together with their accumulation and subsequent effects on biota [2].

Relative chemical hazards to terrestrial organisms do not necessarily follow the same patterns as those seen with aquatic organisms, necessitating separate testing and assessment schemes.

Research Driver

Although considerable scientific investigation into ecotoxicology has been undertaken, few of the more fundamental principles that underpin ecotoxicology and the general questions that must be addressed have been answered. The list of questions is long, reflecting the multi-disciplinary nature of ecotoxicology. Examples of some of key questions that still remain include the following:

- Prediction of ecotoxicological effects on individual species.
- Prediction of effects of pollutants on populations/communities.
- Can organisms and populations fully recover from pollutant exposure?
- What are the ecological consequences for populations and communities of organisms developing physiological tolerance or genetic resistance to exposure to specific pollutants?
- How do mixtures of chemicals affect the toxicity of individual pollutants?

Research Objective

The objective of this work is to utilise the current understanding of existing pollutant effects in ecosystems and apply this knowledge to the non-radiological pollutants relevant to a GDF which are ecotoxic.

Scope					
The scope of work includes (but is not limited to) the following: • Identify ecotoxic substances in non-radiological pollutants in GDF inventory. • Identify the non-human biota affected by non-radiological pollutants that are of interest for the GDF (in a first instance, these could be the same RAPs used for radiation protection). • Review literature on ecotoxicology of these non-radiological pollutants in this subset of non-human biota. • Identify what environments (freshwater, soil, marine water, sediment) the subset of non-human biota inhabit (informs total system model of required output points in the geosphere/biosphere). • Consider possible effects of these ecotoxic non-radiological pollutants on this subset of non-human biota in the presence of mixtures of chemicals. • Expand the studies above to the effect of these non-radiological pollutants on communities. • Identify the relevant UK environmental protection legislation governing ecosystems in different environments. Note that a task specifying how a non-human biota assessment in the OESA and PCSA will be developed on a site-specific basis has been included in a current project on the use of biosphere data across different technical functions (Task 10.1.002).					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A contractor report summarising the current knowledge of the topic.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 3
Further Information					

1 H. Ali, E. Khan, and I. Ilahi, *Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity and bioaccumulation*. Journal of Chemistry, vol. 2019, 2019. [Online]. Available: https://www.researchgate.net/publication/331552340_Environmental_Chemistry_and_Ecotoxicology_of_Hazardous_Heavy_Metals_Environmental_Persistence_Toxicity_and_Bioaccumulation.

2 Defra and Hazardous Substances Advisory Committee, *HSAC paper on key research questions in ecotoxicology*, 2016. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/502254/hsac-paper-ecotoxicology-key-questions.pdf.

B1.5 WBS 10.5 - Non-radiological pollutants

B1.5.1 Effect of Multi-stressors in Addition to Radioactive Exposure

<table>
<tr><td colspan="2">Task Number</td><td>10.5.001</td><td>Status</td><td colspan="2">Start date in FY2023/24</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Biosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Non-radiological Pollutants</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The effects of radiation or chemical pollutants in the environment on biological systems are highly complex. It is very difficult to determine the relationship between a detectable effect in a system and the ultimate consequence for the organism or population. This relationship is particularly obscure where the level of exposure to the agent is very low or when multiple agents occur in the system under examination. Much of the uncertainty surrounding the risk of exposure to low doses of single or multiple stressors is due to this inability to determine risk associated with molecular effects [1].

Both field and laboratory studies are needed to form the scientific basis for environmental assessments. It is noted that field studies are generally based on chronic exposure, while laboratory studies usually use acute exposure, which may be part of an explanation for the different conclusions drawn from field and laboratory studies. In addition, field trials tend to emphasise single stressors and ignore possible combinations whilst laboratory experiments are generally unable to mimic the conditions in the natural environment.

More and more data have become available that suggest that compounds can exert effects in mixtures in concentration ranges in which the single contaminants do not show effects. There is still some debate as to whether the combined effects of multi-stressors and radiation are fundamentally additive, synergistic or antagonistic. [2].</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">There is a lack of understanding about the potential interactions among multiple stressors and the biological responses to multiple stressor exposures. Such understanding is needed to predict how different combinations of contaminants induce adverse effects on non-human biota in addition to the effect of single stressors.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">There is a need for a coordinated, multinational, multidisciplinary research programme to understand the effects of multiple stressors or mixed contaminant exposure conditions on life-history responses such as growth, reproduction and survival of ecosystems and individual species of non-human biota.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This is a highly complex issue in which the effect of multistressors is only just starting to be investigated in field studies. It is recommended that the task on review of the knowledge base of the effect of non-radiological pollutants on non-human biota should be completed first (Task 10.4.005), then a review of the effect of multistressors on non-human biota be carried out.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A contractor report summarising the current knowledge of the topic.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 1</td><td>SRL/TRL at Task End</td><td>SRL 2</td><td>Target SRL/TRL</td><td>SRL 2</td></tr>
</table>

Further Information

1 C. Mothersill, I. Mosse, and C. Seymour, *Multiple Stressors: A Challenge for the Future*. Springer, 2007, pp. 235–246. [Online]. Available: https://link.springer.com/book/10.1007/978-1-4020-6335-0.

2 C. Mothersill, M. Abend, F. Brechignac, D. Copplestone, S. Geraskin, J. Goodman, N. Horemans, P. Jeggo, W. McBride, T. Mousseau, A. OHare, R. Pappineni, G. Powathil, P. Schofield, C. Seymour, J. Sutcliffe, and B. Austin, *The tubercular badger and the uncertain curve: The need for a multiple stressor approach in environmental radiation protection*. Environmental Research, vol. 168, pp. 130–140, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0013935118305176.

B1.5.2 Development of Safety Case Claims, Arguments and Evidence in Consideration of Non-radiological Pollutants

Task Number	10.5.002	**Status**	Start date in FY2020/21
WBS Level 4	Biosphere		
WBS Level 5	Non-radiological Pollutants		

Background

Radioactive wastes that are consigned to a GDF will contain non-radiological pollutants. Non-radiological pollutants will also be present in the waste package, buffer/backfill and the structural components of the facility. The safety case developed for the GDF, which considers the transportation of waste from the site of arising to the GDF, the construction and operation of the GDF and its subsequent long-term evolution post-closure, needs to demonstrate that the impact of radioactive wastes and of non-radiological pollutants on humans and the environment, including non-human biota (flora and fauna), meets regulatory requirements. These requirements include the protection of groundwater; aerial discharges during waste transportation and GDF operations also need consideration.

A RI, relating to understanding the non-radiological component of the wastes, was raised in May 2018. The RI specifies several actions for RWM to address the requirement that the GDF provides adequate protection against non-radiological pollutants.

RWM is undertaking a programme of work to identify the non-radiological pollutants of potential importance for a GDF in the context of the protection of groundwater, and to quantify the amount of these pollutants that will be present in the GDF:

- Updated its Implementation Plan which outlines the work to understand the potential impact of the GWD requirements on several RWM work areas, and the implications for our safety cases.
- The 2019 UK Radioactive Waste Inventory template now includes data fields for significant non-radiological pollutants of concern identified by RWM.
- Developed a non-radiological pollutant screening methodology and a total system model (TSM) and carried out assessment work on non-radiological pollutants. The two sets of modelling results are complete and the reports published [1].
- Identified a list of non-radiological pollutants currently considered to be of potential importance for the GDF which will be referred to in the updated Level 2 waste package specification document.
- Planning a further modelling project on the behaviour of non-radiological pollutants in an evaporite geology.
- Carrying out an experimental programme on the degradation and solubility on organic non-radiological pollutants in the near field environment of a GDF.
- Forming an Integrated Project Team (IPT) to assess the impact of non-radiological pollutants across different technical functions within RWM.

Research Driver

Addressing EC Groundwater Daughter Directive requires that the disposal safety case should consider non-radiological pollutants as well as radionuclides.

Addressing Environmental Agency ‘Observations’ on non-radiological pollutants in RWM safety case.

Research Objective					
To establish an integrated project team to develop the safety case claims, arguments and evidence for non-radiological pollutants related to the UKRWI and the UK GDF. This IPT will bring together ongoing and preceding work within an overall framework, identify knowledge gaps in the current programme of work, and undertake and deliver studies to ensure RWM's position on non-radiological pollutants meets regulatory requirements.					
Scope					
The integrated project will consist of two phases. Phase 1 shall consist of: • the delivery of a roadmap that will present reasoned and prioritised plans for a structured programme of work, to be undertaken in Phase 2 of the project, that will attain the overall project objective of the development of safety case CAE in consideration of non-radiological pollutants in the context of a UK GDF. Phase 2 shall consist of: • the implementation of the roadmap: this could include both desk-based and, if deemed to be a suitable priority, small and large-scale laboratory-based activities.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of Phase 1 is likely to be a number of contractor-approved reports.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
RWM is engaging internationally with other waste management organisations on non-radiological pollutants, e.g. through the BIOPROTA forum. RWM is liaising with Low Level Waste Repository Ltd. and the Nuclear Decommissioning Authority on common issues with non-radiological pollutants, particularly on the derivation of the radiological pollutant inventory. 1 J. Dowle, L. Limer, J. Wilson, and M. Thorne, *Development of a total system model for non-radiological pollutants in a GDF*, Nucleus, Contractor Report RWM/Contr/19/005, 2019. [Online]. Available: http://rwm.nda.gov.uk/publication/development-of-a-total-system-model-for-non-radiological-pollutants-in-a-gdf/.					

B1.6 WBS 10.6 - Estuarine and marine systems

B1.6.1 Updated Marine Model for Climate States Posing a Potential Challenge to the Risk Guidance Level

Task Number		10.6.001	**Status**	Start date in FY2023/24	
WBS Level 4		Biosphere			
WBS Level 5		Estuarine and Marine Systems			
Background					
It is important to consider long-term climate change when representing the biosphere in post-closure assessments. The BIOCLIM project provided the basis for the climate change scenarios that RWM considers in biosphere assessments studies. The science that underpins climate change modelling and the associated modelling capabilities continues to develop. Given recent developments in climate modelling, there is an opportunity to build on the methodology developed in the BIOCLIM project. This would greatly improve the actual predictions made in BIOCLIM by utilising state-of-the-art climate modelling tools and techniques whilst also reviewing the representation of future biosphere scenarios. We aim to increase our understanding of the expected evolution of the geosphere and biosphere and associated consequences for the GDF in response to natural processes with the objective of providing an integrated description of the expected evolution of the surface and sub-surface environments over the timescale of around one million years relevant to geological settings in the UK. Our current marine model corresponds to the temperate terrestrial model used for the PCSA. Since its development, further terrestrial models have been developed for other climate states (tropical, boreal and glacial). This task comprises the development of marine models for these alternative climate states at a site-specific level.					
Research Driver					
To support the post-closure safety case and its underpinning numerical performance assessment by developing an understanding of the site-specific consequences of potential impacts due to climate change on the safety performance of the GDF for different marine scenarios (sea level rise/fall, changes in estuaries, etc.).					
Research Objective					
To determine whether climate change will lead to a site-specific marine pathway which gives rise to doses of significance in comparison to the terrestrial pathway.					
Scope					
The scope comprises the site-specific development of marine models for alternative climate states (tropical, boreal and glacial) which could be used in conjunction with their corresponding terrestrial model.					
Geology Application					
N/A					
Output of Task					
Details of long-term climate prediction for two sites reported in an approved contractor report, models and underpinning data sets.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information
The relevance of this work may be site specific and may be deferred until a site has been identified as requiring this study. Relevant further information can be found in several reports [1]–[4].

1 R. Walke, M. Thorne, and J. Smith, *RWMD Biosphere Assessment Model: Marine Component*, AMEC and Quintessa, Contractor Report 18025/TR/001, Issue 2.0, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/18025tr001%5C_marine%5C_issue2/.

2 R. Walke, M. Thorne, and L. Limer, *RWMD Biosphere Assessment Model: Terrestrial Component*, AMEC and Quintessa, Contractor Report 18025/TR/002, Issue 2, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/biosphere-assessment-model-terrestrial-component/.

3 J. Becker, T. Lindborg, and M. Thorne, *Influence of climate on landscape characteristics in safety assessments of repositories for radioactive wastes*. Journal of Environmental Radioactivity, no. 138, pp. 192–204, 2014.

4 M. Thorne, R. Walke, and M. Kelly, *Representation of climate change and landscape development in post-closure radiological impact assessments*, AMEC and Quintessa, Contractor Report QRS/1667A/1, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/representation-of-climate-change-and-landscape-development-in-post-closure-radiological-impact-assessments-qrs1667a1/.

B1.7 WBS 10.7 - Historical, current and future climate

B1.7.1 Impact of Climate State Transitions

Task Number		10.7.001	**Status**	Start date in FY2025/26	
WBS Level 4		Biosphere			
WBS Level 5		Historical, Current and Future Climate			
Background					
It is important to consider long-term climate change in representing the biosphere in post-closure assessments. The BIOCLIM project provided the basis for the climate change scenarios that RWM considers in biosphere assessment studies. The science that underpins climate change modelling and the associated modelling capabilities continue to develop; given recent developments in climate modelling, there is an opportunity to build on the methodology developed in the BIOCLIM project. This will improve the actual predictions made in BIOCLIM by utilising state-of-the-art climate modelling tools and techniques whilst reviewing the representation of future biosphere scenarios. The IAEA has set up the MODARIA programme which includes a working group addressing environmental change in long-term safety assessments of radioactive waste disposal facilities. The working group has the specific aim of updating the predictions made in BIOCLIM by utilising improved state-of-the-art climate modelling tools and techniques. It has as its members recognised experts in climate modelling and biosphere development. RWM is playing a significant role and has set up a study to review UK climate change scenarios. This task will assist in the development of robust long-term predictions of future climate using plausible sequences of climate scenarios (sub-tropical, temperate, boreal, glacial), including understanding the transitions between the scenarios. This will determine if the change from one climate scenario to another could lead to significant doses above those of the initial and subsequent climate states.					
Research Driver					
To support the ESC for the distant post-closure phase by developing our understanding of the potential radiological impacts of transitions between climate states (sub-tropical, temperate, boreal, glacial).					
Research Objective					
To determine whether the dose to a population from the transition between climate states is bounded by the temperate climate model as propounded in the generic Disposal System Safety Case.					
Scope					
The scope comprises the activities of the collaborative international MODARIA working group on climate change, which will explore transitions between different climate states.					
Geology Application					
N/A					
Output of Task					
There has been little work on climate transitions. There is an IGD-TP proposed group on climate change which RWM is participating in; this could be raised as a topic in that group.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 5

Further Information
This task may need to be revisited circa 2025 unless radical new understanding challenges this approach. There are several publications relevant to this task [1]–[3].

1 SKB, *Climate and Climate-related Issues for the Safety Assessment SR-Site*, SKB Report TR-10-49, 2010. [Online]. Available: http://www.skb.com/publication/2160581/TR-10-49.pdf.

2 J. Becker, T. Lindborg, and M. Thorne, *Influence of climate on landscape characteristics in safety assessments of repositories for radioactive wastes*. Journal of Environmental Radioactivity, no. 138, pp. 192–204, 2014.

3 M. Thorne, R. Walke, and M. Kelly, *Representation of climate change and landscape development in post-closure radiological impact assessments*, AMEC and Quintessa, Contractor Report QRS/1667A/1, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/representation-of-climate-change-and-landscape-development-in-post-closure-radiological-impact-assessments-qrs1667a1/.

B1.7.2 Periodic Review of Climate Change Understanding

<table>
<tr><td colspan="2">Task Number</td><td>10.7.002</td><td>Status</td><td colspan="2">Start date in FY2028/29</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Biosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Historical, Current and Future Climate</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">It is important to consider long-term climate change in representing the biosphere in post-closure assessments. The BIOCLIM project provided the basis for the climate change scenarios that RWM considers in biosphere assessment studies. The science that underpins climate change modelling and the associated modelling capabilities continues to develop and it is anticipated that future advances will require a periodic update to our understanding of climate change in the context of a UK GDF. This task comprises such a review.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop an understanding of how climate states (other than temperate) impact on biosphere assessments of the effects on human and non-human biota of radioactivity emerging from the geosphere in the vicinity of a GDF.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop an improved understanding of climate sequences and the associated land use, human habits, etc. in order to determine whether this will support the choice of a bounding climate state.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To revisit the analysis of climate sequences following significant development of climate change models.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">There is an IGD-TP proposed group on climate change which RWM is participating in; this could be raised as a topic in that group.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1], [2].
1 International Atomic Energy Agency, Development of a common framework for addressing climate and environmental change in post-closure radiological assessment of solid radioactive waste disposal, IAEA-TECDOC-1904, 2020. [Online]. Available: https://www.iaea.org/publications/13642/development-of-a-common-framework-for-addressing-climate-and-environmental-change-in-post-closure-radiological-assessment-of-solid-radioactive-waste-disposal.
2 Modaria - modelling and data for radiological impact assessments web-site. [Online]. Available: http://www-ns.iaea.org/projects/modaria/default.asp?l=116.</td></tr>
</table>

B1.7.3 Downscaling Global Climate Data

Task Number	10.7.003	**Status**	Start date in FY2023/24
WBS Level 4	Biosphere		
WBS Level 5	Historical, Current and Future Climate		
Background			
Global climate models, as used in support of post-closure safety assessments, typically provide results at a grid scale of more than 100 km by 100 km. This scale is too coarse for application to local areas or specific sites in post-closure performance assessments, so consideration has been given as to how such results can be downscaled to a finer resolution.This is addressed by downscaling the outputs from global/regional climate models and assessing the local implications for both climate and landscape. Outputs from both the climate modelling and the landscape development studies can then be used to define the structure and boundary conditions used directly in, or in support of, performance assessment modelling, e.g. in hydrogeological and hydrogeochemical models, as well as in the context of site selection and repository design. Three approaches to downscaling exist [1]: *rule-based downscaling*, in which selected results from a coarse, long-term climate model are used to define rules by which future conditions at a site are classified into one of a small number of climate classes that can be characterised in terms of present-day instrumental data from various meteorological stations; *dynamical, or model-based, downscaling*, in which a regional climate model is embedded within a global model and takes its boundary conditions from the global model; and *physical-statistical downscaling*, in which instrumental records are interpreted using a statistical regression technique informed by an understanding of the factors that affect local climate [2]. Recent work within the RWM programme has focused on the development of an emulator of global long-term climate change that interpolates between results of individual detailed model simulations. This approach is best matched to a physical-statistical approach to downscaling in which the choice of variables to be used in the statistical analysis is informed by physical insights into the factors determining climate at a local scale.			
Research Driver			
Climate projections are used to support performance assessment models of the disposal system and it is necessary to downscale from global climate model output scales to specific site/area scales.			
Research Objective			
The objective of this work is to identify an approach for downscaling the global projections to regional and site-scales in the UK in order to provide information that may be needed for site-specific assessments.			
Scope			
The scope of work includes (but is not limited to) the following: • To provide a detailed methodology as to how downscaling of climatic characteristics from a regional (100-200 km) to a local (5-10 km) scale can be achieved for different future carbon emissions scenarios. • To show how the resulting downscaled climate predictions can be used to determine how the landscape local to a GDF would change. • To apply the downscaling technique to the (assumed) two sites selected for intrusive characterisation.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

A contractor report summarising the current knowledge of the topic.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					

1 M. Thorne, R. Walke, and D. Roberts, *Downscaling of climate modelling results for application to potential sites for a geological disposal facility*, AMEC and Quintessa, Contractor Report AMEC/200041/002, 2015.

2 M. Thorne and G. Towler, *Evolution of the British Landscape and its Implications for Post-Closure Safety Assessment of a Geological Disposal Facility*, AMEC and Quintessa, Contractor Report AMEC/200041/003; QRS-1667A-3, 2017. [Online]. Available: https://rwm.nda.gov.uk/publication/evolution-of-the-british-landscape-and-its-implications-for-the-post-closure-safety-assessment-of-a-geological-disposal-facility/.

B1.8 WBS 10.8 - Near surface hydrology

B1.8.1 BIOPROTA: Geosphere / Biosphere Interface Modelling

<table>
<tr><td colspan="2">Task Number</td><td>10.8.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Biosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Near-surface Hydrology</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Since long-term releases from disposal facilities involve transfers from the geosphere to the biosphere, an important aspect is the combined effects of surface hydrology, near-surface hydrogeology and chemical gradients on speciation and radionuclide mobility in the zone in which the geosphere and biosphere overlap (the GBI). A methodology was developed for characterising the GBI in a wide range of assessment contexts. Three illustrative climate and landscape evolution scenarios were then described and the methodology developed for characterising the GBI was applied to two of these three scenarios in order to define a set of GBI sub-systems for which conceptual models need to be developed. This then led into application of the second part of the methodology for creation of these conceptual models. Consideration has been given to the range of mathematical and computational tools that are available for implementing the conceptual models. Recommendations have been made as to how work in this area could be developed in the future.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the post-closure safety case and its supporting performance assessment by developing an improved understanding of the coupling between the geosphere and biosphere.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine whether an improved understanding of the GBI will support the simplified uncoupled approach used in the performance assessment.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following:
Preparation of a BIOPROTA report setting out the various types of GBI that have been considered in previous assessments, the factors distinguishing qualitatively different types of GBI and the ways in which these different types of GBI could be affected by environmental change.
A two-day workshop to refine the descriptions of the various types of GBI and identify those to be studied in detail.
Consideration of the scenarios that are to be taken forward for detailed study in Task 10.6.001.
Continuing involvement in a possible successor project within BIOPROTA.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report on the further understanding gained of the GBI and a workshop on further consideration of mathematical treatment and method for hydrological mass-transport in the near-surface, considering various GBIs.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [1]–[3].

1 G. Smith, K. Smith, R. Kowe, D. Perez-Sanchez, M. Thorne, Y. Thiery, and J. Molinero, *Recent developments in assessment of long-term radionuclide behaviour in the geosphere biosphere subsystem*. Journal of Environmental Radioactivity, vol. 131, pp. 89–109, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0265931X130023369.

2 BIOPROTA, *An exploration of approaches to representing the geosphere-biosphere interface in assessment models - final report on the project*, Version 2.0, 2014. [Online]. Available: http://www.bioprota.org/wp-content/uploads/2015/01/BIOPROTA_GBI_Final_Report_11_December_14.pdf.

3 *Bioprota web-site*. [Online]. Available: http://www.bioprota.org/.

B2 WBS 20 - Criticality Safety

Criticality safety can be defined [1] as protection against the consequences of an inadvertent nuclear chain reaction, preferably by prevention of the chain reaction. The generic research activities can be summarised into the following work areas:

- Transport criticality safety **(WBS 20.1)**
- Operational criticality safety **(WBS 20.2)**
- Post-closure criticality safety for LHGW**(WBS 20.3)**
- Post-closure criticality safety for HHGW Spent Fuel **(WBS 20.4)**
- Post-closure criticality safety for HHGW Plutonium and HEU**(WBS 20.5)**
- Criticality safety assessments **(WBS 20.6)**

Research activities within **WBS 20.1** and **20.2** will demonstrate safety and ensure that criticality events do not occur during the transport and operational phase of the GDF lifecycle. The tasks will involve supporting concept development and in the latter years of the plan will result in optimised transport criticality safety assessment for the DCTC and SWTC as detailed in Task 20.1.006 and Task 20.1.008. WBS 20.2 will ultimately provide the support in order to develop and optimise a draft criticality emergency plan for the GDF (Task 20.2.005).

WBS 20.3, 20.4 and **20.5** will provide data and understanding on the likelihood of post-closure criticality events in order to demonstrate that RWM can ensure criticality safety in a GDF. The research activities will continue to support the low-likelihood, low-consequence criticality limits, by reviewing proposed waste packages, as well as maintaining support to waste packaging proposals and continuing to review and fully document the operational criticality safety evidence base.

To ensure post-closure criticality safety for LHGW (**WBS 20.3**), the generic work will lead into the review of extant criticality safety assessments against site-specific data and revise them (if required) under the site-specific design, inventory and geological context, therefore ensuring the post-closure criticality safety evidence base is up-to-date.

The outcome of **WBS 20.4** will demonstrate that the nuclear reactivity of spent fuel is at an acceptable level, and will support concept development for Spent Fuel disposal by ensuring criticality safety of future fuels through the transport, operational and post-closure phases, including the use of site-specific data (Task 20.4.005 and Task 20.4.007), with the outcomes of these tasks inputting to the safety case.

Planned tasks within WBS 20.5 will constitute part of the Plutonium IPT (Task 110.3.003) to support concept development by developing a criticality safety assessment for a preferred disposal concept for plutonium residues. In the latter years of the timescale the work will result in an in optimised criticality safety assessment for a plutonium disposal concept based on transport considerations and site-specific data, as well as optimised criticality safety assessments for highly-enriched uranium wastes.

Planned tasks within **WBS 20.6** will support the environmental safety case by conducting site-specific post-closure criticality consequence assessments at the point at which there are two sites (planning assumption) in the siting programme.

B2.1 WBS 20.1 - Transport criticality safety

B2.1.1 Scoping Criticality Safety Assessment for Robust Shielded Box Transport Container

<table>
<tr><td colspan="2">Task Number</td><td>20.1.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Transport Criticality Safety</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety.
With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK).
Recent work has developed a TRL 3 conceptual design for a Type B transport container (RSBTC suitable for waste packages, including the Magnox Type VI Yellow Box® DCICs and Sellafield Limited Self-Shielded Boxes). The current contents specification for this transport container is for non-fissile or fissile excepted packages only, however there are proposals to transport fissile packages in such a container and therefore work is required to develop the criticality safety assessments for the RSBTC.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development by identifying waste package fissile material limits for ILW packages transported in a RSBTC.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake scoping studies to demonstrate criticality safety during ILW transport in a RSBTC by the derivation of appropriate package fissile material limits.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of waste packages to be transported in a RSBTC. This scoping stage will investigate simple geometries and optimisation of parameters to give a baseline understanding of potential fissile material limits that rely on few compliance controls.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. The report(s) will also detail potential areas to increase package fissile material limits if required.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 3</td><td>SRL at Task End</td><td>SRL 4</td><td>Target SRL</td><td>SRL 5</td></tr>
</table>

Further Information
Work is to be undertaken aligned with relevant regulations and guidance [1], [2]. 1 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf. 2 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.2 Detailed Criticality Safety Assessment for Robust Shielded Box Transport Container

<table>
<tr><td colspan="2">Task Number</td><td>20.1.002</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Transport Criticality Safety</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the International Atomic Energy Agency's Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK).
Recent work has developed a TRL 3 conceptual design for a Type B transport container (RSBTC suitable for waste packages, including the Magnox Type VI Yellow Box®DCICs and Sellafield Limited Self-Shielded Boxes). The current contents specification for this transport container is for non-fissile or fissile excepted packages only, however, there are proposals to transport fissile packages in such a container and therefore work is required to develop the criticality safety assessments for the RSBTC.
Following Task 20.1.001, which developed scoping level calculations for the RSBTC, this task will refine these and undertake detailed calculations to derive package fissile material limits.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development by identifying waste package fissile material limits for ILW packages transported in a RSBTC.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake detailed studies to demonstrate criticality safety during ILW transport in a RSBTC by the derivation of appropriate package fissile material limits.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of waste packages to be transported in a RSBTC. This detailed stage will follow Task 20.1.001, scoping stage, to investigate more complex geometries and also optimisation of parameters to allow credit to be taken for beneficial attributes such as the presence of neutron absorbers or diluents. This will give a refined understanding of potential fissile material limits that rely on more compliance controls. It may be identified that the scoping stage derives package fissile material limits that are sufficient; in this case, this task will build on those modelled parameters to develop a more detailed model to align with relevant transport regulations and guidance.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 4</td><td>SRL at Task End</td><td>SRL 5</td><td>Target SRL</td><td>SRL 5</td></tr>
</table>

Further Information
Work is to be undertaken aligned with relevant regulations and guidance [1], [2]. 1 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf. 2 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.3 Criticality Safety for the Disposal of Spent Fuel - Water Carry-over Compliance Validation

Task Number		20.1.003	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Transport Criticality Safety			
Background					
The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK). Preliminary work has shown that a DCTC containing spent fuel with higher uranium-235 enrichments cannot be shown to remain safely sub-critical. The preferred solution has been identified to incorporate multiple high-standard water barrier features in the DCTC design. Criticality safety analysis has shown that such features would enable a demonstration that the packages remain safely sub-critical. A conceptual design for a DCTC incorporating multiple high-standard water barriers features has been developed. The use of multiple high-standard water barrier features is novel in the UK and further work is required to demonstrate that the conceptual design can be licensed. It has been shown that the limit on water is not zero, i.e. no water present at all, but rather a small amount of water can be present. A significant fraction of UK spent fuel is currently wet-stored, and therefore introduction of water through carry-over needs to be accounted for and the package's safety demonstrated to be robustly underpinned.					
Research Driver					
To support concept development for spent fuel disposal by identifying candidate safe moderator (water) mass limits and the availability of records to demonstrate robust compliance.					
Research Objective					
To undertake a review of water carry-over limits to define requirements and necessary compliance records.					
Scope					
This task will define requirements to satisfy compliance with water carry-over limits based on conceptual models developed previously and identify how such requirements can be demonstrated for the range of spent fuels in the inventory for geological disposal. If it is found that challenges exist with demonstrating compliance with suitable records, further work will be developed to minimise the risk that the DCTC containing spent fuel cannot be safely transported to the GDF.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a set of requirements for demonstrating compliance with identified water carry-over limits and identification of whether such information is currently available. If the information is not available, it will identify possible alternatives to demonstrating the criticality safety of spent fuel during transport to a GDF in a DCTC, this will be documented in a contractor approved report.					
SRL at Task Start	SRL 5	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6

Further Information
There are several publications relevant to this task [1], [2]. Work is to be undertaken aligned with relevant regulations and guidance [3], [4].

1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/.

2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

3 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf.

4 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.4 Scoping Transport Phase Criticality Safety Assessment - Plutonium IPT

<table>
<tr><td colspan="2">Task Number</td><td>20.1.004</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Transport Criticality Safety</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK).
The NDA is evaluating options for putting the UK’s plutonium stockpile out of reach in support of the Government’s policy for the future management of the UK’s plutonium stockpile. Whilst the disposition of the UK’s bulk civil grade plutonium stockpile is yet to be determined, there is a need to develop a disposal concept for the portion of plutonium which cannot be reused.
An IPT has been formed to support NDA and de-risk future activities in this area and as part of this project, criticality safety of identified disposal concepts during the transport phase will need to be considered.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development for plutonium disposal by developing outline criticality safety controls for identified disposal concepts during the transport phase.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake scoping studies to demonstrate criticality safety during plutonium transport in identified disposal concepts by the derivation of appropriate package fissile material limits.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This task will include a computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for plutonium wastes to be transported in identified disposal concepts. This scoping stage will investigate simple geometries and optimisation of parameters to give a baseline understanding of potential fissile material limits. It is anticipated that during the plutonium IPT (see Task 110.4.003 and Task 110.4.004), a preferred disposal concept or concepts will be identified and these will be the basis of the work.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. The report(s) will also detail potential areas to facilitate an increase in package fissile material limits if required.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 3</td><td>SRL at Task End</td><td>SRL 4</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
It is anticipated that this task is likely to run in parallel with Task 20.2.004 for the operational phase and activities in the "Develop Understanding, Data & Models (as Appropriate) to Demonstrate Disposability of HHGW – Plutonium and HEU" activity 'lane'. It is also dependent on disposal concepts being identified, and will only be able to start once such disposal concepts have been defined. Work is to be undertaken aligned with relevant regulations and guidance [1], [2]. 1 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf. 2 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.5 Detailed Transport Criticality Safety Assessment for the Disposal Container Transport Container (DCTC)

<table>
<tr><td colspan="2">Task Number</td><td>20.1.005</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Transport Criticality Safety</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK).

Previous studies have identified the preferred option for the transport and disposal of spent fuel should RWM's illustrative disposal concept be used, which includes transport in the DCTC. A scoping criticality safety assessment has been developed for the DCTC, however, this will need to be developed further as more information becomes available on the inventory of spent fuel for disposal and site-specific information becomes available. This work is planned on the anticipation that the DCTC is used in the selected disposal concept; however, if this is not the case then similar work will be required for the selected transport container.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the GDF programme by developing and maintaining transport container design to demonstrate that spent fuel can be safely transported to the GDF.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake detailed studies to demonstrate criticality safety of spent fuel during transport by the derivation of appropriate package fissile material limits and associated compliance requirements.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a detailed computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for spent fuel in disposal containers. The study will build on the existing criticality safety assessments for the DCTC based on available data such as site-specific parameters and will also include all spent fuel in the inventory for geological disposal. It will also consider how compliance with any requirements would be demonstrated.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits for spent fuel and the methodology for deriving such limits, along with underlying model input data. It will also identify compliance requirements.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 4</td><td>SRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1], [2].Work is to be undertaken aligned with relevant regulations and guidance [3], [4].

1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/.

2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

3 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf.

4 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.6 Optimised Transport Criticality Safety Assessment for the Disposal Container Transport Container (DCTC)

<table>
<tr><td>Task Number</td><td colspan="2">20.1.006</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Transport Criticality Safety</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely subcritical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK).

Previous studies have identified the preferred option for the transport and disposal of spent fuel should RWM's illustrative disposal concepts be used, which includes transport in the DCTC. A scoping criticality safety assessment has been developed for the DCTC and Task 20.1.005 will extend this to a detailed assessment. As more specific information becomes available and concepts are more refined, an optimised assessment will be developed that will eventually feed into the package design report for submission. This work is planned in anticipation that the DCTC is used in the selected disposal concept; however, if this is not the case, then similar work will be required for the selected transport container.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the GDF programme by developing and maintaining transport container designs to demonstrate that spent fuel can be safely transported to the GDF.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake optimised studies to demonstrate criticality safety of spent fuel during transport by the derivation of appropriate package fissile material limits and associated compliance requirements.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake an optimised computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for spent fuel in disposal containers. The study will build on the existing criticality safety assessments for the DCTC based on available data such as site-specific parameters and will also include all spent fuel in the inventory for geological disposal. It will also consider how compliance with any requirements would be demonstrated.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits for spent fuel and the methodology for deriving such limits, along with underlying model input data. It will also identify compliance requirements.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 5</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1], [2]. Work is to be undertaken aligned with relevant regulations and guidance [3], [4].

1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/.

2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

3 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf.

4 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.7 Detailed Transport Criticality Safety Assessment for the Standard Waste Transport Container (SWTC)

<table>
<tr><td>Task Number</td><td colspan="2">20.1.007</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Transport Criticality Safety</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK).
Previous work has developed a CSA for a range of ILW packages destined for transport in the SWTC. As more specific information becomes available and concepts are more refined, a detailed assessment will be developed that will further identify compliance requirements to ensure that the transport of fissile wastes can be performed safely.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the GDF programme by developing and maintaining transport container designs to demonstrate that ILW can be safely transported to the GDF.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake detailed studies to demonstrate criticality safety of various ILW packages during transport in the SWTC by the derivation of appropriate package fissile material limits and associated compliance requirements.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a detailed computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for various ILW packages during transport in the SWTC. The study will build on the existing criticality safety assessments for the SWTC based on available data such as site-specific parameters and will include as many ILW waste streams as required in the inventory for geological disposal.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits for ILW packages in the SWTC and the methodology for deriving such limits along with underlying model input data. It will also identify compliance requirements.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 4</td><td>SRL at Task End</td><td>SRL 5</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[3]. Work is to be undertaken aligned with relevant regulations and guidance [4], [5].

1 Sellafield Limited, *Part 3: Additional design information required for fissile materials*, CDSA/SWTC/CR01, 2015. [Online]. Available: https://www.nrc.gov/docs/ML1424/ML14246A472.pdf.

2 Sellafield Limited, *MONK calculations study to support a transport licence application for the standard waste transport container*, SCN-336, 2015.

3 Sellafield Limited, *MONK scoping calculations study to support a transport licence application for the standard waste transport container*, SCN-340, 2015.

4 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf.

5 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.8 Optimised Transport Criticality Safety Assessment for the Standard Waste Transport Container (SWTC)

Task Number		20.1.008	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Transport Criticality Safety			
Background					
The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK). Previous work has developed a criticality safety assessment for a range of ILW packages destined for transport in the SWTC. As more specific information becomes available and concepts are refined, a detailed assessment will be developed, Task 20.1.007. As more specific information becomes available and concepts are more refined, an optimised assessment will be developed that will eventually feed into the package design report for submission to the competent authority.					
Research Driver					
To support the GDF programme by developing and maintaining transport container design to demonstrate that ILW can be safely transported to the GDF.					
Research Objective					
To undertake optimised studies to demonstrate criticality safety of various ILW packages during transport in the SWTC by the derivation of appropriate package fissile material limits and associated compliance requirements.					
Scope					
To undertake an optimised computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for various ILW packages during transport in the SWTC. The study will build on the existing criticality safety assessments for the SWTC based on available data such as site-specific parameters and will include as many ILW waste streams as required in the inventory for geological disposal.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the derived package fissile material limits for ILW packages in the SWTC and the methodology for deriving such limits along with underlying data model input data. It will also identify compliance requirements.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6

Further Information
There are several publications relevant to this task [1]–[3]. Work is to be undertaken aligned with relevant regulations and guidance [4], [5].

1 Sellafield Limited, *Part 3: Additional design information required for fissile materials*, CDSA/SWTC/CR01, 2015. [Online]. Available: https://www.nrc.gov/docs/ML1424/ML14246A472.pdf.

2 Sellafield Limited, *MONK calculations study to support a transport licence application for the standard waste transport container*, SCN-336, 2015.

3 Sellafield Limited, *MONK scoping calculations study to support a transport licence application for the standard waste transport container*, SCN-340, 2015.

4 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf.

5 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.1.9 Scoping Transport Criticality Safety Assessment for the Preferred Plutonium Disposal Concept

Task Number	20.1.009	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Transport Criticality Safety		
Background			
The transport of radioactive waste to a GDF must meet the requirements of national legislation deriving from the IAEA Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety. With respect to criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely sub-critical in routine, normal and accident conditions of transport and approved by a Competent Authority (the ONR in the UK). The NDA is evaluating options for putting the UK's plutonium stockpile out of reach in support of the Government's policy for the future management of the UK's plutonium stockpile. Whilst the disposition of the UK's bulk civil grade plutonium stockpile is yet to be determined, there is a need to develop a disposal concept for the portion of plutonium which cannot be reused. An IPT has been formed to support NDA and de-risk future activities in this area and as part of this, criticality safety of identified disposal concepts during the transport phase will need to be considered. Upon the completion of the IPT (Task 110.4.003 and Task 110.4.004), it is assumed that a preferred disposal concept or concepts will be identified. Upon identification of the preferred concept(s), further scoping criticality safety assessments will be required to ensure initial work (completed as part of Task 110.4.003) is still applicable and also to identify future research needs.			
Research Driver			
To support concept development for plutonium disposal by identifying restraints and limits on fissile material limits and other parameters for identified disposal concepts during the transport phase.			
Research Objective			
To undertake scoping studies to demonstrate criticality safety during plutonium transport in identified disposal concepts by the derivation of appropriate package fissile material limits.			
Scope			
To undertake a computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for plutonium wastes to be transported in identified disposal packages. This scoping stage will investigate simple geometries and optimisation of parameters to give a baseline understanding of potential fissile material limits for the identified disposal packages from the IPT (Task 110.4.003 and Task 110.4.004) and propose further work required to develop detailed and optimised criticality safety assessments.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits along with underlying model input data. The report(s) will also detail potential areas to increase package fissile material limits if required.			

SRL at Task Start	SRL 4	**SRL at Task End**	SRL 5	**Target SRL**	SRL 6

Further Information

Work is dependent on a suitable disposal concept(s) being identified, and will only be able to start once such disposal concept(s) have been defined. Work is to be undertaken aligned with relevant regulations and guidance [1], [2].

1 International Atomic Energy Agency, *Regulations for the safe transport of radioactive material - safety requirements*, IAEA Report SSR-6, 2012. [Online]. Available: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1570%5C_web.pdf.

2 International Atomic Energy Agency, *Advisory material for the IAEA regulations for the Safe Transport of Radioactive Material (2012 edition)*, IAEA Report SSG-26, 2014. [Online]. Available: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1586web-99435183.pdf.

B2.2 WBS 20.2 - Operational criticality safety

B2.2.1 Review Inventory to Identify any Challenges to Criticality Accident Alarm System (CAAS) Omission Case

Task Number	20.2.001	**Status**	Ongoing
WBS Level 4	Criticality Safety		
WBS Level 5	Operational Criticality Safety		
Background			
The principal safety claim for the OSC for a GDF to be demonstrated for the criticality safety assessment is that ”All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or mitigate the consequences of nuclear accidents (i.e. unplanned criticality)”. As the GDF will contain wastes with fissile nuclides, the safety assessment must demonstrate that the magnitude and likelihood of a criticality accident are less than the regulatory and RWM safety criteria whilst also considering whole lifecycle ALARP balance of risk. At the generic stage of research, the illustrative criticality safety assessment has identified that no significant obstacles to making future claims for compliance with targets for tolerability of risk or the ALARP principle remain. However, as site-specific data become available and designs become more detailed, the assumptions underpinning this conclusion will need to be checked for applicability. The materials to be disposed of in the GDF will include significant quantities of fissile material. As such, the potential for a criticality accident requires consideration. As part of this process it is necessary to consider the need to install a CAAS or a CIDS for the GDF operational phase. Recent work has reviewed existing waste storage and disposal facilities to provide insight to better inform and guide the future assessment of CAAS or CIDS for the GDF, which concluded that an omission case is likely to be broadly achievable [1]. Until a final design is agreed a full assessment cannot be made; however, in the meantime, studies can be performed to de-risk the need of retrospectively installing a CAAS/CIDS system such as preparing draft emergency plans and reviewing available data against assumptions.			
Research Driver			
To support GDF design and optimisation by reviewing the need or omission of a CAAS or a CIDS for the GDF operational phase.			
Research Objective			
To undertake a review of the inventory for disposal and identify any wastestreams that may challenge the omission case.			
Scope			
Recent work has identified that a CAAS/CIDS omission case can likely be made for the GDF. This work will review the assumptions underpinning this and compare against available inventory and design information to establish if there are any wastestreams and/or operational phases that are likely to challenge the assumption that a CAAS/CIDS omission case can be made. If it is found that there are challenges to the assumption this task will identify potential mitigation strategies, such as CAAS/CIDS installment in specific areas of the GDF, etc.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

The output of this task will be a report detailing the comparative study for CAAS/CIDS omission and identification of any challenges based on available data, along with proposed mitigation strategies.					
SRL at Task Start	SRL 4	**SRL at Task End**	SRL 5	**Target SRL**	SRL 6
Further Information					
1 N. Harris, *Review of Criticality Accident Alarm System Requirements with Relevance to the United Kingdom Geological Disposal Facility*, National Nuclear Laboratory, NNL Report RWM/Contr/20/025, 2020.					

B2.2.2 Develop Draft Criticality Emergency Plan Based on Site-specific Data

Task Number	20.2.002	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Operational Criticality Safety		
Background			
The principal safety claim for the OSC for a GDF to be demonstrated for the criticality safety assessment is that "All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or mitigate the consequences of nuclear accidents (i.e. unplanned criticality)". As the GDF will contain wastes with fissile nuclides, the safety assessment must demonstrate that the magnitude and likelihood of a criticality accident are less than the regulatory and RWM safety criteria, whilst also considering whole lifecycle ALARP balance of risk. At the generic stage of research, the illustrative criticality safety assessment has identified that no significant obstacles to making future claims for compliance with targets for tolerability of risk or the ALARP principle remain. However, as site-specific data become available and designs become more detailed, the assumptions underpinning this conclusion will need to be checked for applicability. The material to be disposed of in the GDF will include significant quantities of fissile material. As such, the potential for a criticality accident requires consideration. As part of this process it is necessary to consider the need to install a CAAS or a CIDS for the GDF operational phase. Recent work has reviewed existing waste storage and disposal facilities to provide insight to better inform and guide the future assessment of CAAS or CIDS for the GDF, which concluded that an omission case is likely to be broadly achievable. Until a final design is agreed a full assessment cannot be made. However, in the meantime, as is incumbent on all considerations for CAAS/CIDS, even when an argument is presented to not install a system, further consideration as to some form of Criticality Emergency Plan should be made in the interests of ensuring the risks are ALARP. Any limited measures must of course be balanced against any detrimental effects in the interests of overall risk benefit.			
Research Driver			
To support GDF design and optimisation by beginning to develop a draft criticality emergency plan for the GDF operational phase.			
Research Objective			
To undertake a review of the inventory for disposal and potential designs to begin developing a draft criticality emergency plan, based on site specific data for 5 sites (planning assumption).			
Scope			
Recent work has identified that a CAAS/CIDS omission case can likely be made for the GDF and Task 20.2.001 will review the assumptions to identify any challenges. This activity will build on this, and using knowledge from nuclear waste storage and disposal facilities in the UK and internationally begin to develop a draft criticality emergency plan. This will not be a finalised document, but a draft incorporating areas that are required to be considered in order to identify future research needs.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

The output of this task will be a draft criticality emergency plan that details the proposed approach for demonstrating that the risks of criticality during the operational phase are ALARP. This draft will identify areas for consideration and future research needs that will be addressed when data are available and designs are further established.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 5
Further Information					
There are several publications relevant to this task [1]–[3].					

1 N. Harris, *Review of Criticality Accident Alarm System Requirements with Relevance to the United Kingdom Geological Disposal Facility*, National Nuclear Laboratory, NNL Report RWM/Contr/20/025, 2020.
2 American Nuclear Society, *Nuclear criticality accident emergency planning and response*, ANSI/ANS-8.23-2007; R2012, 2019.
3 ISO, *Nuclear criticality safety – emergency preparedness and response*, BS ISO-11320:2011, 2011. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:11320:ed-1:v1:en.

B2.2.3 Scoping Transient Analysis of Hypothetical Criticality

Task Number	20.2.003	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Operational Criticality Safety		
Background			
The principal safety claim for the operational safety case for a GDF to be demonstrated for the criticality safety assessment is that ”All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or mitigate the consequences of nuclear accidents (i.e. unplanned criticality)”. As the GDF will contain wastes with fissile material, the safety assessment must demonstrate that the magnitude and likelihood of a criticality accident are less than the regulatory and RWM safety criteria, whilst also considering whole lifecycle ALARP balance of risk. At the generic stage of research, the illustrative criticality safety assessment has identified that no significant obstacles to making future claims for compliance with targets for tolerability of risk or the ALARP principle remain. However, as site-specific data become available and designs become more detailed, the assumptions underpinning this conclusion will need to be checked for applicability. The material to be disposed of in the GDF will include significant quantities of fissile material. As such, the potential for a criticality accident requires consideration. As part of this process it is necessary to consider the need to install a CAAS or a CIDS for the GDF operational phase. Recent work has reviewed existing waste storage and disposal facilities to provide insight to better inform and guide the future assessment of CAAS or CIDS for the GDF, which concluded that an omission case is likely to be broadly achievable. Until a final design is agreed a full assessment cannot be made. However, an understanding of the radiological risk to workers (and the public) in various parts of the facility in the very unlikely scenario of a criticality excursion occurring will be required to feed into a criticality emergency plan. This is as there will be an overlap between the operational and post-closure phases of a GDF, where waste packages will continue to arrive at the facility after some have already been emplaced, and part of the GDF could be backfilled and closed while other parts are still in active use. During this phase, controls on the presence of water for emplaced packages cannot be claimed to apply and therefore the double-contingency principle approach cannot be demonstrated.			
Research Driver			
To support GDF design and optimisation by beginning to understand radiological risks of hypothetical criticality excursions to feed into a draft criticality emergency plan for the GDF operational phase.			
Research Objective			
To undertake a study to analyse the radiological risks to workers (and the public) in the highly unlikely event that a criticality accident did occur during the GDF operational phase.			
Scope			
To undertake a computational study investigating the impact on radiological risk to workers (and the public) for a range of hypothetical criticality excursions, based on inventory data and fault schedule scenarios. This will investigate the effectiveness of the host rock and proposed backfill materials in providing shielding and input into CAAS/CIDS omission considerations and the criticality emergency plan.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

The output of this task will be a report detailing the radiological risks from a hypothetical criticality excursion during the operational phase for the inventory for disposal. The output will feed into the draft criticality emergency plan (Task 20.2.002) that details the proposed approach for demonstrating that the risks of criticality during the operational phase are ALARP.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5
Further Information					
There are several publications relevant to this task [1]–[3].					

1 N. Harris, *Review of Criticality Accident Alarm System Requirements with Relevance to the United Kingdom Geological Disposal Facility*, National Nuclear Laboratory, NNL Report RWM/Contr/20/025, 2020.
2 American Nuclear Society, *Nuclear criticality accident emergency planning and response*, ANSI/ANS-8.23-2007; R2012, 2019.
3 ISO, *Nuclear criticality safety – emergency preparedness and response*, BS ISO-11320:2011, 2011. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:11320:ed-1:v1:en.

B2.2.4 Scoping Operational Phase Criticality Safety Assessment - Plutonium IPT

Task Number	20.2.004	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Operational Criticality Safety		
Background			
The principal safety claim for the OSC for a GDF to be demonstrated for the criticality safety assessment is that ”All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or mitigate the consequences of nuclear accidents (i.e. unplanned criticality)”. As the GDF will contain wastes with fissile material, the safety assessment must demonstrate that the likelihood and magnitude of a criticality accident are less than the regulatory and RWM safety criteria, whilst also considering whole lifecycle ALARP balance of risk. At the generic stage of research, the illustrative criticality safety assessment has identified that no significant obstacles to making future claims for compliance with targets for tolerability of risk or the ALARP principle remain. However, as site-specific data become available and designs become more detailed, the assumptions underpinning this conclusion will need to be checked for applicability NDA is evaluating options for putting the UK’s plutonium stockpile out of reach in support of the Government’s policy for the future management of the UK’s plutonium stockpile. Whilst the disposition of the UK’s bulk civil grade plutonium stockpile is yet to be determined, there is a need to develop a disposal concept for the portion of plutonium which cannot be reused. An integrated project team has been formed to support NDA and de-risk future activities in this area and as part of this, criticality safety of identified disposal concepts during the transport phase will need to be considered.			
Research Driver			
To support concept development for plutonium disposal by identifying restraints and limits on fissile material and other parameters for identified disposal concepts during the operational phase.			
Research Objective			
To undertake scoping studies to demonstrate criticality safety during the operational phase for plutonium in identified disposal concepts by the derivation of appropriate package fissile material limits.			
Scope			
To undertake a computational study on a set of normal operation and accident condition scenarios utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material content for plutonium wastes to be disposed of in identified disposal concepts. This scoping stage will investigate simple geometries and optimisation of parameters to give a baseline understanding of potential fissile material limits. It is anticipated that during the plutonium IPT, a preferred disposal concept or concepts will be identified and these will be the basis of the work.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. The report(s) will also detail potential areas to increase package fissile material limits if required.			

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
It is anticipated that this task is likely to run in parallel with Task 20.1.001 for the transport phase and activities in the "Develop Understanding, Data & Models (as Appropriate) to Demonstrate Disposability of HHGW – Plutonium and HEU" activity 'lane'. It is also dependent on disposal concepts being identified, and will only be able to start once such disposal concepts have been defined.					

B2.2.5 Review and Update Draft Criticality Emergency Plan for Two Sites

Task Number	20.2.005	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Operational Criticality Safety		
Background			
The principal safety claim for the operational safety case for a geological disposal facility to be demonstrated for the criticality safety assessment is that ”All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or mitigate the consequences of nuclear accidents (i.e. unplanned criticality)”. As the geological disposal facility will contain wastes with fissile nuclides, the safety assessment must demonstrate that the magnitude and likelihood of a criticality accident are less than the regulatory and RWM safety criteria, whilst also considering whole lifecycle ALARP balance of risk. At the generic stage of research, the illustrative criticality safety assessment has identified that no significant obstacles to making future claims for compliance with targets for tolerability of risk or the ALARP principle remain. However, as site-specific data become available and designs become more detailed, the assumptions underpinning this conclusion will need to be checked for applicability. The material to be disposed of in the geological disposal facility will include significant quantities of fissile material. As such, the potential for a criticality accident requires consideration. As part of this process it is necessary to consider the need to install a Criticality Accident Alarm System or a Criticality Incident Detection System for the GDF operational phase. Recent work has reviewed existing waste storage and disposal facilities to provide insight to better inform and guide the future assessment of CAAS or CIDS for the GDF, which concluded that an omission case is likely to be broadly achievable. Until a final design is agreed a full assessment cannot be made. However, in the meantime, as is incumbent on all considerations for CAAS/CIDS, even when an argument is presented to not install a system, further consideration as to some form of Criticality Emergency Plan should be made in the interests of ensuring the risks are ALARP. Any limited measures must of course be balanced against any detrimental effects in the interests of overall risk benefit.			
Research Driver			
To support GDF design and optimisation by further developing a draft criticality emergency plan for the GDF operational phase.			
Research Objective			
To undertake a review of the inventory for disposal and potential designs to further develop a draft criticality emergency plan, based on site-specific data (e.g. groundwater composition, flow and host rock thermal conductivity) for two sites (planning assumption).			
Scope			
Recent work has identified that a CAAS/CIDS omission case can likely be made for the GDF and Task 20.2.001 will review the assumptions to identify any assumptions. Task 20.2.002 will begin to develop a draft criticality emergency plan and this activity will build on this, and using site-specific data for two sites further develop a draft criticality emergency plan. This will not be a finalised document, but a draft incorporating areas that need to be considered to identify future research needs.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

The output of this task will be an update to the draft criticality emergency plan from Task 20.2.002 that details the proposed approach for demonstrating that the risks of criticality during the operational phase are ALARP. This draft will identify areas for consideration and future research needs that will be addressed when data is available and designs are further established.					
SRL at Task Start	SRL 3	**SRL at Task End**	SRL 4	**Target SRL**	SRL 5
Further Information					
There are several publications relevant to this task [1]–[3]. 1 N. Harris, *Review of Criticality Accident Alarm System Requirements with Relevance to the United Kingdom Geological Disposal Facility*, National Nuclear Laboratory, NNL Report RWM/Contr/20/025, 2020. 2 American Nuclear Society, *Nuclear criticality accident emergency planning and response*, ANSI/ANS-8.23-2007; R2012, 2019. 3 ISO, *Nuclear criticality safety – emergency preparedness and response*, BS ISO-11320:2011, 2011. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:11320:ed-1:v1:en.					

B2.2.6 Develop and Document Appropriate Criticality Safety-related Acceptance Criteria

<table>
<tr><td colspan="2">Task Number</td><td>20.2.006</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Operational Criticality Safety</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The principal safety claim for the OSC for a GDF to be demonstrated for the criticality safety assessment is that ”All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or mitigate the consequences of nuclear accidents (i.e. unplanned criticality)”. As the GDF will contain wastes with fissile nuclides, the safety assessment must demonstrate that the magnitude and likelihood of a criticality accident are less than the regulatory and RWM safety criteria, whilst also considering whole lifecycle ALARP balance of risk.

As the siting process progresses, designs are established and refined and associated safety cases developed, it will be important to identify and document records and information that are required to demonstrate compliance against the criticality safety assessments. It is envisaged that the records and knowledge defined here will become acceptance criteria at the time that RWM moves towards Waste Acceptance Criteria.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support development and compliance with the OSC by ensuring existing criticality safety assessments can be underpinned with robust evidence.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review existing criticality safety assessments and operational safety case(s) to identify and document required knowledge and records.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a review of existing criticality safety assessments and the OSC to identify the assumptions in the modelling, the parameters modelled and the values assigned to ensure that records exist/can exist to demonstrate compliance against these. If gaps are identified, a work programme to address them will be developed. The scope will also ensure that knowledge is captured adequately to ensure it is available and accessible for long periods. This work will integrate with wider Disposability Assessment and Package Records work to ensure a consistent approach is applied.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a list of compliance criteria that will eventually become acceptance criteria for various criticality safety assessments against revised operational safety cases, and a methodology for ensuring that the knowledge/records can be accessible for long periods of time. This will feed into any work related to developing and refining Waste Package Specifications and Waste Acceptance Criteria.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 4</td><td>SRL at Task End</td><td>SRL 5</td><td>Target SRL</td><td>SRL 5</td></tr>
</table>

Further Information
This work is based on the output of the work to revise the procedures and develop the OSC, and it cannot start until that is complete. Current criticality safety assessments are aligned with the 2016 generic OSC [1].   1 Radioactive Waste Management, *Geological Disposal: Generic Operational Safety Case*, RWM Report DSSC/202/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-operational-safety-case-main-report/.

B2.2.7 Detailed Transient Analysis of Hypothetical Criticality based on Site-specific Data

Task Number	20.2.007	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Operational Criticality Safety		
Background			
The principal safety claim for the operational safety case for a geological disposal facility to be demonstrated for the criticality safety assessment is that ”All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or mitigate the consequences of nuclear accidents (i.e. unplanned criticality)”. As the geological disposal facility will contain wastes with fissile nuclides, the safety assessment must demonstrate that the magnitude and likelihood of a criticality accident are less than the regulatory and RWM safety criteria, whilst also considering whole life-cycle ALARP balance of risk. At the generic stage of research, the illustrative criticality safety assessment has identified that no significant obstacles to making future claims for compliance with targets for tolerability of risk or the ALARP principle remain. However, as site-specific data become available and designs become more detailed, the assumptions underpinning this conclusion will need to be checked for applicability. The material to be disposed of in the Geological Disposal Facility will include significant quantities of fissile material. As such, the potential for a criticality accident requires consideration. As part of this process it is necessary to consider the need to install a Criticality Accident Alarm System or a Criticality Incident Detection System for the GDF operational phase. Recent work has reviewed existing waste storage and disposal facilities to provide insight to better inform and guide the future assessment of CAAS or CIDS for the GDF, which concluded that an omission case is likely to be broadly achievable [1]. Until a final design is agreed a full assessment cannot be made. However, an understanding of the radiological risk to workers (and the public) in various parts of the facility in the very unlikely scenario of a criticality excursion occurring will be required to feed into a criticality emergency plan. This is as there will be an overlap between the operational and post-closure phases of a GDF, where waste packages will continue to arrive at the facility after some have already been emplaced, and part of the GDF could be backfilled and closed while other parts are still in active use. During this phase, controls on the presence of water for emplaced packages cannot be claimed to apply and therefore the double-contingency principle approach cannot be demonstrated.			
Research Driver			
To support GDF design and optimisation by refining the understanding on the radiological risks of hypothetical criticality excursions to feed into the criticality emergency plan for the GDF operational phase.			
Research Objective			
To undertake a detailed study to analyse the radiological risks to workers (and the public) in the highly unlikely event that a criticality accident did occur during the GDF operational phase.			
Scope			
To undertake a computational study investigating the impact on radiological risk to workers (and the public) for a range of hypothetical criticality excursions, based on inventory data. This will investigate the effectiveness of the host rock and proposed backfill materials in providing shielding and input into CAAS/CIDS omission considerations and the criticality emergency plan. This task is a follow on to Task 20.2.003 and will refine the excursion analysis based on available site-specific data and refined facility designs.			

<table>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report detailing the radiological risks from a hypothetical criticality excursion during the operational phase for the inventory for disposal. The output will feed into the criticality emergency plan that details the proposed approach for demonstrating that the risks of criticality during the operational phase as ALARP.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 5</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">The start date is dependent on the availability of site specific data such as rock characterisation data. There are several publications relevant to this task [2], [3].
1 N. Harris, Review of Criticality Accident Alarm System Requirements with Relevance to the United Kingdom Geological Disposal Facility, National Nuclear Laboratory, NNL Report RWM/Contr/20/025, 2020.
2 American Nuclear Society, Nuclear criticality accident emergency planning and response, ANSI/ANS-8.23-2007; R2012, 2019.
3 ISO, Nuclear criticality safety – emergency preparedness and response, BS ISO-11320:2011, 2011. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:11320:ed-1:v1:en.</td></tr>
</table>

B2.3 WBS 20.3 - Post-closure criticality safety for LHGW

B2.3.1 Extension of Low-Likelihood Package Envelope

<table>
<tr><td colspan="2">Task Number</td><td>20.3.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has a good understanding of the processes that contribute to the low likelihood of fissile material in a GDF accumulating to give a critical configuration at some time after the closure of the facility. Predominantly, this work has been focussed on low-heat generating waste and work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. The work has been undertaken to address the requirement in the environment agencies' Guidance on Requirements for Authorisation, which requires that the safety case for the GDF demonstrates that ”The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern” and that a 'what-if' criticality scenario is considered by assessing ”the impact of a postulated criticality event on the performance of the disposal system”.

Building on the research on the likelihood and consequences of post-closure criticality, RWM developed a generic low-likelihood, low-consequence package envelope for LHGW packages that uses less restrictive probabilistic methods to derive fissile material screening levels.

This task has been developed to recognise that RWM will need to apply the methodology derived for waste packages that are currently identified as non-compliant with the requirements of the package envelope. Previous work has extended the package envelope for grout-entombed wastes and this task is designed to extend the envelope again, based on input from waste producers/packagers.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the environmental safety case by ensuring that the generic low-likelihood, low-consequence package envelope is applicable to as many waste-streams as possible.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review proposed waste packages and revise the low-likelihood, low-consequence package envelope if appropriate.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a computational study to extend the low-likelihood, low-consequence package envelope based on knowledge of existing and future waste packages' contents and designs.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Updated package envelope report with screening levels for existing, and updated, waste packages. The updated information will be used to assess packaging proposals through RWM's disposability assessment process.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 6</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[4].
1 D. Roberts, T. Baldwin, G. Carta, T. Hicks, M. Kelly, R. Mason, and T. Ware, *Gdf post-closure criticality consequences assessment*, AMEC, Contractor Report 203034-DB20-RPT-002, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/gdf-post-closure-criticality-consequences-assessment/. 2 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/. 3 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/. 4 T. Hicks and S. Doudou, *Development of a methodology for defining waste package characteristics that ensure long-term criticality safety in a geological disposal facility*, Galson Sciences, Contractor Report 1402-4, Version 3.3, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/development-of-a-methodology-for-defining-waste-package-characteristics-that-ensure-long-term-criticality-safety-in-a-geological-disposal-facility/.

B2.3.2 Applying the Likelihood and Consequences of Criticality Models to Future Concept, Facility Designs and Inventories

<table>
<tr><td colspan="2">Task Number</td><td>20.3.002</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has a good understanding of the processes that contribute to the low likelihood of fissile material in a GDF accumulating to give a critical configuration at some time after the closure of the facility. Predominantly, this work has been focussed on low-heat generating waste and work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. The work has been undertaken to address the requirement in the environment agencies' Guidance on Requirements for Authorisation, which requires that the safety case for the GDF demonstrates that "The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern" and that a 'what-if' criticality scenario is considered by assessing "the impact of a postulated criticality event on the performance of the disposal system".
Historically, RWM's low likelihood work focused predominantly on ILW in higher strength rock GDFs. More recent work has extended the knowledge base and RWM's capability/toolkit to cover all of the higher activity wastes (e.g. LLW, ILW, DNLEU, HLW, spent fuel, Pu and HEU) in the three illustrative geologies. This task has been developed to recognise that RWM will need to apply these new likelihood and consequences of post-closure criticality assessment capabilities to future concepts, facility designs and/or revised inventories as they become available.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the environmental safety case by applying RWM's methodology for estimating the likelihood of criticality (e.g. to underpin our low likelihood position).</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The environmental safety case needs to be able to demonstrate, substantiate and communicate its position that post-closure criticality is a low likelihood event and therefore work is required to ensure this is kept live and builds on available knowledge.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To be defined on the basis of future waste disposal concepts, facility designs and/or revised inventories.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Updated package envelope report with screening levels for existing, and updated waste packages. The updated information will be used to assess packaging proposals through RWM's disposability assessment process.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 6</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[4]. 1 D. Roberts, T. Baldwin, G. Carta, T. Hicks, M. Kelly, R. Mason, and T. Ware, *Gdf post-closure criticality consequences assessment*, AMEC, Contractor Report 203034-DB20-RPT-002, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/gdf-post-closure-criticality-consequences-assessment/. 2 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/. 3 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/. 4 T. Hicks and S. Doudou, *Development of a methodology for defining waste package characteristics that ensure long-term criticality safety in a geological disposal facility*, Galson Sciences, Contractor Report 1402-4, Version 3.3, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/development-of-a-methodology-for-defining-waste-package-characteristics-that-ensure-long-term-criticality-safety-in-a-geological-disposal-facility/.

B2.3.3 Review of Existing generic Criticality Safety Assessments (gCSAs) and Revision, if necessary

<table>
<tr><td colspan="2">Task Number</td><td>20.3.003</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has produced a suite of generic Criticality Safety Assessments (gCSAs) that have derived waste packaging constraints, including limits on the fissile material content of waste packages, which must be met in order to ensure criticality safety during transport to a Geological Disposal Facility, during GDF operations and after facility closure. There are 6 gCSAs based on either common categories of waste or container type, plus the earlier General CSA (GCSA). These have been produced over a number of years, based on a deterministic modelling approach and are still used. These gCSAs have been used to assist waste producers/packagers in deriving suitable package fissile material limits for waste destined for disposal. To ensure longevity and accessibility of the assessments, it will be required to review, update and capture relevant records and knowledge related to this suite.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support transport, operational and post-closure safety case development by reviewing existing gCSAs to ensure they are suitable.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The safety cases need to be able to demonstrate, substantiate and communicate their positions related to criticality safety and therefore work is required to ensure that existing assessments are reviewed, maintained and build on available knowledge.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a review of the six existing gCSAs and GCSA to ensure that the modelling assumptions are valid based on current knowledge, that the suite are consistent with each other and the approach is still justified. If it is found that work is required to address any identified challenges, a work programme will be developed and delivered.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Updated suite of gCSAs that have been reviewed for consistency and applicability, with any identified challenges being addressed through separate reports. The updated information will be used to assess packaging proposals through RWM's disposability assessment process and also by reviewing extant LoC.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 6</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[7].

1 T. Hicks, *The general criticality safety assessment*, Galson Sciences, Contractor Report 0914-1, Version 1.1, 2009. [Online]. Available: http://rwm.nda.gov.uk/publication/the-general-criticality-safety-assessment/.

2 T. Hicks, *Criticality safety assessment for waste packages containing high-enriched uranium*, Galson Sciences, Contractor Report 0560-3 Version 1, 2007. [Online]. Available: http://rwm.nda.gov.uk/publication/criticality-safety-assessment-for-waste-packages-containing-high-enriched-uranium/.

3 T. Hicks, *Criticality safety assessment for waste packages containing low-enriched uranium*, Galson Sciences, Contractor Report 0465-4 Version 2, 2007.

4 T. Hicks, *Criticality safety assessment for waste packages containing irradiated natural uranium*, Galson Sciences, Contractor Report 0560-1 Version 1.1, 2007. [Online]. Available: http://rwm.nda.gov.uk/publication/criticality-safety-assessment-for-waste-packages-containing-irradiated-natural-uranium-554333-v1/.

5 T. Hicks, *Criticality safety assessment for waste packages containing separated plutonium*, Galson Sciences, Contractor Report 0560-2 Version 1.1, 2007. [Online]. Available: http://rwm.nda.gov.uk/publication/criticality-safety-assessment-for-waste-packages-containing-separated-plutonium-t-w-hicks-0560-2-version-1-1-554352-6497394-2007/.

6 T. Hicks and T. Baldwin, *A generic criticality safety assessment for irradiated natural and low-enriched uranium wastes packaged in robust shielded containers: Volume 1 - assessment*, Galson Sciences, Contractor Report 1241-5, Version 2, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/a-generic-criticality-safety-assessment-for-irradiated-natural-and-low-enriched-uranium-wastes-packaged-in-robust-shielded-containers-volume-1-assessment/.

7 T. W. Hicks, E. K. Swain-Phipps, R. A. Houghton, and T. D. Baldwin, *Generic csa for lhgw in shielded containers*, Galson Sciences, Contractor Report RWM/Contr/20/023, 2020. [Online]. Available: http://rwm.nda.gov.uk/publication/generic-csa-for-lhgw-in-shielded-containers/.

B2.3.4 Review of Likelihood and Consequences Assumptions Based on Revised Concepts, Facility Designs and Inventories

<table>
<tr><td colspan="2">Task Number</td><td>20.3.004</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has a good understanding of the processes that contribute to the low likelihood of fissile material in a GDF accumulating to give a critical configuration at some time after the closure of the facility. Work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event are both very low. The work has been undertaken to address the requirement in the environment agencies' Guidance on Requirements for Authorisation, which requires that the safety case for the GDF demonstrates that "The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern" and that a 'what-if' criticality scenario is considered by assessing "the impact of a postulated criticality event on the performance of the disposal system".
Historically, RWM's low likelihood work focused predominantly on ILW in higher strength rock GDFs. More recent work has extended the knowledge base and RWM's capability/toolkit to cover all of the higher activity wastes (e.g. LLW, ILW, DNLEU, HLW, spent fuel, Pu and HEU) in the three illustrative geologies. This task has been developed to recognise that RWM will need to review the assumptions made in the likelihood and consequences of post-closure criticality assessment based on revised concepts, facility designs and/or revised inventories, as they become available.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the environmental safety case by assessing the applicability of RWM's methodology for demonstrating the likelihood and consequences of criticality based on current knowledge.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The environmental safety case needs to be able to demonstrate, substantiate and communicate its position that post-closure criticality is a low likelihood and low consequence event and therefore work is required to ensure this is kept live and builds on available knowledge.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a review of the assumptions used in RWM's likelihood and consequences research against current knowledge to identify any discrepancies and propose a forward work programme to address these if required. An example of this is whether the disposal of a significant amount of plutonium in different concepts might challenge the assumptions made in the original work.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report detailing the comparative study and identified research needs, ensuring that the underpinning knowledge to demonstrate that post-closure criticality is not a significant concern is up to date and clearly described .</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 5</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[3].

1 D. Roberts, T. Baldwin, G. Carta, T. Hicks, M. Kelly, R. Mason, and T. Ware, *Gdf post-closure criticality consequences assessment*, AMEC, Contractor Report 203034-DB20-RPT-002, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/gdf-post-closure-criticality-consequences-assessment/.

2 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/.

3 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

B2.3.5 Scoping Criticality Safety Assessment for Metallic Uranic Fuel in Self-Shielded Boxes

Task Number	20.3.005	**Status**	Ongoing
WBS Level 4	Criticality Safety		
WBS Level 5	Post-closure criticality safety for LHGW		
Background			
RWM has previously undertaken a significant amount of work to demonstrate the post-closure criticality safety of LHGW and there has been less focus on HHGW. However, work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. Recent work has determined the preferred design and control options to demonstrate criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in a UK illustrative design. The work has been undertaken to address the requirement in the environment agencies' GRA, which requires that the safety case for the GDF demonstrates that "*The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern*" and that a 'what-if' criticality scenario is considered by assessing "*the impact of a postulated criticality event on the performance of the disposal system*". Alongside AGR and PWR spent fuel, which has been the primary focus of work to date, the inventory for disposal will also contain metallic, carbide and unconventional oxide fuel types. These fuels, grouped for the purposes of this work as *exotics*, represent a number of spent fuels from research, experimental and other reactors, typically of low volume and with varied, currently unstudied disposal characteristics. This can be further broken down as metallic uranic fuel (as used in Magnox reactors) that has a low initial enrichment and therefore alternative methods for treatment and disposal are being investigated, which is the focus of this task. Task 20.4.001 is related to other types of fuel in the inventory that will require disposal. There have been proposals to package spent Magnox fuel into Self-Shielded Boxes to assist in decommissioning activities, and therefore work is proposed to identify any challenges related to the disposability of such packages. Criticality safety is a smaller part of a wider work programme to investigate these proposals.			
Research Driver			
To support concept development by developing a scoping criticality safety assessment for spent Magnox fuel in SSBs that aims to reduce overall costs and operator dose at Sellafield.			
Research Objective			
To assess the criticality safety of spent Magnox fuel packaged in SSBs.			
Scope			
To undertake a scoping computational study on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of exotic spent fuels for the leading disposal concept for these fuels.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. As this work is at a scoping level, the report(s) will also detail potential areas to increase package fissile material limits if required.			

SRL at Task Start	SRL 4	**SRL at Task End**	SRL 5	**Target SRL**	SRL 6
Further Information					

This work may be one task looking at the full range of exotic fuels, or may be broken down into sub-sets based on available information. There are several publications relevant to this task [1], [2]. Work will be aligned with likelihood and consequences for post-closure as detailed in various reports on criticality [3]–[6].

1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/.

2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

3 T. Hicks, T. Baldwin, J. Solano, and D. Bennett, *Likelihood of Criticality: The Likelihood of Criticality Following Disposal of HLW/SF/HEU/Pu*, AMEC, Contractor Report 17293-TR-022, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-following-disposal-of-sfhlwheupu-rwmd003001/.

4 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/.

5 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

6 R. Mason and P. Smith, *Modelling of Consequences of Hypothetical Criticality: Post-closure Criticality Consequence Analysis for HLW, Spent Fuel, Plutonium and HEU Disposal*, AMEC, Contractor Report AMEC/SF2409/012 Issue 3, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-post-closure-criticality-consequence-analysis-for-hlw-spent-fuel-plutonium-and-heu-disposal/.

B2.3.6 Collation of Records and Inputs against Assumptions for generic Criticality Safety Assessments (gCSAs)

<table>
<tr><td>Task Number</td><td colspan="2">20.3.006</td><td colspan="2">Status</td><td>Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has produced a suite of generic Criticality Safety Assessments (gCSAs) that have derived waste packaging constraints, including limits on the fissile material content of waste packages, which must be met in order to ensure criticality safety during transport to a Geological Disposal Facility, during GDF operations and after facility closure. There are 6 gCSAs based on either common categories of waste or container type, plus the earlier General CSA (GCSA). These have been produced over a number of years, based on a deterministic modelling approach and are still used. These gCSAs have been used to assist waste producers/packagers in deriving suitable package fissile material limits for waste destined for disposal. To ensure longevity and accessibility of the assessments it will be necessary to review, update and capture relevant records and knowledge related to this suite.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support transport, operational and post-closure safety case development by reviewing existing gCSAs to ensure relevant records and knowledge are maintained.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The safety cases need to be able to demonstrate, substantiate and communicate their positions related to criticality safety and therefore work is required to ensure that existing assessments are reviewed, maintained and build on available knowledge.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Following a review of the six existing gCSAs and GCSA to ensure that the modelling assumptions are valid based on current knowledge, that the suite are consistent with each other and the approach is still justified and any work to address identified gaps is completed (Task 20.3.003), it will be critical to ensure that the records and knowledge that underpin them are captured adequately. To perform this activity this task will review and identify the assumptions and inputs used in the assessments and collate these in a manner that allows them to be accessed in the long-term. This activity will align with relevant knowledge management activities within RWM to ensure data and knowledge are captured adequately.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Identification and capture of relevant records and knowledge related to gCSAs and GCSA that will input into safety cases. This will be captured in a form that is consistent with requirements arising from knowledge management activities within RWM.</td></tr>
<tr><td>SRL at
Task Start</td><td>SRL 5</td><td>SRL at
Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[7].

1 T. Hicks, *The general criticality safety assessment*, Galson Sciences, Contractor Report 0914-1, Version 1.1, 2009. [Online]. Available: http://rwm.nda.gov.uk/publication/the-general-criticality-safety-assessment/.

2 T. Hicks, *Criticality safety assessment for waste packages containing high-enriched uranium*, Galson Sciences, Contractor Report 0560-3 Version 1, 2007. [Online]. Available: http://rwm.nda.gov.uk/publication/criticality-safety-assessment-for-waste-packages-containing-high-enriched-uranium/.

3 T. Hicks, *Criticality safety assessment for waste packages containing low-enriched uranium*, Galson Sciences, Contractor Report 0465-4 Version 2, 2007.

4 T. Hicks, *Criticality safety assessment for waste packages containing irradiated natural uranium*, Galson Sciences, Contractor Report 0560-1 Version 1.1, 2007. [Online]. Available: http://rwm.nda.gov.uk/publication/criticality-safety-assessment-for-waste-packages-containing-irradiated-natural-uranium-554333-v1/.

5 T. Hicks, *Criticality safety assessment for waste packages containing separated plutonium*, Galson Sciences, Contractor Report 0560-2 Version 1.1, 2007. [Online]. Available: http://rwm.nda.gov.uk/publication/criticality-safety-assessment-for-waste-packages-containing-separated-plutonium-t-w-hicks-0560-2-version-1-1-554352-6497394-2007/.

6 T. Hicks and T. Baldwin, *A generic criticality safety assessment for irradiated natural and low-enriched uranium wastes packaged in robust shielded containers: Volume 1 - assessment*, Galson Sciences, Contractor Report 1241-5, Version 2, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/a-generic-criticality-safety-assessment-for-irradiated-natural-and-low-enriched-uranium-wastes-packaged-in-robust-shielded-containers-volume-1-assessment/.

7 T. W. Hicks, E. K. Swain-Phipps, R. A. Houghton, and T. D. Baldwin, *Generic csa for lhgw in shielded containers*, Galson Sciences, Contractor Report RWM/Contr/20/023, 2020. [Online]. Available: http://rwm.nda.gov.uk/publication/generic-csa-for-lhgw-in-shielded-containers/.

B2.3.7 Collation of Records and Inputs against Assumptions from Extant Criticality Safety Assessments

<table>
<tr><td colspan="2">Task Number</td><td>20.3.007</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has produced a suite of generic Criticality Safety Assessments that have derived waste packaging constraints, including limits on the fissile material content of waste packages, which must be met in order to ensure criticality safety during transport to a GDF, during GDF operations and after facility closure. There are 6 generic CSAs based on either common categories of waste or container type, plus the earlier General CSA. These have been produced over a number of years, based on a deterministic modelling approach and are still used. These generic CSAs have been used to assist waste producers/packagers in deriving suitable package fissile material limits for waste destined for disposal. In addition to RWM's suite of generic work, there are also a number of package specific CSAs that take credit for specific properties of a waste package to allow a suitable package fissile material limit to be derived. In a similar manner to the suite of generic work, it will be important to ensure that the underpinning records and knowledge for these package specific CSAs are captured to ensure they can be used as robust inputs in the development of safety cases.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support transport, operational and post-closure safety case development by reviewing extant CSAs to ensure relevant records and knowledge are maintained.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The safety cases need to be able to demonstrate, substantiate and communicate their positions related to criticality safety and therefore work is required to ensure that existing assessments are reviewed, maintained and build on available knowledge.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">In parallel to Task 20.3.006, which reviews RWM's generic work, it will be critical to ensure that the records and knowledge that underpin any criticality safety assessments, which are predominantly completed outside of RWM, are captured adequately. To perform this activity this task will review and identify the assumptions and inputs used in the assessments and collate these in a manner that allows them to be accessed in the long-term.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Identification and capture of relevant records and knowledge related to generic CSAs and General CSA that will input into safety cases. This will be captured in a form that is consistent with requirements arising from knowledge management activities within RWM.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 5</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">The focus of this work will be to investigate package specific CSAs and others that are not captured in Task 20.3.006 that have been used to support a final LoC submission. If appropriate, those that are used for earlier stages of submission will be reviewed, but only if sufficient progress has been made on developing these and the compliance requirements associated with them.</td></tr>
</table>

B2.3.8 Review and Refinement of Criticality Safety Models and Assumptions to Maintain Capability

<table>
<tr><td>Task Number</td><td colspan="2">20.3.008</td><td colspan="2">Status</td><td>Start date in the future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Criticality Safety</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has completed a range of work investigating the likelihood and consequences of post-closure criticality. As part of this, a number of models have been used that each serve a specific purpose. The work has been undertaken to address the requirement in the environment agencies’ Guidance on Requirements for Authorisation, which requires that the safety case for the GDF demonstrates that ”The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern” and that a ’what-if’ criticality scenario is considered by assessing ”the impact of a postulated criticality event on the performance of the disposal system”.
The models used for understanding the likelihood and consequences of post-closure criticality are varied, and have largely been developed by the supply chain. These include neutron transport codes such as MCNP and MONK and probabilistic models to evaluate the evolution of waste packages and migration of fissile material such as GoldSim. Most applications are widely used, however, the specific applications for post-closure are limited. Therefore, there is a risk that the modelling capability developed as part of earlier work is not maintained and therefore not available when it is needed in the future to underpin the environmental safety case. Therefore, this task has been developed to recognise that RWM will need to maintain the models developed to understand the likelihood and consequences of post-closure criticality and update them based on revised concepts, facility designs and/or revised inventories, as they become available.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the environmental safety case by ensuring that the models required to underpin understanding of RWM’s methodology for estimating the likelihood and consequences of criticality are maintained.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The environmental safety case needs to be able to demonstrate, substantiate and communicate its position that post-closure criticality is a low likelihood and low consequence event and therefore work is required to ensure this is kept live, builds on available knowledge and modelling capability is maintained.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This task will review and revise models used for RWM’s likelihood and consequence understanding based on current knowledge to ensure that the capability is maintained. There may also be significant activities to host models and input data in appropriate knowledge management systems as part of wider work.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Updated and maintained modelling capability for RWM’s likelihood and consequence of post-closure criticality understanding.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 6</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[5].

1 D. Roberts, T. Baldwin, G. Carta, T. Hicks, M. Kelly, R. Mason, and T. Ware, *Gdf post-closure criticality consequences assessment*, AMEC, Contractor Report 203034-DB20-RPT-002, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/gdf-post-closure-criticality-consequences-assessment/.

2 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/.

3 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

4 P. Smith, *Modelling of consequences of hypothetical criticality: User guide for the qss model*, AMEC, Contractor Report AMEC/SF2409/006 Issue 2, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/user-guide-for-the-quasi-steady-state-model/.

5 R. Mason and P. Smith, *Modelling of consequences of hypothetical criticality: User guide for the rapid transient model and the bounding approach*, AMEC, Contractor Report AMEC/SF2409/005 Issue 1, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-user-guide-for-the-rapid-transient-model-and-the-bounding-approach-r-m-mason-p-n-smith-AMEC-sf2409-005-issue-1-19289230-2013/.

B2.3.9 Review of Extant Criticality Safety Assessment Assumptions Against Site-Specific Data

<table>
<tr><td colspan="2">Task Number</td><td>20.3.009</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has produced a suite of generic CSAs that have derived waste packaging constraints, including limits on the fissile material content of waste packages, which must be met in order to ensure criticality safety during transport to a GDF, during GDF operations and after facility closure. There are 6 generic CSAs based on either common categories of waste or container type plus the earlier General CSA. These have been produced over a number of years, based on a deterministic modelling approach and are still used. These generic CSAs have been used to assist waste producers/packagers in deriving suitable package fissile material limits for waste destined for disposal. In addition to RWM’s suite of generic work, there are also a number of package specific CSAs that take credit for specific properties of a waste package to allow a suitable package fissile material limit to be derived.

Part of safety case development will be based on demonstrating compliance with criticality safety assessments, therefore it is important to ensure that criticality safety assessments developed during the generic stage are still applicable when site-specific data are available.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support transport, operational and post-closure safety case development by reviewing extant CSAs to ensure and assumptions and inputs are still applicable on knowledge of site-specific data (e.g. groundwater composition, flow and host-rock thermal conductivity).</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The safety cases need to be able to demonstrate, substantiate and communicate their positions related to criticality safety and therefore work is required to ensure that existing assessments are reviewed, maintained and build on available knowledge.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Following Task 20.3.006 and Task 20.3.007, which will have collated the assumptions, inputs and record requirements for existing assessments, this activity will compare those against site-specific data to ensure alignment and identify any gaps that will require addressing. This activity is predominantly identifying areas that are in conflict (i.e. assumptions do not match site-specific data) and require immediate resolution, however, there will also be an opportunity to reduce some of the conservative assumptions that were required during the generic stage of research, if applicable.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">This task will deliver a report detailing the comparative study between assumptions and inputs into criticality safety assessments and available site-specific data and programme of work to address any risks or opportunities.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 6</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
The focus of this work will be to investigate RWM's generic CSAs and also package-specific CSAs that have been used to support a final LoC submission. If appropriate, those that are used for earlier stages of submission will be reviewed, but only if sufficient progress has been made on developing these and the compliance requirements associated with them.

B2.3.10 Revision, if required, of any Extant Criticality Safety Assessments Based on Site-Specific Data

<table>
<tr><td>Task Number</td><td colspan="2">20.3.010</td><td colspan="2">Status</td><td>Start date in the future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Criticality Safety</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Post-closure criticality safety for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has produced a suite of generic CSAs that have derived waste packaging constraints, including limits on the fissile material content of waste packages, which must be met in order to ensure criticality safety during transport to a GDF, during GDF operations and after facility closure. There are 6 gCSAs based on either common categories of waste or container type plus the earlier General CSA. These have been produced over a number of years, based on a deterministic modelling approach and are still used. These generic CSAs have been used to assist waste producers/packagers in deriving suitable package fissile material limits for waste destined for disposal. In addition to RWM's suite of generic work, there are also a number of package-specific CSA that take credit for specific properties of a waste package to allow a suitable package fissile material limit to be derived.

Part of safety case development will be based on demonstrating compliance with criticality safety assessments, and as site-specific information becomes available there may be a risk that existing criticality safety assessments may need refinement to ensure they can be robustly complied with. Conversely, as the work performed at the generic stage is conservative, there may be an opportunity to refine the assessments based on site-specific data to increase package fissile material limits or demonstrate an increased margin of safety.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support transport, operational and post-closure safety case development by revising any extant CSAs to ensure that assumptions and inputs are still applicable based on knowledge of site-specific data (e.g. groundwater composition, flow and host-rock thermal conductivity). It is recognised that there may be some over-conservatism in the existing approach due to the generic nature and reducing this would support waste producers in maximising packaging efficiency.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The safety cases need to be able to demonstrate, substantiate and communicate their positions related to criticality safety and therefore work is required to ensure that existing assessments are reviewed, maintained and build on available knowledge.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Following Task 20.3.009, which will have collated the assumptions, inputs and record requirements for existing assessments based on site-specific data, this activity will undertake computational studies to revise any criticality safety assessments that are identified. This activity is predominantly resolving areas that are in conflict (i.e. assumptions do not match site-specific data) and require immediate resolution, however there will also be an opportunity to reduce some of the conservative assumptions that were required during the generic stage of research, if applicable.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">This task will deliver a revised suite of criticality safety assessments based on site-specific data that are more targeted than the generic work delivered previously.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 6</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
The focus of this work will be to investigate RWM's generic CSAs and also package-specific CSAs that have been used to support a final LoC submission. If appropriate, those that are used for earlier stages of submission will be reviewed, but only if sufficient progress has been made on developing these and the compliance requirements associated with them.

B2.4 WBS 20.4 - Post-closure criticality safety for HHGW - Spent Fuel

B2.4.1 Criticality Safety for the Disposal of Spent Fuel - Scoping Criticality Safety Assessment for Exotics

<table>
<tr><td colspan="2">Task Number</td><td>20.4.001</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure criticality safety for HHGW - Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has previously undertaken a significant amount of work to demonstrate the post-closure criticality safety of LHGW and there has been less focus on HHGW. However, work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. Recent work has determined the preferred design and control options to demonstrate criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in a UK illustrative design. The work has been undertaken to address the requirement in the environment agencies' GRA, which requires that the safety case for the GDF demonstrates that "The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern" and that a 'what-if' criticality scenario is considered by assessing "the impact of a postulated criticality event on the performance of the disposal system".

Alongside AGR and PWR spent fuel, which has been the primary focus of work to date, the inventory for disposal will also contain metallic, carbide and unconventional oxide fuel types. These fuels, grouped for the purposes of this work as exotics, represent a number of spent fuels from research, experimental and other reactors, typically of low volume and with varied, currently unstudied disposal characteristics.

This can be further broken down as metallic uranic fuel (as used in Magnox reactors) that has a low initial enrichment and therefore alternative methods for treatment and disposal are being investigated, which is the focus of Task 20.3.005. This activity is related to other types of fuel in the inventory that will require disposal.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development by developing a criticality safety assessment for a preferred disposal concept for the range of exotics.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To assess the criticality safety of the preferred disposal concept for the range of exotics.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a scoping computational study on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of exotic spent fuels for the leading disposal concept for these fuels.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. As this work is at a scoping level the report(s) will also detail potential areas to increase package fissile material limits if required.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 4</td><td>SRL at Task End</td><td>SRL 5</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
This work may be one task looking at the full range of exotic fuels, or may be broken down into sub-sets based on available information. There are several publications relevant to this task [1], [2]. Work will be aligned with likelihood and consequences for post-closure [3]–[6].

1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/.

2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

3 T. Hicks, T. Baldwin, J. Solano, and D. Bennett, *Likelihood of Criticality: The Likelihood of Criticality Following Disposal of HLW/SF/HEU/Pu*, AMEC, Contractor Report 17293-TR-022, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-following-disposal-of-sfhlwheupu-rwmd003001/.

4 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/.

5 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

6 R. Mason and P. Smith, *Modelling of Consequences of Hypothetical Criticality: Post-closure Criticality Consequence Analysis for HLW, Spent Fuel, Plutonium and HEU Disposal*, AMEC, Contractor Report AMEC/SF2409/012 Issue 3, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-post-closure-criticality-consequence-analysis-for-hlw-spent-fuel-plutonium-and-heu-disposal/.

B2.4.2 Criticality Safety for the Disposal of Spent Fuel - Burn-up Credit Validation

Task Number		20.4.002	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Post-closure criticality safety for HHGW - Spent Fuel			
Background					
RWM has previously undertaken a significant amount of work to demonstrate the post-closure criticality safety of LHGW and there has been less focus on HHGW. However, work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. Recent work has determined the preferred design and control options to demonstrate criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in a UK illustrative design. The work has been undertaken to address the requirement in the environment agencies' GRA, which requires that the safety case for the GDF demonstrates that "*The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern*" and that a 'what-if' criticality scenario is considered by assessing "*the impact of a postulated criticality event on the performance of the disposal system*". For the post-closure phase, it has been identified that taking credit for the decrease in reactivity due to the formation of fission products and actinides in fuel during irradiation (known as burn-up credit) is required to demonstrate meeting the requirements of the GRA. Since the information will need to be recorded for the post-closure phase there may also be a possibility of using burn-up credit in other phases. However, such burn-up credit arguments require a detailed record of the spent fuel irradiation history and a robust management control.					
Research Driver					
To support concept development for spent fuel disposal by identifying required burn-up credit information and the availability of records to demonstrate robust compliance.					
Research Objective					
To undertake a review of the burn-up credit approach to define requirements and necessary compliance records and identify any existing gaps.					
Scope					
This task will define requirements to satisfy compliance with burn-up credit arguments based on conceptual models developed previously and will identify if such requirements can be demonstrated for the range of spent fuels in the inventory for geological disposal. This work will primarily focus on the post-closure phase, however, the transport and operational phases will be considered concurrently to assess applicability. If it is found that challenges exist with demonstrating compliance with suitable records, further work will be developed to minimise the risk that the spent fuel cannot be safely transported to, and disposed of in, the GDF.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a set of requirements for demonstrating compliance with identified burn-up credit arguments and identification of whether such information is currently available. If the information is not available, it will identify possible alternatives to demonstrating the criticality safety of spent fuel.					
SRL at Task Start	SRL 5	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6

Further Information
There are several publications relevant to this task [1], [2]. Work will focus on post-closure as burn-up credit will be required; however, consideration of applicability to other phases will be included. 1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/. 2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

B2.4.3 Underpinning the Persistence of Iron-corrosion Products to aid Criticality Safety Assessments

Task Number	20.4.003	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Post-closure criticality safety for HHGW - Spent Fuel		

Background

RWM has previously undertaken a significant amount of work to demonstrate the post-closure criticality safety of LHGW and there has been less focus on HHGW. However, work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. Recent work has determined the preferred design and control options to demonstrate criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in a UK illustrative design. The work has been undertaken to address the requirement in the environment agencies' GRA, which requires that the safety case for the GDF demonstrates that "*The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern*" and that a 'what-if' criticality scenario is considered by assessing "*the impact of a postulated criticality event on the performance of the disposal system*".

One potentially important assumption concerns the fate of iron corrosion products. The waste packages contain significant quantities of iron; iron corrosion products have largely been assumed to be dissolved and removed from corroded waste packages, which may be cautious. Early analysis of the behaviour of iron corrosion products under disposal conditions has indicated that iron would remain in solid form for long periods. The persistence of iron may significantly reduce the likelihood of criticality within a waste package and therefore underpinning this assumption would have benefits. The application of such an argument would predominantly be for HHGW, however it may also have applications for LHGW such as waste packaged in Self-Shielded Boxes.

Research Driver

To support criticality safety assessments for the post-closure phase by underpinning assumptions around the persistence of iron-corrosion products.

Research Objective

To assess whether utilising arguments related to the persistence of iron-corrosion products can be robustly underpinned.

Scope

To undertake a review of available literature and information on the persistence of iron-corrosion products under disposal conditions to assess whether assumptions that a percentage remain can be robustly defended. If it is found that there is limited information in the literature, a programme of work will be developed. This programme of work would set out the requirements to develop the underpinning knowledge, with such work being completed as part of another task sheet. It should be noted that demonstrating that 100% of the iron remains will not be required, as even using 10% persistence has significant benefits.

Geology Application

HSR, LSSR, Evaporite

Output of Task

The output of this task will be a report detailing the state-of-the-art knowledge on the persistence of iron-corrosion products under disposal conditions. If required, a work programme for further development will also be generated.

SRL at Task Start	SRL 4	**SRL at Task End**	SRL 5	**Target SRL**	SRL 6

Further Information
Utilising the persistence of iron-corrosion products has been assessed in recent spent fuel criticality safety assessments. There are several publications relevant to this task [1], [2]. Work will be aligned with likelihood and consequences for post-closure [3]–[6].

1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/.

2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

3 T. Hicks, T. Baldwin, J. Solano, and D. Bennett, *Likelihood of Criticality: The Likelihood of Criticality Following Disposal of HLW/SF/HEU/Pu*, AMEC, Contractor Report 17293-TR-022, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-following-disposal-of-sfhlwheupu-rwmd003001/.

4 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/.

5 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

6 R. Mason and P. Smith, *Modelling of Consequences of Hypothetical Criticality: Post-closure Criticality Consequence Analysis for HLW, Spent Fuel, Plutonium and HEU Disposal*, AMEC, Contractor Report AMEC/SF2409/012 Issue 3, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-post-closure-criticality-consequence-analysis-for-hlw-spent-fuel-plutonium-and-heu-disposal/.

B2.4.4 Criticality Safety for the Disposal of Spent Fuel - Extending Burn-up Credit to Future/Different Fuels

Task Number	20.4.004	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Post-closure Criticality Safety for HHGW - Spent Fuel		
Background			
RWM has previously undertaken a significant amount of work to demonstrate the post-closure criticality safety of LHGW and there has been less focus on HHGW. However, work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. Recent work has determined the preferred design and control options to demonstrate criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in a UK illustrative design. The work has been undertaken to address the requirement in the environment agencies' GRA, which requires that the safety case for the GDF demonstrates that "*The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern*" and that a 'what-if' criticality scenario is considered by assessing "*the impact of a postulated criticality event on the performance of the disposal system*". For the post-closure phase, it has been identified for existing fuels that taking credit for the decrease in reactivity due to the formation of fission products and actinides in fuel during irradiation (known as burn-up credit) is required to demonstrate meeting the requirements of the GRA. Since the information will need to be recorded for the post-closure phase there may also be a possibility of using burn-up credit in other phases. As and when different and future fuels are included in the inventory, the applicability of the burn-up credit approach will need to be reviewed and identified gaps addressed.			
Research Driver			
To support concept development for spent fuel disposal by extending the burn-up credit approach to future/different fuels and identifying the availability of records to demonstrate robust compliance.			
Research Objective			
To review the applicability of the burn-up credit approach to future/different fuels and identify any gaps. The work will also define requirements and necessary compliance records for any fuels which utilise the approach.			
Scope			
This task will define requirements to satisfy compliance with burn-up credit arguments based on conceptual models developed previously and identify if such requirements can be demonstrated for the range of spent fuels in the inventory for geological disposal. This work will primarily focus on the post-closure phase; however, the transport and operational phases will be considered concurrently to assess applicability. If it is found that challenges exist with demonstrating compliance with suitable records further work will be developed to minimise the risk that the spent fuel cannot be safely transported to, and disposed of in, a GDF.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
The output of this task will be a set of requirements for demonstrating compliance with identified burn-up credit arguments and identification of whether such information is currently available for any future and different fuels requiring disposal. If the information is not available it will identify possible alternatives to demonstrating the criticality safety of spent fuel.			

SRL at Task Start	SRL 5	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6
Further Information					
There are several publications relevant to this task [1], [2]. Work will focus on post-closure as burn-up credit will be required, however, consideration of applicability to other phases will be included. It is anticipated that this would work would be supported by the New Build Company that owns any future fuels. 1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/. 2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.					

B2.4.5 Criticality Safety for the Disposal of Spent Fuel – Assessment for Future Fuels (if required)

<table>
<tr><td>Task Number</td><td>20.4.005</td><td>Status</td><td colspan="3">Start date in the future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Criticality Safety</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Post-closure Criticality Safety for HHGW - Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has previously undertaken a significant amount of work to demonstrate the post-closure criticality safety of LHGW and there has been less focus on HHGW. However, work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low. Recent work has determined the preferred design and control options to demonstrate criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in a UK illustrative design.

The work has been undertaken to address the requirement in the environment agencies' GRA, which requires that the safety case for the GDF demonstrates that ”The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern” and that a 'what-if' criticality scenario is considered by assessing ”the impact of a postulated criticality event on the performance of the disposal system”.

Work up to this point would have been focussed on available information, predominantly legacy spent fuels. However, dependent on decisions on new-build reactors and potential re-use of existing stocks of fissile material new fuels may be introduced into the inventory for disposal.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development for spent fuel disposal by ensuring criticality safety of future fuels through the transport, operational and post-closure phases.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To assess the impact of introducing future fuels into the inventory for disposal and the applicability of any existing criticality safety assessments. To develop alternative criticality control options, if required, which may be utilised in order to optimise the disposability of future fuels.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This task will first assess future fuels against existing criticality safety assessments/options for legacy fuels to identify if an existing assessment is applicable. If not, this task will undertake computational modelling on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of future spent fuels for the leading disposal concept for these fuels.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits along with underlying data model input data.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 5</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
This work is dependent on decisions on future fuels being made and may be performed on a single type of fuel or a range of fuels. There are several publications relevant to this task [1], [2]. Work will focus on post-closure as burn-up credit will be required; however, consideration of applicability to other phases will be included. It is anticipated that this would work would be supported by the New Build Company that owns any future fuels. 1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/. 2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

B2.4.6 Criticality Safety for the Disposal of Spent Fuel - Refined Assessments Based on Available Records

Task Number	20.4.006	**Status**	Start date in the future
WBS Level 4	Criticality Safety		
WBS Level 5	Post-closure Criticality Safety for HHGW - Spent Fuel		

Background

During the generic stage of the GDF programme, certain assumptions are made to allow package fissile material limits to be developed that de-risk the concern that packages made will not be disposable in the future. For spent fuel, a range of scoping criticality safety assessments/options will have been developed for a range of spent fuels requiring disposal. The work has been undertaken to address the requirement in the environment agencies' Guidance on Requirements for Authorisation, which requires that the safety case for the GDF demonstrates that "*The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern*" and that a 'what-if' criticality scenario is considered by assessing "*the impact of a postulated criticality event on the performance of the disposal system*".

Some of the assumptions are based on certain information or records being available, however a full study of whether such records are available will be reviewed as part of Task 20.1.003 and Task 20.4.002.

Research Driver

To support concept development for spent fuel disposal by optimising the criticality safety arguments of spent fuel through the transport, operational and post-closure phases using available records knowledge.

Research Objective

The safety cases need to be able to demonstrate, substantiate and communicate their positions related to criticality safety and therefore work is required to ensure that existing assessments are reviewed, maintained and build on available knowledge.

Scope

To undertake a review of whether available records will be sufficient to robustly demonstrate criticality safety based on the assessments performed. If gaps are identified, this task will undertake refined assessments using computational modelling on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of spent fuels for the leading disposal concept for these fuels based on available records.

Geology Application

HSR, LSSR, Evaporite

Output of Task

The output of this task will be a report (or reports) detailing the output of the review and applicability of assessments based on available records and suggested future needs.
It will then follow with a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data.

SRL at Task Start	SRL 5	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6

Further Information
This work is dependent on available record data becoming available and may be performed on a single type of fuel or a range of fuels at the same time. It is envisaged that this work will aim to reduce conservatisms within existing generic work; however, the first stage to review against assumptions will identify any gaps that will require addressing as well. There are several publications relevant to this task [1], [2]. Work will focus on post-closure as burn-up credit will be required, however, consideration of applicability to other phases will be included. 1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/. 2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

B2.4.7 Criticality Safety for the Disposal of Spent Fuel - Detailed Assessments Based on Site-specific Data

Task Number		20.4.007	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Post-closure Criticality Safety for HHGW - Spent Fuel			
Background					
During the generic stage of the GDF programme, certain assumptions are made to allow package fissile material limits to be developed that de-risk the concern that packages made will not be disposable in the future. For spent fuel, a range of scoping criticality safety assessments/options will have been developed for a range of spent fuels requiring disposal. The work has been undertaken to address the requirement in the environment agencies' Guidance on Requirements for Authorisation, which requires that the safety case for the GDF demonstrates that "*The possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern*" and that a 'what-if' criticality scenario is considered by assessing "*the impact of a postulated criticality event on the performance of the disposal system*". As site-specific data (e.g. groundwater composition, flow and host rock thermal conductivity) become available, more detailed assessments can be performed based on increased knowledge.					
Research Driver					
To support concept development for spent fuel disposal by optimising the criticality safety arguments of spent fuel through the transport, operational and post-closure phases using site-specific knowledge.					
Research Objective					
The safety cases need to be able to demonstrate, substantiate and communicate their positions related to criticality safety and therefore work is required to ensure that existing assessments are reviewed, maintained and build on available knowledge.					
Scope					
To undertake computational modelling on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of spent fuels for the leading disposal concept for these fuels based on site-specific data.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying data model input data.					
SRL at Task Start	SRL 5	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6

Further Information
This work is dependent on site-specific data becoming available and may be performed on a single type of fuel or a range of fuels at the same time. It is envisaged that this work will aim to reduce conservatisms within existing generic work, however, the first stage of reviewing assumptions for applicability will identify any identified gaps that will require addressing as well. There are several publications relevant to this task [1], [2]. Work will focus on post-closure as burn-up credit will be required; however, consideration of applicability to other phases will be included. It is anticipated that this work would be supported by the New Build Company that owns any future fuels. 1 T. W. Hicks, S. Doudou, and W. S. Walters, *Demonstrating the criticality safety of spent fuel disposal*, Orchid, Contractor Report GSL-1649-5-V3.1, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/demonstrating-the-criticality-safety-of-spent-fuel-disposal/. 2 D. Hanlon, S. Lonsdale, R. Mason, D. Putley, and A. Thallon, *Criticality safety for the disposal of spent fuel in UK disposal containers*, Wood, Contractor Report RWM/Contr/20/016, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/criticality-safety-for-the-disposal-of-spent-fuel-in-uk-disposal-containers/.

B2.5 WBS 20.5 - Post-closure criticality safety for HHGW - Plutonium and HEU

B2.5.1 Scoping Post-closure In-package Criticality Safety Assessment

Task Number	20.5.001	**Status**	Ongoing
WBS Level 4	Criticality Safety		
WBS Level 5	Post-closure Criticality Safety for HHGW - Plutonium and HEU		
Background			
The fissile material content of separated plutonium is considerable. Per unit mass of disposed wasteform, immobilised plutonium will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. In the post-closure safety case for the GDF, it will be necessary to demonstrate that criticality would be of low-likelihood and low-consequence. Criticality assessments for the post-closure period typically consider two sets of scenarios: ‘in-package’ scenarios after groundwater has penetrated into packages and comes into contact with the wasteform(s) within, and the package contents have subsequently evolved; and ‘out-of-package’ scenarios in which fissile material has been transported in groundwater out of the packages and redeposited elsewhere (e.g. in the backfill/buffer material surrounding the containers).			
Research Driver			
To support concept development by developing a criticality safety assessment for a preferred disposal concept for plutonium.			
Research Objective			
To explore fully what ‘in-package’ scenarios might be examined in a GDF post-closure safety case; what credit might be taken for features of the package and the wasteform(s) it contains (disposal MOX or titanate ceramics) that could reduce the ‘reactivity’ of the system from a criticality perspective in those scenarios; and what sub-critical masses might be obtained in the scenarios.			
Scope			
To undertake the following three activities: • Explore what ‘in-package’ criticality scenarios might be examined in a GDF post-closure safety case. This should consider a range of scenarios that take different types and amounts of credit for features of the package and wasteform(s) that reduce the ‘reactivity’ of the system from a criticality perspective (e.g. doping of the wasteform with neutron poisons), including at least one scenario that makes extremely pessimistic assumptions about fissile material geometry, moderation, etc. • Perform criticality calculations for the scenarios identified for which calculations have not previously been performed [1]. This should include calculating the minimum sub-critical mass for each scenario and examining the sensitivity of the results to realistic ranges of input parameters within each scenario (e.g. the concentration of neutron poisons within the wasteform). • Using the output from the above two activities, and relevant previous work [1], explore the optimum solution for reducing the ‘reactivity’ of the system from a criticality perspective in ‘in-package’ scenarios. This should consider a number of potentially competing factors that might influence where the optimum lies: *inter alia* ease, simplicity and robustness of the safety case; and the mass of fissile material per package that can be shown to give a low likelihood of criticality in the examined scenario(s).			

Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits along with underlying model input data. As this work is at a scoping level, the report(s) will also detail potential areas to increase package fissile material limits if required.					
SRL at Task Start	SRL 3	**SRL at Task End**	SRL 4	**Target SRL**	SRL 6
Further Information					
There are several publications relevant to this task [2]. 1 T. Hicks *et al.*, *Criticality sensitivity study for a cold pressed and sintered plutonium product*, Galson Sciences, 1801-1, 2018. 2 M. Sarsfield *et al.*, *A Study on the Choice of Neutron Poisons for Plutonium Immobilisation*, NNL 14743, 2019.					

B2.5.2 Scoping Post-closure Out-of-package Criticality Safety Assessment

Task Number	20.5.002	**Status**	Ongoing
WBS Level 4	Criticality Safety		
WBS Level 5	Post-closure Criticality Safety for HHGW - Plutonium and HEU		
Background			
The fissile material content of separated plutonium is considerable. Per unit mass of disposed wasteform, immobilised plutonium will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. In the post-closure safety case for the GDF, it will be necessary to demonstrate that criticality would be of low-likelihood and low-consequence. Criticality assessments for the post-closure period typically consider two sets of scenarios: 'in-package' scenarios after groundwater has penetrated into packages and comes into contact with the wasteform(s) within and the package contents have subsequently evolved; and 'out-of-package' scenarios in which fissile material has been transported in groundwater out of the packages and redeposited elsewhere (e.g. in the backfill/buffer material surrounding the containers).			
Research Driver			
To support concept development by developing a criticality safety assessment for a preferred disposal concept for plutonium.			
Research Objective			
To understand in what envelopes of 'parameter-space' fissile material release from candidate immobilised plutonium wasteforms in a GDF (disposal MOX or titanate ceramics) could be 'solubility-limited' and 'wasteform-dictated' and how that might depend on repository type/conditions. Work to increase understanding in: exploring the options for U-238 dilution; inclusion of neutron absorbers; and the impact of buffer/backfill will also be performed.			
Scope			
To undertake a range of review activities and computational calculations to improve understanding on post-closure scenarios. This will include the following: • Performing scoping calculations to explore in what envelopes of 'parameter-space' fissile material release from immobilised plutonium wasteforms in a GDF could be 'solubility-limited' and 'wasteform-dictated'. • Identifying a range of options to incorporate U-238 into the Engineered Barrier System and assess the viability and effectiveness of such options. • Identifying a range of options to incorporate neutron absorbers into the Engineered Barrier System and assess the viability and effectiveness of such options. • Identifying a range of options to incorporate favourable backfill/buffer (e.g. low moderator content) into the Engineered Barrier System and assess the viability and effectiveness of such options.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits along with underlying data model input data. As this work is at a scoping level, the report(s) will also detail potential areas to increase package fissile material limits if required.			

SRL at Task Start	SRL 3	**SRL at Task End**	SRL 4	**Target SRL**	SRL 6
Further Information					
There are several publications relevant to this task [1]–[3].					

1 M. Sarsfield *et al.*, *A Study on the Choice of Neutron Poisons for Plutonium Immobilisation*, NNL 14743, 2019.

2 C. Padovani *et al.*, *Radiation and damage and leach rates for plutonium bearing ceramic wasteforms*, TRP-STS-NUC-2019-0247, 2019.

3 G. Deissmann, S. Neumeier, G. Modolo, and D. Bosbach, *Review of the durability of potential plutonium wasteforms under conditions relevant to geological disposal*. FZ Julich / Brenk Systemplanung, 2011.

B2.5.3 Scoping Plutonium Criticality Safety Assessment Based on Concept Development and Experimental Outputs

Task Number		20.5.003	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Post-closure Criticality Safety for HHGW - Plutonium and HEU			
Background					
The fissile material content of separated plutonium is considerable. Per unit mass of disposed wasteform, immobilised plutonium will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. In the post-closure safety case for the GDF, it will be necessary to demonstrate that criticality would be of low-likelihood and low-consequence. Criticality assessments for the post-closure period typically consider two sets of scenarios: in-package scenarios after groundwater has penetrated into packages and comes into contact with the wasteform(s) within and the package contents have subsequently evolved; and out-of-package scenarios in which fissile material has been transported in groundwater out of the packages and redeposited elsewhere (e.g. in the backfill/buffer material surrounding the containers).					
Research Driver					
To support concept development by developing a criticality safety assessment for a preferred disposal concept for plutonium.					
Research Objective					
Following outputs from the plutonium Integrated Project Team, to undertake scoping criticality safety assessments on preferred disposal concepts.					
Scope					
To undertake a scoping computational study on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for plutonium disposal for the leading disposal concept(s) for this material following increased knowledge from the plutonium IPT.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. As this work is at a scoping level, the report(s) will also detail potential areas to increase package fissile material limits if required.					
SRL at Task Start	SRL 4	**SRL at Task End**	SRL 4	**Target SRL**	SRL 6
Further Information					
This task may be part of the plutonium IPT, or may be conducted in parallel.					

B2.5.4 Detailed Criticality Safety Assessment for Plutonium Disposal Concept

Task Number		20.5.004	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Post-closure Criticality Safety for HHGW - Plutonium and HEU			
Background					
The fissile material content of separated plutonium is considerable. Per unit mass of disposed wasteform, immobilised plutonium will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. In the post-closure safety case for the GDF, it will be necessary to demonstrate that criticality would be of low-likelihood and low-consequence. Criticality assessments for the post-closure period typically consider two sets of scenarios: in-package scenarios after groundwater has penetrated into packages and comes into contact with the wasteform(s) within and the package contents have subsequently evolved; and out-of-package scenarios in which fissile material has been transported in groundwater out of the packages and redeposited elsewhere (e.g. in the backfill/buffer material surrounding the containers).					
Research Driver					
To support concept development by developing a criticality safety assessment for a preferred disposal concept for plutonium.					
Research Objective					
Following outputs from the plutonium IPT and RWM detailed design, the objective is to undertake detailed criticality safety assessments on preferred disposal concepts.					
Scope					
To undertake a detailed computational study on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for plutonium disposal for the leading disposal concept(s) for this material following increased knowledge from the plutonium IPT.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. As this work is at a scoping level, the report(s) will also detail potential areas to increase package fissile material limits if required.					
SRL at Task Start	SRL 4	**SRL at Task End**	SRL 5	**Target SRL**	SRL 6
Further Information					

B2.5.5 Optimised Criticality Safety Assessment for Plutonium Disposal Concept Based on Transport Considerations and Site-specific Data

<table>
<tr><td colspan="2">Task Number</td><td>20.5.005</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure Criticality Safety for HHGW - Plutonium and HEU</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The fissile material content of separated plutonium is considerable. Per unit mass of disposed wasteform, immobilised plutonium will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. The plutonium IPT has been established with the purpose of progressing the development of disposal concepts for immobilised plutonium by December 2024.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To optimise concept development by refining the criticality safety assessment for the preferred disposal concept for plutonium.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">Following the detailed criticality safety assessment on the preferred disposal concept(s), the optimised study will refine this by taking knowledge arising from site-specific data (e.g. groundwater composition, flow and host rock thermal conductivity) and also work on the possible transport options for the disposal concept (Task 20.1.009).</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a computational study on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to optimise waste package fissile material limits for plutonium disposal for the preferred disposal concept(s) for this material.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits along with underlying model input data.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 5</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">This task will follow from Task 20.5.004 which would have developed detailed level criticality safety assessments for disposal concepts under consideration at the time, one of which would be assumed to be taken forward as the preferred option. This work cannot start until a detailed assessment is complete, scoping transport options are complete and intrusive site-specific data are available.</td></tr>
</table>

B2.5.6 Scoping HEU Criticality Safety Assessment Based on Concept Development

<table>
<tr><td>Task Number</td><td colspan="2">20.5.006</td><td colspan="1">Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Criticality Safety</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Post-closure Criticality Safety for HHGW - Plutonium and HEU</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The fissile material content of HEU is considerable. Per unit mass of disposed wasteform, HEU will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. RWM will be required to demonstrate the criticality safety of materials during transport, operations and following facility closure. During the process of siting, the number of options under consideration will reduce, which, together with any optioneering, will result in refinement of the final design of the disposal system.
For HEU wasteforms, concept selection has been limited, however it is anticipated that advancement in plutonium disposal concepts will have some applicability to HEU wasteforms.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development by developing a criticality safety assessment for a preferred disposal concept for HEU.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">Following outputs from the plutonium IPT and refinement of the preferred disposal concept for plutonium disposal, to undertake scoping criticality safety assessments to assess applicability to HEU wasteforms.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a scoping computational study on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for HEU disposal for the leading disposal concept(s) for this material following increased knowledge from the plutonium IPT. This may take the form of a full study or a sensitivity study using the plutonium work as a basis of assessment.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits along with underlying model input data. As this work is at a scoping level, the report(s) will also detail potential areas to increase package fissile material limits if required.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 3</td><td>SRL at Task End</td><td>SRL 4</td><td>Target SRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">This task is dependent on decisions about the disposal concept for HEU being made. It is assumed that work on plutonium wasteforms can be used as a basis for assessment; however, if this is not the case earlier work may be required to define a preferred disposal concept.</td></tr>
</table>

B2.5.7 Detailed Criticality Safety Assessment for HEU Disposal Concept

Task Number		20.5.007	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Post-closure Criticality Safety for HHGW - Plutonium and HEU			
Background					
The fissile material content of HEU is considerable. Per unit mass of disposed wasteform, HEU will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. RWM will be required to demonstrate the criticality safety of materials during transport, operations and following facility closure. During the process of siting, the number of options under consideration will reduce, which, together with any option-eering, will result in refinement of the final design of the disposal system. For HEU wasteforms, concept selection has been limited, however it is anticipated that advancement in plutonium disposal concepts will have some applicability to HEU wasteforms.					
Research Driver					
To support concept development by developing a detailed criticality safety assessment for a preferred disposal concept for HEU.					
Research Objective					
Following scoping criticality safety assessments on HEU wasteform disposal concepts, to perform detailed assessments based on available knowledge.					
Scope					
To undertake a detailed computational study on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for HEU disposal for the leading disposal concept(s) for this material following increased disposal concept maturity.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data. As this work is at a scoping level, the report(s) will also detail potential areas to increase package fissile material limits if required.					
SRL at Task Start	SRL 4	**SRL at Task End**	SRL 5	**Target SRL**	SRL 6
Further Information					
This task will follow Task 20.5.006 and is dependent on decisions about the disposal concept for HEU being made. It is assumed that work on plutonium wasteforms can be used as a basis for assessment, however if this is not the case earlier work may be required to define a preferred disposal concept.					

B2.5.8 Optimised Criticality Safety Assessment for HEU Disposal Concept Based on Transport Considerations and Site-specific Data

Task Number		20.5.008	**Status**	Start date in the future	
WBS Level 4		Criticality Safety			
WBS Level 5		Post-closure Criticality Safety for HHGW - Plutonium and HEU			
Background					
The fissile material content of HEU is considerable. Per unit mass of disposed waste-form, HEU will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. RWM will be required to demonstrate the criticality safety of materials during transport, operations and following facility closure. During the process of siting, the number of options under consideration will reduce, which, together with any option-eering, will result in refinement of the final design of the disposal system. For HEU wasteforms, concept selection has been limited, however it is anticipated that advancement in plutonium disposal concepts will have some applicability to HEU waste-forms.					
Research Driver					
To optimise concept development by refining the criticality safety assessment for the preferred disposal concept for HEU.					
Research Objective					
Following the detailed criticality safety assessment on the preferred disposal concept(s), the optimised study will refine this by taking knowledge arising from site-specific data (e.g. groundwater composition, flow and host-rock thermal conductivity) and also work on the possible transport options for the disposal concept .					
Scope					
To undertake a computational study on a set of normal operation and accident condi-tion scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to optimise waste package fissile material limits for HEU disposal for the preferred disposal concept(s) for this material.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the derived package fissile material limits and the methodology for deriving such limits, along with underlying model input data.					
SRL at Task Start	SRL 5	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6
Further Information					
This task will follow from Task 20.5.007, which would have developed detailed level crit-icality safety assessments for disposal concepts under consideration at the time, one of which would be assumed to be taken forward as the preferred option. This work cannot start until a detailed assessment is complete, scoping transport options are complete and intrusive site-specific data are available.					

B2.5.9 Plutonium IPT - Wasteform Review

<table>
<tr><td colspan="2">Task Number</td><td>20.5.009</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Post-closure Criticality Safety for HHGW - Plutonium and HEU</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The fissile material content of separated plutonium is considerable. Per unit mass of disposed wasteform, immobilised plutonium will have a higher fissile material concentration than other forms of HHGW earmarked for disposal in a GDF (spent fuel and vitrified HLW) over the whole post-closure period. In the post-closure safety case for a GDF, it will be necessary to demonstrate that criticality would be of low-likelihood and low-consequence. Criticality assessments for the post-closure period typically consider two sets of scenarios: in-package scenarios after groundwater has penetrated into packages and come into contact with the wasteform(s) within and the package contents have subsequently evolved; and out-of-package scenarios in which fissile material has been transported in groundwater out of the packages and redeposited elsewhere (e.g. in the backfill/buffer material surrounding the containers).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development by developing a criticality safety assessment for a preferred disposal concept for plutonium.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine what evidence already exists that could allow credit to be taken for certain wasteform features that could reduce the reactivity of the system from a criticality perspective for both in-package and out-of-package scenarios, where there are gaps in the evidence and how those gaps might be filled by performing further work.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">For both the in-package and out-of-package scenarios, the task is to perform a literature review to compile and analyse information on how the fissile material leach rate (including any contribution from the release of colloids) from candidate plutonium wasteforms (disposal MOX and titanate ceramics) would be likely to evolve over the post-closure period. It will also need to investigate the impact of certain features on the evolution of the wasteform, such as durability, porosity, irradiation damage and dissolution behaviour.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the state of the art knowledge on short and long term leaching behaviour of candidate Pu wasteforms under consideration and their relevance to post-closure criticality safety.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 3</td><td>SRL at Task End</td><td>SRL 4</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
This task is part of a plutonium Integrated Project(see Task 110.3.003 and Task 110.3.004).There are several publications relevant to this task [1], [2]. 1 G. Deissmann, S. Neumeier, G. Modolo, and D. Bosbach, *Review of the durability of potential plutonium wasteforms under conditions relevant to geological disposal*. FZ Julich / Brenk Systemplanung, 2011. 2 C. Padovani *et al.*, *Radiation and damage and leach rates for plutonium bearing ceramic wasteforms*, TRP-STS-NUC-2019-0247, 2019.

B2.6 WBS 20.6 - Criticality safety assessments

B2.6.1 Undertake Sensitivity Study on PCCCA Using Existing Desk Based Site-Specific data (5 sites)

<table>
<tr><td colspan="2">Task Number</td><td>20.6.001</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Criticality Safety Assessments</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">To date, generic post-closure criticality consequences assessments (PCCCAs) have been conducted based on illustrative disposal concepts. For the 2016 PCCCA the consequences used as a baseline for estimates of risk are based on information produced in the 2010 generic Disposal System Safety Case, as the 2016 gDSSC was not available at the time of the work. The assessments in the PCCCA are intended to fulfil the ‘what-if’ analysis required by the GRA. To this end, in addition to the assessment of criticality events that are (on the basis of current understanding) considered to be credible, criticality events that are not judged credible are also assessed. The assessments are based on illustrative disposal concepts, using input parameters considered to be suitably bounding at the time. It is not anticipated to undertake a PCCCA on five sites prior to down-selection (planning assumption), however work will be required to establish whether previous assessments are sufficiently bounding.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the environmental safety case by using available data to establish if the 2016 PCCCA is sufficiently bounding for sites identified.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake sensitivity studies on available site-specific data against the assumptions made in the PCCCA to assess the applicability of existing assessments.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">At this stage of the programme, the assessments will not be re-run; rather, the scope will be to undertake a sensitivity study to compare available data from the siting process and updates to the inventory for disposal from that used in the 2016 PCCCA. This study will assess whether the assumptions in the PCCCA and underlying work are suitably bounding, or whether some parameter values fall outside of the range previously studied. It is anticipated that the preference for this work would be a single task investigating all five sites (planning assumption) at once. However, if data are available at different times, it might be more appropriate to investigate each site separately.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report or reports detailing the comparison of the 2016 PCCCA against current knowledge of relevant parameters, identifying if any are outside of the range considered previously.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 6</td><td>SRL at Task End</td><td>SRL 6</td><td>Target SRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[3].

1 D. Roberts, T. Baldwin, G. Carta, T. Hicks, M. Kelly, R. Mason, and T. Ware, *Gdf post-closure criticality consequences assessment*, AMEC, Contractor Report 203034-DB20-RPT-002, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/gdf-post-closure-criticality-consequences-assessment/.

2 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/.

3 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

B2.6.2 Scoping Assessment of Alternative Disposal Concepts - Evaporite

<table>
<tr><td colspan="2">Task Number</td><td>20.6.002</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Criticality Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Criticality Safety Assessments</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">To date, criticality safety assessments (CSAs) have been conducted based on illustrative disposal concepts for deep geological disposal. This includes consideration of an evaporite host rock. For this concept, it has been assumed that there is no unbound water present so that the waste packages will not become saturated and there is no potential for fissile material to be removed from waste packages, therefore conditions will remain sub-critical. Wider work on variant scenarios, including evaporite variants, will be performed for the environmental safety case to assess impacts. As part of this, criticality safety will be considered to ensure the assumptions made are robust. During this work, any sensitivities for the transport and operational safety cases will also be considered.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the transport, operational and environmental safety cases by assessing the assumptions currently in the criticality safety assessments for disposal in an evaporite host rock.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake sensitivity studies on variant scenarios compared to the assumptions previously used to assess sensitivity of existing assessments to changes in the environment of the waste package.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This study will use computational models on a set of normal operation and accident condition scenarios (for the transport, operational and post-closure phases) utilising MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for variant scenarios for disposal in an evaporite host rock. This will include the impact of: flowing groundwater through the host rock; brine-pocket intrusion; and the presence of chlorine (chlorine is a neutron absorber).</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the comparison of the existing CSAs against variant scenarios and the results of any sensitivity calculations.</td></tr>
<tr><td>SRL at Task Start</td><td>SRL 3</td><td>SRL at Task End</td><td>SRL 4</td><td>Target SRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">This task will be undertaken in line with wider work on consideration of variant scenarios. The timings are based on current assumptions but could change based on the wider work programme.</td></tr>
</table>

B2.6.3 Undertake PCCCA Using Existing Desk-based Site-specific Data (Two Sites)

Task Number		20.6.003	**Status**	Start date in future	
WBS Level 4		Criticality Safety			
WBS Level 5		Criticality Safety Assessments			
Background					
To date, generic PCCCAs have been conducted based on illustrative disposal concepts. For the 2016 PCCCA, the consequences used as a baseline for estimates of risk are based on information produced in the 2010 gDSSC, as the 2016 gDSSC was not available at the time of the work. The assessments in the PCCCA are intended to fulfil the 'what-if' analysis required by the GRA. To this end, in addition to the assessment of criticality events that are (on the basis of current understanding) considered to be credible, criticality events that are not judged credible are also assessed. The assessments are based on illustrative disposal concepts, using input parameters considered to be suitably bounding at the time. Following on from Task 20.5.002, which assessed the sensitivity of the 2016 PCCCA to data available for five sites (planning assumption), this task will undertake assessments for the two down-selected sites based on site-specific data and updated inventory information.					
Research Driver					
To support the ESC by using available data and results of refined consequences and likelihood of post-closure criticality projects to conduct post-closure criticality consequence assessments on two sites.					
Research Objective					
To provide a post-closure criticality safety assessment for the two sites identified.					
Scope					
The results generated in the likelihood and consequences research programmes need to be jointly applied to demonstrate that criticality in a GDF following closure of the facility is not a significant concern by showing that the impacts on pathways that give rise to risk in the post-closure safety assessment are negligible. The scope will comprise work to assess the consequences of the impacts of a range of criticality events on the safety performance of a GDF for the two sites selected.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The deliverable will be the safety arguments and calculations for use in an update to the ESC and post-closure safety assessment for the two down-selected sites to demonstrate that post-closure criticality is not a significant concern.					
SRL at Task Start	SRL 6	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6

Further Information
There are several publications relevant to this task [1]–[3]. 1 D. Roberts, T. Baldwin, G. Carta, T. Hicks, M. Kelly, R. Mason, and T. Ware, *Gdf post-closure criticality consequences assessment*, AMEC, Contractor Report 203034-DB20-RPT-002, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/gdf-post-closure-criticality-consequences-assessment/. 2 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/. 3 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

B2.6.4 Undertake Sensitivity Study on PCCCA Using Existing Desk-based Site-Specific data (Two Sites Refined Data)

Task Number		20.6.004	**Status**	Start date in future	
WBS Level 4		Criticality Safety			
WBS Level 5		Criticality Safety Assessments			
Background					
To date, generic post-closure criticality consequences assessments (PCCCAs) have been conducted based on illustrative disposal concepts. For the 2016 PCCCA, the consequences used as a baseline for estimates of risk are based on information produced in the 2010 generic Disposal System Safety Case as the 2016 gDSSC was not available at the time of the work. The assessments in the PCCCA are intended to fulfil the 'what-if' analysis required by the GRA. To this end, in addition to the assessment of criticality events that are (on the basis of current understanding) considered to be credible, criticality events that are not judged credible are also assessed. The assessments are based on illustrative disposal concepts, using input parameters considered to be suitably bounding at the time. Following on from Task 20.5.004, which undertook PCCCAs for two sites based on site-specific data and updated inventory information, this task will comprise a sensitivity study (similar to Task 20.5.002) for the two sites and any data that have become available during the site characterisation process.					
Research Driver					
To support the environmental safety case by using available data to establish if the PCCCA for each of the two sites is sufficiently bounding based on new site characterisation data and inventory changes.					
Research Objective					
To undertake sensitivity studies on available site-specific data (e.g. groundwater composition, flow and host rock thermal conductivity) against the assumptions made in the PCCCA to assess applicability of existing assessments.					
Scope					
The results generated in the likelihood and consequences research programmes need to be jointly applied to demonstrate that criticality in a GDF following closure of the facility is not a significant concern by showing that the impacts on pathways that give rise to risk in the post-closure safety assessment are negligible. At this stage of the programme, the assessments will not be re-run; rather, the scope will be to undertake a sensitivity study to compare available data from the siting process and updates to the inventory for disposal from those used in the PCCCA for each of the two sites. This study will assess whether the assumptions in the PCCCA and underlying work are suitably bounding, or whether some parameter values fall outside of the range previously studied. It is anticipated that the preference for this work would be a single task, investigating both sites (planning assumption) at once. However, if data are available at different times, it might be more appropriate to investigate each site separately.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of this task will be a report (or reports) detailing the comparison of the PCCCAs for the (assumed) two down-selected sites against current knowledge of relevant parameters, identifying if any are outside of the range considered previously.					
SRL at Task Start	SRL 6	**SRL at Task End**	SRL 6	**Target SRL**	SRL 6

Further Information
The start date is dependent on the availability of site specific data such as rock characterisation data. There are several publications relevant to this task [1]–[3].

1 D. Roberts, T. Baldwin, G. Carta, T. Hicks, M. Kelly, R. Mason, and T. Ware, *Gdf post-closure criticality consequences assessment*, AMEC, Contractor Report 203034-DB20-RPT-002, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/gdf-post-closure-criticality-consequences-assessment/.

2 T. Hicks and T. Baldwin, *Likelihood of criticality: The likelihood of criticality synthesis report*, AMEC, Contractor Report 17293-TR-023, Version 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/the-likelihood-of-criticality-synthesis-report-rwmd003001/.

3 R. Mason, P. Smith, and D. Holton, *Modelling of consequences of hypothetical criticality: Synthesis report for post-closure criticality consequence analysis*, AMEC, Contractor Report AMEC/SF2409/013 Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-consequences-of-hypothetical-criticality-synthesis-report-for-post-closure-criticality-consequence-analysis-rwm005140/.

B3 WBS 30 - Engineered Barrier Systems (EBS) and their Evolution

The generic research activities to be concluded can be summarised in the following work areas:

- EBS for Low Heat Generating Waste **(WBS 30.1)**
- EBS for High Heat Generating Waste **(WBS 30.2)**
- Clay-based EBS**(WBS 30.3)**
- Cement-based EBS**(WBS 30.4)**
- Plugs and Seals **(WBS 30.5)**
- Thermal Modelling of Heat generating processes **(WBS 30.6)**
    - **WBS 30.1** comprises the Backfill IPT and its related tasks, in order to address the development of backfill materials for the range of illustrative geological environments and waste types (Task 30.1.001-Task 30.1.010). Based on the outcome of the Backfill IPT, 30.001 will identify any resulting site-specific research needs. These tasks will input to the LHGW system requirements and conceptual, preliminary, preferred and detailed design development.
    - **WBS 30.2** (Task 30.2.001 and Task 30.2.002) supports concept development by building an understanding of the effect of elevated temperatures (e.g. 100^{o}C) on backfill performance in high heat generating waste disposal concepts.

WBS 30.3 focuses on a clay-based EBS, in order to understand viable bentonite reserves which may be suitable for the UK programme and quality constraints and data limitations that may require further investigation. Activities will also develop capability for testing and characterising bentonite buffer materials to demonstrate they satisfy required future disposal system requirements, and will develop and maintain a toolkit and personnel capability (in supply chain and academia). Site-specific research is also needed, such as survivability of geosphere microbes in the EBS, understanding of the thermal evolution of the GDF and site-specific bio-fauna characterisation will enable RWM to understand the influence of microbial activity on the physico-chemistry of radionuclides under a realistic range of scenarios, such that associated uncertainty can be more effectively constrained, enabling system optimisation and design efficiency.

WBS 30.4 (Task 30.4.001-30.4.011) relates to cement-based EBS development, primarily for low heat generating wastes. Much of the work supports the post-closure safety case by developing a sufficiently detailed understanding of mechanisms and chronology of NRVB evolution over long timescales. The work also addresses the continued development and validation of the near-field component model to support the environmental safety case and identify outstanding research needs so as to provide further data and understanding of individual processes shown via the application of the near-field component model to have significant knowledge gaps with respect to the safety case.

WBS 30.5 (Task 30.5.001) comprises a fully integrated and justified roadmap for delivery of technically feasible and scientifically underpinned plug and seal components that meet long-term safety requirements. RWM has participated in international plugging and sealing projects in the past (EC DOPAS), however it is recognised that a significant UK plugging and sealing RD&D programme will be required.

Finally, **WBS 30.6** (Task 30.6.001) continues to develop RWM's thermal dimensioning tool as necessary for its continued use in RWM.

B3.1 WBS 30.1 - EBS for LHGW

B3.1.1 Integrated Project to Develop Backfill Materials for the Range of Geological Environments and Waste Types

Task Number	30.1.001	**Status**	Ongoing
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for LHGW		

Background

In low-heat-generating-waste geological disposal concepts, the backfill is the material that immediately surrounds the waste packages. Mass backfill is the material used to fill geological disposal facility accessways. The backfill material is one of the multiple barriers that contribute to isolation and containment of the waste. The way in which the backfill is required to contribute to isolation and containment will depend on the geochemistry, the groundwater flow regime and the mechanical stability and the thermal properties of the selected geological environment.

The generic cement Engineered Barrier System R&D programme has focussed on understanding cement evolution and the processes and parameters that are sensitive in terms of delivery of required safety functions. This understanding is documented in the [1].

Research Driver

RWM has undertaken work to develop the Geological Disposal Technical Programme. This work has identified the high-level scope and programme required to deliver a Geological Disposal Facility in the UK. Following on from this work, and to further develop the more detailed technical scope to underpin the Geological Disposal Technical Programme, this work aims to specifically address the development of backfill materials for the range of illustrative geological environments and waste types.

Research Objective

The objective of this task is to deliver the following outcomes: Phase 1

- A fully integrated and justified roadmap for delivery of technically feasible and scientifically underpinned backfill materials that meets the long-term safety requirements.
- A justified Business Case for the next phase of technical work detailing links to key decisions and interfaces within the Geological Disposal Technical Programme and the implications of delaying/deferring work.
- Confidence in alignment of R&D activities with the needs of other activities within the overall technical programme.

Phase 2

- Implementation and delivery of Roadmap Issue 1

Future phases of the project will follow - the scope of which will be defined as a result of the information delivered in the previous phases.

Scope

This long-term project aims to build on the programme established in the Geological Disposal Technical Programme with a specific focus on delivery of backfill materials for the range of geological environments considered suitable for hosting a GDF in the UK. Phase 1 shall consist of:

- the development of a fully integrated and justified Roadmap Issue 1;

- a detailed and fully costed business case supporting implementation of the Roadmap Issue 1; and
- for the near-term (~5 years) tasks, development of an approved S&T Task Sheet along with a detailed specification, programme, deliverables, proposed sub-contractors (if any) and fixed cost to delivery.

Phase 2 shall consist of the implementation and delivery of the approved tasks in the roadmap and it is envisaged this will include:

- Backfill and mass backfill requirements development;
- Desk-based development and modelling studies to support backfill formulation;
- Small-scale laboratory formulation development;
- Larger-scale technology development and demonstration; and
- Modelling and performance assessment.

Geology Application

HSR, LSSR, Evaporite

Output of Task

- Phase 1
  - Roadmap for the delivery of suitable GDF backfill materials
  - S&T Plan task sheets detailing the tasks required for the next -five years
- Phase 2
  - Delivery of the detailed five year work activities as set out in the approved roadmap.

SRL/TRL at Task Start	TRL 4	**SRL/TRL at Task End**	TRL 7	**Target SRL/TRL**	

Further Information

For further information: [2]

1 Radioactive Waste Management, *Geological Disposal: Engineered Barrier System Status Report*, RWM Report DSSC/452/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-engineered-barrier-system-status-report/.

2 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.

B3.1.2 Identifying Options for Backfill

<table>
<tr><td>Task Number</td><td>30.1.002</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">EBS for LHGW</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Work on backfill in the UK has historically been focused on the LHGW concept for HSR and the development of the NRVB. There are, however, a range of other options that require consideration, suitable for the range of potential host geological environments for specific waste types, or as subjects for further development, such as:

”Green cements” (that are considered better for the environment);
Backfills with superplasticiser. Backfill formulations with superplasticiser have been proposed by certain waste management organisations and could simplify emplacement and reduce cost;
Low-pH cements;
Phosphate based cements (potentially for specific wastes such as DNLEU);
Sulfate resistant cements;
Bentonite based backfills. Bentonite is a nuclear industry standard material used as a buffer for heat-generating wastes. However, bentonite could be a suitable alternative material for use as a backfill in concepts for the disposal of LHGW in certain geological environments and for wastes where there may be compatibility issues with some materials such as highly alkaline cements. They could also be used as a mass backfill for certain waste types; and
Prefabricated engineered structures, for example overpacks or vault liners that could be used to perform some of the functions of backfill.

The requirements for the mass backfill, for example to fill the access tunnels, have been considered in less detail than those for the local backfill by RWM. These requirements will be different to those of the local backfill around waste packages and will need to be considered separately.
This task is identified in the Backfill IPT Roadmap as Task P2-CC-T0.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development site-specific designs.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To identify options for backfill materials for the range of potential host geological environments, including a short-list of options to take forward to small-scale laboratory testing. This includes looking for opportunities to modify the formulation of NRVB to address revised requirements and advances in the cement industry. Down-selection of options will be robust, evidence-based and documented.</td></tr>
</table>

Scope					
In this task the options for development of a backfill will be evaluated. The outcomes could range from a robust demonstration that the options selected in the illustrative designs are preferred, through minor modifications to account for UK applicability of international concepts and changes in the availability of feed stocks, to more significant and fundamental changes. The case for proceeding with research and development activities will be clearly presented, supported by robust technical justification. Crushed host rock is often proposed as a mass backfill in some sections of access tunnels (with grout or bentonite additives if required); this is a cost-effective solution and reduces the environmental impact of a disposal facility by potentially re-using the excavated material. A further objective relating to the mass backfill could also be the transport of gas into defined volumes to avoid an increase in pressure in the disposal areas. The options for mass backfills will be reviewed, and the advantages and challenges associated with each identified. It is noted that the function of the mass backfill may differ depending on its location in the GDF and one material may not be suitable for use in all areas. Different materials may be specified in HHGW disposal areas, LHGW disposal areas, access ways, and tunnels with higher inflow. Specific consideration will be given to: • Local backfill in HSR, LSSR and evaporite (including pre-fabricated structures); • Mass backfill in HSR, LSSR and evaporite; and • Backfills potentially suitable for wastes associated with elevated temperatures in HSR, LSSR and evaporite (including prefabricated structures). A systematic and robust methodology will be developed to justify any down-selection and to identify knowledge gaps, based on the requirements identified in Phase 1 of the Backfill IPT. A small number of options could be brought forward for laboratory-scale testing, subject to a gate review.					
Geology Application					
HSR, LSSR, Evaporite - however as part of this task the potential to use a common backfill in various host geologies (particularly HSR and LSSR) will be considered.					
Output of Task					
A topic report outlining the opportunities for backfill development, including a short-list to take forward to laboratory-scale tests. It is anticipated that short-listed candidates would be identified for HSR, LSSR, evaporite and for local and mass backfills.					
SRL/TRL at Task Start	SRL1 / TRL 2	**SRL/TRL at Task End**	SRL 2 / TRL 3	**Target SRL/TRL**	
Further Information					
There are other publications relevant to this task [1]. 1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.					

B3.1.3 Requirements and Backfill Formulation Guidance

<table>
<tr><td>Task Number</td><td>30.1.003</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">EBS for LHGW</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">To support the development of disposal system requirements it will be important to develop an understanding of how the requirements management process would be applied to backfill development, and in particular, the process by which potential formulations can be developed. The requirements to be placed on backfill have been considered, but will not be definitive until the siting process develops and greater information is available on the hydrogeological regime and geochemistry of a particular site. This task is associated with maintaining a working understanding and development of requirements to be placed on the backfill, and how the requirements would be refined as GDF siting progress.
This task is identified in the Backfill IPT Roadmap as Task P2-CC-T1.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">RWM has undertaken work to develop the Geological Disposal Technical Programme. This work identified the high level scope and programme required to deliver a GDF in the UK. Following on from this work, and to further develop the more detailed technical scope to underpin the Geological Disposal Technical Programme, the Backfill Integrated Project aims to ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development site-specific designs.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To provide a single document that integrates the work of the Backfill Integrated Project regarding the requirements to be placed on backfill. To provide support to the documentation of requirements, specification and guidance for backfill formulation as the GDF programme develops.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">This task will provide the following:
• In the context of backfill development, a description of how the RWM requirements process works and how it will be integrated with the siting process and the GDF sub-programme business case stages.
• A description of how the requirements process could be applied to backfill, to ensure this aspect of the disposal system is developed to a level of detail appropriate to the siting stage, ensuring compatibility with RWM's developing Requirements Management framework.
• Integration of the results of the Backfill Integrated Project as they are produced. The Integrated Project has developed a set of requirements as part of Phase 1. Phase 2 includes a range of tasks aimed at unpacking a high-level requirement into a technical specification for each illustrative geological environment/waste type.
• Guidance on how requirements might be translated into a backfill formulation/backfilling design. Different requirements often have contrary consequences for the selection of the source materials and composition of the backfill and a balance may need to be sought.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR, Evaporite</td></tr>
</table>

Output of Task					
A working document that describes the process by which the requirements on backfill can be managed as the Integrated Project and GDF programme develop. As the Integrated Project develops, the requirements will become more quantitative as understanding is developed.					
SRL/TRL at Task Start	SRL 1 / TRL 2	**SRL/TRL at Task End**	SRL 4 / TRL 6	**Target SRL/TRL**	
Further Information					
There are other publications relevant to this task [1]. 1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.					

B3.1.4 Consideration of Security of Supply and Sustainability of Backfill Materials

Task Number	30.1.004	**Status**	Ongoing
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for LHGW		

Background

Substantial quantities of materials will be required to backfill the GDF over an extended period of time. The radwaste industry is a relatively small consumer compared with the construction industry at large and may therefore have limited influence on the supply of specific materials. Some of these materials may be specialised, and their availability over the extended period may be in question. The focus of this task will be to identify potential issues so that they are factored into the development of the backfill specification. The availability and suitability of materials over long time frames could be limited due to the following:

- Changes to industrial practices resulting from globalisation and rationalisation that could limit the availability of certain supplementary cement materials. PFA, GGBS and other construction materials; for example, supplies of fly ash are already limited in the UK due to the run down of coal fired power stations and the supply of BFS is dependent on the steel industry, the future of which is currently uncertain in the UK.
- Changes in construction practices that could lead to changes in the formulation of cement and/or additives for cementitious materials. For example, over the past 50 years the chemistry of OPC has changed to enable more rapid construction.
- Changes to environmental standards that may restrict the use of cement or other construction materials in the future. These include the desire to limit CO_2 generation and potentially the desire to limit the input of some chemical constituents of backfills to groundwater. In particular, there is increasing recognition of the environmental impact of Portland cement production and the need to minimise its use, leading to new cement technologies such as geopolymer cements (e.g. alkali-activated GGBS or fly ash) being adopted, particularly where very high strength is not required.

The materials to be considered are the constituents of the cementitious backfills under consideration, along with bentonite. Similarly, the security or variability of supplies of any additives, such as superplasticisers, will be addressed.

RWM has considered the carbon footprint of a GDF as part of its design work. This work only considered the backfills specified in the illustrative designs, and identified a number of knowledge gaps. This task is identified in the Backfill IPT Roadmap as Task P2-CC-T2.

Research Driver

To ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development of site-specific designs.

Research Objective

To identify potential issues around security of supply and environmental sustainability, to ensure that proposed backfilling approach is robust and sustainable over the long time periods associated with GDF operations.

Scope					
This task will: • Identify potential changes in practice that could affect the availability of cementitious and construction materials over the 100+ year GDF operational period. Consideration will be given to alternative materials that may become more widely used in the future. This will include engagement with cement producers; • Identifying opportunities to learn from experience. Waste producers have been packaging (grouting) waste for several decades and have had to adapt their approaches in response to changes in the availability of materials; • Consider how environmental standards concerning, for example, CO_2 production or groundwater protection, could affect the choice of backfill; • Assess the carbon footprint for different backfill options. The basis for comparison between options will require justification, as the backfill to waste ratio may differ. This work will aim to ensure that backfill solutions adopted are justified and optimised in terms of their carbon footprint; • Assess a range of potential backfills in terms of their potential to be impacted by changes in availability or environmental standards; • Make a preliminary comparison between options, identifying those which may be less susceptible to changes, and make recommendations for any future work, e.g. the need to undertake periodic reviews of industry practice; • Consider approaches to specification that mitigate potential issues with security of supply, e.g. by developing performance based specifications with procedures for approval by assessment of constituents and composition and testing.					
Geology Application					
HSR, LSSR, evaporite					
Output of Task					
A working document that describes the process by which the requirements on backfill can be managed as the integrated project and GDF sub-programme develop. As the project develops the requirements will become more quantitative as understanding is developed.					
SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 5	**Target SRL/TRL**	TRL 9
Further Information					
There are other publications relevant to this task [1]. 1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.					

B3.1.5 Implications of Gas Generation on Backfill Selection

Task Number	30.1.005	**Status**	Ongoing
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for LHGW		

Background

Gas will be generated in disposal areas for LHGW by: corrosion of metals, radiolysis, and degradation of organic materials. The gases will include non-active bulk gas (principally hydrogen) and radioactive gases including tritium, carbon-14 labelled methane, and radon. The backfill for a LHGW disposal area will be required to manage the gases generated.

The backfill can affect gas generation and migration in a number of ways, including the following:

- The backfill may provide a geochemical environment that reduces corrosion rates and hence gas generation rates (e.g. a passivating environment). Degradation rates of organic materials are also dependent on pH, as is microbial activity.
- The backfill may limit the rate at which groundwater contacts the waste.
- The backfill may limit the ingress of aggressive species present in groundwater such as chloride or sulfide, that accelerate the corrosion of metals.
- CO_2 generated by the waste may react with a cementitious grout, effectively preventing the release of carbon-14 labelled CO_2.
- The gas permeability and mechanical strength of the backfill will determine whether any gas generated can migrate through the backfill without cracking it. The significance of backfill cracking to the safety case is being considered in a separate task. Properties of the backfill can change with time, e.g. while a cementitious backfill cures, or due to carbonation.
- The backfill porosity may provide storage capacity, reducing the pressure rise experienced by the host rock.
- By increasing the temperature (and hence corrosion rates) during the period of curing.

Both NRVB and the Nagra M1 mortar development considered gas generation and migration as a design criterion which effected the resulting grout specification in the 1990s. It is necessary to revisit and generalise this work to understand the requirements on any revised backfill formulation.

This task is identified in the Backfill IPT Roadmap as Task P2-CC-T8.

Research Driver

To ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development of site-specific designs.

Research Objective

To understand how a requirement to manage gas generation in LHGW disposal areas could translate into a material technical specification, covering aspects such as gas permeability, porosity, strength and geochemistry.

Scope					
The scope covers performing a literature review and a synthesis of previous work and simple scoping calculations. The work will: • Discuss the effect of the choice of local backfill on gas generation and migration and the effect of mass backfill on gas migration, describing the consequences for the safety case. Both radioactive and non-active gases will be considered in HSR, LSSR and evaporite geological environments; • Review the approaches used by other waste management organisations to determine the requirements imposed on backfill by the need to manage the production and migration of gas; • Indicate how quantitative requirements on the physical and chemical properties of backfill might be developed as more information on the site and disposal concept is developed. The physical and chemical properties of interest could include gas permeability, porosity and pH; • Derive illustrative ranges of quantitative requirements on backfill using scoping calculations for a range of assumptions about the host geology and gas generation rate; and • Identify knowledge gaps and discuss their implications for the experimental work programme on backfill development.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A topic report summarising the work.					
SRL/TRL at Task Start	SRL 1 / TRL 2	**SRL/TRL at Task End**	SRL 4 / TRL 5	**Target SRL/TRL**	
Further Information					
There are other publications relevant to this task [1]. 1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.					

B3.1.6 Quality Assurance Aspects of Backfill Emplacement

Task Number	30.1.006	**Status**	Start date in the future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for LHGW		

Background

Quality Assurance of the backfill emplacement will be required to build confidence that the GDF will perform in line with the safety arguments made in the disposal system safety case, i.e. as part of a demonstration that the requirements being placed on backfill are being met. This task will document the QA regime that may be required to ensure the backfill is emplaced within the agreed formulation envelope, and how appropriate controls can be demonstrated. This task is identified in the Backfill IPT Roadmap as Task P2-CC-T3.

Research Driver

To ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development site-specific designs.

Research Objective

To deliver a QA process based on a combination of documentation review and testing of the constituent materials, measurement and recording of the batching process and testing of the mixed backfill.

Scope

This task will consider:

- The types of QA activities that may be necessary, covering, for example, the following:
  - Testing samples from input materials and how variability in raw materials/acceptable ranges can be defined. This may be based on assured documentation from the material suppliers.
  - Methods for recording the backfill mixing process to ensure that the correct formulation is produced within allowable limits.
  - Physical testing of the rheology of the mixed backfill to ensure that it is acceptable for the particular placement method being used.
  - Methods for measurement during the backfilling process to ensure an acceptable level of filling.
  - Destructive tests on samples (e.g. strength) to ensure conformity with the specification and to measure variability.
  - Non-destructive tests and monitoring.
- The criteria against which the review/testing will assess compliance with a sufficiently high level of confidence. The practical implications of QA, including the following:
  - The types of facilities and staff required.
  - The way in which documentation is obtained and logged.
  - The options for either surface and/or underground laboratories.
  - The method for accreditation of the QA process, including documentation and testing procedures, qualifications of lab staff, etc.
  - Any implications for the backfilling schedule.

<table>
<tr><td colspan="6">• The options for remediation in the event that any non-compliance is measured.
The scope covers cementitious and bentonite-based backfills in HSR and LSSR, as well as backfills suitable for evaporite host rocks. The work should draw on relevant experience/case studies from the general construction industry and from radioactive waste disposal industries.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report giving recommendations for processes for document review and testing to provide an acceptable level of QA and summarising any issues.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 1 / TRL 2</td><td>SRL/TRL at Task End</td><td>SRL 4 / TRL 5</td><td>Target SRL/TRL</td><td>TRL 9</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1].
1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, Backfill development integrated project: Roadmap, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.</td></tr>
</table>

B3.1.7 Practical Aspects of Backfill Emplacement

Task Number	30.1.007	**Status**	Ongoing
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for LHGW		
Background			
Backfill can be emplaced in a GDF using a range of methods that will affect the GDF design and the OSC. There is an inter-dependency between the backfill specification and the emplacement method that means these two aspects cannot be considered in isolation. The technology available to emplace backfill can have a significant role in the practicability and cost of backfilling operations. Backfill emplacement options developed by RWM have focused on NRVB; however there has been less emphasis on other materials/methods. This task is identified in the Backfill IPT Roadmap as Task P2-CC-T7.			
Research Driver			
To ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development site specific designs.			
Research Objective			
To develop the emplacement options and assessment methodology necessary to enable informed decisions on the practicability of different backfilling options. To understand the requirements on the backfill formulation arising from practical considerations.			

<table>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The task will involve the following:

A review of possible emplacement methods and their advantages and disadvantages. The possible methods could include: hydraulic pumping or pouring (as used in the illustrative designs in HSR and LSSR); pneumatic methods; slinger methods; projected granular material; prefabricated modules/overpacks; in-situ compaction; and the use of multiple methods within the same vault.
Consideration of various emplacement strategies and the factors that may lead to one approach over another. The potential topics should include:

backfilling in long sections (300m) versus shuttering shorter (50m) sections;
backfill-as-you-go versus at closure of the GDF;
mixing backfill at the ground surface versus mixing underground (depending on the working time of different backfills); and
Alternatives to the excavation of galleries specifically for backfill emplacement.

Discussing the implications of different backfilling options on other aspects of the GDF design or operational safety case. The aspects that could be affected include the following:

Operational safety: The chemical hazards associated with different backfills will differ, and should be reported. Similarly, dose implications of the various technologies will require ALARP consideration;
Cost and schedule: Some options are likely to be considerably more time-consuming than others; and
GDF design: Some of the potential changes could include the heat of hydration and consequences for the ventilation system. Or variations in bleed water and consequences for the effluent management system.

Development of metrics to help assess the practicability of different options to support down selection. These could include: ease of engineering; timescales; operational safety issues; costs.
Determining how the requirements on practicality of backfill emplacement should be interpreted in terms of quantitative metrics.

This task will require input from industrial users of large volumes of backfilling materials, with practical experience of emplacing significant volumes of cementitious materials. A range of cementitious and bentonite based backfills should be considered, as well as backfills suitable for an evaporite host rock, and prefabricated engineered structures.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report describing how backfill can be practically emplaced and a comparison of options.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 1 / TRL 2</td><td>SRL/TRL at Task End</td><td>SRL 4 / TRL 5</td><td>Target SRL/TRL</td><td>TRL 9</td></tr>
</table>

Further Information
There are other publications relevant to this task [1].   1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.

B3.1.8 Model Development to Support Backfill Selection

Task Number	30.1.008	**Status**	Ongoing
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for LHGW		

Background

Modelling capability will be required to help underpin the selection of backfill. RWM currently uses two models that are potentially useful for understanding the performance of backfill with respect to contaminant release from the near field and subsequent radiological risk:

- The Near-field Component Model, which is a probabilistic model with detailed chemistry and transport through an evolving near field, combining the advantages of GoldSim and ToughReact.
- The Total System Model, which models the whole disposal system, using a simplified representation of chemistry and transport. It is particularly suitable for stochastic simulations of GDF performance against post-closure safety requirements.

Some development of modelling capability is necessary to develop insight into the parameters which may drive potential requirements on the backfill relating to:

- Implications of different backfill options on post-closure performance;
- Geochemical evolution, particularly for any formulations that differ from NRVB;
- Geotechnical interactions with waste packages and the host rock; and
- Modelling the safety implications of different mass backfill options.

These modelling tasks are needed to help underpin the specification of preliminary quantitative requirements of the backfill.

A topic of particular interest concerns the potential for an appropriate backfill to mitigate the implications of any in-waste package voidage; this will require work in each of the areas above. This task is identified in the Backfill IPT Roadmap as Task P2-CC-T4.

Research Driver

The Backfill Integrated Project aims to ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development of site-specific designs.

Research Objective

To develop modelling capability to underpin the development of technical requirements on backfill selection and assessment. To understand the potential for an appropriate backfill to mitigate the implications of any in-package voidage.

Scope

Five sub-tasks are identified, covering post-closure assessment; geochemical evolution; mechanical evolution; groundwater flow and the potential for backfill to mitigate in-waste package voidage.

Post-closure Assessment.

This task will:

- Summarise the post-closure safety functions of backfill in LHGW disposal concepts;
- Explore the potential for alternative EBS designs to affect post-closure performance. These should cover designs intended to limit and/or divert flow from the disposal areas;
- Develop simple models of post-closure evolution to understand how the performance of the backfill could affect the overall safety case for the groundwater pathway in HSR and LSSR. These would be based on developments of the existing total system model to cover:
  - Alternative geochemical evolution;
  - Alternative hydraulic properties, compared to the base case assumptions, including the potential for cracking, and the role of flow-focussing, and the potential for low-conductivity barriers to improve post-closure performance.

  The outputs of the model would be post-closure risk and fluxes from the near-field;
- Discuss data availability and develop and implement an approach to parameterising models of post-closure performance. For example, this could use expert judgement initially then focused reviews of key parameters; and
- Discuss the implications of the results on backfill selection. Can we distinguish between options, or are they all within the bounds of uncertainty?

Geochemical Evolution

The purpose of this task is to generalise the work RWM has done on the geochemical evolution of NRVB to cover other potential cementitious backfills. This will develop understanding of the potential for other backfill specifications to meet any requirements relating to porewater conditioning and radionuclide sorption.

One aim of the task is to model the geochemical evolution of different cementitious backfill options using analytic models and geochemical software such as PHREEQC. The outputs would be an understanding of the pH evolution as a function of time for a range of cementitious backfill materials. The materials considered will include modifications to NRVB (including the additions of aggregate), variations on the Nagra M1 mortar, self-compacting cements and examples of magnesium cements. Consideration will be given to how to treat uncertainty in site properties (groundwater composition). The use of superplasticisers in the backfill will be considered as a potential option.

The modelling will develop the capability to determine an appropriate backfill to waste ratio to achieve a specified degree of pH buffering. The potential for un-encapsulated waste will be considered as part of these estimates.

The task will also provide a discussion of those aspects of the geochemical evolution of backfill that are not amenable to geochemical modelling, or where significant data gaps exist. These topics include calcite armouring, porosity evolution, and sorption potential. Data gaps will be identified.

Mechanical Evolution

An important requirement on the backfill relates to providing mechanical stability of the host rock. Providing mechanical stability reduces the potential for damage to the host rock and therefore the formation of preferential flow paths. It is expected that the mechanical requirements may vary significantly depending on the characteristics of the host geology and disposal design, and that this task therefore will not be able to determine definitive requirements at the current stage of siting. This task will:

- Review geotechnical/mechanical requirements on backfills for LHGW from other waste management organisations
- Outline the potential modelling approaches used to demonstrate long-term stability, covering simple 'bulking-factor' approaches, standard geotechnical stability analyses/factor-of-safety and more advanced transient calculations;
- Discuss the evolution in mechanical parameters of backfill and packages as they degrade. This should include consideration of the likelihood and effects of cracking as the backfill cures;
- Provide illustrative calculations using standard equilibrium calculations that explore the implications of:
  - Vault design, including the presence of crown space;
  - Vault depth/ rock stress;
  - The mechanical properties of the backfill;
  - Package stacking arrangements, including the ability to stack packages on interim floors;
  - The amount of in-package voidage.
- Provide ranges of indicative geotechnical parameters that might be applicable; and
- Propose a method of evaluating the geotechnical requirements on backfill as the design and site properties become better known.

Modelling the Safety Implications of Different Mass Backfill Options

This work stream would involve modelling groundwater flow in and around a generic GDF. The properties of the mass backfill would be varied and the flow and particle tracks would be compared. The safety implications would then be considered. The task would consider:

- A range of potential GDF designs in the three illustrative geological environments. The hydraulic properties of overlying units would also be varied; and
- Suitable chosen representative mass backfill material properties.

The modelling would discuss the implications of different backfill options on the flow paths and post-closure safety.

Integrated Topic Report on the Potential for an Appropriate Choice of Backfill to Mitigate the Implications of Voidage within the Disposal System

In-package voidage has been raised as an issue meriting a specific topic report. It is possible that over long time scales in-package voidage could reduce confidence in the post-closure performance of a disposal facility. However, an appropriate backfill selection, vault design, and package stacking arrangement may mitigate the implications of this voidage. It may also potentially prevent the need for re-packaging of specific existing waste packages, or the need for unnecessarily onerous waste package specifications.

This task will:

• Summarise RWM's current position on in-package voidage and its potential implications in different geological environments; and • Use the work undertaken in the tasks on: post-closure modelling, geotechnical modelling and mechanical modelling to summarise how different backfilling, stacking or vault design options might mitigate the implications of in-package voidage.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task • A separate topic report on each of: post-closure assessment; geochemical modelling; modelling the safety implications of different mass backfill options; and geotechnical modelling. • A topic report on the potential for an appropriate choice of backfill to mitigate the implications on in-package voidage.					
SRL/TRL at Task Start	SRL 1 / TRL 2	**SRL/TRL at Task End**	SRL 4 / TRL 5	**Target SRL/TRL**	TRL 9
Further Information					
There are other publications relevant to this task [1]. 1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.					

B3.1.9 Small-scale Testing of Backfills for HSR, LSSR and Evaporite

Task Number	30.1.009	**Status**	Start date in future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for LHGW		

Background

These tasks involve a programme of small-scale testing (with supporting modelling activities) to establish a range of backfill properties for comparison with the technical specification.

The work is organised into three strands, as the requirements on the backfill are potentially different in different hot geologies:

- P2-HSR-T1: Small-scale testing backfills for HSR
- P2-LSSR-T1: Small-scale testing backfills for LSSR
- P2-Evap-T1: Small-scale testing backfills for evaporite

These tasks are identified in the Backfill IPT Roadmap as Task P2-HSR-T1., P2-LSSR-T1 and P2-Evap-T1. These tasks follow on from Backfill IPT Task P2-CC-T0 (Task 30.1.002).

Research Driver

To ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development site-specific designs.

Research Objective

To understand and confirm that the backfills being tested have properties in line with the requirements. Laboratory-scale testing is necessary to determine the basic physical and chemical properties of backfill candidate materials, ahead of larger-scale experiments or technical demonstrations

Scope

The scope will depend on both the requirements specified in P2-CC-T1 and the candidate materials proposed in Task 30.1.002.

The basic physical properties might be tested at this stage, and a subset of the other properties. Testing radionuclide transport properties (solubility and sorption data) may not be a priority at this stage, as the existing parameters are likely to be applicable to a relatively wide range of cementitious grouts. However, a few ‘spot-checks’ on key species may be useful to build confidence.

If it was concluded in Task 30.1.002 that NRVB was still the preferred option in HSR, then only a relatively limited number of tests would be required to reconfirm properties and redevelop capability. More extensive testing would be needed if the backfill specifications differed significantly from that of NRVB and for the material and implementation options under consideration for LSSR and Evaporite since these options have not been developed to the extent of NRVB.

<table>
<tr><td colspan="6">Testing will begin with a small number of tests, which will be able to cover basic properties such as rheology, setting time, bleed water, density and early age compressive strength. Depending on whether the formulation has been significantly adjusted, historical data may remain applicable. It is important to record the formulations investigated in detail, including the source and standard of all powders used and the properties achieved, in order to limit any reworking that may be required when sources and standards inevitably change again in future years. Subject to successful testing and a gate review, a small number of options could be brought forward for larger-scale testing and demonstration.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR and Evaporite.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A set of interim technical notes to report progress and a topic report documenting the overall test results and their implications.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 2/ TRL 3</td><td>SRL/TRL at Task End</td><td>SRL 3/ TRL 4</td><td>Target SRL/TRL</td><td>TRL 9</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">Relevant publications include: [1]
1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, Backfill development integrated project: Roadmap, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.</td></tr>
</table>

B3.1.10 Larger-scale Testing of Backfills for HSR, LSSR and Evaporite

<table>
<tr><td colspan="2">Task Number</td><td>30.1.010</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">EBS for LHGW</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Examples of testing and information obtained from larger-scale tests may include testing proposed deployment equipment (i.e. mixers and pumps), or smaller scale analogues. Larger-scale tests could identify any issues associated with mixing or deploying at a large scale that may not have been observed when mixing at smaller-scale, such as changes to fluidity using different mixing techniques and scales. The results of the larger-scale testing should confirm and support results obtained at small-scale. In the event of any major potential issues being experienced, however, there is opportunity to adapt formulations if required by feeding back to laboratory trials.

These tasks are identified in the Backfill IPT Roadmap as Task P2-HSR-T2, P2-LSSR-T2 and P2-Evap-T2. These tasks follow on from Backfill IPT Tasks P2-HSR-T1, P2-LSSR-T1 and P2-Evap-T1.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To ensure that RWM has underpinned backfill materials and emplacement methods for the range of potential host geological environments to inform concept selection and support the development site-specific designs.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To provide a convincing demonstration of practical capability in backfilling in HSR, facilitating engagement with a range of stakeholders.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Potential topics to investigate could include:
• Long-range, more realistic flow testing;
• Changes to setting time brought on by increased exotherm at large scale;
• The possibility of matrix cracking, either at the surface through localised loss of water, or deeper due to segregation or variations in setting times and exotherms;
• The effects of multiple batch mixes on overall integrity, i.e. bonding and interface of multiple batches;
• The influence of, and effect on, packages encapsulated within the backfill;
• Mix variations cause by flow around packages; and
• The effects of variation in stacking uniformity and spacing of packages.

Samples can be cast and cores taken from the large pours to determine these and other properties. The option of larger-scale retrievability/recoverability tests could also be considered if necessary. The effects of retrieval on the waste package could be investigated, as could the potential for remote retrieval operations.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">Separate tasks focused on backfills in HSR, LSSR and Evaporite may be specified. However the potential to use a common backfill in HSR and LSSR will be considered.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A topic report describing the results of the tests.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3/TRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4/TRL 5</td><td>Target SRL/TRL</td><td>TRL 9</td></tr>
</table>

Further Information
There are other publications relevant to this task [1].

1 D. Holton, P. Bamforth, A. Clark, V. Cloet, J. Engelhardt, D. Lever, N. Marcos, P. Martensson, F. Neall, H. Pairaudeau, J. Pearson, D. Roberts, and A. Shelton, *Backfill development integrated project: Roadmap*, Orchid, Contractor Report RWM/Contr/20/004, 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/backfill-development-integrated-project-consortium-roadmap/.

B3.2 WBS 30.2 - EBS for HHGW

B3.2.1 Experimental Design: High Temperature Backfill Functional Requirements

Task Number	30.2.001	**Status**	Start date in future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	EBS for HHGW		

Background

One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. Over several decades waste management organisations internationally have undertaken a significant programme of R&D on cementitious backfills for use in ILW disposal concepts. Previous work to develop disposal concepts for high heat generating wastes has introduced the possibility of temperatures well in excess of 100°C where alternative buffers/backfills to bentonite clay may be required. Cement-based systems may be one such alternative, but there is currently inadequate understanding of their performance and evolution at such high temperatures in a geological disposal context. This task concerns the development of a scope for a programme of work to identify and characterise potential cement-based systems for use in this context. A significant input is the review undertaken by the HHIPT on performance of cements and concretes at high temperature.

Research Driver

To support concept development by building an understanding of the effect of elevated temperatures (e.g. 100°C) on backfill performance.

Research Objective

To develop an experimental programme which will inform the testing and development of cementitious backfills to meet the safety functional requirements for a cement based disposal system for HHGW.

Scope

- To identify the safety functions required from a cementitious backfill in high heat generating waste disposal concepts.
- To identify a range of possible backfill materials for investigation.
- To identify processes which are likely to affect the performance of the backfill in achieving its safety functions at high temperatures.
- To develop the scope for an experimental and modelling programme to underpin alternative backfill performance.

Geology Application

HSR, LSSR

Output of Task

Understanding, data and an experimental and modelling programme to inform an evaluation of cementitious materials in concept options for HHGW. It is envisaged that this task will be reported via a combination of a contractor report and supporting technical journal publications.

SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4

Further Information
This task draws the relevant outcomes of the HHIPT and the concepts IPT into the near-field research programme. There are several publications relevant to this task [1], [2]. 1 Radioactive Waste Management, *Geological disposal: High heat generating project - final report*, RWM Report NDA/RWM/136, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-high-heat-generating-wastes-project-final-report/. 2 P. Bamforth *et al.*, *Project ankhiale: Task E2.3 review of cement performance at high temperatures*, Ref 103726-0009-UA00-TLN-0001, 2016.

B3.2.2 Effect of High Temperatures (>100°C) on Cement Backfill for Spent Fuel (SF) / Multi-Purpose Containers (MPC)

Task Number		30.2.002	**Status**	Start date in future	
WBS Level 4		Engineered Barrier Systems (EBS) and their Evolution			
WBS Level 5		EBS for HHGW			
Background					
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. Over several decades waste management organisations internationally have undertaken a significant programme of R&D on cementitious backfills for use in ILW disposal concepts. Recent work to develop disposal concepts for high-heat generating wastes has introduced the possibility of temperatures well in excess of 100°C where alternative buffers/backfills to bentonite clay may be required. Cement-based systems may be one such alternative but there is currently inadequate understanding of their performance and evolution at such high temperatures in a geological disposal context. This task implements the scope defined in Task 30.2.001.					
Research Driver					
To support concept development by building an understanding of the effect of elevated temperatures (>100°C) on backfill performance in a cavern concept for spent fuel.					
Research Objective					
To determine whether high temperatures affect the long-term performance of a cement backfill and its ability to deliver the required safety functions (e.g. its ability to condition porewater to the required pH range, to enable gas migration to the far field, and to sorb radionuclides).					
Scope					
Implement the experimental scope will be defined in the predecessor task (Task 30.2.001).					
Geology Application					
HSR, LSSR					
Output of Task					
Understanding and data to inform an evaluation of cementitious materials in concept options for high heat generating waste. It is envisaged that this task will be reported via a combination of a contractor report and supporting technical journal publications.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					

B3.3 WBS 30.3 - Clay-Based EBS

B3.3.1 Microbiology in the Near-field

Task Number	30.3.001	**Status**	Ongoing
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Clay-based EBS		
Background			
Disposal of radioactive wastes in a GDF creates an environment within which a range of microbes can thrive. Microbial activity in this environment harnesses a range of electron acceptors and donors present within the waste, barrier systems and adjacent host rock, ultimately influencing the evolution and performance of the disposal system [1]. In RWM's illustrative designs for LSSR and HSR, bentonite is chosen as an EBS for HHGW. Bentonite has a number of favourable properties which allow it to fulfil specific safety functions. Studies have shown, however, that microbial populations exist within bentonite [2] and host rock material adjacent to excavations, as well as interfacial areas between barrier components [3]. Such microbes can be resistant to stresses present within a repository environment [1]. Together, the system of waste container, engineered barriers and adjacent host rock can be considered as the 'near-field' and, for this task, will be considered as a single unit to capture microbial processes which act across these components.			
Research Driver			
Microbial processes have the potential to influence processes in the near-field such as the formation of mineral phases, geochemistry and the transport of radionuclides. The processes should therefore be accounted for within safety assessments and are currently subsumed into generic uncertainty within total system models. Some early attempts have been made to develop models to capture the influence of microbial processes [1], [4], although since publication of these works there have been significant advances in both understanding of microbial processes and numerical modelling capability. Yet, there is a general lack of published work exploring the development of numerical models in recent years, which are able to help bound uncertainty associated with microbial activity.			
Research Objective			
Explore the influence of microbial activity on processes within a GDF, identifying the influence they have on the physicochemistry under a realistic range of scenarios, such that associated uncertainty can be more effectively constrained. More effectively constrained uncertainty within the post-closure safety case will have knock-on implications for system optimisation and design efficiency.			
Scope			
The scope for this task is as follows: • To develop a numerical model to represent known geochemical processes influenced by microbiology in the near-field of HHGW. • To develop *in-situ* experiments or use existing experimental data to allow the model to be tested. • Testing of numerical model using laboratory data.			

• Use model to predict ranges of geochemical processes influenced by microbial processes within a GDF environment and identify key sensitivities. This scope is planned to be delivered through an RWM led, university delivered work-in-kind contribution to the MA experiment at Mont Terri Underground Rock Laboratory. Further scope may be identified as a result of this PhD, for example a need for further data collection to validate models. Additional scope within the remit of the stated research need will be conducted under this task.
Geology Application
LSSR, HSR
Output of Task
This work will be delivered through a PhD to be let through RWM's Research Support Office. Outputs will include: • A minimum of two peer-reviewed papers. • PhD thesis and presentation to RWM staff. • Knowledge capture in RWM's knowledge base.

SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 4

Further Information

1 I. G. McKinley, I. Hagenlocher, W. Russell-Alexander, and B. Schwyn, *Microbiology in nuclear waste disposal: Interfaces and reaction fronts*. FEMS Mircobiology Reviews, vol. 2019, pp. 545–556, Issues 3-4 1997. [Online]. Available: https://doi.org/10.1111/j.1574-6976.1997.tb00337.x.

2 H. Liu, X. Dang, H. Zhang, J. Dong, Z. Zhang, C. Wang, R. Zhang, Y. Yuan Y.and Ren, and W. Liu, *Microbial diversity in bentonite, a potential buffer material for deep geological disposal of radioactive waste*. IOP Conference Series: Earth and Environmental Science, vol. 227, 2019. [Online]. Available: https://www.researchgate.net/publication/331472406_Microbial_diversity_in_bentonite_a_potential_buffer_material_for_deep_geological_disposal_of_radioactive_waste.

3 O. X. Leupin, R. Bernier-Latmani, A. Bagnoud, H. Moors, N. Leys, K. Wouters, and S. Stroes-Gascoyne, *Fifteen Years of Microbiological Investigation in Opalinus Clay at the Mont Terri rock Laboratory*. Swiss Journal Geosciences, vol. 110, pp. 343–354, 2017. [Online]. Available: https://link.springer.com/article/10.1007/s00015-016-0255-y.

4 H. E. Arter, K. W. Hanselmann, and R. Bachofen, *Modelling of microbial degradation processes: The behaviour of microorganisms in a waste repository*. Experientia, vol. 47, pp. 578–583, Issue 6 1991. [Online]. Available: https://link.springer.com/article/10.1007/BF01949880.

B3.3.2 Bentonite Sourcing for Clay-based EBS

Task Number	30.3.002	**Status**	Start date in future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Clay-based EBS		

Background

Bentonite is currently used as an EBS material within RWM's illustrative designs for the disposal of HHGW in lower strength sedimentary and higher strength generic rock types. Its utility as an EBS material is due to several beneficial properties, notably low hydraulic conductivity and ability to achieve high swelling pressures upon re-saturation. The specific type of bentonite identified in RWM's illustrative designs is a high sodium montmorillonite content material, sourced from a deposit in Wyoming. This Wyoming bentonite, historically known by the trade name MX80, has been extensively studied by both UK and international programmes. The science underpinning its use is generally well understood.

As repository programmes have advanced, European WMOs have started to consider the use of alternative bentonites, given constraints of supply and cost [1]. However, global bentonite reserves are highly variable in composition and therefore performance related properties may differ considerably. Since alternatives to Wyoming bentonite are less well studied, there is greater uncertainty surrounding their performance within a radioactive waste repository.

Research Driver

This is a high-level task that will inform the long-term development of generic GDF concepts, but will also be of significance to near-term tasks, particularly research into bentonite evolution which, to date, has been dominated by studies focussing on Wyoming type material. This research will, in time, inform the design requirements of the barrier systems. It is noted that there are overseas efforts to conduct similar work, and therefore where collaboration and participation in international projects exists, this should be considered as part of this task.

Research Objective

To understand viable bentonite reserves which may be suitable for the UK programme and quality constraints and data limitations which may require further investigation.

Scope

This work will identify bentonite resources, reserves and implications on cost, availability and performance which will be essential in making effective concept selection and design decisions as well as accurate budget forecasts. It will be delivered via a literature review that will assess sources of bentonite, factors affecting ongoing and long-term availability and, potential alternative strategies for securing suitable bentonite material (or equivalent). Follow on activities are to be identified by the literature review and may consist, for example, of some sampling and analysis (see follow on Task 30.3.003). Key aspects of this task are as follows:

- Literature review of bentonite reserves and suitability for use in the UK programme.
- Participation in overseas characterisation programmes and knowledge capture, e.g. proposed EURAD project: Industrial scale operations for buffer and backfill (topic 3.2). Criteria for Clay Component Materials.
- Follow on scope to be defined by literature review with the objective of further defining suitable bentonite EBS materials for the UK programme.

Geology Application

LSSR, HSR

Output of Task					
A contractor approved report presenting the literature review and future research needs.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					
There are other publications relevant to this task [2].					

1 E. Thurner, *Short comparison between MX80 and BARA-KADE*, SKB Document ID 1887259, 2020.

2 D. Svensson, C. Lundgren, and L. Johannesson, *Developing strategies for acquisition and control of bentonite for a high level radioactive waste repository*, SKB, SKB Report TR-16-14, 2017. [Online]. Available: http://www.skb.com/publication/2489029/TR-16-14.pdf.

B3.3.3 Bentonite Sourcing for Clay-based EBS (follow on)

<table>
<tr><td colspan="2">Task Number</td><td>30.3.003</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Clay-based EBS</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Bentonite is currently used as an EBS material within RWM’s illustrative designs for the disposal of HHGW in lower strength sedimentary and higher strength generic rock types. Its utility as an EBS material is due to several beneficial properties, notably low hydraulic conductivity and ability to achieve high swelling pressures upon re-saturation. The specific type of bentonite identified in RWM’s illustrative designs is a high sodium montmorillonite content material, sourced from a deposit in Wyoming. This Wyoming bentonite, historically known by the trade name MX80, has been extensively studied by both UK and international programmes. The science underpinning its use is generally well understood.

As repository programmes have advanced, European WMOs have started to consider the use of alternative bentonites, given constraints of supply and cost [1]. However, global bentonite reserves are highly variable in composition and therefore performance related properties may differ considerably. Since alternatives to Wyoming bentonite are less well studied, there is greater uncertainty surrounding their performance within radioactive waste repositories.

This task follows on from literature review work conducted in precedingTask 30.3.002 to address identified high-priority knowledge gaps.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">This task will address knowledge gaps to ensure RWM is equipped with the necessary knowledge to make decisions on bentonite sourcing for its programme. It will contribute to concept development and ultimately inform work to underpin the site-specific disposal system specification.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To understand viable bentonite reserves which may be suitable for the UK programme and understand the properties and behaviour of these materials.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task will be defined once the literature review phase has been completed (Task 30.3.002) but is likely to consist of exploratory and analytical work, database creation, as well as initiating a programme of experimental and modelling work to validate performance of alternative bentonites against current understanding.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR, HSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">High quality parametric data to support decision making on bentonite sourcing for GDF.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">It is noted that there are overseas efforts to conduct similar work, and therefore where collaboration and participation in international projects exists, this should be considered as part of this task.</td></tr>
</table>

There are other publications relevant to this task [2].

1 E. Thurner, *Short comparison between MX80 and BARA-KADE*, SKB Document ID 1887259, 2020.

2 D. Svensson, C. Lundgren, and L. Johannesson, *Developing strategies for acquisition and control of bentonite for a high level radioactive waste repository*, SKB, SKB Report TR-16-14, 2017. [Online]. Available: http://www.skb.com/publication/2489029/TR-16-14.pdf.

B3.3.4 Development of a Clay EBS Material Characterisation

Task Number	30.3.004	**Status**	Start date in the future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Clay-based EBS		

Background

Once prospective sites have been down-selected to two, site-specific information will start to inform disposal concepts, designs and repository components such as bentonite-based EBS. To be ready to do this, we first need to understand what properties we need to characterise and what techniques exist to do this. Some key properties for investigation are likely to include the following:

- Swelling pressure (since high swelling pressures are required to preclude microbial activity).
- Hydraulic conductivity (since flow in the EBS will be diffusion controlled).
- Shear strength (since, in the case of displacement across a deposition hole, the EBS must deform to protect the container from shear forces).

We will also need to develop and build capability within the UK supply chain to perform these tests and/or to develop methodologies and approaches that we can use. In the longer-term, as our site-specific programme progresses, we will also need to develop strategies for validating and verifying bentonite materials on a bulk scale. As part of which, we will need to decide what type, and extent of facilities would be needed to do this.

Research Driver

To identify the steps required to move RWM from our current state of understanding and capability to take us to the point of specifying a bentonite testing programme for the GDF. For this we need to understand how long these steps may take and when they need to be started relative to GDF first waste emplacement, allowing us to manage our programme.

Research Objective

To develop a strategy and capability for testing and characterising bentonite buffer materials to demonstrate they satisfy required future disposal system requirements. The objectives are to:

- Understand what is required to characterise bentonite for use in the GDF (i.e. *in-situ* field-scale tests, laboratory experiments and interpretational capabilities);
- Understand what capability currently exists within our supply chain to characterise bentonite;
- Develop supply chain capabilities in order that they meet the needs of the programme at the point they are required; and
- Develop a characterisation and testing strategy for the bentonite EBS from which compliance to required performance criteria can be demonstrated.

It will be necessary to develop a step-wise, time-bound programme to be followed to achieve the required capabilities in support of expected first waste emplacement timeframes.

Scope

The objectives for this task are broad and the timescale to deliver the scope of works will be in the order of years and decades. This task sheet will be regularly updated to ensure progress against the objectives. The scope commencing in financial year 2021/22 is likely to include the following:

<table>
<tr><td colspan="6">

- Develop a roadmap to define RWM’s approach to experimental planning, sourcing analytical equipment and resourcing of an analytical facility.
- Participation in international programmes, exposing RWM’s supply chain and internal Intelligent Client to methods and strategies used to characterise bentonite.
- Maintain a watching brief of techniques being undertaken by other WMOs as part of their bentonite characterisation programme and ensuring knowledge capture for RWM.

</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR, HSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Roadmap and bentonite characterisation strategy with appropriately resourced programme.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B3.3.5 Clay EBS THM-C Coupled Process Model Development

Task Number	30.3.005	**Status**	Ongoing
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Clay-based EBS		

Background

Re-saturation and mechanical evolution of clay-based EBS is a complex process which depends upon the properties both of the buffer and the host rock, as well as upon the influence of thermal loading. At the time of writing, RWM assumes illustrative designs for lower strength sedimentary and higher strength rock types to fulfil defined requirements. There are, however, a number of ways in which buffers could be deployed in a future concept to achieve these requirements which can influence their re-saturation. For example, this can include compacted bentonite rings, blocks, pelletised bentonite or graded granular backfill; all of which behave differently when subjected to water inflows. Furthermore, the nature (geochemistry; hydrogeology) and rate of inflow can influence buffer re-saturation.

There is a combined effort among waste management organisations internationally to better understand the nature of EBS re-saturation, as well as movement of solutes through them, in order to more effectively underpin defined safety functions. This includes numerical model development and testing through SKB's EBS Task Force, the EC Beacon and DECOVALEX projects, in which RWM has participated over recent years [1]–[9].

Thermo-Hydro-Mechanical

Once site-specific information becomes available for the UK programme, having embedded knowledge and capability to develop models to explain EBS re-saturation and mechanical evolution will be central to developing understanding of the near-field and wider HHGW disposal system. Re-saturation rates exert a key control on the evolution of the geotechnical stress regime of the repository as well as heat transfer and gas migration. These processes must be well understood to properly inform the development of site-specific designs, specifically relating to engineering geotechnics, EBS emplacement procedure and thermal dimensioning.

(Thermo-Hydro-Mechanical) – Chemical

Solute movement through the EBS has significant implications for container corrosion and radionuclide mobility. Transport of solutes through re-saturated clay-based EBS is controlled by the chemistry and geometry of the inter-layer space within the clay. Recent advances in development of numerical models to explain the transport of solutes have, however, identified a predictive capability for the development of swelling pressures within these materials (Hoch and Birgersson, in-press [10] – [11, Task 462]). Although the capability to model this coupled process is only emerging, further development could offer an alternative 'whole system' approach to modelling coupled processes in clay-based EBS.

Research Driver

This task ensures that RWM has the required capability to develop site-specific designs and an integrated safety case at the right time in the GDF programme. This will be achieved through participation in modelling forums such as DECOVALEX, BEACON, the EBS Task Force.

Research Objective

The development and maintenance of a toolkit and personnel capability (in supply chain and academia) to be able to develop process-based models to describe the THM-C evolution of bentonite EBS.

<table>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Clay-based EBS modelling capability will be developed and maintained by the following:
Participating in SKB's EBS Task Force at a 'maintaining capability' level (commercial supply chain).
Participating in additional modelling tasks relating to the Grimsel hotBENT and Mont Terri FE experiments in Switzerland (via sponsored PhD projects).
Participating in the international EC BEACON project which explores the mechanical evolution of bentonite (commercial supply chain).
Participating in barrier system elements of the international DECOVALEX 2023 project (commercial supply chain). DECOVALEX also explores coupled processes in the geosphere which is covered byTask 50.3.002, Task 50.3.003 and Task 50.3.004).
Seeking co-funding for further development of work conducted by Hoch and Birgersson (in press) [10].</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR, HSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">PhD theses and contractor approved technical note/report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information

For further information see: https://www.beacon-h2020.eu/%5D https://decovalex.org/

1 S. Baxter, D. Holton, and A. Hoch, *Modelling Bentonite Resaturation in the Bentonite Rock Interaction Experiment (BRIE) - Task 8C*, AMEC, Contractor Report D.005529/13/01 (Version 2), 2014.

2 A. Bond, N. Chittenden, and K. Thatcher, *Rwm coupled processes project – first annual report for decovalex-2019*, Quintessa, Contractor Report QRS-1612D-R1-v1.2, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/rwm-coupled-processes-project-first-annual-report-for-decovalex-2019/.

3 S. Baxter, D. Holton, and A. Hoch, *Calibrated modelling of resaturation in the bentonite rock interaction experiment (brie) - task 8d*, AMEC, Contractor Report 103453-AG-0001/T8012013/14, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/calibrated-modelling-of-resaturation-in-the-bentonite-rock-interaction-experiment-brie-task-8d/.

4 A. Bond, N. Chittenden, and K. Thatcher, *Second annual report for DECOVALEX-2019*, QRS-1612D-R2, 2018. [Online]. Available: https://rwm.nda.gov.uk/publication/15197/.

5 G. Carta, S. Baxter, V. Tsitsopoulos, D. Holton, and A. Gordon, *Task force on engineered barrier systems: Code comparison and sensitivity analysis*, AMEC Foster Wheeler, Contractor Report 024127-AA-UA00-00001-01-3, Mar. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/task-force-on-engineered-barrier-systems-code-comparison-and-sensitivity-analysis/.

6 A. Bond, N. Chittenden, and K. Thatcher, *Rwm coupled processes project - second annual report for decovalex-2019*, Quintessa, Contractor Report RWM/Contr/19/026, 2019. [Online]. Available: http://rwm.nda.gov.uk/publication/15197/.

7 V. Tsitsopoulos, S. Baxter, G. Carta, and D. Holton, *Modelling of the Prototype Repository Experiment at the Aspo Hard Rock Laboratory: Part of the Aspo Engineered Barrier Systems Task Force*, AMEC, Contractor Report 204127-AA-UA00-00001-02-6, 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/modelling-of-the-prototype-repository-experiment-at-the-%d3%93sp%d3%a7-hard-rock-laboratory-part-of-the-%d3%93sp%d3%a7-engineered-barrier-systems-task-force/.

8 K. Thatcher, *Febex-dp: Thm modelling*, Quintessa, Contractor Report QRS-1713A-R2 v1.8, Mar. 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/febex-dp-thm-modelling/.

9 J. Wilson, *Febex-dp - geochemical modelling of iron-bentonite interactions*, Quintessa, Contractor Report QRS-1713A-R3 Version 1.3, May 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/febex-dp-geochemical-modelling-of-iron-bentonite-interactions/.

10 A. Hoch and M. Birgersson, *Solute transport through saturated, compacted bentonite - theoretical considerations and the development of a prototype software tool*, Wood, Contractor Report RWM/Contr/20/007, Apr. 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/solute-transport-through-saturated-compacted-bentonite-theoretical-considerations-and-the-development-of-a-prototype-software-tool/.

11 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

B3.3.6 Impacts of High Temperature on a Clay-based EBS

Task Number	30.3.006	**Status**	Ongoing
WBS Level 4	Engineered barrier Systems (EBS) and their Evolution		
WBS Level 5	Clay-based EBS		
Background			
Bentonite is currently used by RWM in its illustrative designs as part of an EBS to surround the disposal containers of HHGW. Radioactive decay within these wastes exposes the buffer to heat. When heated to high temperatures, however, bentonite can be affected by processes which cause changes to its mineralogical and physical structure. Such changes may adversely impact the properties of bentonite EBS and therefore its ability to deliver its safety functions (as set out in RWM 2016a). In the current illustrative designs, it is the bentonite buffer component which constrains the overall thermal loading to the HHGW disposal system (RWM 2016b); while RWM may not necessarily utilise these illustrative designs it is likely that bentonite would comprise an EBS component in HSR or LSSR. Due to arbitrary thermal constraints adopted by international programmes and adopted in RWM's illustrative designs, there is a general lack of knowledge of the processes which occur in bentonite much above 100°C. However, for the UK programme in particular, there is a need to understand bentonite evolution at higher temperatures. This is driven by the need to dispose of high-burn up fuels in our inventory, and those planned for new-build nuclear. An increased understanding of the effect of higher temperatures on the EBS will help us to optimise disposal concepts; container loading and disposal gallery designs. It will also reduce the required surface storage times for these fuels, with a significant impact on surface storage costs. To date, RWM has been involved in a number of overseas heated emplacement experiments, including FEBEX [1], and the Alternative Buffers project [2]. These have provided RWM with some good opportunities for THM coupled process model development [3] and analytical method development [4] respectively. However, a need remains to understand the phenomenological impacts of higher temperatures, such that the thermal limits of bentonite can be robustly underpinned and possibly extended.			
Research Driver			
In order to develop the EBS for HHGW it is necessary to understand the maximum temperature requirement associated with degradation of bentonite performance through thermal illitisation. This requirement may impact the spacing of disposal containers and hence the GDF footprint, hence it is important to identify the constraining temperature in the use of bentonite.			
Research Objective			
• To gain a mechanistic understanding of the THM-C performance of bentonite at temperatures above 100/125°C in HSR and LSSR respectively. • To gain an understanding of the impacts of steam generation on bentonite barrier systems. • To underpin decisions regarding the ability of bentonite to perform the required safety function at temperatures above 100/125°C in HSR/LSSR, respectively. • To develop supply-chain capability in numerical modelling and experimental work, in particular the ability to deliver and operate large-scale underground experiments and parallel laboratory campaigns.			
Scope			
In order to assess the impacts of higher temperatures on the safety functions of the EBS, RWM will participate in several international experimental projects. These include:			

HotBENT, High temperature emplacement experiment at the Grimsel Test Site

The proposed HotBENT experiment at the Grimsel URL is intended to assess phenomenological aspects of bentonite performance at high temperatures, in excess of the limits currently adopted in the gDSSC. The experiment will comprise a series of full-scale heater tests, exploring the impacts of temperatures of up to between 150 and 200°C on the bentonite buffers in a high strength rock environment. A major spin-off benefit of HotBENT is the ability for RWM and its supply chain to be involved with the design and development of a large in-situ emplacement experiment. In addition to the main HotBENT experiment, the US DOE (via LBNL) has developed a bench-scale mock-up of HotBENT, which was proposed for a modelling task in the EBS Task Force. RWM plans to explore the options for modelling this experiment as an EBS Task Force participant.

European Joint Programme (EURAD) high-temperature clay laboratory programme

A laboratory based programme which will support interpretation of underground heater test data. RWM will co-fund work by BGS to evaluate the i) nearfield and farfield performance of LSSR host rocks, and ii) the evolution of bentonite at high temperatures through a matrix of laboratory tests. RWM's participation to EURAD will also produce a synthesis report that will evaluate the learning from the experiments in the context of the safety case.

Mont-Terri Full-Scale Emplacement (FE) experiment

RWM is a partner to the FE experiment at Mont Terri. This project is in two parts, FE-M evaluates the THM evolution and performance of the bentonite buffer, and FE-G evaluates the evolution and generation of gases within the bentonite buffer of the FE*in-situ* experiment. This experiment is the first of its kind in which RWM will participate, since the clay host rock provides different boundary conditions to those encountered in higher strength rocks explored elsewhere. In-kind work will be delivered through the supply chain and university partnerships. Additional related research/capability needs may arise throughout the duration of the campaign of work, which will be captured by this task.

Geology Application

LSSR, HSR

Output of Task

Development of supply chain and delivery of improved understanding of 'bentonite performance at high temperature', together with underpinning data, as captured in the suite of contractor reports delivered under this contract.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
For further information, see the 2016 ESC.

1 G. W. Lanyon and G. I., *Main outcomes and review of the FEBEX in situ test (GTS) and mock-up after 15 years of operation*, Nagra, Nagra Report NAB 13-096, 2013.

2 T. Sanden, U. Nilsson, and D. Svensson, *ABM45 experiment at Äspö Hard Rock Laboratory: Installation report*, SKB, SKB Report P-18-20, 2018. [Online]. Available: https://www.skb.com/publication/2491709/P-18-20.pdf.

3 K. Thatcher, *Febex-dp: Thm modelling*, Quintessa, Contractor Report QRS-1713A-R2 v1.8, Mar. 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/febex-dp-thm-modelling/.

4 M. Leal Olloqui, J. C. P., K. R. Hallam, and T. B. Scott, *A study of bentonite alteration at heated steel surfaces in a geological disposal facility setting*.

B3.3.7 Piping and Erosion of Clay-based EBS: Review

<table>
<tr><td>Task Number</td><td>30.3.007</td><td>Status</td><td>Ongoing (subsumes [1, Task 468] and [1, Task 471])</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Clay-based EBS</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">The safety function of a bentonite clay-based EBS relies upon high swelling pressures which arise when compacted bentonite resaturates. However, piping and erosion are mechanisms by which groundwater can cause a net reduction in effective dry density within the engineered barrier. In this case, the bentonite may not consistently achieve desired swelling pressures to adequately fulfil its safety function.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">A significant body of knowledge on piping and erosion exists internationally, for example work undertaken by researchers in Finland and Sweden [2]–[4]. However, little research on piping and erosion has been conducted by the UK programme, which, for example, has specific high-temperature disposal requirements. A broad review of bentonite erosion work is therefore required to update the current knowledge base, identify knowledge gaps and future research needs for the UK programme.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To understand the relevance of piping and erosion of the EBS to the UK programme, bringing together international expertise and considering factors relevant to the UK (e.g. groundwater quality).</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">The first phase consists of conducting a literature review, seeking expertise through a technical review group and production of a literature review, covering the following key areas:
Background, including UK context such as water quality.
Review of mechanical erosion, defining mechanisms for piping and erosion, including the production of a literature review.
Review of chemical erosion, of particular relevance to HSR environments and glacial meltwater.
Assessment of capability to understand safety implications and, if necessary, develop numerical models to explain piping and erosion.
A second follow-on phase may be required following initial literature review work. It is expected that, if required, follow on work will consist of a laboratory and modelling programme to assess the potential and nature of erosional processes, relating to UK specific factors such as water quality, concept and bentonite type.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR</td></tr>
<tr><td colspan="4">Output of Task
Deliverable consisting of a literature review and gap analysis, peer reviewed and publishable to RWM's bibliography. This report is expected by the end of 2020/21.
Follow on tasks will be identified by this review, if required.</td></tr>
</table>

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5
Further Information					

There are other publications relevant to this task [5].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 T. Laurila, M. Olin, K. Koskinen, and P. Sane, *Current Status of Mechanical Erosion Studies of Bentonite Buffer*, Posiva Oy, Posiva Oy Report 2012-45, 2013. [Online]. Available: http://www.posiva.fi/files/3349/POSIVA_2012-45.pdf.

3 I. Neretnieks and L. Moreno, *Revisiting bentonite errosion understanding and modelling based on the BELBaR project findings*, SKB, SKB Report TR-17-12, 2018. [Online]. Available: http://www.skb.com/publication/2490990/TR-17-12.pdf.

4 L. Börgesson and T. Sandén, *Piping and erosion in buffer and backfill materials: Current knowledge*, SKB, SKB Report R-06-80, 2006. [Online]. Available: http://www.skb.com/publication/1152536/R-06-80.pdf.

5 P. Sellin, *Bentonite erosion: Effects on the long-term performance of the engineered barrier and radionuclide transport (BELBaR) Final Report*, 2016. [Online]. Available: https://cordis.europa.eu/docs/results/295/295487/final1-final-report-en-final-20160428.pdf.

B3.3.8 Piping and Erosion of Clay-based EBS – Follow on Task, Laboratory and Modelling Programme

<table>
<tr><td colspan="2">Task Number</td><td>30.3.008</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Clay-based EBS</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The safety function of a bentonite clay based Engineered Barrier Systems relies upon high swelling pressures which arise when compacted bentonite resaturates. However, piping and erosion are mechanisms by which groundwater can cause a net reduction in effective dry density within the engineered barrier. In this case, the bentonite may not consistently achieve desired swelling pressures to adequately fulfil its safety function.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">A significant body of knowledge on piping and erosion exists internationally, for example work undertaken by researchers in Finland and Sweden [1]–[3]. However, little research on piping and erosion has been conducted by the UK programme, which, for example, has specific high temperature disposal requirements. A broad review of bentonite erosion work is therefore to be conducted in Task 30.3.007, to update the current knowledge base, identifying knowledge gaps and future research needs for the UK programme. This task is a follow-on from the review task, acknowledging that there may be a need to address knowledge gaps through a sustained experimental (and possibly numerical) work campaign.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake further work to advance our understanding of the risks of piping and erosion within bentonite barrier systems such that safety case arguments are robustly underpinned.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this follow-on phase of work will be developed following the initial literature review (Task 30.3.007). It is expected that, if required, this follow-on work will consist of a laboratory and modelling programme to assess the potential and nature of erosional processes, relating to UK specific factors such as water quality, concept and bentonite type.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Follow-on tasks will be identified by this review and would be expected to start in 21/22.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task [4].

1 T. Laurila, M. Olin, K. Koskinen, and P. Sane, *Current Status of Mechanical Erosion Studies of Bentonite Buffer*, Posiva Oy, Posiva Oy Report 2012-45, 2013. [Online]. Available: http://www.posiva.fi/files/3349/POSIVA_2012-45.pdf.

2 I. Neretnieks and L. Moreno, *Revisiting bentonite errosion understanding and modelling based on the BELBaR project findings*, SKB, SKB Report TR-17-12, 2018. [Online]. Available: http://www.skb.com/publication/2490990/TR-17-12.pdf.

3 L. Börgesson and T. Sandén, *Piping and erosion in buffer and backfill materials: Current knowledge*, SKB, SKB Report R-06-80, 2006. [Online]. Available: http://www.skb.com/publication/1152536/R-06-80.pdf.

4 P. Sellin, *Bentonite erosion: Effects on the long-term performance of the engineered barrier and radionuclide transport (BELBaR) Final Report*, 2016. [Online]. Available: https://cordis.europa.eu/docs/results/295/295487/final1-final-report-en-final-20160428.pdf.

B3.4 WBS 30.4 - Cement-based EBS

B3.4.1 Rate and Extent of Reactions between NRVB and Robust Shielded Containers or Vitrified ILW

<table>
<tr><td colspan="2">Task Number</td><td>30.4.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Cement-based EBS</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work to support understanding of this safety function. In recent years a number of waste producers have proposed alternative packaging solutions, such as robust shielded containers, formerly known as Ductile Cast Iron Containers (DCICs) and vitrified ILW wasteforms. This has led to a need to develop a better understanding of the possible impact of these wasteforms on the near-field environment, in particular the effectiveness of the backfill in providing chemical containment. This task is an experimental investigation of the evolution of the interfaces between the Nirex Reference Vault Backfill and robust shielded containers or vitrified ILW to build confidence in the conclusions of the modelling study undertaken as part of [1, Task 418] and to determine the likely rates and extent of reaction.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development, the Disposal System Safety Case and the waste package assessment process by improving the understanding of backfill alteration through its reaction/interactions with new waste packages such as robust shielded containers or vitrified ILW.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine whether:
• Potential new waste packaging solutions will significantly impact the safety functions provided by a cement-based backfill and, if so, whether the amount of backfill can be adjusted to ameliorate these effects; and
• Assumptions can be developed on backfill ratios and repository chemistry for use in the change control assessment relating to DCICs.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Experimental study of rate, products and extent of interactions between corroding cast iron and NRVB and between vitrified ILW and NRVB to determine the impact on physical and chemical properties of the altered NRVB.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Experimental data and advanced understanding to validate the conclusions of the previously reported modelling study.
This work will be reported via contractor approved reports and associated technical journal publications.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
The published modelling study - output from [1, Task 418] - forms an important input to this task [2]. 1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/. 2 F. M. I. Hunter and G. M. Baston, *Understanding potential new types of waste packages within a geological disposal facility: The impact of vitrified ILW or DCICs on cementitious backfill*, AMEC, Contractor Report RWM/03/043, Feb. 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/understanding-potential-new-types-of-waste-packages-within-a-geological-disposal-facility-the-impact-of-vitrified-ilw-or-dcics-on-cementitious-backfill/.

B3.4.2 Understanding the Impact of Alternative Wasteforms on Cement Backfill Performance

Task Number		30.4.002	**Status**	Start date in future	
WBS Level 4		Engineered Barrier Systems (EBS) and their Evolution			
WBS Level 5		Cement-based EBS			
Background					
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. In recent years a number of waste producers have proposed alternative packaging solutions. Alternative wasteform options include the use of geopolymer and cements such as magnesium phosphate and calcium aluminate as encapsulation matrices. This has led to a need to develop a better understanding of the possible impact of alternative wasteforms on the near-field environment, in particular the effectiveness of the backfill in delivering its safety functions.					
Research Driver					
To support concept development, the DSSC and the provision of appropriate waste package disposability advice by improving the understanding of backfill alteration through its reaction/interactions with alternative wasteforms.					
Research Objective					
To determine whether potential new waste packaging solutions will significantly impact the safety functions provided by a cement-based backfill and, if so, whether the amount of backfill can be adjusted to ameliorate these effects.					
Scope					
It is envisaged that the scope of this work will be in two parts: 1. Review and modelling of expected interactions between alternative wasteform matrices and cementitious backfill material to evaluate the effect on safety functions provided by a cementitious backfill and the impact on planning assumptions; and, based on the results of Part 1 and a decision on the feasibility of the alterative wasteform options 2. An experimental study to underpin and verify the conclusions of the modelling study.					
Geology Application					
Applicable to all three illustrative geological environments with respect to disposal concepts utilising OPC-based cementitious engineered barriers.					
Output of Task					
An experimental study and associated reporting detailing the investigations undertaken to underpin the modelling feasibility study and provide knowledge and data to underpin the evolution of the near field and thus enable the provision of appropriate disposability advice. It is envisaged that this work would be delivered as contractor reports and associated technical journal publications.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					
The start of this work is dependent on a decision on the selected alternative wasteform options from waste producers.					

B3.4.3 Hydrothermal Treatment of Cement Backfill as a Method for Accelerated Cement Ageing

Task Number	30.4.003	**Status**	Start date in future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Cement-based EBS		
Background			
Cementitious grouts used to encapsulate intermediate-level radioactive wastes usually consist of OPC that is blended with a large amount of GGBS or PFA. In contrast, backfill materials are cementitious materials that will be placed around the waste containers in a GDF. NRVB, an example of a backfill material, is a blend of OPC, calcium hydroxide and calcium carbonate. Whilst the main binding phase in both the grout and backfill is a calcium alumino-silicate hydrate (C-A-S-H) that is initially nearly amorphous, the two differ greatly in chemical composition, nanostructure and morphology; in particular, when compared with the C-A-S-H in the grout, the C-A-S-H in the backfill will have high mean Ca/Si ratio, a low level of substitution of Al^{3+} for Si^{4+} ions, shorter aluminosilicate anions, and fibrillar rather than foil-like morphology. C-A-S-H in hardened cements is not a thermodynamically stable phase but it is kinetically persistent under the normal service conditions for concrete, which is the reason why some thermodynamically stable phases (crystalline calcium silicate hydrates and siliceous hydrogarnet) are suppressed in current thermodynamic equilibrium calculations for cementitious systems [1], [2] i.e. the kinetics of transformation are so slow that the stable phases do not occur over relevant timescales. However, it is likely that at the ambient conditions in a GDF disposal area for LHGW (wet, with a possible peak average temperature in the range 40 to 50°C [3], [4]) and over the very long timescales that are relevant to the disposal of radioactive waste, that the amorphous C-A-S-H formed during the hydration of the cements will convert to crystalline calcium silicate hydrates (tobermorite, jennite, afwillite, xonotlite, jaffeite, etc.). The chemistry of the repository will evolve as a result of these transformations (e.g. lower pH and surface area for sorption). It is therefore important to understand these processes which may have an effect on the ability of the system to retain radionuclides. Previous studies of the crystallisation processes have shown that the reduction in alkalinity may be high in a cement with high replacement by GGBS and PFA (i.e. the grouts) but that one based on neat Portland cement could be unaffected (i.e. the NRVB) [5]. However, these processes have not been systematically quantified and therefore there is uncertainty about the extrapolation of model studies of cement performance – based on simplified systems – to the long timescales relevant in the context of GDF evolution.			
Research Driver			
To support the development of the DSSC by investigating hydrothermal treatment as a methodology for accelerating the ageing of cement phases to develop a better understanding of long-term cement evolution under GDF relevant conditions.			
Research Objective			
To establish whether thermal treatment of cementitious materials can be reliably utilised to accelerate the ageing of cementitious backfills to understand the effects of cement evolution of the long-term radionuclide migration behaviour.			
Scope			
Investigate the potential of using hydrothermal treatment of samples of NRVB to simulate the "ageing" that would occur if the samples were left for extended times in the conditions expected in the GDF.			
Geology Application			

HSR, LSSR, Evaporite (with respect to disposal concepts utilising OPC-based cementitious engineered barriers).					
Output of Task					
Knowledge and data to support understanding of long-term evolution of cementitious materials. This work will in particular provide greater insight into the applicability of accelerated aging techniques to long-term cement phase evolution. This work will be reported via a PhD thesis and associated technical journal publications.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	
Further Information					

1 B. Lothenbach, E. Wieland, B. Grambow, C. Landesmann, and A. Nonat, *Proceedings of 2nd international workshop 'mechanisms and modelling of waste/cement interactions*. Cement and Concrete Research, no. 40 (8), 2010.

2 D. Damidot, B. Lothenbach, D. Herfort, and F. Glasser, *Thermodynamics and cement science*. Cement and Concrete Research, vol. 41, pp. 679–695, 2011. [Online]. Available: https://www.researchgate.net/publication/251552181_Thermodynamics_and_Cement_Science.

3 S. Worth and A. Faulkner, *Ilw repository thermal analysis using abaqus*, PÖYRY ABS Consulting, Contractor Report PE/200579/001, Revision 3, 2009.

4 N. Butler, *3d thermal modelling of waste packages in backfilled vaults*, Serco, Contractor Report SERCO/TAS/2584/W1 Issue 3, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/3d-thermal-modelling-of-waste-packages-in-backfilled-vaults-june-2010/.

5 S. Hong and F. Glasser, *Phase Relations in the CaO–SiO2–H2O System to 200 °C at Saturated Steam Pressure*. Cement and Concrete Research, vol. 34, pp. 1529–1534, 2004.

B3.4.4 Further Experimental / Modelling Study

<table>
<tr><td>Task Number</td><td colspan="2">30.4.004</td><td colspan="2">Status</td><td>Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Cement-based EBS</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. This includes development and application of a near-field component model that builds confidence that the individual components within the near-field, such as the various waste modules or individual barriers, work together to provide a system that functions correctly (see Task 30.4.006, 30.4.007, and 30.4.009). It is expected that application of the near-field component model may identify further research needs and this task has been created as a placeholder, recognising a likely need for further studies in this area.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To provide further data and understanding on individual processes shown via application of the near-field component model to have significant knowledge gaps with respect to the safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake experimental and modelling studies as defined by 30.4.009.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To be reviewed on the outcome of Task 30.4.006.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A contractor-approved report, datasets and developed near-field component models.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B3.4.5 Effect of Crack Armouring on Groundwater Conditioning for Backfill Under Advective Flow Conditions

Task Number	30.4.005	**Status**	Start date in future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Cement-based EBS		

Background

One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. This includes development and application of a near-field component model that builds confidence that the individual components within the near field, such as the various waste modules or individual barriers, work together to provide a system that functions correctly (see Task 30.4.006, 30.4.007 and 30.4.009). It is expected that application of the near-field component model may identify uncertainties that require further understanding. One such example is crack armouring and its effect on conditioning of groundwater. Crack armouring is a process believed to occur in cements, whereby groundwater solutes form precipitates in the high pH environment on the surfaces of cracks; these may impede the migration of hydroxyl ions from the bulk cement into the water within the crack.

Research Driver

To provide further data and understanding on crack armouring and its influence on groundwater conditioning and impact on the safety functions of a cementitious backfill material in an advective groundwater flow regime.

Research Objective

- To improve our understanding on the factors influencing crack armouring (e.g. rate of formation, transport properties of such layers, dependence on groundwater composition and rate of flow).
- To apply this understanding to determine the effect crack armouring has on groundwater conditioning for backfill under advective flow conditions.

Scope

Experimental and modelling task (e.g. reactive transport modelling using PHREEQC and TOUGHREACT). The scope will be further defined depending on the outcomes of Task 30.4.006.

Geology Application

HSR, LSSR

Output of Task

Experimental data and understanding of the evolution of cementitious materials on interaction with groundwater solutes. It is envisaged that this work will be reported via a contractor report.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
There are several publications relevant to this task [1], [2]. 1 A. Hoch, G. Baston, F. Glasser, F. Hunter, and V. Smith, *Modelling Evolution in the Near Field of a Cementitious Repository*. Mineralogical Magazine, no. 76(8), pp. 3055–3069, 2012. 2 B. Swift, P. Bamforth, A. Hoch, C. Jackson, and D. Roberts, *Cracking, Flow and Chemistry in NRVB*. SERCO/TAS/000505/001 Issue 2, SERCO Technical Consulting Services, 2010.

B3.4.6 Acceptance Test and Further Development of the Near Field - Component Model

Task Number	30.4.006	**Status**	Completed, undergoing review
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Cement-based EBS		

Background

Ensuring that an engineered barrier system will perform its required safety functions requires integration – of an iterative nature – of site-specific information, information on the waste properties, understanding of material properties and performance, and *in-situ* and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM's programme develops it will be important to build confidence that the individual parts of the near field, such as waste packages and backfill, work together to provide a system that achieves its safety functions. In order to demonstrate adequate long-term performance of a cement-based disposal system RWM is developing and applying a near-field component model. In RMW's modelling hierarchy we define a component model as a collection of process models that use multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development, some representation of uncertainty is usually required. A near-field component model considers the relevant processes (and associated uncertainty) that affect near-field evolution and radionuclide behaviour and that could impact on the performance of the system, e.g. heterogeneity, carbonation and pH evolution. During the period 2012-2014 RWM developed a prototype near-field component model, this task further develops the NFCM.

Research Driver

To apply the prototype component model for the near-field of a cementitious ILW GDF in order that it can be used to support the disposal system safety case and to identify further research needs.

Research Objective

To ensure that the near-field component model:

- includes a robust treatment of uncertainty;
- can be used to provide a number of key inputs to the total system model;
- can be used to demonstrate understanding of near-field processes that will affect the post-closure safety of the UK ILW disposal concept;
- is able to supply information to aid design;
- can support the representation of the near field in performance assessments; and
- can support the development of safety function indicator criteria for the near field.

To identify research needs through application of the near-field component model with respect to cement buffer/backfill performance over time.

Scope

The scope of this task is to use the near-field component model developed in the earlier tasks to research the nature of the uncertainties around the evolution of a cementitious GDF for ILW, and to identify further required development of the model.

Geology Application					
HSR, LSSR					
Output of Task					
The output of this task will result in a report.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 4
Further Information					
There are other publications relevant to this task [1]. 1 Nuclear Decommissioning Authority, *Geological Disposal - Framework for Application of Modelling in the Radioactive Waste Management Directorate*, NDA Report NDA/RWMD/101, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-framework-for-application-of-modelling-in-the-radioactive-waste-management-directorate/.					

B3.4.7 Further Development of Near-field Component Model

Task Number	30.4.007	**Status**	Start date in future
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Cement-based EBS		
Background			
Ensuring that an EBS will perform its desired functions requires integration – of an iterative nature – of site-specific information, information on the waste properties, understanding of material properties and performance, and *in-situ* and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM's programme develops it will be important to build confidence that the individual parts of the near field, such as waste packages and backfill, work together to provide a system that achieves its safety functions. In order to demonstrate adequate long-term performance of a cement-based disposal system we are developing and applying a near-field component model. In our modelling hierarchy we define a component model as a collection of process models that use multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development, some representation of uncertainty is usually required. A near-field component model considers the relevant processes (and associated uncertainty) that affect near-field evolution and radionuclide behaviour and that could impact on the performance of the system, e.g. cracking, heterogeneity, carbonation and pH evolution. During the period 2012-2014 we developed a prototype near-field component model and this task will support further development subsequent to initial application (in Task 30.4.006)			
Research Driver • To further develop the component model for the near field of a cementitious ILW GDF to include consideration of additional processes, such as cracking, carbonation and crack armouring, and alternative data inputs. • To develop the interface requirements between the near-field component model and the total system model, based on the understanding gained from Task 30.4.006.			
Research Objective • To further develop a component model to determine whether the effects of differing boundary conditions, such as groundwater flow and chemistry, on the long term buffer/backfill performance can be modelled effectively. • To identify research needs through application of the near-field component model with respect to cement buffer/backfill performance over time. • To ensure that the near-field component model interfaces appropriately with the total system model.			
Scope			
The scope comprises the further development of the near-field component model, informed by its application (in Task 30.4.006). This includes the development of the interface between the near-field component model and the total system model, e.g. to support the current representation, evaluate 'response surfaces' for solubility and sorption, or direct data transfer.			
Geology Application			
HSR, LSSR			
Output of Task			

The output of this task will result in a contractor approved report.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					
There are other publications relevant to this task [1].					

1 Nuclear Decommissioning Authority, *Geological Disposal - Framework for Application of Modelling in the Radioactive Waste Management Directorate*, NDA Report NDA/RWMD/101, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-framework-for-application-of-modelling-in-the-radioactive-waste-management-directorate/.

B3.4.8 Further Investigation of the Effects of Ionising Radiation on Engineered Barrier System (EBS) Performance in Cement and Clay Systems (e.g. Effects on Redox, Organic Degradation Products, Microbial Processes, etc.)

Task Number		30.4.008	**Status**	Start date in future	
WBS Level 4		Engineered Barrier Systems (EBS) and their Evolution			
WBS Level 5		Cement-based EBS			
Background					
Ensuring that an EBS will perform its desired functions requires integration – of an iterative nature – of the following: site-specific information; information on the waste properties; understanding of material properties and performance, and *in-situ*/laboratory testing and modelling relating to key processes that will affect near-field evolution. Within this research sub-topic RWM considers additional processes (to those already discussed) that overlap with other key research areas (such as radiation effects) that impact on near-field evolution. In general, cementitious materials have good resistance to physical degradation upon irradiation, although some wasteforms associated with specific wastes (e.g. those containing large proportions of organic material) are less resistant. Similarly the effects of radiation on clay alteration and radiolysis of pore-water have been studied. In general for typical HLW and spent fuel concepts it is considered that radiolysis of pore-water in a clay-based buffer would be insignificant, as the dose rate outside the container would be relatively low. Similar conclusions were reached for the effects of radiation damage and radiolysis in the backfill (as the radiation field is even lower in these regions). Work considering long-term redox evolution has also investigated the impacts of radiolysis on redox conditions with respect to Spent Fuel dissolution and bentonite porewater conditions. For cement-based ILW concepts, the potential effects of radiolysis were surveyed a number of years ago as part of the UK Nirex research programme. This task will address any research needs identified by the outcome of [1, Task 442] to develop our understanding of the potential impact of ionising radiation on the post-closure safety functions provided by cement-based and clay-based EBS.					
Research Driver					
To inform safety case development by improving our understanding of whether ionising radiation has a significant impact on the evolution of the near-field environment by undertaking required experimental or modelling studies identified in the previous review.					
Research Objective					
To determine whether uncertainties can be reduced relating to radiation impacts on the performance of the engineered barrier system as a result of further investigation.					
Scope					
The scope for this task will be defined by the outcome of Task 30.4.006.					
Geology Application					
HSR, LSSR					
Output of Task					
The output of the task will result in a contractor approved report and/or publications in scientific journals.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
This task may be partly addressed by a university research study managed through RWM's Research Support Office. 1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

B3.4.9 Application of Near-field Component Model Using Updated Understanding of Backfill Evolution

<table>
<tr><td colspan="2">Task Number</td><td>30.4.009</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Cement-based EBS</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Ensuring that an EBS will perform its desired functions requires integration – of an iterative nature – of site-specific information, information on the waste properties, understanding of material properties and performance, and in-situ and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM's programme develops it will be important to build confidence that the individual parts of the near-field, such as waste packages and backfill, work together to provide a system that achieves its safety functions. In order to demonstrate adequate long-term performance of a cement-based disposal system we are developing and applying a near-field component model. In our modelling hierarchy we define a component model as a collection of process models that use multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development, some representation of uncertainty is usually required. A near-field component model considers the relevant processes (and associated uncertainty) that affect near-field evolution and radionuclide behaviour and that could impact on the performance of the system, e.g. cracking, heterogeneity, carbonation and pH evolution. During the period 2012-2014 we developed a prototype near-field component model and this task will support further development subsequent to initial application ([1, Task 442] and 30.4.007).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To further develop the component model for the near field of a cementitious ILW GDF taking account of new information from work on the evolution of the cement-based EBS.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To ensure that the near-field component model takes account of new information provided by [1, Task 418], [1, Task 419], [1, Task 423] and [1, Task 424], as well as current awareness.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To be defined based on the outcome of Task 30.4.006.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will result in a contractor approved report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
</table>

Further Information
There are other publications relevant to this task [2].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Nuclear Decommissioning Authority, *Geological Disposal - Framework for Application of Modelling in the Radioactive Waste Management Directorate*, NDA Report NDA/RWMD/101, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-framework-for-application-of-modelling-in-the-radioactive-waste-management-directorate/.

B3.4.10 Participation in EC project CEBAMA

Task Number	30.4.010	**Status**	Complete
WBS Level 4	Engineered Barrier Systems (EBS) and their Evolution		
WBS Level 5	Cement-Based EBS		
Background			
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work to support understanding of this safety function. There is a need to understand the interaction of cement backfill with common groundwater solutes and the impact this has on the physical properties of the backfill, e.g. reduced permeability or porosity due to pore clogging by precipitation of mineral phases. The HORIZON 2020 EURATOM Collaborative Project “CEment-BAsed MAterials, properties, evolution, barrier functions (CEBAMA)” is a four year project with 27 partners that commenced in Summer 2015. The specific objectives of CEBAMA are (i) experimental studies of interface processes between cement-based materials and host rocks or bentonite, and assessing the specific impact on transport properties (WP1), (ii) quantifying radionuclide retention under high pH cement conditions (WP2), and (iii) developing comprehensive modelling approaches to support interpretation of results and prediction of the long-term evolution of key transport characteristics such as porosity, permeability and diffusion parameters (WP3). RWM is supporting two partners (Universities of Sheffield and Surrey) participating in WP1. This work is complementary to Task 30.4.011. In addition, RWM is a member of the End User group of CEBAMA.			
Research Driver			
To support the post-closure safety case by developing an improved understanding of the changes in physical and chemical transport properties of the Nirex Reference Vault Backfill (NRVB) and other cements as a result of reaction with groundwater solutes.			
Research Objective			
To build a mechanistic understanding of the alteration of selected cements of relevance to international GDF concepts at the cement/groundwater interface and how this influences transport through changes to porosity, permeability and cement mineral phase assemblages.			
Scope			
The scope is to build a mechanistic understanding of how interactions at the cement / groundwater interface are likely to influence transport through their impact on porosity, permeability and cement mineral phase assemblages as a function of carbonation, pH, salinity and groundwater composition. It will be undertaken by two PhD students in collaboration at the Universities of Sheffield and Loughborough. The PhD studentship at the University of Loughborough will focus primarily on the chemical characterisation of these interactions, while the student at the University of Sheffield will focus on the physical characterisation. Cement formulations representative of: low strength, high-pH cement (NRVB); low-pH, PC - silica fume cement (representative of Swedish and Finnish concepts); and low pH, PC - silica fume - FA blended cement (representative of the French concept) will be studied. These will be exposed to groundwater solutions representative of crystalline rock, Corallian-Oxfordian Clay, and a higher ionic strength solution representative of sea water or saline groundwater. Porosimetry and permeability techniques, μ-XCT, electron microscopy and neutron radiography and tomography will be applied to identify changes in porosity, permeability, tortuosity and microstructure. Porewaters will be recovered by porewater squeezing and analysed. The datasets generated will be applied in chemical speciation and transport modelling studies.			
Geology Application			

HSR, LSSR					
Output of Task					
This work will be reported via the PhD theses of the two students along with associated technical journal publications.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	
Further Information					
For further information: https://www.cebama.eu/					

B3.4.11 Effect of Groundwater Solutes on Physical Properties of Cementitious Backfill

Task Number		30.4.011	**Status**	Complete, undergoing review	
WBS Level 4		Engineered Barrier Systems (EBS) and their Evolution			
WBS Level 5		Cement-Based EBS			
Background					
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. There is a need to understand the interaction of cement backfill with common groundwater solutes and the impact this has on the physical properties of the backfill, e.g. reduced permeability or porosity due to pore clogging by precipitation of mineral phases. This task forms part of a project on the long-term evolution of cement backfills relevant to near-field evolution - this task addresses the impact of groundwater ions on the long-term behaviour of the Nirex Reference Vault Backfill (NRVB).					
Research Driver					
To support the post-closure safety case by developing an improved understanding of the changes in physical and chemical transport properties of NRVB and the consequent effect on the safety functions provided by the backfill.					
Research Objective • To determine whether changes in the permeability of the backfill reduce advective transport of water through a vault (e.g. does the backfill 'seal'). • To determine whether armouring of cracks within the backfill inhibits the conditioning of pore water within such cracks and influences the long-term pH buffering behaviour.					
Scope					
Experimental and modelling studies of the interaction of common groundwater solutes with NRVB, changes in transport properties of the NRVB and pore-water chemistry.					
Geology Application					
HSR, LSSR					
Output of Task					
Experimental data and advanced understanding of the long-term properties of cementitious backfill on interaction with groundwater solutes. This project will be reported via contractor reports and associated technical journal publications.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6

Further Information
Relevant publications include: [1]–[3] 1 P. Bamforth, G. Baston, J. Berry, F. Glasser, T. Heath, C. Jackson, D. Savage, and S. Swanton, *Cement materials for use as backfill, sealing and structural materials in geological disposal concepts. a review of current status*, Serco, Contractor Report SERCO/005125/001 Issue 3, 2012. 2 A. Hoch, G. Baston, F. Glasser, F. Hunter, and V. Smith, *Modelling Evolution in the Near Field of a Cementitious Repository*. Mineralogical Magazine, no. 76(8), pp. 3055–3069, 2012. 3 B. Swift, P. Bamforth, A. Hoch, C. Jackson, and D. Roberts, *Cracking, Flow and Chemistry in NRVB*. SERCO/TAS/000505/001 Issue 2, SERCO Technical Consulting Services, 2010.

B3.4.12 Characterisation of Hydrothermally Aged Grout

Task Number		30.4.012	**Status**	Start date in future	
WBS Level 4		Engineered Barrier Systems (EBS) and their Evolution			
WBS Level 5		Cement-based EBS			
Background					
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. A series of small scale samples of the NRVB in direct contact with either BFS, OPC or PFA, OPC waste matrix grouts, have been aged over a ten year period under water saturated conditions (Previously [1, Task 416]). This ageing has been performed at ambient, 35°C and 80°C respectively. Samples have been removed from the overall set at 1, 2, 4, 7 and 10 years and subject to analysis to determine microstructure (SEM and XRD), degree of hydration and acid buffering capacity. The analysis has been performed on the interface zone between the grouts and in the bulk material to provide data on the effects of temperature, time and the grout interactions.					
Research Driver					
To support the post-closure safety case by developing a sufficiently detailed understanding of mechanisms and chronology of NRVB evolution over long timescales.					
Research Objective					
To determine whether the evolution of the long term behaviour of the grouts and their interaction at the interface can be informed by examination of the changes in the microstructure and physical characteristics which occur on laboratory timescales.					
Scope					
This task will be delivered as a PhD project. The scope will involve the development of a proposed set of characterisation techniques and analytical method development to provide data to support an assessment of cement evolution against the engineered barrier safety functions. An initial view on experimental techniques which complement existing analysis include, TEM, Micropermeametry, Thermogravimetric Analysis, FTIR, BET and potentially MIP.					
Geology Application					
HSR, LSSR					
Output of Task					
Advanced understanding and data to support the evidence base on long term evolution of cement materials. This understanding will be documented appropriate reporting such as contractor deliverables, a PhD thesis and supporting technical journal publications.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information
There are other publications relevant to this task [2]–[4].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 P. Bamforth, G. Baston, J. Berry, F. Glasser, T. Heath, C. Jackson, D. Savage, and S. Swanton, *Cement materials for use as backfill, sealing and structural materials in geological disposal concepts. a review of current status*, Serco, Contractor Report SERCO/005125/001 Issue 3, 2012.

3 A. Harris and A. Nickerson, *Hydrothermal Alteration of Nirex Reference Vault Backfill*. AEAT/ERRA-0321, AEAT, 2002.

4 A. Francis, R. Cather, and I. Crossland, *Nirex safety assessment research programme: Development of the Nirex Reference Vault Backfill; report on current status in 1994*, UK Nirex, Nirex Report S/97/014, 1997.

B3.5 WBS 30.5 - Plugs and Seals

B3.5.1 Integrated Project to Develop Plugs and Seals for the Range of Geological Environments and Waste Types

<table>
<tr><td>Task Number</td><td>30.5.001</td><td>Status</td><td>Start date in the future.</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Plugs and Seals</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Plugs and seals are components of the multiple barrier system that contribute to isolation and containment of the waste. The specific requirements of plug and seal components will depend on their location within the GDF and site-specific conditions such as geochemistry, the groundwater flow regime, the mechanical stability and the thermal properties of the selected geological environment. Illustrative designs for plugs and seals are documented in the generic GDF Designs report [1] whilst RWM's generic understanding of the evolution of plug and seal components is documented in the [2].
The illustrative designs for plugs and seals are based on a wide range of international designs underpinned by research programmes such as the DOPAS Project. The EC DOPAS project included numerous international partners and aimed to develop and test the performance of a range of designs for plug and sealing components for geological disposal facilities in different host geological environments. Lessons learnt from DOPAS will be applied to UK-specific plug and sealing component development work.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">RWM has undertaken work to develop the Geological Disposal Technical Programme. This work has identified the high level scope and programme required to deliver a GDF in the UK. Following on from this work, and to develop further the more detailed technical scope to underpin the Geological Disposal Technical Programme, this work aims to specifically address the development of plugs and seals for the range of illustrative geological environments and waste types.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">The objective of this task is to deliver the following outcomes: Phase 1
A fully integrated and justified roadmap for delivery of technically feasible and scientifically underpinned plug and seal components for the GDF that meet the long-term safety requirements.
A justified business case for the next phase of technical work detailing links to key decisions and interfaces within the Geological Disposal Technical Programme and the implications of delaying/deferring work.
Confidence in alignment of R&D activities with the needs of other RWM functions and the activities within the overall technical programme.
Phase 2
Implementation and delivery of Roadmap Issue 1.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">This long-term project aims to build on the programme established in the Geological Disposal Technical Programme with a specific focus on delivery of plug and seal components for the range of geological environments considered suitable for hosting a GDF in the UK. Phase 1 shall consist of:
The development of a fully integrated and justified Roadmap Issue 1;
A detailed and fully costed business case supporting implementation of the Roadmap Issue 1; and</td></tr>
</table>

- For the near-term (~5 years) tasks, development of an approved S&T Task Sheet along with a detailed specification, programme, deliverables, proposed sub-contractors (if any) and fixed cost to delivery.

Phase 2 shall consist of the implementation and delivery of the approved tasks in Roadmap.

Geology Application

HSR, LSSR, Evaporite

Output of Task

- Phase 1
  - Roadmap for the delivery of suitable GDF plug and seal components.
  - S&T Plan Task sheets detailing the tasks required for the next -5 years.
- Phase 2
  - Delivery of the detailed 5 year work activities as set out in the approved Roadmap.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	TRL 7	**Target SRL/TRL**	TRL 9

Further Information

1 Radioactive Waste Management, *Geological Disposal: Generic Disposal Facility Designs*, RWM Report DSSC/412/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-disposal-facility-designs/.

2 Radioactive Waste Management, *Geological Disposal: Engineered Barrier System Status Report*, RWM Report DSSC/452/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-engineered-barrier-system-status-report/.

B3.6 WBS 30.6 - Thermal Modelling of Heat-generating Processes

B3.6.1 Watching brief: Maintenance and Development of the Thermal Dimensioning Tool (TDT)

<table>
<tr><td colspan="2">Task Number</td><td>30.6.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Engineered Barrier Systems (EBS) and their Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Thermal Modelling of Heat-generating Processes</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The TDT has been developed to explore, for a series of disposal concepts, the impact of a range of key physical parameters and engineering decisions on the temperature in the engineered barrier system. Through use in RWM's ongoing work, potential improvements for the tool may be identified and the need for further modifications may be identified to maintain the tool. Following identification, improvements will be prioritised and addressed as required.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To extend the capability of the thermal dimensioning tool and implement potential improvements identified during its application such that it can be used to support its ongoing application for design updates, disposability assessments and underpinning concept development work.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To continue to develop the thermal dimensioning tool as necessary for its continued use in RWM.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To prioritise, implement and test modifications to the thermal dimensioning tool as required by RWM.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A well maintained and documented TDT that supports the range of disposal concepts under consideration by RWM.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1].
1 Project Ankhiale: Disposability and Full Life Cycle Implications of High-heat Generating UK Wastes Roadmap, AMEC, Contractor Report D.006297/001 Issue 1, Dec. 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/high-heat-generating-wastes-ipt-roadmap-finalv2-nda-rwmd-095-tn%5C_18043/.</td></tr>
</table>

B3.7 Site-Specific Research Needs Identification

Task Number		30.001	**Status**	Start date in future	
WBS Level 4		Engineered Barrier Systems (EBS) and their Evolution			
WBS Level 5					
Background					
In December 2018 RWM launched its siting programme and we are engaging with communities that have an interest in hosting a GDF [1]. As the siting process moves forward, site characterisation will progress through surface-based and intrusive (borehole) investigations. While waste packaging proposals from waste owners will continue to draw upon the generic safety case and its underpinning, many of the more generic research activities will be concluded, while site-specific research and development activities will take place for an assumed two potential candidate host sites, driving our understanding and data maturity towards that required for GDF permissions.					
Research Driver					
To identify future site-specific research and development associated with this work area as a result of initial understanding of potential GDF sites.					
Research Objective					
To further develop the Science and Technology Plan to identify site-specific research and development needs.					
Scope					
• To identify site-specific knowledge gaps and key uncertainties requiring further research and development. • To assess and review the resourcing and capability for the requirements of site-specific activities based on the outcome of the conclusion of generic activities. • To assess the applicability of generic work to the site(s) taken forward for site characterisation. • To develop supply chain capability where necessary to transition into Tranche 3.					
Geology Application					
Site-specific – To be confirmed.					
Output of Task					
An understanding of the site-specific knowledge gaps for an assumed two sites.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					
This task will be based on the outcome of the Backfill IPT (Task 30.1.001) 1 BEIS, *Implementing geological disposal - working with communities*, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766643/Implementing_Geological_Disposal_-_Working_with_Communities.pdf.					

B4 WBS 40 - Gas Pathway

The generic research activities to be concluded before the site-specific stage commences can be summarised in the following work areas:

- Gas in the disposal system safety case **(WBS 40.1)**
- Development of generic knowledge base on gas generation **(WBS 40.2)**
- Development of generic knowledge base on gas migration and reaction **(WBS 40.3)**
- Development of gas related conceptual models and numerical solutions **(WBS 40.4)**

WBS 40.1 will focus on the development of mitigation approaches to ensure that waste-derived gas is managed so as not to challenge the safety-case (Task 40.1.001).

WBS 40.2 will maintain and develop, as necessary, an up-to-date understanding of bulk gas generation in a range of geologies and disposal concepts in order to continue to support conceptual design and safety case.

WBS 40.3 is supported by international collaboration through EC EURAD (Task 40.3.003) which builds upon the outcomes of EC FORGE, to support and increase the understanding of gas migration in different host rocks and captures the relevant learning for the UK context. Also, collaboration through LASGIT in order to study the impact of gas build up and subsequent migration through the engineered barrier system of the Swedish KBS-3 disposal concept for high-level radioactive waste via a full-scale *in situ* experiment (Task 40.3.002).

WBS 40.4 will address the issue of gas generation in the transport, operational and environmental safety case, as well as sustaining the capability to model gas generation via progressing upgrades to the SMOGG modelling tool (Task 40.4.001).

On the outcome of the generic research activities, Task 40.001 will develop a strategy to consider the relevance of RWM's current gas knowledge base in the context of the evolving UK GDF siting programme and site-specific knowledge, identifying knowledge gaps in order to transition the knowledge base from being site-generic to site-specific. This will also involve relevant learning being transferred to other site-specific areas.

B4.1 WBS 40.1 - Gas in the disposal system Safety Case

B4.1.1 Review of Approaches to the Management of Gas During the Operational and Post-closure Phases

Task Number	40.1.001	**Status**	Start date in future
WBS Level 4	Gas Pathway		
WBS Level 5	Gas in the Disposal System Safety Case		
Background			
The generation, accumulation and migration of gas in a GDF will vary with waste inventory and with GDF concept (itself a function of the geological setting). Different design strategies aiming to reach one or several of the following objectives may be adopted to ensure that the release of any gases to the biosphere does not challenge regulatory limits: • Prevent the degradation of the performance of GDF barriers. • Reduce uncertainties on factors controlling the generation and migration of gases. • Limit adverse consequences of gas release in case of the variant human intrusion scenario. The optimum strategy is directly dependent on the waste inventory and disposal concept, as well as on the boundary conditions associated with the host rock and its environment. These boundary conditions include the availability of water and the chemical conditions (controlling the corrosion processes and the free gas phase), gas entry pressure (controlling the gas accumulation and the subsequent pressurisation) and sealing capacities (controlling the resilience of the host-rock). With respect to GDF-derived gas, the EC FORGE project has considered gas generation and gas migration, with migration concerning both clay-based and cement-based EBS materials, and disturbed and undisturbed host rock. Significant new numerical modelling has also been undertaken at the cell, module and GDF scale to better understand how gas could interact with GDF infrastructure (e.g. plugs, seals and interfaces) and how migration of waste-derived gas could occur over the post-closure period. Interaction with groundwater has been considered (both in the desaturation period occurring whilst the GDF is open and in the re-saturation period after the GDF is closed).			
Research Driver			
To support the DSSC by developing concept and design solutions to potential issues posed by GDF gas generation.			
Research Objective			
• To develop mitigation approaches to ensure waste-derived gas is managed so as not to be a safety case-relevant concern. • To demonstrate surface radiological or flammability hazards potentially posed by GDF-derived hydrogen in the form of bulk gas can be managed by appropriate choice of EBS for a given geosphere.			
Scope			
To ensure benefits from EC FORGE project are integrated into the RWM knowledge base on gas, and are utilised in safety case and design studies. This task is a desk study identifying gas issues for the UKRWI and the range of potential mitigation approaches through concept and design measures (covering GDF construction, operation, closure and sealing).			
Geology Application			

HSR, LSSR, Evaporite					
Output of Task					
The output of the task will result in contractor approved reports and models.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are other publications relevant to this task [1].					

1 S. Norris, F. Lemy, C.-A. del Honeux, G. Volckaert, E. Weetjens, K. Wouters, J. Wendling, M. Dymitrowski, D. Pellegrini, P. Sellin, L. Johnson, M. Sentis, and J. Harrington, *Synthesis report: Updated treatment of gas generation and migration in the safety case*, EC FORGE Project Milestone M68, 2013.

B4.2 WBS 40.2 - Development of generic knowledge base on gas generation

B4.2.1 Experimental Study on Rate and Speciation of C-14 Release to the Gas Phase from Irradiated Uranium

<table>
<tr><td colspan="2">Task Number</td><td colspan="2">40.2.001</td><td>Status</td><td>Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Gas Pathway</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Development of Generic Knowledge Base on Gas Generation</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM established an IPT which developed an holistic approach to C-14 management in the disposal system. We also led a collaborative EC funded project, CAST, which included an experimental programme to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
corrosion of irradiated reactive metals (operational and early post-closure time frame); and
corrosion of irradiated stainless steel and leaching of irradiated graphite (longer-term).
It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the measurement of the rate and speciation of C-14 released to the aqueous and gaseous phases by irradiated uranium (a reactive metal) due to its corrosion upon GDF resaturation.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the operational and environmental safety cases and disposal concept development through an appropriate understanding of the rate and speciation of C-14 releases from irradiated uranium.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To measure the rate and speciation of C-14 release from irradiated uranium to the gas and solution phase for use as a basis for better parameterised assessment models.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To measure the rate of gaseous C-14 release from the corrosion of irradiated uranium samples in alkaline solution and to understand the distribution between $^{14}CO_2$, ^{14}CO and ^{14}C-hydrocarbon/organic gaseous and C-14 aqueous species.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in contractor approved reports and data.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task, including the [1] [2]–[4].

1 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

2 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

3 Nuclear Decommissioning Authority, *Geological disposal: Carbon-14 project phase 2 – overview report*, NDA Report NDA/RWM/137, May 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-carbon-14-project-phase-2-overview-report/.

4 S. Norris and M. Capouet, *Overview of CAST project*. Radiocarbon, vol. 60, pp. 1649–1656, Special Issue 6 2018. [Online]. Available: https://doi.org/10.1017/RDC.2018.142.

B4.2.2 Update Task with New Understanding of C-14 Release from Irradiated Uranium

<table>
<tr><td colspan="2">Task Number</td><td>40.2.002</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Gas Pathway</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Development of Generic Knowledge Base on Gas Generation</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM established an IPT which developed an holistic approach to C-14 management in the disposal system. We also led a collaborative EC funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
• corrosion of irradiated reactive metals (operational and early post-closure time frame); and
• corrosion of irradiated stainless steel and leaching of irradiated graphite (longer-term).
It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task follows the experimental measurement of the rate and speciation of C-14 released to the aqueous and gaseous phases by the reactive metal uranium upon its corrosion following resaturation (Task 40.2.001). It integrates these new data with our existing parametric models and understanding of the package scale evolution of C-14 bearing gases.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the operational and environmental safety cases and disposal concept development by developing an appropriate understanding of the rate and speciation of C-14 releases from irradiated uranium.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop an improved understanding of the rate, speciation and timing of the release of gaseous C-14 from irradiated uranium based on new data (Task 40.2.001), together with consideration of package-scale effects, in order to determine whether the calculated post-closure risk is reduced.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises a desk-based and modelling study updating our understanding of the likely timing, rate of release and speciation of C-14 to the gas phase using the output from Task 40.2.001.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in contractor approved reports.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task, including the [1] [2], [3].

1 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

2 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

3 Radioactive Waste Management, *Geological disposal: Carbon-14 project phase 2: Overview report*, RWM Report NDA/RWM/137, Issue 1, Mar. 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-carbon-14-project-phase-2-overview-report/.

B4.2.3 Mechanistic Study on C-14 Release and Speciation from Zircaloy

<table>
<tr><td>Task Number</td><td>40.2.003</td><td>Status</td><td>Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Gas Pathway</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Development of Generic Knowledge Base on Gas Generation</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Carbon-14 is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM established an IPT to develop an holistic approach to C-14 management in the disposal system. We also led a collaborative EC funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
• corrosion of irradiated reactive metals (operational and early post-closure time frame); and
• corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).
It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. Zircaloy, the clad for PWR fuel, is a minor C-14 bearing waste stream resulting from the reprocessing of overseas fuels at Sellafield. CAST provided information on the speciation and rate of release of C-14 from irradiated Zircaloys relevant to overseas WMOs ([1, Task 206]) and this task comprises any further work required in the UK context should it be required.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To support the development of the operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 releases from Zircaloy.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To better understand the speciation and rate of C-14 release from irradiated Zircaloys relevant to UK ILW under conditions appropriate to UK disposal concepts as a basis for better parameterised process and assessment models.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">The need and scope of this experimental and/or modelling study will be defined by [1, Task 210], following the completion of the EC CAST WP3 project ([1, Task 206]).</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
<tr><td colspan="4">The output of the task will result in contractor approved reports.</td></tr>
</table>

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
The outcome is likely to be that at the end of this task further work will be required with respect to GDF-gas processes. Work related to the aqueous pathway might continue under site-specific conditions and would thus form part of the radionuclide behaviour research programme. There are other publications relevant to this task, including the [2], [3], [4].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

3 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

4 Nuclear Decommissioning Authority, *Geological disposal: Carbon-14 project phase 2 – overview report*, NDA Report NDA/RWM/137, May 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-carbon-14-project-phase-2-overview-report/.

B4.2.4 Further Update Model of C-14 Release from Irradiated Stainless Steel

<table>
<tr><td colspan="2">Task Number</td><td>40.2.004</td><td>Status</td><td colspan="2">Completed, undergoing review</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Gas Pathway</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Development of Generic Knowledge Base on Gas Generation</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM established a project which developed an holistic approach to C-14 management in the disposal system. RWM also led a collaborative EC funded project, CAST, which included experimental programmes which filled knowledge gaps in the data for the rate and speciation of C-14 release from key materials. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
• corrosion of irradiated reactive metals (operational and early post-closure time frame); and
• corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).
It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the incorporation of data and understanding gained from [1, Task 203] and [1, Task 210] in our model of the release of C-14 from irradiated steels.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the operational and environmental safety cases by gaining an appropriate understanding of the rate and speciation of C-14 release from irradiated stainless steels.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine whether, by integrating an improved understanding of the inventory with consideration of corrosion rates and speciation of C-14 released from irradiated stainless steels it will be possible to demonstrate a reduction in the calculated risk to operators, the public and non-human biota.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To update, as necessary, the model of carbon-14 release from irradiated stainless steel (developed in [1, Task 203]) using the understanding gained in [1, Task 210] from WP2 of the EC-CAST project.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in contractor approved reports.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task, including the [2] [3], [4].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

3 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

4 Nuclear Decommissioning Authority, *Geological disposal: Carbon-14 project phase 2 – overview report*, NDA Report NDA/RWM/137, May 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-carbon-14-project-phase-2-overview-report/.

B4.2.5 Carbon-14 Release from AGR Steels

Task Number		40.2.005	**Status**	Start date in future	
WBS Level 4		Gas Pathway			
WBS Level 5		Development of Generic Knowledge Base on Gas Generation			
Background					
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM established an IPT which developed an holistic approach to C-14 management in the disposal system. RWM also led a collaborative EC-funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by: • corrosion of irradiated reactive metals (in the operational and early post-closure time frame); and • corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term). After graphite, steels provide the largest inventory of C-14 associated with irradiated material in ILW. Recent work has shown that a better understanding of the speciation and rate of corrosion could reduce the calculated radiological consequences for these wastes. Work undertaken within CAST determined the release of C-14 from a number of irradiated steels as there is little information on the form of C-14 released from irradiated steels. Work within the C-14 IPT showed that the release from irradiated AGR stainless steel hulls may be an important contributor to the rate of release of C-14 from steels in ILW after closure of a GDF. In addition, it is possible that any carbon deposits on AGR steel components (although these are unlikely to have remained on hulls that have been through the dissolver in the Thermal Oxide Reprocessing Plant or may have been leached of C-14 during pond storage) or carburisation during reactor operation may affect the rate of corrosion and C-14 release from steel AGR components.					
Research Driver					
To support the development of the transport, operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 release from irradiated AGR steels.					
Research Objective					
To determine the rate of release of C-14 from irradiated AGR hulls and steel components.					
Scope					
Measurements of corrosion rates, rate of release of C-14 and speciation from irradiated AGR stainless steel hulls, steel components and associated carbon deposits (if present).					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of the task will result in contractor approved reports.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
There are other publications relevant to this task, including the [1] [2], [3]. 1 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/. 2 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/. 3 Nuclear Decommissioning Authority, *Geological disposal: Carbon-14 project phase 2 – overview report*, NDA Report NDA/RWM/137, May 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-carbon-14-project-phase-2-overview-report/.

B4.2.6 Studies of C-14 Release from Irradiated Graphite from Reactors Other Than Oldbury

<table>
<tr><td>Task Number</td><td>40.2.006</td><td>Status</td><td>Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Gas Pathway</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Development of Generic Knowledge Base on Gas Generation</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM led a collaborative EC-funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
• corrosion of irradiated reactive metals (in the operational and early post-closure time frame); and
• corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).
Graphite provides the largest inventory of C-14 associated with irradiated material in ILW. Recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. Only limited work, recently reported on Oldbury Power Station graphite by RWM, has been undertaken on the form of C-14 released from irradiated graphite. An understanding of the rate and speciation of C-14 associated releases from a broader range of irradiated graphite would enable us to better parameterise assessment models.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To support the development of the post-closure safety case by better underpinned parameterisation of the model of carbon-14 release from irradiated graphite through investigation of the behaviour of irradiated graphites with a wider range of characteristics and irradiation histories than previously studied.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To develop an improved understanding of the behaviour of irradiated graphites in a GDF by carrying out experiments on a wider range of irradiated graphite samples.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">The scope includes the following:
• Depending on the outcomes of the C-14-BIG project ([1, Task 226]) and the EC CAST project ([1, Task 227]), measure dissolved and gaseous C-14 releases from UK graphite samples with different characteristics and irradiation histories than the Oldbury and BEP0 samples studied previously.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
<tr><td colspan="4">The output of the task will result in contractor approved reports.</td></tr>
</table>

SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
This task may not be required, depending on the importance of the related uncertainties in the safety case. There are other publications relevant to this task, including the [2] [2]–[7].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

3 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

4 G. Baston, R. Preston S. Otlet, A. Walker, A. Clacher, M. Kirkham, and B. Swift, *Carbon-14 Release from Oldbury Graphite*, AMEC, Contractor Report AMEC Report AMEC/5352/002 Issue 3, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-release-from-oldbury-graphite-npo004819/.

5 T. Marshall, G. Baston, R. Otlet, A. Walker, and I. Mather, *Longer term release of carbon-14 from irradiated graphite*, Serco, Contractor Report SERCO/TAS/001190/001 issue 2, 2011.

6 Radioactive Waste Management, *Geological disposal: Carbon-14 project phase 2: Overview report*, RWM Report NDA/RWM/137, Issue 1, Mar. 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-carbon-14-project-phase-2-overview-report/.

7 S. Swanton, B. Swift, M. Plews, and N. Smart, *Carbon-14 project phase 2: Irradiated steel wastes*, AMEC, Contractor Report AMEC/2000047/005, issue 1, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-team-phase-2-irradiated-steel-wastes/.

B4.2.7 Mechanistic Study on C-14 Release and Speciation from Ion-Exchange Resins

<table>
<tr><td colspan="2">Task Number</td><td>40.2.007</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Gas Pathway</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Development of Generic Knowledge Base on Gas Generation</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by the corrosion of irradiated reactive metals and leaching of irradiated graphite. Light Water Reactors, such as Sizewell B in the UK, utilise ion-exchange resins for the clean-up of aqueous wastes and this wastestream comprises a further high specific activity inventory of C-14. A better understanding of the inventory and post-closure behaviour of these wastes could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. RWM led a collaborative EC-funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. The outputs from CAST have been reviewed in the UK context under [1, Task 210] to identify any further research that is required for the UK programme. This task comprises any required follow-on work on spent ion-exchange resins arising from the review.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 release from UK spent ion-exchange resins.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine the release and speciation of C-14 from spent ion-exchange resins relevant to the UK (if necessary).</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task has been defined based on the findings from [1, Task 210]. The outcome is likely to be that at the end of this task, focused further work will be required with respect to GDF-gas processes. Work related to the aqueous pathway might continue under site-specific conditions and would thus form part of the radionuclide behaviour research programme.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a contractor approved report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task [2], [3].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

3 CAST, *CAST WP4: Final synthesis report of spent ion-exchange resins 14C source term and leaching (D4.9)*, 2018. [Online]. Available: https://www.projectcast.eu/programme/wp4-ion-exchange-resins.

B4.2.8 Radon Emanation from Polymer Encapsulated Wastes

Task Number		40.2.008	**Status**	Start date in future	
WBS Level 4		Gas Pathway			
WBS Level 5		Development of Generic Knowledge Base on Gas Generation			
Background					
In the generic OESA, the radiological consequences of gases containing carbon-14 (C-14) and radon-222 (Rn-222) are potentially significant. There is however considerable uncertainty over the extent to which Rn-222 decays as it migrates within and from waste packages, and the manner it is transported through the engineered systems in a GDF during the operational period. The retention of Rn-222 within a waste package is expressed in terms of an 'emanation coefficient', which corresponds to the fraction of Rn-222 that is released from a waste package in comparison to the in-package Rn-222 generation rate. The dose arising from radon in the OESA is currently calculated using an assumed radon emanation coefficient of $2x10^{-3}$. The calculated dose has the potential to exceed safety limits during the operational period. This emanation coefficient was however calculated using conservative data, for a grout-encapsulated waste within a 500 l steel drum, and applied holistically to the entire inventory. Guidelines for radium-containing wastes now suggest it would be beneficial to package them using an encapsulant with a greater hold-up factor, for example, polymer, facilitating the radioactive decay of the short-lived (3.8 day) Rn-222 radionuclide within the package. Recent disposability assessment (LoC) submissions have implied an emanation coefficient several orders of magnitude lower can be achieved using bespoke packaging methods, utilising polymer for particularly high radium containing waste streams. It is therefore necessary to review the models and parameters used to ensure they are appropriate.					
Research Driver					
To support the operational environmental safety assessment by proposing appropriately justified radon emanation coefficients for a range of encapsulants, including polymers.					
Research Objective					
To determine appropriate radon emanation coefficients for use in updates to the OESA.					
Scope					
To experimentally derive radon hold-up factors for bespoke encapsulants for radium containing wastes (e.g. polymer formulations), and corresponding radon emanation coefficients to be used to update the estimated dose arising from radon within the OESA.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of the task will result in contractor approved reports.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are other publications relevant to this task [1]. 1 F. Hunter, C. Leung, and A. Adeogun, *Emanation Coefficients Relating to In-package Behaviour of Radon*, AMEC, Contractor Report AMEC/000142/001, Issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/emanation-coefficients-relating-to-in-package-behaviour-of-radon-rwmd03026/.					

B4.2.9 Gas Generation from Microbial Degradation of Organic Wastes Including Cellulose

Task Number		40.2.009	**Status**	Start date in future	
WBS Level 4		Gas Pathway			
WBS Level 5		Development of Generic Knowledge Base on Gas Generation			
Background					
Gas generation from the microbial degradation of cellulose is an important contributor to the overall gas generation from ILW. The SMOGG gas generation tool incorporates two models for gas generation from cellulose – one applicable to near-neutral pH conditions and the other applicable to highly alkaline conditions relevant to a cementitious backfill. Review of these models and the availability of suitable data [1] for calibration and validation identified that there were no data available for the calibration or validation of the high-pH model and also suggested some possible refinements to SMOGG itself. In general, there are uncertainties in the viability, activity and distribution of microbial activity at high-pH and corresponding uncertainties in gas generation. There is therefore uncertainty regarding whether or not the current SMOGG model leads to an overestimate of the rate of gas production from cellulosic wastes under high-pH conditions.					
Research Driver					
To support the DSSC and the LoC process by determining the rate of gas generation from the microbial degradation of cellulose in a high pH environment.					
Research Objective					
To determine whether the rate of bulk gas generation from the microbial degradation of grout-encapsulated cellulosic material in the UK ILW concept: • is compatible with the safety functions of the concept and whether or not it is significantly affected by the dose-rate present in the vault; and • may be simply bounded by a suitably conservative gas generation rate incorporating credible microbial population evolution scenarios.					
Scope					
The scope will involve, where necessary, acquisition of experimental data relevant to bulk-gas generation rates arising from the microbial degradation of cellulosic materials in high pH environments. Additionally, the output of "Effects of Radiation on Microbial Survival and Activity" (a recently-completed Ph.D with University of Manchester and NNL), in which further understanding on related gas generation processes was gained, will inform our knowledge base such that suitable gas generation rate assumptions are incorporated in a gas-generation modelling tool (i.e. SMOGG).					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of the task will result in contractor approved reports.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4

Further Information
There are other publications relevant to this task, namely a report prepared by NNL for NDA [1]. 1 J. Small and M. Dutton, *Review of research on cellulose degradation and input data for the Simplified Model of Gas Generation (SMOGG)*. NNL(09)8870, 2010.

B4.2.10 Review of Bulk Gas Generation from Corrosion, Radiolysis and Microbial Action

<table>
<tr><td colspan="2">Task Number</td><td>40.2.010</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Gas Pathway</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Development of Generic Knowledge Base on Gas Generation</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Bulk gas generation is of interest in all phases of a GDF with the relative importance of some of the aspects dependent on the concept (e.g. potential pressurisation of a GDF in the post-closure phase in a clay environment). Corrosion of metals in ILW packages (whether as waste or containers) is a significant contributor to gas generation. The mechanisms and rates of corrosion (and hence hydrogen generation) from steels, Zircaloy, Magnox, uranium and aluminium have been reviewed for high-pH conditions and these data input to our SMOGG gas-generation model. Other contributors to bulk gas generation are radiolysis and microbial degradation of some organic materials (e.g. cellulosic wastes), reviews of which have also been carried out in the context of data input parameters to SMOGG.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To provide support to the safety case and disposability assessment by maintaining and developing, as necessary, an up-to-date understanding of bulk gas generation in a range of geologies and disposal concepts.</td></tr>
<tr><td colspan="6">Research Objective
To update the understanding of metal corrosion rates, radiolytic yields and microbial degradation under GDF-relevant conditions to ensure our understanding of bulk gas generation in a range of geologies and disposal concepts is developed and maintained.
To determine the rate of bulk gas generation from the corrosion of steels, Zircaloy, Magnox, uranium and aluminium under GDF-relevant conditions, noting existing data and understanding on mechanisms and rates of corrosion (and H_2 generation) from steels, Zircaloy, Magnox, uranium and aluminium under high pH conditions.
To consider the impact of gas generation on the safety functions of the disposal system.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises a review of the input corrosion rate, radiolytic yield and microbial degradation data utilised in SMOGG for an appropriate range of disposal concepts to recommend any changes to these input data that may be required and to identify where additional data may be beneficial.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in contractor approved reports.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information

There are other publications relevant to this task [1]–[4].

1 B. Swift, *SMOGG (version 5.0), a simplified model of gas generation from radioactive wastes: User guide*, Serco, Contractor Report SA/ENV-0511 (Version 6), 2006.

2 N. Smart and A. Hoch, *A survey of steel and zircaloy corrosion data for use in the smogg gas generation model*, Serco, Contractor Report SA/ENV-0841, 2010.

3 A. Hoch, N. Smart, and B. Reddy, *A survey of reactive metal corrosion data for use in the smogg gas generation model*, Serco, Contractor Report SA/ENV-0895, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/a-survey-of-reactive-metal-corrosion-data-for-use-in-the-smogg-gas-generation-model/.

4 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

B4.3 WBS 40.3 - Development of generic knowledge base on gas migration and reaction

B4.3.1 LASGIT (Large-scale Gas Injection Test) International Collaborative Project at Aspo URL

Task Number	40.3.001	**Status**	Ongoing
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Knowledge Base on Gas Migration and Reaction		
Background			
In the current phase of preparatory studies, RWM will continue with a programme of experiments and models of gas migration in clays and the effects of pressurisation on clay barrier performance in order to develop a capability in this area. Such work will also feed into the development of GDF concepts in the future. Much of this work will involve participation in international collaborative projects such as LASGIT at Äspö in Sweden and the EC FORGE project conducted under the EC 7th Framework to investigate the fate of gases generated in a GDF. If gas were to form in a GDF its subsequent migration would be dependent on the properties of the host rock, properties of the surrounding rock, and the extent of dissolution in groundwater. In the absence of a migrating free gas phase the only transport of trace radioactive gases, e.g. carbon-14 (C-14) bearing methane, would be as dissolved species. If the rate of gas generation were to become sufficiently high there would be a potential for over-pressurisation and cracking of very low permeability rocks, which have no significant natural fractures that would allow gas to escape. Clays typically have very small inter-granular pores which make it difficult for gas to migrate. The presence of gas in clay environments could therefore cause damage due to over-pressurisation, leading to preferential pathways for contaminated groundwater migration through the EBS or clay host rock. The mechanisms of movement and healing properties of clay require additional understanding. Work carried out on such rock types in other countries' waste management programmes has shown that a gas over-pressure can be relieved by the formation of micro-fissures in the rock. In the cases studied, the micro-fissures 'heal' after the pressure is relieved because of the rock's intrinsic properties and the compressive forces acting on the rocks at depth. In addition, there are also international studies to assess the potential for gas to be transported along the Engineering Disturbed Zone at the tunnel/rock interface. This task comprises RWM's participation in the aforementioned LASGIT project, which is a field scale experiment operated by the British Geological Survey located at approximately 420m depth in SKB's Äspö Hard Rock Laboratory in Sweden. LASGIT has yielded high quality data relating to the hydration of the bentonite and the evolution in hydrogeological properties adjacent to the deposition hole.			
Research Driver			
To support concept development by developing an understanding of gas migration through a bentonite buffer.			
Research Objective			
To determine whether the interaction of waste-derived gas and bentonite material present in the EBS has a negative impact on the safety functions provided by the bentonite.			
Scope			
LASGIT has been designed to study the impact of gas build up and subsequent migration through the engineered barrier system of the Swedish KBS-3 disposal concept for high level radioactive waste via a full-scale *in situ* experiment.			
Geology Application			

HSR, LSSR					
Output of Task.					
The output of the task will result in a contractor approved report and models.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are other publications relevant to this task [1]. 1 *Large scale gas injection test (Lasgit) performed at the Aspo Hard Rock Laboratory: Summary report 2008*, SKB, SKB Report TR-10-38, 2010. [Online]. Available: http://www.skb.com/publication/1995067/TR-10-38.pdf.					

B4.3.2 Mechanistic Understanding of Gas Transport in Clay Materials (GAS) EC EURAD

<table>
<tr><td colspan="2">Task Number</td><td>40.3.002</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Gas Pathway</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Development of Knowledge Base on Gas Migration and Reaction</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">EURAD-1 (2019-2024) is a result of a collaborative process between WMOs, Technical Support Organisations and Nationally funded Research Entities. WP6 of EC EURAD builds upon the outcomes of EC FORGE and other projects. Experiments in EC FORGE revealed complex mechanisms and emphasised the importance of the mechanical control exerted by the porous material. Hence, this should allow the development of robust evaluation approaches that support the expert judgement formulated at the end of FORGE that gas is not a feasibility challenging issue for geological disposal but more a challenge of managing uncertainties.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">In Theme 4 of the EURAD Roadmap (Geoscience to understand rock properties, radionuclide transport and long-term geological evolution) increasing the understanding of gas migration is a high priority topic. Gas generation and transport is a key issue as it is possible that gas could be generated at a faster rate than it can be removed through clay host rocks (and clay EBS components) without creating discrete, gas-specific pathways through these low-permeability components. In several disposal concepts, the potential for migration of free gas containing radionuclides to the biosphere is an important issue.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To increase understanding and predictability of gas migration in different host rocks and to apply the knowledge to a UK context.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To review outputs from EURAD WP6 in a UK Context:
How can gas migrate within the repository and which water soluble and volatile radionuclides could be associated with it?
How and to what extent could the hydro-mechanical perturbations induced by gas affect barrier integrity and performance?</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Reports, reflecting experimental work and modelling.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
</table>

Further Information
There are other publications relevant to this task [1]–[3]. 1 S. Norris, F. Lemy, C.-A. del Honeux, G. Volckaert, E. Weetjens, K. Wouters, J. Wendling, M. Dymitrowski, D. Pellegrini, P. Sellin, L. Johnson, M. Sentis, and J. Harrington, *Synthesis report: Updated treatment of gas generation and migration in the safety case*, EC FORGE Project Milestone M68, 2013. 2 S. Norris, "FORGE project: updated consideration of gas generation and migration in the safety case," in *Gas generation and migration in deep geological waste repositories*. R. (Shaw, Ed., 415. 2015, pp. 241–258. 3 A. Bond, K. Thatcher, and S. Norris, *Multi-scale gas transport modelling for the EC FORGE project*. Mineralogical Magazine, vol. 79, pp. 1251–1263, 2015. [Online]. Available: doi:10.1180/minmag.2015.079.7.01.

B4.3.3 GDF-derived Gas Migration Through Salt Host Rock and Interactions with Salt-bearing Geological Environments

<table>
<tr><td>Task Number</td><td>40.3.003</td><td>Status</td><td>Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Gas Pathway</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Development of Knowledge Base on Gas Migration and Reaction</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">The programme to implement the UK GDF currently considers a number of potential host rocks, including salt (also referred to as rock salt or halite). LHGW emplaced in the GDF will generate gas, for example, from the corrosion of metals and the degradation of organic materials in reaction with water. Gas generation will be ongoing when waste is emplaced, utilising free water in the waste container that derives from encapsulation with cementitious materials. Water derived from the host rock can subsequently also lead to gas generation on contact with the waste and, in the case of a salt host rock, brines (water saturated or strongly impregnated with common salt) present naturally may migrate from the host rock to the GDF itself and will be available to interact with wastes, resulting in further gas generation.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">There is a need to ensure RWM maintains research activities relevant to a salt host rock; this PhD will form a contribution to that capability. The programme of work needs to consider how the permeability of the salt evolves with time, noting the effects of construction of the GDF and subsequent rock creep.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To explore the potential influence of such large-scale stresses on the salt formation and the ensuing gas migration, with the purpose of establishing the likelihood of gas migrating through the salt as a function of the gas volume and the gas production rate.
To establish the rate of migration of the gas through the salt and the associated evolution of the pressure field.
To build a series of small scale laboratory experiments in which a salt layer will be grown in a Hele-Shaw type cell and gas will be injected through the cell to examine the evolution of the permeability and gas migration pathway.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">A PhD programme at the Cambridge BP Institute to build a suite of models to investigate the potential migration of gas through a salt deposit.
To build a coupled model of this dilation and flow, predicting the size of the gas-filled zone as a function of the volume and rate of production of the gas.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">Evaporite</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
<tr><td colspan="4">A PhD thesis and publications in the academic literature, in order to maintain research activities relevant to a salt host rock.</td></tr>
</table>

SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 5

Further Information
This task is being undertaken via a PhD at the University of Cambridge with support from an NDA iCASE award. There are several publications relevant to this task [1], [2]. This task is related to Tasks 003 and 006. 1 S. Rocco, A. Woods, J. Harrington, and S. Norris, *An experimental model of episodic gas release through rracture of fluid confined within a pressurized elastic reservoir*. Geophysical Research Letters, vol. 43, 2016. [Online]. Available: doi:10.1002/2016GL0715. 2 Wilmot, R. and White, M. and Crawford, M. and Gilbert, A. and Evans, D. and Hough, E. Field, L. and Reay, D. and Milodowski, A. and McHenry, J. and Wolf,J., *UK Halite Deposits – Structure, Stratigraphy, Properties and Post-closure Performance*, Galson Science, Contractor Report 1735-1, 2018.

B4.3.4 Bentonite Permeability under Relevant Material Conditions

Task Number	40.3.004	**Status**	Start date in future
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		

Background

RWM needs to ensure that the permeability of the range of bentonites that may be used in engineered barriers in UK relevant environments (e.g groundwaters) is appropriate (as has been demonstrated for MX-80 by SKB). There is UK capability to perform these measurements, although it has yet to be applied to bentonite, rather than natural shales. It is thus desirable to develop capability and gain experience in these techniques in advance of the actual requirement and then to deploy that capability efficiently. Measurement of gas transport parameters for the range of bentonites under consideration will also facilitate optimisation of required properties. Assuming the influence of stress conditions is assessed, this testing could also be conducted in advance of site characterisation activities.

Research Driver

To understand the hydraulic and gaseous permeability properties of bentonite under UK-relevant conditions of bentonite composition (including sand content), compaction density, effective stress and groundwater composition to ensure that bentonite performs as required under UK-specific conditions.

Research Objective

Generic pre-site characterisation:

- Ensure capability to measure permeability properties of compacted bentonite in the laboratory.
- To better underpin the understanding of the main mechanisms for the movement of gas through a thin bentonite or clay buffer

During surface-based site characterisation:

- Assess site-specific effects of ambient groundwaters (and other material choices, e.g. sand content) on bentonite permeability.
- Production of a systematic database of bentonite hydraulic conductivity, as a function of composition of the buffer (including sand content), the dry density, groundwater conditions and stress conditions.
- Production of a systematic database of bentonite gaseous permeability/gas entry pressure, as a function of composition of the buffer (including sand content), the dry density, groundwater conditions and stress conditions.

Scope

Generic pre-site characterisation:

- Ensure capability to measure permeability properties of UK-relevant compacted bentonite in the laboratory.

During surface-based site characterisation:

- Experimental studies using site-specific groundwater compositions.

Geology Application

HSR, LSSR

Output of Task					
The output of this task will be a suite of reports.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are several publications relevant to this report [1], [2].					

1 O. Karnland, S. Olsson, and U. Nilsson, *Mineralogy and sealing properties of various bentonites and smectite-rich clay materials*, SKB, SKB Report TR-06-30, 2006. [Online]. Available: http://skb.se/upload/publications/pdf/TR-06-30.pdf.

2 D. Savage and R. Arthur, *Exchangeability of bentonite buffer and backfill materials*, STUK, STUK-TR 12, 2012. [Online]. Available: http://www.julkari.fi/bitstream/handle/10024/124116/stuk-tr12.pdf;sequence=1.

B4.3.5 Assessment of GDF-induced Effects in an Evaporite: Excavation Damaged Zone (EDZ) Formation, Evolution and Effect on Gas Migration

Task Number	40.3.005	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		
Background			
Excavation of tunnels and vaults and other construction activities in evaporite causes a readjustment of rock stresses, which might lead to the formation of an excavation damaged zone in the immediate vicinity of the openings. Excavation damaged zone formation in evaporite needs to be assessed in all stages of the programme as it potentially affects construction methods, GDF design and layout, and engineered barrier design, as well as operational safety and safety for some time into the post-closure period. GDF-induced effects can be divided into four categories: (1) suitability of the site with respect to gas generation, (2) impact of the thermal pulse on the site, (3) chemical impacts induced by the GDF (focus excavation damaged zone and host rock), (4) extent and properties of the excavation damaged zone at the sites.			
Research Driver			
Although an excavation damaged zone in evaporite is likely to heal over time so that its properties return to those of the host rock, there is expected to be significant gas generation from LHGW during the operational and early post-closure periods, before healing can occur. As such, it remains important to understand the properties of the excavation damaged zone and its evolution, and therefore its importance to gas migration, during this period. Currently, there is no detailed understanding of how an excavation damaged zone will affect gas migration for a UK GDF in an evaporite host rock. There is therefore initially a need to develop a high-level understanding the evolution of the excavation damaged zone and its range of potential interactions with generated gas.			
Research Objective			
The initial objective is to obtain sufficient understanding of the properties and longevity of the excavation damaged zone, particularly around LHGW disposal vaults, in order to determine its likely range of effects on gas migration behaviour (e.g. the potential for gas to bypass EBS components) and the impacts of this in terms of the safety functions of the EBS. Depending on the potential importance of the excavation damaged zone, as determined by the initial understanding, further research objectives may be highlighted.			
Scope			
Generic pre-site characterisation: • To review other international GDF programmes in order to grasp an initial understanding of the development and evolution of the excavation damaged zone. • To carry out scoping calculations considering gas migration behaviour for the range of potential excavation damaged zone properties and gas generation rates for LHGW during the GDF operational and early post-closure period, in order to provide an initial understanding of the importance of the excavation damaged zone to gas migration. **During surface-based site characterisation:** • The surface-based site characterisation scope will be determined depending on the outcome of initial work.			
Geology Application			
Evaporite			

Output of Task					
Reports and Academic papers.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 6
Further Information					
Task 40.3.004 progresses some of the generic/surface characterisation objectives. There are other publications relevant to this task [1]–[4]. For more information, see the Gas Migration Experimentation .					

1 J. Helton, J. Bean, B. Butcher, J. Garner, P. Vaughn, J. Schreiber, and P. Swift, *Uncertainty and sensitivity analyses for gas and brine migration at the waste isolation pilot plant*, SAND-92-2013, 1993. [Online]. Available: https://www.osti.gov/biblio/10190139-uncertainty-sensitivity-analyses-gas-brine-migration-waste-isolation-pilot-plant-may.

2 G. Freeze, K. Larson, and P. Davies, *Coupled multiphase flow and closure analysis of repository response to waste-generated gas at the waste isolation pilot plant*, SAND-93-1986, 1995. [Online]. Available: https://digital.library.unt.edu/ark:/67531/metadc668144/.

3 J. Helton J.C.and Bean, B. Butcher, J. Garner, J. Schreiber, P. Swift, and P. Vaughn, *Uncertainty and sensitivity analysis for gas and brine migration at the waste isolation pilot plant: Permeable shaft with panel seals.*. Journal of Hazardous Materials, vol. 45, pp. 107–139, 1996. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/0304389495000828.

4 J. Weber, S. Mrugalla, J. Weber, S. Mrugalla, C. Dresbach, and J. Hammer, *Preliminary safety analysis of the gorleben site: Geological database – 13300*. Proceedings of the WM2013 Conference, 2013.

B4.3.6 Assessment of GDF-induced Effects in a Lower Strength Sedimentary Rock (LSSR): Excavation Damaged Zone (EDZ) Formation, Evolution and Effect on Gas Migration

Task Number	40.3.006	**Status**	Ongoing
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		
Background			
GDF-induced effects are relevant for all host rock types, in LSSR especially, their impacts need to be assessed in all stages of the programme as they potentially affect the required footprint, long-term safety, GDF layout and engineered barrier design as well as operational safety. GDF-induced effects can be grouped into four categories: suitability of the site with respect to gas generation, impact of the thermal pulse on the site, chemical impacts induced by the GDF (focus: engineering disturbed zone and host rock) and the extent and properties of the Excavation Damaged Zone at the sites. The excavation of tunnels and drifts in the host rock leads to stress redistribution that results in micro and macro-scale fractures within an Excavation Damaged Zone. The Excavation Damaged Zone develops during the operational phase of the GDF and consolidates after backfilling of the underground structures. The formation and evolution of the Excavation Damaged Zone modifies safety-relevant properties of the host rock adjacent to the disposal tunnels, sealing zones and other underground structures. In particular, damage to the host rock results in an increased porosity, thus leading to higher hydraulic conductivity, gas permeability and thermal conductivity. After GDF closure, stress redistribution in response to the consolidation process and pore-pressure recovery affect the final properties of the near field.			
Research Driver			
The Excavation Damaged Zone around backfilled underground structures represents a viable release path for radionuclides as well as a possible escape route for corrosion and degradation gases. The efficiency of this release path depends on the shape and extent of the Excavation Damaged Zone and the degree of self-sealing that occurs during resaturation. There is a need to assess and understand the role of the Excavation Damaged Zone in the ESC for all three host geologies (HSR, LSSR and Evaporite).			
Research Objective			
To obtain an improved understanding of the development of the Excavation Damaged Zone around disposal tunnels, sealing zones and shafts and its impact on the safety functions of the EBS under conditions close to those anticipated in the GDF, with a focus on the temporal evolution of rock stress, pore pressure (irreversible and reversible) strains and hydraulic and gaseous conductivity in the near field during the entire lifetime of the GDF, extending from construction to the late post-closure phase.			
Scope			

Generic pre-site characterisation: • To develop capability for constructing in LSSRs through the potential of participation in sampling campaigns during tunnelling construction projects through LSSRs in the UK and LSSR URLs abroad. • To compile Excavation Damaged Zone-related data from underground laboratories in clay host rock, in order to assess the impact of tectonic overprint, burial history and mineralogical variability. • To log data from existing and future deep boreholes across the UK that could be used to link borehole stability to Excavation Damaged Zone related properties. • To develop a model of a simplified representation of the Excavation Damaged Zone in safety assessments to allow the simulation of the impact of variability of hydraulic conductivity on radionuclide transport and gas release along the backfilled tunnels and seal sections. **During surface-based characterisation:** • To experimentally determine the damage effects on gas properties (entry pressure and permeability) of host formation, as a function of stress field magnitude and orientation, sample size and rock-fabric anisotropy.

Geology Application					
LSSR					
Output of Task					
Reports and academic papers.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					

Further Excavation Damaged Zone-related *in-situ* experiments were conducted as part of the Mont Terri research programme. A recent synopsis of the state-of-the-art in Excavation Damaged Zone-related research at Mont Terri has been compiled by Lanyon et al. [1], [2] .

1 S. G. Survey, *Bossart and Thury, Mont Terri Rock Laboratory Project, Programme 1996 to 2007 and Results, Annex 8*, Other Technical Report No 3, 2008.

2 G. Lanyon, D. Martin, S. Giger, and P. Marschall, *Development and evolution of the Excavation Damaged Zone in the Opalinus Clay – a synopsis of the state of knowledge from Mont Terri*, Nagra, Nagra Report NAB 14-87, 2014. [Online]. Available: https://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NABs%202004%20-%202015/e_nab14-087.pdf.

B4.3.7 Assessment of GDF-induced Effects in High Strength Rock (HSR): Excavation Damaged Zone (EDZ) Formation, Evolution and Effect on Gas Migration

Task Number	40.3.007	**Status**	Start date in future
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		
Background			
Excavation of tunnels and vaults, construction of deposition holes, and other construction activities in HSR causes a readjustment of rock stresses. In the immediate vicinity of an opening, this might lead to the formation of an excavation damaged zone [1]. Formation of micro- or macro-scale fracturing in brittle HSR is significant because it potentially produces irreversible axially connected pathways for groundwater, gas and radionuclides along the annulus of rock around deposition holes and tunnels. In HSR deposition holes for HLW/spent fuel containers, excavation damaged zone formation and rock spalling are closely related outcomes of rock stress redistribution and are also coupled with response to the thermal pulse [2]. The impact of excavation damaged zone formation needs to be assessed in the context of construction methods, long-term safety, GDF design and layout and engineered barrier design, as well as operational safety. GDF induced effects can be grouped into four categories: suitability of the site with respect to gas generation, impact of the thermal pulse on the site, chemical impacts induced by the GDF (focus: excavation damaged zone and host rock) and the extent and properties of the excavation damaged zone at the sites.			
Research Driver			
There is a need for research that is both generic and site-specific. Firstly, a methodology is required for investigating the existence of, and for characterising the geometry and properties of, an excavation damaged zone in HSR. Secondly, the impacts of various excavation methods on excavation damaged zone formation needs to be investigated to provide input to requirements. Research concerning potential sites for a GDF and likely rock, structural and stress settings, site-specific studies of excavation damaged zone formation, properties and temporal evolution will be required. Experience in existing GDF programmes in HSR indicates that prior to site-selection and at the surface-based investigation stage, only a generic conceptual approach to incorporating excavation damaged zone in design and safety assessment will be plausible. At the current stage, generic underground rock laboratories will have an essential role in developing concepts, characterisation methods and parameter ranges for preliminary modelling. At the stage of underground investigations, the methods developed in the generic stage should be applied to GDF conditions by carrying out intensive localised investigations for the monitoring of excavation damaged zone development.			
Research Objective			
To obtain an improved understanding of the development of the excavation damaged zone around tunnels, vaults, deposition holes, tunnel seals and shafts and its impact on the safety functions of the EBS under conditions close to those anticipated in a GDF in HSR. Focus needs to be on the temporal evolution of rock stress, irreversible strains and gas permeability in the rock in the vicinity of openings during the construction and operation phase, and in rock around filled and sealed deposition holes and backfilled/sealed tunnels and shafts during the lifetime of the GDF to the late post-closure phase.			

Scope					
Generic pre-site characterisation: • To develop capability for constructing in HSR through the potential of participation in sampling campaigns during tunnelling construction projects through HSR in the UK and HSR URLs abroad. • To compile excavation damaged zone-related data from underground laboratories in HSR in order to assess the impact of stress regime, rock strength, lithology, anisotropy, crystal/grain size, etc. on the development of an excavation damaged zone. • To log data from existing and future deep boreholes across the UK that could be used to link borehole stability to excavation damaged zone related properties. • To develop a THM modelling approach for a simplified representation of the excavation damaged zone in safety assessment applications based on a range of relevant HSR properties in order to simulate the impact of variability of gas release along deposition holes for HLW/spent fuel, from ILW vaults and through the annulus of backfilled HLW deposition tunnels. **During surface-based site characterisation:** • To experimentally determine the damage effects on gas properties (entry pressure and permeability) of host formation, as a function of stress-field magnitude and orientation, sample size and rock fabric anisotropy.					
Geology Application					
HSR					
Output of Task					
A series of reports and academic papers.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 6
Further Information					
Experimental and modelling work on characterising and representing the excavation damaged zone in various types of HSR has been carried out in the international EC DOPAS project for full-scale demonstration of plugs and seals, in the DECOVALEX (Task 50.2.002, Task 50.2.003 and Task 50.2.004) project, and at the Grimsel Test Site [3]. This task is linked to the LASGIT 40.1.003.For more information, see: Gas Migration Experimentation . 1 SKB, *Underground Openings Construction Report: Design, Construction and Initial State of the Underground Openings*, SKB, SKB Report TR-10-18, 2010. [Online]. Available: https://skb.se/upload/publications/pdf/TR-10-18.pdf. 2 SKB, *Long-term Safety for the Final Repository for Spent Fuel at Forsmark: Main Report of the SR-Site Project*, SKB, SKB Report TR-11-01, 2011. [Online]. Available: http://www.mkg.se/uploads/Aktbilagor/77_TR-11-01_V1_Errata_aktbil_77.pdf. 3 B. Frieg and P. Blaser, *Excavation Disturbed Zone experiment, Grimsel Test Site*, 98-01, 2012. [Online]. Available: https://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NTBs%201994-2000/e_ntb98-01.pdf.					

B4.3.8 Gas Migration in a Tight Fractured Rock and Gas Hold-up by Cap Rocks (HSR)

Task Number	40.3.008	**Status**	Start date in the future
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		

Background

Various gases will be produced from wastestreams and engineered barrier components in HLW and LLW/ILW GDFs after closure. CH_4, CO_2 and H_2 could be produced within waste containers from wastes and/or steel components. The released gas would then pass through additional engineered containment such as buffer, backfill or cementitious grout and seals. Experiments have identified the circumstances of release at Äspö HRL [1] and through concrete box and bentonite/sand buffer by gas injection test at Grimsel Test Site [2], [3]. In such cases, the gas will tend to dissolve in groundwater or migrate as a discrete gas phase if exceeding the solubility limit. It is often cautiously assumed that a free gas phase will migrate rapidly in groundwater to the biosphere and will be a pathway by which potentially gaseous radionuclides such as ^{14}C, ^{3}H and ^{222}Rn could be released. A discrete gas phase would migrate through fractures in HSR and migration would be impeded by lower permeability, less fractured rock and by low permeability strata ('cap rocks') in overlying sedimentary rocks if present. Migration pathways would then be controlled by gas entry pressures and transmissivities of the fractures.

The LLW/ILW inventory will potentially produce a significant volume of gas. This issue has been scoped by [4] and the [5]. RWM's DSSC update in 2016 concluded that 'the processes that contribute to gas generation during the transport of waste packages to the GDF, during the operational phase of the GDF and after closure of the GDF are understood. Gas migration from the GDF after closure will be site-specific and would need to be addressed in detail after a site has been chosen'.

Research Driver

There is a need to demonstrate an in-depth understanding of gas migration from a GDF, relative to the rate and distribution of gas release and the geometry and properties of fractures in HSR, to support the ESC.

Research Objective

Generic pre-site characterisation:

- To gather robust empirical evidence to support the conceptual understanding of the relevant phenomena and processes in the host rock and allow validation of numerical modelling approaches at the small-scale.
- To develop modelling tools for site-specific model analyses of gas transfer through the host rock (fracture flow).
- To utilise evidence from *in-situ* (validation) experiments, in order to demonstrate the transferability of gas transport mechanisms and the corresponding properties from the laboratory scale (centimetre scale) to the tunnel scale (decimetre to metre scale).
- To undertake studies of analogues of discrete gas phase in HSR, e.g. in gas storage schemes, in order to improve conceptual understanding of the effects of gas migration in HSR to address the potential gas production in the LLW/ILW inventory.

During surface-based site characterisation:

- To compile an experimental database, representing the relevant gas transport mechanisms and the corresponding gas-related properties of the host rock (expected values and uncertainties). This includes gas transport in the pore network of the intact/dilated rock matrix and gas transport along (re-)activated fractures.

Scope

Generic pre-site characterisation:

- The further development of modelling approaches for 2-phase flow, e.g. preliminary research by Keto [6]. A practicable generic approach to *in situ* evidence of processes is to study analogues for gas migration in HSR-type rock.
- Literature review on specific topics (gas dissolution, sorption, saturation-dependent diffusion coefficients, natural gas seeps and case studies of the failure of natural gas storage systems, large-scale onshore CO_2 studies providing further information regarding potential induced seismicity).
- Experiments to be carried out are not yet determined and might involve studies of:
    - Individual fractures (either artificial or an individual fracture) – to establish some fundamental parameters on gas entry pressures, and basic information on the migration of gas under a range of boundary conditions (*in situ* total stress and gas pressure).
    - Larger network of fractures in experiments performed in URLs – to upscale the learning from the individual to the small network scale. This could also involve the reappraisal of previous experimental work (to maximise learning and potential for using the information for parameterisation of models).

During surface-based site characterisation:

- To develop an experimental database, representing the relevant gas transport mechanisms and the corresponding gas-related properties of the host rock (expected values and uncertainties). This will include gas transport in the pore network of the intact/dilated rock matrix and gas transport along (re-)activated fractures.

Geology Application

HSR

Output of Task

Contractor report, including an experimental database.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 5

Further Information

For more information, see the Gas Migration Experimentation . The EC-FP7 FORGE project (2009-2013; http://www.bgs.ac.uk/forge/home.html) carried out research on the generation and migration of gases from repositories and on its handling in safety assessments [7]. However, the main focus of most of the work packages was on LSSR host rock.

There are other publications relevant to this task [8].

1 R. Cuss, J. Harrington, D. Noy, C. Graham, and P. Sellin, *Evidence of localised gas propagation pathways in a field-scale bentonite engineered barrier system; results from three gas injection tests in the large-scale gas injection test (LASGIT)*. Applied Clay Science, vol. 102, pp. 81–92, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0169131714004098.

2 S. Okamoto, S. Yamamoto, A. Fujiwara, S. Vomvoris, P. Marschall, G. Lanyon, K. Ando, and S. Shimura, *The In-situ Gas Migration Test (GMT) at the Grimsel Test Site: Gas Injection and System Hydraulic Tests*. Clays in Natural and Engineered barriers for Radioactive Waste Confinement, pp. 452–453, 2005.

3 R. Senger, W. Lanyon, P. Marschall, S. Vomvoris, and A. Fujiwara, *Numerical Modelling of the Gas Migration Test at the Grimsel Test Site, Switzerland*. Nuclear Technology, vol. 164, 2008. [Online]. Available: https://www.researchgate.net/publication/260189954_Numerical_Modeling_of_the_Gas_Migration_Test_at_the_Grimsel_Test_Site_Switzerland.

4 P. Agg, R. Cummings, J. Rees, W. Rodwell, and R. Wikramaratna, *Nirex Safety Assessment Research Programme: Nirex Gas Generation and Migration Research: Report on Current Status in 1994*. S/96/002, 1996.

5 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

6 V. Keto, *Developing Two-phase Flow Concepts for Rock Fractures*, Posiva Oy, Posiva Report 2010-10, 2010. [Online]. Available: http://www.posiva.fi/files/1202/WR_2010-10web.pdf.

7 J. Harrington, *FORGE milestone D4.24-R summary report: Experiments and modelling of excavation damage zone behaviour in argillaceous and crystalline rocks (work package 4)*, EC FORGE Project Report D4.24-R, 2013. [Online]. Available: https://www.bgs.ac.uk/forge/docs/reports/D4.24-R.pdf.

8 A. Hoch, C. Rochelle, P. Humphreys, J. Lloyd, T. Heath, and K. Thatcher, *Carbon-14 Project Phase 2: Formation of a Gas Phase and its Migration*, AMEC, Contractor Report AMEC/2000247/007, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-2-formation-of-a-gas-phase-and-its-migration/.

B4.3.9 Gas Migration in Cementitious Backfills

<table>
<tr><td>Task Number</td><td>40.3.009</td><td>Status</td><td>Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Gas Pathway</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Development of Generic Knowledge Base on Gas Migration and Reaction</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">For HSR, the backfill material for use around low-heat-generating waste in the illustrative concept for a UK GDF is the cement-based NRVB, which was developed in the 1990s. For LSSR, the illustrative concept for ILW and LLW involves cementitious mortars. The transport properties of cementitious backfills have been the subject of research over many years and a significant body of understanding has been developed. However, it is also important to consider the interaction of GDF-derived gases with cementitious backfills. This interaction will involve a number of important processes including carbonation. The carbonation of C-14 bearing CO_2 in backfill material is potentially an important process. Carbonation will also affect the evolution of physical properties (porosity, permeability) of the backfill. There is also a trade-off between strength and transport properties in cementitious materials and a need to balance these, both with and without carbonation.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To understand key gas-migration processes in cementitious backfills in HSR & LSSR.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">Generic pre-site characterisation:
• Ensure, for the range of backfill materials under discussion, that gas permeability and permeability evolution are in an acceptable range to manage gas pressure in the EBS.
• Ensure, for the range of backfill materials under discussion, the degree of expected carbonation is well understood.
During surface-based site characterisation:
• Ensure, for the backfill material finally identified, that the gas permeability and permeability evolution are in an acceptable range to manage gas pressure in the EBS.
• Ensure, for the backfill material finally identified, the degree of expected carbonation is well understood.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">Generic pre-site characterisation:
• To collate an understanding of the properties of the full range of cementitious materials that may be suitable as backfill materials.
• To measure the gas permeability and permeability evolution of a range of backfill materials in order to understand the management of gas pressure in the EBS (consisting of a matrix of gas permeability measurements for the chosen range of backfill materials and a range of injection rates of a representative mixture of gases to provide understanding of the evolution and degree of carbonation for the backfill materials).
• To consider the impact of gas migration through carbonation of cementitious materials on the strength of the backfill, triaxial testing of material (under in situ conditions) before, during and after gas injection can be used to track the evolution in moduli and ultimately strength.</td></tr>
</table>

<table>
<tr><td colspan="6">During surface-based site characterisation:
Ensure, for the backfill material finally identified, the gas permeability and permeability evolution are in an acceptable range to manage gas pressure in the EBS.
Ensure, for the backfill material finally identified, the degree of expected carbonation is well understood.
To undertake modelling and experimental studies using site-specific groundwater compositions.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A suite of contractor approved reports and academic papers.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">This task is related to the Backfill IPT Task 30.1.001. For more information, see the Gas Migration Experimentation . There are several publications relevant to this task, including the [1] [2]–[7].

1 Radioactive Waste Management, Geological disposal: Generic post-closure safety assessment, RWM Report DSSC/321/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-post-closure-safety-assessment/.
2 N. Collier, D. Heyes, E. Butcher, J. Borwick, A. Milodowski, L. Field, S. Kemp, I. Mounteney, S. Bernal, C. Corkhill, and N. Hyatt, Gaseous carbonation of cementitious backfill for geological disposal of radioactive waste: Nirex reference vault backfill. Applied Geochemistry, vol. 106, pp. 120–133, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0883292719301131.
3 A. Harris, A. Atkinson, and P. Claisse, Transport of Gases in Concrete Barriers. 1992.
4 L. Hoglund and K. Konsult, The impact of concrete degradation on the BMA barrier functions, SKB, SKB Report R-13-40, 2014. [Online]. Available: https://www.skb.se/publikation/2478306/R-13-40.pdf.
5 G. Purser, A. Milodowski, D. Noy, C. Rochelle, J. Harrington, A. Butcher, and D. Wagner, “Modification to the flow properties of repository cement as a result of carbonation,” in Gas generation and migration in deep geological waste repositories. R. Shaw, Ed., 415. London: Geological Society, Special Publications, 2015, pp. 35–46.
6 C. Rochelle, G. Purser, A. Milodowski, D. Noy, D. Wagner, A. Butcher, and J. Harrington, Co2 migration and reaction in cementitious repositories: A summary of work conducted as part of the forge project, British Geological Survey, BGS Report OR/13/004, FORGE report D3.37, 2013.
7 J. Wilson, S. Benbow, and R. Metcalfe, Understanding the long-term evolution of cement backfills: Alteration of NRVB due to reaction with groundwater solutes, Quintessa, AMEC, Contractor Report RWM/03/043, Mar. 17, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/understanding-the-long-term-evolution-of-cement-backfills-alteration-of-nrvb-due-to-reaction-with-groundwater-solutes/.</td></tr>
</table>

B4.3.10 Gas Migration in Clay: Lower Strength Sedimentary Rock (LSSR)

Task Number	40.3.010	**Status**	Ongoing
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		
Background			
Various gases may be produced in both HLW and LLW/ILW GDFs, principally as a result of the corrosion of metals and (microbial) degradation of organic matter. The principal impacts of gas are expected to be increased pore pressures and thus changes in effective stress in the surrounding host rock, associated with potential effects on integrity of the host rock (reactivation of natural faults, creation of gas fractures). In addition, the creation of a sustained gas pressure in the near field may affect water flow in the host rock, ramp/access tunnel and shaft and thus have some effect on the transport of dissolved and volatile radionuclides. It needs to be ensured that gas does not significantly and adversely affect the barrier function of the host rock, and that safety function indicator criteria defined related to overpressures are fulfilled. Since [1], significant confirmation of the phenomenological understanding of gas transport in disturbed and undisturbed clay rocks has been obtained through the EURATOM NF-PRO (near-field processes) and especially the FORGE projects. The topic is the focus of WP6-Mechanistic understanding of gas transport in clay materials, within the newly-funded European Joint Programme on Radioactive Waste Management 40.1.004.			
Research Driver			
Research is needed to develop experimental methods to consider the potential for gas migration in LSSR. If the permeability is very low (and gas entry pressure high), there may be little experimentation needed. In this case the EBS (backfill and seals working in tandem) will potentially be required to be the main conduit for gas and the management of gas pressure in the GDF. However, in bedded material there may be potential for gas flow along the bedding planes and an understanding of the impact of lithological variations on gas-flow properties will be required. The need is to develop an improved description of the evolution of the near field during the resaturation phase and the subsequent formation pressure recovery.			
Research Objective			
To demonstrate that the build-up of gas overpressures in the backfilled GDF structures will not impair the ESC, requiring a detailed assessment of the role of the host rock as a potential escape route for the gases generated in a GDF.			
Scope			
Generic pre-site characterisation: • To develop analytical or simple (at first, later more complex) coupled modelling capability in order to conduct a screening of typical LSSR in the UK based on a range of potential gas relevant properties. • To liaise with the hydrocarbon industry, CCS and gas storage communities, in order to obtain the existing information on low permeability LSSR rocks in a UK context, to contribute to the development of an experimental database on the relevant gas transport mechanisms and the corresponding gas-related properties in potential candidate LSSR as well as the corresponding stress conditions in these rocks.			

<table>
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To develop up-scaling techniques for modelling gas transport in heterogeneous media (porous media, fractured media) within the framework of existing international collaborations (European Joint Programme on Radioactive Waste Management; EBS Task Force).

During surface-based site characterisation:

To continue to develop the capability of coupled modelling and gas modelling techniques.
To improve the capability for gas experiments, with increased capability for detailed characterisation of hydromechanical site conditions in the anticipation of drilling.
To carry out full characterisation of the gas transport mechanisms and properties of recovered core with consideration of saturation, stress conditions and lithological variation with depth.

</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a suite of contractor approved reports.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information

This work is being underpinned further through participation in the Mont Terri Project for the hydro-geological, geochemical and geotechnical characterisation of a clay formation, with involvement in the experiment ”Hydrogen Transfer” (https://www.mont-terri.ch/en/homepage.html). For more information, see: Gas Migration Experimentation . There are other publications relevant to this task [2]–[7].

1 R. K. Senger and J. Ewing, *Gas pressure build-up and transport in a deep geologic L/ILW repository in Opalinus Clay using large-scale and local-scale models*, SKB, SKB Report NAB-09-17, 2009.

2 N. Diomidis, V. Cloet, O. Leupin, P. Marschall, A. Poller, and M. Stein, *Production, consumption and transport of gases in deep geological repositories according to the swiss disposal concept*, 2017. [Online]. Available: http://www.nagra.ch/display.cfm/id/102548/disp_type/display/filename/e_Faltblatt%20Gas_2017.pdf.

3 J. Harrington, *FORGE milestone D4.24-R summary report: Experiments and modelling of excavation damage zone behaviour in argillaceous and crystalline rocks (work package 4)*, EC FORGE Project Report D4.24-R, 2013. [Online]. Available: https://www.bgs.ac.uk/forge/docs/reports/D4.24-R.pdf.

4 A. Hoch, C. Rochelle, P. Humphreys, J. Lloyd, T. Heath, and K. Thatcher, *Carbon-14 Project Phase 2: Formation of a Gas Phase and its Migration*, AMEC, Contractor Report AMEC/2000247/007, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-2-formation-of-a-gas-phase-and-its-migration/.

5 O. Leupin, J. Zeyer, V. Cloet, P. Smith, R. Bernier-Latmani, P. Marschall, A. Papafotiou, B. Schwyn, and S. Stroes-Gascoyne, *An assessment of the possible fate of gas generated in a repository for low- and intermediate-level waste*, Nagra Report NTB 16-05, 2016. [Online]. Available: http://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NTBs%202014%20-%202015/e_ntb16-05.pdf.

6 P. Marschall, B. Lanyon, I. Gaus, and J. Ruedi, *FORGE D4-16: Gas Transport Processes at Mont Terri Test Site (EDZ and host rock) - Field Results and Conceptual Understanding of Self-sealing Processes*, FORGE D4-16, 2013. [Online]. Available: https://www.bgs.ac.uk/forge/docs/reports/D4.16-R.pdf.

7 A. Poller, G. Mayer, M. Darcis, and P. Smith, *Modelling of gas generation in deep geological repositories after closure*, Nagra, Nagra Report NTB 16-04, 2016. [Online]. Available: http://www.nagra.ch/display.cfm/id/102540/disp_type/display/filename/e_ntb16-04.pdf.

B4.3.11 Gas Migration in a Bedded Salt

Task Number	40.3.011	**Status**	Start date in future
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		

Background

The issues related to gases in a GDF site in evaporite would derive from two broad categories: (i) production of gases from the waste inventory and/or engineering components, and (ii) natural gases that are contained in the evaporite. In the first category, the LLW/ILW inventory could be a source of CO_2, CH_4 and H_2, and steel containers and construction components could produce H_2. Trapping and migration of these produced gases, the rate of production and the controlling variables would be the main issues. In the second category, hydrocarbons might have been produced in interlayered strata or adjacent strata with significant organic source material and migrated into the salt layers. In some circumstances, the trapped hydrocarbons could represent a construction hazard and they are also a source of potentially mobile gases in which radon could be entrained.

Research Driver

There is a need for research to better understand: (i) the potential gas migration routes through evaporite rock, i.e. generic data on gas permeabilities at various scales and depth intervals, also the strength of evaporite rock in terms of its behaviour as a trapping medium (i.e. in relation to an increasing gas pressure); (ii) the occurrence, origins, abundances and compositions of natural gases trapped in potential GDF host locations.

Research Objective

To assess the implications of gas production build-up and migration for post-closure safety, in order to increase the understanding of gas migration and potential overpressures, as well as the understanding of the possible adverse effects on the barrier function of the host rock.

Scope

Generic pre-site characterisation:

- To improve process understanding for validation of numerical simulation and up-scaling approaches - this could potentially involve the use of laboratory testing using archive drill core or *in situ* testing, for example in a suitable UK mine.
- To develop modelling capability to screen various types of evaporite rock in the UK based on their ranges of gas permeabilities, strengths/stress conditions, rock stress, etc.
- To liaise with the hydrocarbon/CCS industry and gas storage community to obtain existing data and supporting information for gas storage and migration through evaporite rocks in a UK context. The data will contribute to the development of an experimental database on the relevant gas transport mechanisms and the corresponding gas-related properties in potential candidate evaporite rock formations as well as the corresponding stress conditions in these rocks.
- To undertake modelling of gas percolation processes through evaporite rocks in order to provide guidance for canalling flow parameters from the core scale to GDF scale.

During surface-based site characterisation:

- To continue the development of modelling capability and gas modelling techniques.

• To obtain measurements of site-specific geomechanical properties and gas migration/sorption properties using drillcore samples. The testing of intact, damaged, impure host rock, as well as interbedded layers, will be necessary in order to assess the impact of lithological variation.					
Geology Application					
Evaporite (in particular halite)					
Output of Task					
Reports and academic papers.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5
Further Information					

For more information, see the Gas Migration Experimentation . There are other publications relevant to this task [1]–[7].

1 N. Diomidis, V. Cloet, O. Leupin, P. Marschall, A. Poller, and M. Stein, *Production, consumption and transport of gases in deep geological repositories according to the swiss disposal concept*, 2017. [Online]. Available: http://www.nagra.ch/display.cfm/id/102548/disp_type/display/filename/e_Faltblatt%20Gas_2017.pdf.

2 J. Harrington, *FORGE milestone D4.24-R summary report: Experiments and modelling of excavation damage zone behaviour in argillaceous and crystalline rocks (work package 4)*, EC FORGE Project Report D4.24-R, 2013. [Online]. Available: https://www.bgs.ac.uk/forge/docs/reports/D4.24-R.pdf.

3 A. Hoch, C. Rochelle, P. Humphreys, J. Lloyd, T. Heath, and K. Thatcher, *Carbon-14 Project Phase 2: Formation of a Gas Phase and its Migration*, AMEC, Contractor Report AMEC/2000247/007, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-2-formation-of-a-gas-phase-and-its-migration/.

4 O. Leupin, J. Zeyer, V. Cloet, P. Smith, R. Bernier-Latmani, P. Marschall, A. Papafotiou, B. Schwyn, and S. Stroes-Gascoyne, *An assessment of the possible fate of gas generated in a repository for low- and intermediate-level waste*, Nagra Report NTB 16-05, 2016. [Online]. Available: http://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NTBs%202014%20-%202015/e_ntb16-05.pdf.

5 P. Marschall, B. Lanyon, I. Gaus, and J. Ruedi, *FORGE D4-16: Gas Transport Processes at Mont Terri Test Site (EDZ and host rock) - Field Results and Conceptual Understanding of Self-sealing Processes*, FORGE D4-16, 2013. [Online]. Available: https://www.bgs.ac.uk/forge/docs/reports/D4.16-R.pdf.

6 A. Poller, G. Mayer, M. Darcis, and P. Smith, *Modelling of gas generation in deep geological repositories after closure*, Nagra, Nagra Report NTB 16-04, 2016. [Online]. Available: http://www.nagra.ch/display.cfm/id/102540/disp_type/display/filename/e_ntb16-04.pdf.

7 Nagra, *The Nagra Research, Development and Demonstration (RD&D) Plan for the Disposal of Radioactive Waste in Switzerland*, Nagra Report NTB 09-06, 2009. [Online]. Available: http://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NTBs%202001-2010/e_ntb09-06.pdf.

B4.3.12 Gas Migration in Relation to GDF - Plugs and Seals

Task Number	40.3.012	**Status**	Start date in future
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Generic Knowledge Base on Gas Migration and Reaction		

Background

As part of the GDF design, the generic ESC requires that plugs and seals are installed within the LHGW module, HHGW module and tunnel/shaft infrastructure, in addition to buffer and backfill materials to ensure that gas (and fluid) movement is managed as appropriate and necessary and therefore to manage the migration of any waste-derived radionuclides through the bentonite buffer and backfill. The disposal tunnel seals will resist the swelling (and prevent loss of density) of the bentonite buffer if used to backfill the tunnels. In addition, the seals may be designed to be gas permeable, allowing managed migration of gas from disposal areas into other parts of a GDF, thereby mitigating the potential for over-pressurisation, while preventing the flow of water.

Research Driver

To understand the need for, and ability of, plug and seal materials and designs, including how they are emplaced and their relationship with the host rock and GDF infrastructure, to transmit or retain gas within the GDF design as required to ensure necessary safety functions.

Research Objective

Generic pre-site characterisation:

- To investigate the effects of installing plugs and seals throughout the GDF design based on site-scale characterisation models and a consideration of a range of mass-backfill transport properties in order to deliver a safety requirement of the mass backfill and seals working in tandem to manage gas in the GDF.
- To develop and improve methodologies for the assessment of the degree of hydraulic displacement during gas testing, in order to deliver a safety requirement of the mass backfill and seals working in tandem to manage gas in the GDF.

During surface-based site characterisation:

- On the basis of site-specific information derived from surface-based site characterization, including analyses of borehole cores and the rock volume made accessible by coring activities, to update the knowledge base on geosphere gas transport properties, to the extent justifiable to do so and with due recognition of related uncertainties, and update the generic study of waste-derived gas behaviour to identify gas-EBS-geosphere interactions and sensitivities, including the potential for gas egress via GDF infrastructure and EDZ/EdZ; this shall inform both the post-closure safety case and future site-characterisation activities.

Scope

Generic pre-site characterisation:

- To simulate gas (and groundwater) pathways within generic GDF designs based on site-scale characterisation models with the consideration of a range of buffer and backfill permeabilities, excavation damaged zone properties and plug/seal designs.

- To assess the plugs and seals installed within the tunnel system in order to investigate the effects on gas migration and the potential for gas over-pressurisation (gas generation rates will need consideration), as well as considering alternative plug and seal designs to mitigate unfavourable conditions.
- To conduct experiments under GDF-relevant conditions on candidate materials examining the gas entry pressures and permeabilities, as a function of key controls.
- To use existing capability to perform laboratory based studies to underpin seal design, including defining gas migration behaviour as a function of seal saturation and assessment of seal heterogeneity on permeability, where the development of improved capability for the assessment of the degree of hydraulic displacement will be key.

During surface-based site characterisation:

- To utilise the learning at generic pre-site characterisation stage in order to simulate models with the latest GDF designs and site understanding to evaluate the necessity for plugs and seals within the GDF design to minimise preferential groundwater pathways and gas over-pressurisation.

Geology Application

HSR, LSSR, Evaporite (in particular halite)

Output of Task

The output of the task will result in contractor approved reports and academic papers.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5

Further Information

There are other publications relevant to this task, including the [1] [2]. For more information, see the Gas Migration Experimentation .

1 Radioactive Waste Management, *Geological disposal: Generic environmental safety case - main report*, RWM Report DSSC/203/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-environmental-safety-case-main-report/.

2 DOPAS, *DOPAS project final summary report, DOPAS project work package 6*, 2016. [Online]. Available: https://3okrv814vuhc2ncex71gwd1e-wpengine.netdna-ssl.com/wp-content/uploads/2018/04/DOPAS-2016_D6_4_31102016_final_ver8.pdf.

B4.3.13 Gas Migration Processes in Clay Materials

<table>
<tr><td colspan="2">Task Number</td><td>40.3.013</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Gas Pathway</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Development of Generic Knowledge Base on Gas Migration and Reaction</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">One of the main mechanisms for the movement of gas through a thin bentonite or clay buffer is through overcoming the material gas-entry pressure. Dependent on the nature of the buffer this disruption of the buffer can result in a dilatant transmission of the gas (as a gas bubble or stream), after which the buffer could either partially or completely reseal. Good experimental data, combined with appropriately physically-based numerical models, have not been well-established. Therefore, there is a research need to better understand the dilatancy of bentonite buffer under UK-specific conditions (e.g. under estimated gas-generation rates).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To increase the understanding of the key process of dilatancy of bentonite buffer under UK-specific conditions (e.g. under estimated gas-generation rates).</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">Generic pre-site characterisation:
To improve the conceptual understanding of the transmission of gas through bentonite.
During surface-based site characterisation:
To demonstrate sufficient understanding of the movement of gas and its effect on the EBS at a site-specific stage.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Generic pre-site characterisation:
To develop a numerical framework and supporting evidence as a basis for experiments. Participate in collaborative programmes where possible (especially for in situ tests).
To develop novel experimental capabilities to allow the necessary information for model parameterisation to be obtained (quantification of spatial distribution, long-term evolution and scaling). This may include novel remote sensing methodologies or high resolution imaging, taking advantage of capability development in recent years.
During surface-based site characterisation:
To build upon the knowledge base to refine modelling approaches, i.e. continuous or discrete migration, selecting suitable models to represent specific consequences of gas migration.
To ensure alignment with conceptual and constitutive models reflecting geological and geochemical conditions encountered.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A suite of reports.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task [1]–[7]. For more information, see the Gas Migration Experimentation .

1 R. Cuss, J. Harrington, D. Noy, C. Graham, and P. Sellin, *Evidence of localised gas propagation pathways in a field-scale bentonite engineered barrier system; results from three gas injection tests in the large-scale gas injection test (LASGIT)*. Applied Clay Science, vol. 102, pp. 81–92, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0169131714004098.

2 P. Gerard, J. Harrington, R. Charlier, and F. Collin, *Modelling of localised gas preferential pathways in claystone*. International Journal of Rock Mechanics and Mining Sciences, vol. 67, pp. 104–114, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1365160914000306.

3 J. Harrington, A. Milodowski, C. Graham, J. Rushton, and R. Cuss, *Evidence for gas-induced pathways in clay using a nanoparticle injection technique*. Mineralogical Magazine, vol. 76, pp. 3327–3336, Issue 8 2012. [Online]. Available: DOI:%2010.1180/minmag.2012.076.8.45.

4 J. Harrington, C. Graham, R. Cuss, and S. Norris, *Gas network development in a precompacted bentonite experiment: Evidence of generation and evolution*. Applied Clay Science, vol. 1475, pp. 80–89, 2017. [Online]. Available: http://dx.doi.org/10.1016/j.clay.2017.07.005.

5 J. Harrington, C. Graham, R. Cuss, and S. Norris, *Gas network development in compact bentonite: Key controls on the stability of flow pathways*. Geofluids, vol. 19, 2019. [Online]. Available: https://www.hindawi.com/journals/geofluids/2019/3815095/.

6 S. Rocco, A. Woods, J. Harrington, and S. Norris, *An experimental model of episodic gas release through rracture of fluid confined within a pressurized elastic reservoir*. Geophysical Research Letters, vol. 43, 2016. [Online]. Available: doi:10.1002/2016GL0715.

7 E. Tamayo-Mas, J. Harrington, H. Shao, E. Dagher, J. Lee, K. Kim, J. Rutqvist, S. Lai, N. Chittenden, Y. Wang, I. Damians, and S. Olivella. DFNE 2018: International Discrete Fracture Network Engineering Conference, 2018.

B4.4 WBS 40.4 - Development of gas related conceptual models and numerical solutions (modelling)

B4.4.1 Ongoing Development of SMOGG Toolkit

Task Number	40.4.001	**Status**	Ongoing
WBS Level 4	Gas Pathway		
WBS Level 5	Development of Gas-related Conceptual Models and Numerical Solutions (modelling)		
Background			
The UKRWI will generate bulk gas and radioactive gas in relation to: corrosion of metals; degradation of organic materials; radiolysis of water, polymers, plastics, non-aqueous phase liquids; radioactive decay; and evolution of irradiated graphite, as present in the inventory. Gas generation occurs in relation to high-heat generating and low-heat generating wastes and could potentially occur during the transportation of waste to the GDF, during the operational period of the GDF after waste has been received and before closure, and following GDF sealing and closure. Gas generation is an issue to be considered in the transport, operational and environmental safety case components of the DSSC, and the propensity for waste to generate gas is an issue regardless of host rock type (it is an artefact of properties of the waste). Waste-derived bulk gases of interest include hydrogen, methane and carbon dioxide, and waste-derived radioactive gases of interest include carbon-14 bearing methane and carbon dioxide, tritium and radon.			
Research Driver			
There is a need to model gas generation in relation to the UKRWI as a whole and in relation to individual waste streams, and to understand the rate of both bulk gas generation and radioactive gas generation and how these vary with time and evolving GDF conditions (e.g. during the transport period, operational period and post-closure period of the GDF). Package-scale gas generation modelling may also be needed. How gas generation varies with water availability (which in turn is an artefact of host geology and the surrounding geological environment) needs to be understood, as does how gas generation varies with evolving GDF conditions, e.g. temperature.			
Research Objective			
The objective is to model gas generation associated with the UKRWI to provide input to the DSSC (including transport, operational and environmental safety cases). Gas generation on a waste stream and package-scale basis is also considered as part of the disposability assessment process.			
Scope			
RWM uses SMOGG to model gas generation. SMOGG is the intellectual property of the Nuclear Decommissioning Authority, and is used by RWM under licence. Other OneNDA Group companies, e.g. Low Level Waste Repository Ltd, have access to SMOGG. SMOGG is run either in-house by RWM personnel, or in the supply chain. Development of the SMOGG toolkit is needed periodically, e.g. to include additional gas generation processes, to reflect new boundary conditions or for use in different GDF-related scenarios than envisaged to date. Development of SMOGG is an enduring task; RWM liaises with other SMOGG users, e.g. Low Level Waste Repository Ltd, to ensure any toolkit enhancements meet respective specifications and requirements. The output of SMOGG development is a new version of the toolkit.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

Updated version of SMOGG toolkit, together with updated Specification and User Guide for publication on the RWM bibliography.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					
There are other publications relevant to this task, including the [1] [2], [3]. 1 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/. 2 Swift, B.T., *Specification for SMOGG Version 7.0: A Simplified Model of Gas Generation from Radioactive Wastes*, AMEC, Contractor Report AMEC/204651/001, 2016. [Online]. Available: https://rwm.nda.gov.uk/publication/specification-for-smogg-version-7-0-a-simplified-model-of-gas-generation-from-radioactive-wastes/. 3 Swift, B.T., *User guide for SMOGG version 7.0: A simplified model of gas generation from radioactive waste*, AMEC, Contractor Report AMEC/204651/002, 2016. [Online]. Available: https://rwm.nda.gov.uk/publication/user-guide-for-smogg-version-7-0-a-simplified-model-of-gas-generation-from-radioactive-waste/?download.					

B4.5 Development of Strategy for Generic to Site(s)-Specific Geosphere and Gas Research Transitioning

<table>
<tr><td>Task Number</td><td>40.001</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Geosphere</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Preparatory Geosphere Studies to Facilitate Site-specific Characterisation and Investigation (to Include Thermal, Mechanical, Chemical etc. Processes)</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">The remits of the Geosphere and Gas research areas are identified in respective status reports (both 2016). RWM geosphere and gas research is currently undertaken in the context of the UK GDF programme being generic, i.e. it is not specific to a UK site or sites. It covers understandings of HSR, LSSR and evaporite host rocks that may be informed by knowledge bases derived from international site-specific studies undertaken in a range of geological environments, often in relation to existing underground research laboratories (e.g. Mont Terri, Grimsel Test Site, Äspö, WIPP). Such international studies are not undertaken in consideration of the UKRWI and its associated properties, and the HSR, LSSR and evaporite geosphere and gas knowledge bases relevant to international site-specific studies are not necessarily transferable to a UK site(s)-specific context (given that UK HSR, LSSR and evaporite rocks may differ from those considered internationally, and/or may respond differently in relation to processes associated with the evolution of the UKRWI). There is also a possible need for the UK GDF siting programme to consider alternative host rocks and a unique range of surrounding geological environments, and for a site-specific GDF implementation schedule (timing, duration of activities) to raise knowledge gaps not considered in international studies to date.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">There is a need to develop a strategy for considering the relevance and thoroughness of RWM's current geosphere and gas knowledge bases as the UK GDF siting programme proceeds, and to develop a procedure for undertaking more appropriately-focussed research in a site(s)-specific context. Furthermore, it may well be the case that differences between geological environments relevant to international URLs and specific UK site(s) may well require aspects of RWM current knowledge bases to be discontinued.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To develop a strategy and related procedures to consider the relevance of RWM's current geosphere and gas research knowledge bases in the context of the evolving UK GDF siting programme and site(s)-specific knowledge, recognising RWM may as a consequence need to undertake new geosphere and gas knowledge-enhancement, whilst also discontinuing some current research activities. Examples of related new work could consider the thermal, hydraulic, mechanical, chemical, gas and microbiological properties of site-specific rocks (proposed host rocks and surrounding geology), which may not have been studied previously in the context of radioactive waste management, covering in situ (undisturbed) conditions, and conditions relating to the construction, long term presence and evolution of a GDF.</td></tr>
</table>

Scope					
The current knowledge bases for, and remits of work covered under, the geosphere and gas research areas are detailed in the respective [1] and [2] status reports (complementary work is also being progressed in relation to hydrogeology of potential host rocks and surrounding geologies). The expected outcome of this project will be a strategy for the systematic, documented inter-comparison of the RWM geosphere and gas knowledge bases with geoscience information and understanding derived from site-specific studies undertaken in the GDF siting programme. This will ascertain how the knowledge bases can be used in forward work and will identify knowledge gaps that will need to be filled through newly-commissioned work, and will be based on the UKRWI and a detailed knowledge of how the waste will evolve in the GDF post-closure period, as affected by and affecting GDF host rock(s) and the geological environment. The above will ensure RWM has in place an approach to the transitioning of geosphere and gas knowledge bases from being site-generic to site(s)-specific as the UK GDF programme advances, providing substantiation of (and robustness in) safety case arguments that will be deployed in the Environmental Safety Case.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Contractor report to RWM, including strategic and procedural components. Approach to be trialled and to provide input to RWM's internal capability building project for development of a Site Descriptive Model.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					
While this pilot study will focus on Gas and Geosphere, relevant learning will be transferred to other site-specific research areas (e.g. radionuclide behaviour in groundwater). For more information, see the [2] and [1] Status Reports [3].					

1 Radioactive Waste Management, *Geological disposal: Criticality safety status report*, RWM Report DSSC/458/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-criticality-safety-status-report/.

2 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

3 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

B5 WBS 50 - Geosphere

RWM's current approach is to maintain an understanding of key geosphere processes and of relevant work undertaken in more mature overseas programmes, as well as to carry out generic research into specific aspects, such as sealing of site investigation boreholes. The generic research activities to be concluded can be summarised in the following work areas:

- Develop generic understanding of potential implications of past, present and future large-scale natural processes for a UK GDF (**WBS 50.1**)
- Develop generic understanding of GDF-induced impacts on the geosphere (**WBS 50.2**)
- Development of geosphere conceptual models and numerical solutions (modelling) **(WBS 50.3)**
- Preparatory geosphere studies to facilitate site-specific characterisation and investigation (to include thermal, hydraulic, mechanical and chemical processes) (**WBS 50.4**)
- Groundwater tools, techniques and methods (**WBS 50.5**)

RWM will continue to participate in a number of international studies in order to gain access to relevant site-based information, to demonstrate capabilities and to enhance its experience.

Research activities within **WBS 50.1** will consider, on a site-specific basis, the very-long term impact of seismicity, tectonism, uplift, subsidence, erosion and climate change (including permafrost) on the GDF. Complementing this consideration of external factors, **WBS 50.2** considers how the presence of the GDF and its contents can affect the surrounding geological environment; thermal, mechanical, hydraulic, chemical, gas and microbiological processes can all require consideration at some point.

WBS 50.4 develops capabilities that will be required at the site-specific stage, including understanding whether rock-matrix diffusion is a process relevant to the retardation of contaminants on the path to the surface, work on natural analogues, development of technologies to monitor the neighbouring geosphere (and EDZ) throughout operations and the development of borehole sealing technologies in support of the site-characterisation programme. The development of hydrogeochemical models and THMC coupled models to develop understanding of the long-term evolution of the geosphere is undertaken under **WBS 50.3**.

WBS 50.5 concerns the development of EDZ understanding, tools and capabilities that will be required to characterise the site(s) and modelling capability that will facilitate the conceptual design of aspects of the GDF sub-surface infrastructure and support the geosphere component level model.

B5.1 WBS 50.1 - Develop generic understanding of potential implications of past, present and future large-scale natural processes for a UK GDF

B5.1.1 Periodic Review of the Potential Impact of Natural Processes on a GDF – Tectonics & Seismicity

<table>
<tr><td colspan="2">Task Number</td><td colspan="1">50.1.001</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Geosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of Potential Implications of Past, Present and Future Large-scale Natural Processes for a UK GDF</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The geosphere is a key component of a multi-barrier disposal concept. As noted in the [1], the geosphere is continually evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety. The UK is a relatively stable tectonic environment, well removed from major plate boundaries. Therefore consideration of tectonic activity, and related phenomena such as earthquakes, is of much lower significance in the UK geological disposal programme than in those of some other organisations in countries such as Japan. In 2013 we published a major review of the potential impact of natural processes on a GDF [2] produced under contract for us by the British Geological Survey. As the GDF siting process progresses it will be appropriate to review and update this understanding with a particular focus on the sites being considered for hosting the GDF.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the post-closure safety case by developing and updating our site-specific understanding of the potential impact of tectonism and earthquakes in a UK context and related impacts on the geosphere and biosphere on a timescale of a million years.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">In relation to tectonism and earthquakes in a UK context:
To review our understanding of the related evolution of geosphere processes so as to underpin safety case studies for a UK GDF.
To review whether the impact of tectonism and earthquakes over the post-closure period could have a significant impact on a UK GDF and surrounding geology.
To review whether the magnitude of earthquakes expected in the UK over the post-closure period, including glacially-induced seismicity, could have a significant impact on the performance of a UK GDF and surrounding geology.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task comprises a site-specific review of the UK and international understanding of tectonism and earthquakes, building on the recent British Geological Survey project. The impact of these natural processes and events over the lifetime of the GDF will be considered with respect to their potential to influence GDF performance.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a contractor approved report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
</table>

Further Information
There are other publications relevant to this task [3].

1 Radioactive Waste Management, *Geological disposal: Criticality safety status report*, RWM Report DSSC/458/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-criticality-safety-status-report/.

2 R. Shaw, C. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. Evans, L. Field, S. Gregory, E. Henderson, A. Hughes, A. Milodowski, D. Parkes, J. Rees, J. Small, N. Smith, A. Tye, and J. West, *Potential Natural Changes and Implications for a UK GDF*, British Geological Survey, BGS Report CR/12/127, 2012, p. 198. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.

3 R. P. Shaw, C. A. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. J. Evans, L. P. Field, S. P. G. Gregory, E. Henderson, A. J. Hughes, A. E. Milodowski, D. Parkes, J. Rees, J. Small, S. N., A. Tye, and J. M. West, *British Geological Survey Report Potential Natural Changes and Implications for a UK GDF*, British Geological Survey, BGS Report CR/12/127, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.

B5.1.2 Periodic Review of the Potential Impact of Natural Processes on a GDF – Uplift, Erosion & Subsidence

<table>
<tr><td colspan="2">Task Number</td><td>50.1.002</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Geosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of Potential Implications of Past, Present and Future Large-scale Natural Processes for a UK GDF</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The geosphere is a key component of a multi-barrier disposal concept. As noted in the [1], the geosphere is continually evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety. In 2013 we published a major review of the potential impact of natural processes on a GDF produced under contract for us by the British Geological Survey. As the GDF siting process progresses it will be appropriate to review and update this understanding with a particular focus on the sites being considered for hosting the GDF.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support our post-closure safety case by developing and updating our site-specific understanding of the potential impact of the evolution of the geosphere from the natural processes of uplift, subsidence, erosion and deposition.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review whether uplift, subsidence, erosion and deposition processes will be of a magnitude deemed to pose a significant risk to the performance of the GDF over post-closure timescales.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task comprises a site-specific review of the UK and international understanding of the impact of the natural processes of uplift, subsidence, erosion and deposition with respect to their potential to influence GDF performance.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in contractor approved reports.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [2], [3].

1 Radioactive Waste Management, *Geological disposal: Criticality safety status report*, RWM Report DSSC/458/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-criticality-safety-status-report/.

2 R. P. Shaw, C. A. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. J. Evans, L. P. Field, S. P. G. Gregory, E. Henderson, A. J. Hughes, A. E. Milodowski, D. Parkes, J. Rees, J. Small, S. N., A. Tye, and J. M. West, *British Geological Survey Report Potential Natural Changes and Implications for a UK GDF*, British Geological Survey, BGS Report CR/12/127, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.

3 R. Shaw, C. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. Evans, L. Field, S. Gregory, E. Henderson, A. Hughes, A. Milodowski, D. Parkes, J. Rees, J. Small, N. Smith, A. Tye, and J. West, *Potential Natural Changes and Implications for a UK GDF*, British Geological Survey, BGS Report CR/12/127, 2012, p. 198. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.

B5.1.3 Application of Permafrost Modelling Methodology: Consideration of Implications

Task Number	50.1.003	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Develop Generic Understanding of Potential Implications of Past, Present and Future Large-scale Natural Processes for a UK GDF		

Background

The geosphere is a key component of a multi-barrier disposal concept and it is continually, albeit very slowly, evolving. In order to build confidence in the performance of the geosphere barrier, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the required isolation and containment. While current predictions indicate the next period of glaciation is unlikely to occur for approximately 200,000 years, it is important to consider the effects of glaciation upon the GDF. A number of processes may occur during a glaciation event, including the mechanical deformation of the geosphere in response to ice-sheet loading, surface erosion and the subsequent changes to groundwater flow patterns as the ice-sheet grows and retreats (including the effects of permafrost). The disposal system specification currently identifies a suitable GDF depth to be in the range 200m to approximately 1000m. Dependent on the location in the UK, it is possible that permafrost formation/decay associated with climate change could affect performance of the geological barrier and EBS. This may lead to a requirement to increase the minimum depth of a GDF at a specific UK location to take account of the effects of permafrost. This is an issue that can be progressed in the absence of a site as permafrost will affect the whole of the UK. The learning from this task will inform whether or not site-specific considerations of permafrost may subsequently need to be undertaken.

Research Driver

To support the siting process and the environmental safety case by determining the significance on the post-closure system performance of the formation, presence and decay of permafrost at a UK GDF site over a time period of the next one million years (including impacts on the EBS and geosphere safety functions).

Research Objective

To identify likely depths of permafrost penetration across the UK, in order to inform the siting process and thereby manage (by choice of suitable depth) the potential for permafrost to significantly affect the performance of at least some of the geological barrier and the performance of the EBS (e.g. as a result of changing groundwater pathways).

Scope

The scope comprises the following:

- Desk-based study to model the depth of penetration of permafrost based on historical climatic conditions and the thermal properties of rocks to the order of 1 km depth below the surface. The output will be a contour map showing the depth of permafrost penetration in a reference case and in cases considering uncertainties in rock thermal properties and climate change.
- Desk-based study to model how evolving and decaying permafrost could affect the chemistry of groundwater beneath the permafrost layer, and to investigate if any e.g. salinity increases could detrimentally impact on a GDF (host rock or EBS), even if below permafrost depth.
- Desk-based study to consider gas hydrate stability in the vicinity of a GDF, related to permafrost conditions.

Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Report and academic papers.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					

There are other publications relevant to this task [1]–[3]. Further research is comprised in CatchNet PhD (Task 50.1.006) at UCL 'Long-term performance of a geological disposal facility in response to permafrost and climatic variation'.

1 J. Busby, S. Kender, J. Williamson, and J. Lee, *Regional Modelling of the Potential for Permafrost Development in Great Britain*, British Geological Survey, BGS Report CR/14/023, 2014, p. 23. [Online]. Available: http://rwm.nda.gov.uk/publication/regional-modelling-of-the-potential-for-permafrost-development-in-great-britain/.

2 R. P. Shaw, C. A. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. J. Evans, L. P. Field, S. P. G. Gregory, E. Henderson, A. J. Hughes, A. E. Milodowski, D. Parkes, J. Rees, J. Small, S. N., A. Tye, and J. M. West, *British Geological Survey Report Potential Natural Changes and Implications for a UK GDF*, British Geological Survey, BGS Report CR/12/127, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.

3 J. Scheidegger, C. Jackson, J. Busby, F. McEvoy, and S. Norris, *Modelling Permafrost Thickness in Great Britain over Glacial Cycles*. Science of the Total Environment, vol. 666, no. ISSN 0048-9697, pp. 928–943, 2019. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0048969719306400.

B5.1.4 Periodic Review of the Potential Impact of Natural Processes on a GDF - Climate Change

<table>
<tr><td colspan="2">Task Number</td><td>50.1.004</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Geosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of Potential Implications of Past, Present and Future Large-scale Natural Processes for a UK GDF</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The geosphere is a key component of a multi-barrier disposal concept and it is continually, albeit very slowly, evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety. The most significant aspect of climate change affecting the performance of the GDF is likely to arise in future periods of glaciation; current predictions indicate the next such period is unlikely to occur for approximately 200,000 years. A number of processes may occur during a glaciation event, including the mechanical deformation of the geosphere in response to ice-sheet loading, surface erosion and the subsequent changes to groundwater flow patterns as the ice-sheet grows and retreats (including the effects of permafrost). In 2013 we published a major review of the potential impact of natural processes on a GDF [1] produced under contract for us by the British Geological Survey. We recognise however that further research, contracted either by RWM (such as our work on permafrost (Task 50.1.003) or undertaken elsewhere, may make it necessary to update this aspect of our knowledge base, particularly in the field of climate science. This task comprises such a review.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the environmental safety case by determining the significance on the post-closure system performance of a UK GDF of climate change over a time period of the next one million years (including impacts on engineered barrier system and geosphere safety functions).</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review UK and international developments in the understanding of climate science and its effect on the geosphere.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task comprises a periodic review of the UK and international understanding of climate evolution over the next million years and application of this understanding to consider how climate change might impact the performance of the geosphere and potentially the EBS of a UK GDF.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in contractor approved reports and academic papers.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [2].

1 R. Shaw, C. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. Evans, L. Field, S. Gregory, E. Henderson, A. Hughes, A. Milodowski, D. Parkes, J. Rees, J. Small, N. Smith, A. Tye, and J. West, *Potential Natural Changes and Implications for a UK GDF*, British Geological Survey, BGS Report CR/12/127, 2012, p. 198. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.

2 R. P. Shaw, C. A. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. J. Evans, L. P. Field, S. P. G. Gregory, E. Henderson, A. J. Hughes, A. E. Milodowski, D. Parkes, J. Rees, J. Small, S. N., A. Tye, and J. M. West, *British Geological Survey Report Potential Natural Changes and Implications for a UK GDF*, British Geological Survey, BGS Report CR/12/127, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.

B5.1.5 PhD to Investigate Implications of Permafrost Growth on GDF EBS Performance

Task Number	50.1.005	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Develop Generic Understanding of Potential Implications of Past, Present and Future Large-scale Natural Processes for a UK GDF		

Background

The geosphere is a key component of a multi-barrier disposal concept and it is continually, albeit very slowly, evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere – and any consequential effect on the GDF engineered barrier system (EBS) - will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety. While current predictions indicate the next period of glaciation is unlikely to occur for approximately 200,000 years, it is important to consider the effects of glaciation upon the GDF. A number of processes may occur during a glaciation event, including the mechanical deformation of the geosphere in response to ice-sheet loading, surface erosion and the subsequent changes to groundwater flow patterns as the ice-sheet grows and retreats (including the effects of permafrost). The disposal system specification currently identifies a suitable GDF depth to be in the range 200m to approximately 1000m. Dependent on the location in the UK, it is possible that permafrost formation/decay associated with climate change could affect performance of the geological barrier and EBS. This may lead to a requirement to increase the minimum depth of a GDF at a specific UK location to take account of the effects of permafrost. It also necessitates understanding how the performance of the GDF EBS could be affected by freeze - thaw cycling, as could occur during permafrost growth and decay. This is an issue that can be progressed in the absence of a site, as permafrost will affect the whole of the UK. The learning from this task will inform whether or not site-specific considerations of permafrost may subsequently need to be undertaken.

Research Driver

To support the siting process and the environmental safety case by determining the significance on the post-closure system performance of the formation, presence and decay of permafrost at a UK GDF site over a time period of the next one million years (focussing on impacts on EBS safety functions).

Research Objective

To investigate and build understanding of the following aspects related to the impact of permafrost on the natural and engineered barriers:

- Direct freeze - thaw cycles could occur concurrently with changes in groundwater salinity and regional groundwater flow patterns. These could affect the strength and stability of the engineered barriers and the surrounding host rocks.
- The impact on bentonite which plays an integral role within the engineered barrier, present in all current worldwide repository concepts.
- A host of tests on bentonite are to be performed, investigating both direct and indirect effects of permafrost on bentonite and its properties and, therefore, to develop understanding of how EBS functionality could be impacted by long term freeze – thaw events as could affect a UK GDF.

<table>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The PhD will have laboratory-based experimental and modelling aspects:
• A host of UCS, triaxial, permeability, and saturation tests on bentonite are to be performed.
• A combination of rock and soil mechanics techniques are to be employed in this study to thoroughly probe into the suitability and longevity of bentonite at the laboratory scale.
Work links to BGS work investigating permafrost impact on groundwater chemistry (in the region affected by permafrost and beneath permafrost) [1], [2].</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">PhD thesis; conference papers, journal paper.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [3], [4].
1 A. D. Kilpatrick, Geochemical modelling of permafrost processes, BGS, Contractor Report BGS/CR/16/144 v6, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-cr-16-144-geochemical-modelling-of-permafrost-processes/.
2 J. Scheidegger, J. P. Busby, C. R. Jackson, F. M. McEvoy, and R. P. Shaw, Coupled modelling of permafrost and groundwater. a case study approach, BGS, Contractor Report BGS/CR/16/053 V6, Jul. 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-cr-16-053-coupled-modelling-of-permafrost-and-groundwater-a-case-study-approach/.
3 J. Busby, S. Kender, J. Williamson, and J. Lee, Regional Modelling of the Potential for Permafrost Development in Great Britain, British Geological Survey, BGS Report CR/14/023, 2014, p. 23. [Online]. Available: http://rwm.nda.gov.uk/publication/regional-modelling-of-the-potential-for-permafrost-development-in-great-britain/.
4 R. P. Shaw, C. A. Auton, B. Baptie, S. Brocklehurst, M. Dutton, D. J. Evans, L. P. Field, S. P. G. Gregory, E. Henderson, A. J. Hughes, A. E. Milodowski, D. Parkes, J. Rees, J. Small, S. N., A. Tye, and J. M. West, British Geological Survey Report Potential Natural Changes and Implications for a UK GDF, British Geological Survey, BGS Report CR/12/127, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-report-cr-12-127-potential-natural-changes-and-implciations-for-a-uk/.</td></tr>
</table>

B5.1.6 CatchNet (Catchment transport and Cryo-hydrology Network)

<table>
<tr><td>Task Number</td><td colspan="2">50.1.006</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Geosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of Potential Implications of Past, Present and Future Large-scale Natural Processes for a UK GDF</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Geological disposal of higher activity wastes requires safety assessments that consider a very long time frame, and accordingly different climatic states. Climate induced changes such as the growth of ice sheets and permafrost will alter the ground surface environment and impose a significant perturbation to the geosphere within a time frame that is considered relevant to repository safety. The aim of CatchNet is to involve other nuclear waste organisations and academic research groups in an effort to bridge both the industrial and academic worlds, with the main focus being the hydrology in the periglacial landscape.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the post-closure safety case by understanding how the geosphere and engineered barrier respond to climate change in the long term, including permafrost growth and decay and the associated effect on hydrogeology and hydrogeochemistry.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review the outputs of CatchNet in a UK context.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises a PhD study to investigate the long-term performance of a geological disposal facility in response to permafrost and climatic variation. The project aims to use the principles of rock mechanics to model specific scenarios to investigate the potential effects of permafrost on the safe disposal of radioactive waste in the UK.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR (learning)</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">PhD thesis/ Reports and papers.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are several publications relevant to this task [1]–[3].
1 J. Scheidegger, J. P. Busby, C. R. Jackson, F. M. McEvoy, and R. P. Shaw, Coupled modelling of permafrost and groundwater. a case study approach, BGS, Contractor Report BGS/CR/16/053 V6, Jul. 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/bgs-cr-16-053-coupled-modelling-of-permafrost-and-groundwater-a-case-study-approach/.
2 A. Kilpatrick, Geochemical modelling of permafrost processes, CR/16/144, 2017, pp76. [Online]. Available: https://rwm.nda.gov.uk/publication/bgs-cr-16-144-geochemical-modelling-of-permafrost-processes/.
3 J. Scheidegger, C. Jackson, J. Busby, F. McEvoy, and S. Norris, Modelling Permafrost Thickness in Great Britain over Glacial Cycles. Science of the Total Environment, vol. 666, no. ISSN 0048-9697, pp. 928–943, 2019. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0048969719306400.</td></tr>
</table>

B5.1.7 Strategy for Considering Long-term Transients in the Environmental Safety Case and Supporting Assessment Studies

<table>
<tr><td colspan="2">Task Number</td><td>50.1.007</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Geosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of Potential Implications of Past, Present and Future Large-scale Natural Processes for a UK GDF</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Changes in climate, and related effects such as glaciation and permafrost, affect the magnitude and extent of groundwater recharge and discharge and groundwater movement at GDF-relevant depths. Due to some rocks at depth having very low permeabilities, it is possible that a time-lag occurs between a change affecting surface boundary conditions, and when a related change affects the deeper geosphere. Groundwater movement at a site is often therefore not in steady state, and the pattern of groundwater movement at depth could still be responding to an earlier change in surface conditions that is no longer present. This phenomenon needs to be considered in site investigation, site-specific R&D, and the ESC; a steady-state based approach cannot be justified, given the very long timescales considered.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the disposal system safety case by developing a strategy to support the appropriate consideration of transient boundary conditions as relevant to groundwater movement, ensuring site characterisation can develop an understanding of a site at the present day that considers how the groundwater movement system is being affected by past events, and how such a system will evolve to 1 million years in the future. The strategy needs to be mindful of the ESC approach, and to consider how long term geosphere transients can be considered in supporting assessment studies.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">Noting recent work (e.g. [1] and [2] Interpreting fluid pressure anomalies in shallow intraplate argillaceous formations (Chris Neuzil); EC PADAMOT project and CatchNet), to consider:
how RWM should approach the issue of long-term geosphere transients in safety case and siting activities; and
the appropriateness of the existing suite of models available to RWM for addressing long-term transients in activities supporting the safety case and siting.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Desk-based study.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Strategy for consideration of long term geosphere transients in RWM work, reported in a contractor approved report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 2</td><td>SRL/TRL at Task End</td><td>SRL 3</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">Interpreting fluid pressure anomalies in shallow intraplate argillaceous formations (Chris Neuzil) EC PADAMOT</td></tr>
</table>

B5.2 WBS 50.2 - Develop generic understanding of GDF-induced impacts on the geosphere

B5.2.1 Stress-induced Anisotropy in Crustal Rocks and its Influence on Underground Excavations

Task Number	50.2.001	**Status**	Start date in future
WBS Level 4	Geosphere		
WBS Level 5	Develop Generic Understanding of GDF-induced Impacts on the Geosphere		
Background			
Shallow underground excavations are engineered for numerous reasons, from hydro-electric stations to deep underground railways. Whilst the challenges are generally understood in short timescales expected in a civil engineering context, the stability of such structures over geological timescales (of thousands to hundreds of thousands of years) is poorly known. However, such data are now gaining new importance for the purposes of Geological Disposal Facilities, both in the UK and overseas. Well-controlled laboratory studies have the potential to provide the required information. The approach has the advantage that key parameters of stress, temperature and strain may be directly monitored and controlled. As a result of recent technological advances this can now be achieved using the synergy created by the new generation of rock physics testing apparatus and acoustic emission instrumentation that can operate in both passive and active mode. In such studies, emphasis should be placed on the complex interplay between the pressure and temperature of the formation and the influence of these variables on the deformation of the rock in "creep" mode – where the rock fails at a stress level far below its nominal strength due to being loaded at temperature over an extended time in the presence of active fluids (a process called "stress corrosion"). Developing a knowledge of this overall bulk anisotropy and stress corrosion will allow RWM greater understanding of the long-term evolution of the rock mass around the GDF and is important in developing monitoring methods of the repository via long-term active or passive seismic surveys. Further, this research will elucidate the feedback between rock mass damage evolution at elevated temperature/stress (if any) and the fluid permeability (and permeability anisotropy) of the rock mass.			
Research Driver			
To support the development of the safety case and the engineering design of the disposal facility, and to demonstrate confidence to stakeholders that the geosphere of a potential disposal facility site is adequately understood, there is a need to build understanding of the stability of underground excavations over timescales of thousands to hundreds of thousands of years.			
Research Objective			
To build an understanding of the short-term and long-term stability of rock caverns through a well-controlled laboratory approach in which recent technological advances are employed.			

Scope					
This laboratory-based task will investigate the influence of externally-applied stress fields as a function of the natural anisotropy using several rock types. New rock physics laboratory investigation techniques will be utilised to establish stress corrosion of rock over long timescales. This will be achieved by measuring the overall anisotropy of the rock mass, using P-wave tomography methods, as it changes due to the overprinted mechanical stresses (from overburden and due to cavity excavation) and the inherent anisotropy in the rock mass itself. The changing P-wave anisotropy will then be used as a diagnostic tool and related to other rock physics parameters, principally the evolving permeability along the sample symmetry axis. These parameters are fundamental in all branches of rock mechanics, allowing rock physical properties to be used with confidence when they are otherwise unavailable.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of the task will be a contractor approved report and models.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					
This task is related to Task 220.1.002.					

B5.2.2 Natural Analogue and Modelling Study of the Implications of GDF Operations on Geosphere Host Rock Properties

Task Number	50.2.002	**Status**	Start date in future
WBS Level 4	Geosphere		
WBS Level 5	Develop Generic Understanding of GDF-induced Impacts on the Geosphere		

Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. Understanding the perturbation to the evolution of the host rock and the surrounding geosphere as a result of the construction and operation of a GDF is a topic that we are progressing within our programme and through our involvement in international collaborations such as the ongoing DECOVALEX project. This complementary task considers how properties of the geosphere in the zone of rock affected by the introduction, operation and closure of GDF infrastructure (access tunnels, shafts, vaults, etc.) evolve with time, from undisturbed state prior to GDF construction to a long-term steady state in the post-closure period. Knowledge of this evolution will facilitate communication with scientists and engineers familiar with the evolution of voids from e.g. a construction and mining perspective, and will provide input to the safety case. As well as potential changes to the hydrogeological properties (e.g. permeability and porosity) of the disturbed zone, mechanical and chemical changes need to be considered (including Eh, pH, oxygen profile, temperature, presence of groundwater, presence of gas and microbiological changes). This task may follow the previous review of learning from natural analogues (Task 50.4.002) and includes modelling of the information gained from the previous task. This task is of particular significance when considering a possible period of extended retrievability.

Research Driver

- To support the disposal system safety case by developing a better understanding of the implications of extended GDF operations on the safety functions provided by the geosphere.
- To consider changes to the geosphere that occur in going from an unperturbed state (pre-GDF) to a perturbed state (during construction and in the presence of a GDF), and for the latter to demonstrate an understanding pre- to post-closure evolution for incorporation in the environmental safety case, with emphasis on the incorporation of processes on a sub-year, year and 10s-100s years timescale (noting this timescale is short-term in consideration of the environmental safety case, yet will be of significant interest to stakeholders and regulators).

Research Objective

To understand the effect the opening of access tunnels, shafts, vaults, etc. (GDF underground infrastructure) has on the geosphere, including the generation and evolution of the excavation disturbed zone with respect to hydrogeological, chemical, mechanical, biological and thermal properties, and the impact this can have on disposal system performance.

Scope					
The scope comprises a desk-based study on the disturbed zone, its evolution and its safety case significance. A modelling component will include analysis of information derived from natural and industrial analogues and will include an investigation of what can be learned from existing underground voids to inform GDF-relevant studies (for example, the evolution of rock-bolting; evolution of the excavation disturbed zone; and the relationship between vault construction methodology, its resulting excavation disturbed zone, and how that excavation disturbed zone has evolved).					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of the task will be a contractor approved report.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					
There are other publications relevant to this task [1]. For more information, see the DECOVALEX website .					
1 A. Milodowski, W. Alexander, J. West, R. Shaw, F. McEvoy, J. Scheidegger, and J. Rushton, *A Catalogue of Analogues for Radioactive Waste Management*, British Geological Survey, BGS Report CR/15/106, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/a-catalogue-of-analogues-for-radioactive-waste-management/.					

B5.2.3 Copper Stability Natural Analogues Study (Keweenaw Peninsula, Michigan, USA – "Michigan International Copper Analogue Project")

Task Number	50.2.003	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Develop Generic Understanding of GDF-induced Impacts on the Geosphere		

Background

The long-term stability of copper is of interest in assessing the long-term performance of high-level radioactive waste repositories, therefore a number of scenarios need to be considered for the post-closure safety case. Copper corrosion is driven by water prevailing in contact with the copper canister, the presence of microbial-induced sulphide, and in the shorter term by contact with air, before saturation. Copper is an important part of many waste packaging concepts, e.g. KBS-3 (Sweden and Finland) and Mark II (Canada). The Keweenaw native copper site provides a natural analogue for examining copper corrosion processes of metallic copper in two important scenarios of HLW disposal.

Research Driver

Observations made from geological systems can be utilised in the safety case, with growing importance, as the assessment time-frame becomes longer. Natural analogues are also part of the basic system understanding and can be used in conceptualisation of the processes affecting repository performance. Model verification for the performance assessment of copper-containing waste packaging designs (copper canister in Swedish/Finnish KBS-3 and copper coated used fuel contained in Canadian Mark II used fuel container) could be obtained using natural analogues.

Research Objective

Regarding the project based on the Keweenaw Peninsula Native Copper District (Michigan, USA), the main status and potential contribution of natural analogues to the safety case regarding copper performance is summarised below:

- Existence of native copper has been well established, but it is not a very good argument alone, if the geological environment and setting are not understood.
- To understand the whole complex picture, processes need to be studied in variable conditions (e.g. time, redox, salinity).
- Information on copper natural analogues would be needed for:
  - conceptualisation processes (FEPs and conceptual models);
  - validation of thermodynamic data and verification of models (enhancing confidence in the safety case);
  - providing a "reality check" for the performance assessment models that may have conservative assumptions (enhancing confidence in the safety case); and
  - evidence to estimate characteristics of corrosion over long periods of time, especially non-linearity of corrosion process (enhancing confidence in the safety case).

Scope

The scope will comprise the following: Phase I – Literature study and detailed research plan for selected sites:

- Compilation of existing data.

• Review against selected disposal concept and relevant scenario considerations. • Sample inventory. • Detailed sampling and analytical plan. Phase II – Characterisation of copper systems: • Sampling (in case there are no existing samples to use). • Characterisation of the copper and its alteration products. • Characterisation of geological environment. • Characterisation of fluids. Phase III – Theory and models for native copper alteration: • Theoretical concepts of expected native copper alteration. • Thermodynamic model predictions. • Rate of natural native copper alteration. Phase IV - Copper stability predictions to support safety case: • Summary of natural analogue observations and modelling. • Comparison of natural analogue environment to the disposal site. • Predictions of native copper stability in bedrock with respect to metallic copper used in waste packaging (used fuel container).					
Geology Application					
HSR, LSSR					
Output of Task					
The output of the task will be a contractor approved report.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information
There are other publications relevant to this task [1]–[3] as well as more recent work that lends context to the earlier reports [4], [5].

1 P. Szakalos, G. Hultqvist, and G. Wikmark, *Corrosion of copper by water*. Electrochemical and Solid State Letters, no. 10(11), pp. C63–C67, 2007.

2 G. Hultqvist, P. Szakalos, M. Graham, A. Belonoshko, G. Sproule, L. Grasjo, P. Dorogokupets, B. Danilov, T. AAstrup, G. Wikmark, G.-K. Chuah, J.-C. Eriksson, and A. Rosengren, *Water corrodes copper*. Catalysis Letters, no. 132(3-4), pp. 311–316, 2009.

3 Hultquist *et al.*, *Detection of hydrogen in corrosion of copper in pure water*. 17th International Corrosion Congress, no. Paper no. 3884, 2008. [Online]. Available: https://www.researchgate.net/publication/238102363_Detection_of_hydrogen_in_corrosion_of_copper_in_pure_water.

4 M. Ottosson, M. Boman, P. Berastegui, Y. Anderson, M. Hahlin, M. Korvela, and R. Berger, *Copper in ultrapure water*, OPG, SKB Report SKB TR-16-01, 2016.

5 M. Boman, M. Ottosson, R. Berger, Y. Andersson, M. Hahlin, F. Björefors, and T. Gustafsson, *Corrosion of copper in ultrapure water*, SKB, SKB Report SKB R-14-07, 2014. [Online]. Available: http://www.skb.com/publication/2718444/R-14-07.pdf.

B5.2.4 Host Rock Thickness, GDF Vault/Tunnel/Cavern Height and Choice of EBS Materials – Determination of Inter-relationships to Ensure Delivery of Isolation and Containment Safety Functions

<table>
<tr><td>Task Number</td><td>50.2.004</td><td>Status</td><td>Start date in FY20/21</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Geosphere</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Develop Generic Understanding of GDF-induced Impacts on the Geosphere</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">There are two high-level principles of geological disposal of radioactive waste, namely to isolate the waste from the biosphere and to contain the radionuclides associated with the wastes. In order to assure that these objectives of isolation and containment are delivered over the long timescales of interest, geological disposal facilities are designed as multiple barrier systems. This involves designing engineered barriers that will work together and in combination with the natural barrier afforded by the geosphere to prevent radionuclides being released to the surface environment in amounts that could cause harm to life and the environment.

• The geosphere contributes to isolation by providing a stable location deep underground that protects the GDF from any perturbations to the natural environment that may occur over the timescales of interest.

• The geosphere contributes to containment by delaying the movement of any potential small amounts of long-lived radionuclides that are released from the EBS.

The UK GDF could be constructed in LSSR or evaporite (halite), with a sedimentary sequence as the surrounding geology, or could be built in a HSR possibly with an overlying sedimentary sequence. The thickness of an LSSR or evaporite host rock layer may influence the dimensions, in particular the height, of caverns, vaults, tunnels, etc. of a GDF that could be constructed in it and the nature of backfill required to retain the integrity of the surrounding geosphere.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">Recognising the geosphere shall provide isolation and containment safety functions, there may need to be a minimum thickness of host rock remaining above and below the GDF once it is constructed. A GDF constructed in HSR may need a minimum thickness of host-rock above the GDF (assuming the thickness below it is effectively very thick). Surrounding geology will also contribute to attainment of isolation and containment safety functions, and its contribution needs to be factored-in. The properties of the EBS are relevant here too.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To determine inter-relationships between host-rock thicknesses, GDF dimensions (in particular height of vaults, tunnels, caverns, etc.) and choice of EBS materials to ensure delivery of GDF isolation and containment safety functions. To determine if, for a GDF design of given height, there is a minimum thickness of host rock necessary such that, once the GDF is constructed and host rock remains intact above and below the GDF itself, such that isolation and containment safety functions are attained.</td></tr>
</table>

Scope					
Assumptions about GDF construction and operation will be necessary, as will assumptions about the surrounding rock types and their role in contributing to overall isolation and containment safety functions. Whilst it could be assumed that the EBS and its surrounding geology provide the necessary isolation and containment without any contribution from the remaining host-rock geological environment, this should be viewed as an end-member scenario only. Other scenarios shall require the host rock and EBS to contribute, to extents to be decided as part of the study, to isolation and containment safety functions. The surrounding geology may also significantly influence waste-derived gas migration. The scope shall also consider the structural strength/stability of overlying layers, the impacts of any micro- and macro-voidage within the EBS (were this to be present; assumptions will have to made here as part of the project), radionuclide transport times in any overlying LSSR present in the surrounding geology, and the effect of variability of LSSR properties (LSSR being a convenient, albeit broad, definition of diffusion-dominated rocks).					
Geology Application					
LSSR, HSR, Evaporite (halite, bedded)					
Output of Task					
Report to RWM supported by modelling and reasoned argument identifying (where possible) information that can support the early consideration of site suitability based on seismic survey information.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					

The [1] provides information on UK-relevant LSSR and evaporite and the [2] provides information on waste-derived gas in the context of the UK radioactive waste inventory – host rock.

There are other reports on halites that are relevant to this task [3]. The possible choice of EBS shall be informed by RWM's [4]. The Concept Status Report provides information on possible disposal concepts [5]. The Design Status Report describes GDF designs [6].

1 Radioactive Waste Management, *Geological disposal: Criticality safety status report*, RWM Report DSSC/458/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-criticality-safety-status-report/.

2 Radioactive Waste Management, *Geological disposal: Gas status report*, RWM Report DSSC/455/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/.

3 Wilmot, R. and White, M. and Crawford, M. and Gilbert, A. and Evans, D. and Hough, E. Field, L. and Reay, D. and Milodowski, A. and McHenry, J. and Wolf,J., *UK Halite Deposits – Structure, Stratigraphy, Properties and Post-closure Performance*, Galson Science, Contractor Report 1735-1, 2018.

4 Radioactive Waste Management, *Geological Disposal: Engineered Barrier System Status Report*, RWM Report DSSC/452/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-engineered-barrier-system-status-report/.

5 Radioactive Waste Management, *Geological disposal: Concept status report*, RWM Report NDA/RWM/155 Issue 1, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-concept-status-report/.

6 *Geological disposal: Design status report nda/rwm/141*, 2017.

B5.3 WBS 50.3 - Development of geosphere conceptual models and numerical solutions (modelling)

B5.3.1 Modelling the Evolution of the Alkali-disturbed Zone in Fractured Rock

Task Number		50.3.001	**Status**	Start date in future	
WBS Level 4		Geosphere			
WBS Level 5		Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)			
Background					
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. The disposal concept for ILW/LLW in HSR requires a hyper-alkaline backfill in order to provide a long-term chemical barrier to the mobilisation of radionuclides. This safety function is achieved by conditioning the pore-water within the backfill to a very high pH. Inevitably, this pore water will migrate through the surrounding host rock in an alkaline plume to create an alkali-disturbed zone. The effect of the alkaline plume on the geochemistry of the host rock and the consequent effects on its properties is an area of some uncertainty, particularly in terms of the spatial and temporal distribution of the plume. For a number of years the ‘Long-term Cement Study (see [1, Task 381]) has been in place at the Grimsel Test Site underground research laboratory with the aim of providing data in a real HSR environment. This task concerns the development of a model, on the basis of Long-term Cement Study data, which can be applied at a potential UK GDF site in HSR.					
Research Driver					
To support the post-closure safety case by developing a more robust understanding of how cement leachates derived from the engineered barrier system will interact with the host rock.					
Research Objective					
To determine whether learning from the evolution of the alkali-disturbed zone gained through the Long-term Cement Study project at the Grimsel Test Site can be applied within a UK relevant environment.					
Scope					
The scope comprises the development of a model of the evolution of the alkali-disturbed zone within a fractured host rock by taking the learning from the Long-term Cement Study project into a UK relevant environment.					
Geology Application					
HSR, LSSR					
Output of Task					
The output of the task will be a contractor approved report and scientific paper.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
There are other publications relevant to this task [2]–[5].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 W. Alexander and A. Milodowski, *Cyprus Natural Analogue Project (CNAP) The contribution of CNAP to NDA-RWMD's R&D Programme and Geosphere Status Report*, Bedrock Geosciences, Contractor Report BG13-03, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/cyprus-natural-analogue-project-cnap-the-contribution-of-cnap-to-nda-rwmds-rd-programme-and-geosphere-status-report/.

3 C. Watson, D. Savage, and J. Wilson, *Long-term Cement Studies Maqarin Natural Analogue*. Quintessa QRS-1523B-1, Quintessa, 2012.

4 C. Watson, D. Savage, J. Wilson, and C. Walker, *Reactive transport modelling of the tournemire analogue*, Quintessa, Contractor Report QRS-1523A-1, Version 2.0, 2011. [Online]. Available: http://rwm.nda.gov.uk/publication/reactive-transport-modelling-of-the-tournemire-analogue-lcs-phase-ii-november-2011/.

5 A. Milodowski, S. Norris, and W. Alexander, *Minimal alteration of montmorillonite following long-term interaction with natural alkaline groundwater: Implications for geological disposal of radioactive waste*. Applied Geochemistry, no. 66, pp. 184–197, 2016. DOI: http://dx.doi.org/10.1016/j.apgeochem.2015.12.016..

B5.3.2 DECOVALEX 2023: Task A ”Heat and Gas Fracturing Initiation in Claystone”

<table>
<tr><td>Task Number</td><td>50.3.002</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Geosphere</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

THMC coupled processes for higher strength rocks, lower strength sedimentary rocks and evaporites (in particular halite) are extremely complex areas of scientific research, which may have a significant bearing on the potential design and performance of radioactive waste disposal facilities. The DECOVALEX project is an international research and model comparison collaboration, initiated in 1992, for advancing the understanding and modelling of coupled THM and THMC processes in geological systems. Prediction of these coupled effects is an essential part of the performance and safety assessment of geological disposal systems. Through this collaborative work, in-depth knowledge has been gained of coupled THM and THMC processes, as well as the suitability of numerical simulation models for their quantitative analysis. This task represents RWM’s participation in DECOVALEX, with the aim of developing understanding, knowledge and experience relevant to THMC processes in claystone.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To support safety case development by maintaining an understanding of international developments relating to the modelling of THMC processes and their relevance to UK disposal concepts, as well as developing supply-chain capability.</td></tr>
<tr><td colspan="4">Research Objective
To improve the ability of models to predict the processes and mechanisms of fracture initiation and growth in claystone due to a rapid increase of heat or gas overpressure.
To develop the availability of models to predict fracturing processes under different loading paths.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">Specific experimental work to following the stress path under which pore-pressure build-up due to temperature increase leads to fracturing of claystone. The proposed work programme reflects the available experiments, consisting of two main tasks:
Step 1 – Hydraulic fracturing due to thermally-induced overpressure.
Step 2 – Gas hydraulic fracturing due to gas injection.</td></tr>
</table>

Geology Application					
LSSR					
Output of Task					
The output of the task will be contractor approved reports, papers and modelling experience.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1], [2]. For more information see the DECOVALEX website [3]. This task is related to other DECOVALEX tasks (Task 50.2.003, Task 50.2.004 and 50.2.008). 1 A. Bond, K. Thatcher, N. Chittenden, C. McDermott, A. Fraser-Harris, and J. Wilson, *Final Report of the Coupled Processes Project: Outcomes from DECOVALEX-2015*, Quintessa and AMEC, Contractor Report 18040-TR-005, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/final-report-of-the-coupled-processes-project-outcomes-from-decovalex-2015/. 2 A. Bond, N. Chittenden, and K. Thatcher, *Rwm coupled processes project – first annual report for decovalex-2019*, Quintessa, Contractor Report QRS-1612D-R1-v1.2, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/rwm-coupled-processes-project-first-annual-report-for-decovalex-2019/. 3 *DECOVALEX website*. [Online]. Available: https://decovalex.org/index.html.					

B5.3.3 DECOVALEX 2023: Task E ”Heated Brine Availability Test in Salt (BATS)”

Task Number	50.3.003	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)		

Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field. THMC coupled processes for higher strength rocks, lower strength sedimentary rocks and evaporites (in particular halite) are extremely complex areas of scientific research, which may have a significant bearing on the potential design and performance of radioactive waste disposal facilities. The DECOVALEX project is an international research and model comparison collaboration, initiated in 1992, for advancing the understanding and modelling of coupled THM and THMC processes in geological systems. Prediction of these coupled effects is an essential part of the performance and safety assessment of geological disposal systems. Through this collaborative work, in-depth knowledge has been gained of coupled THM and THMC processes, as well as the suitability of numerical simulation models for their quantitative analysis. This task represents RWM’s participation in DECOVALEX, with the aim of developing understanding, knowledge and experience relevant to THMC processes in a salt repository.

Task E of DECOVALEX D2023 seeks to understand and predict coupled processes which impact brine availability in bedded salt deposits under heated conditions associated with disposal of heat-generating waste in a salt repository. Brine can impact repository long-term performance by corroding metal waste forms and packages, mobilising radionuclides from the repository to the biosphere, and providing mechanical resistance to eventual drift creep closure.

Research Driver

To support safety case development by maintaining an understanding of international developments relating to the modelling of THMC processes and their relevance to UK disposal concepts.

Research Objective

To predict and quantify the importance of coupled THMC processes relating to the availability of fluid, in particular brine, to flow into heated excavations in bedded halite evaporite deposits.

Scope

- Confirm the strengths and types of coupled processes (i.e. thermal, hydrologic, mechanical, and chemical - THMC) that govern preferential brine flowpaths and canister corrosion.

- Experimentally (lab and field) characterize salt/cement seal interactions.
- Develop and validate numerical constitutive models.
- Laboratory tests will investigate the hydraulic-chemical (HC-Test), hydraulic-mechanic-chemical (HMC-Test) and thermal-mechanical (TM-Test) coupled behaviour of sealing systems in rock salt, consisting of the seal itself, the DRZ and the contact seam between sealing and DRZ.

Field tests are being conducted in short horizontal boreholes at the repository level (~650 m depth) in the US Department of Energy's WIPP. The WIPP is located in the bedded salt of the Permian Salado Formation near Carlsbad, New Mexico, USA. No backfill is being considered as part of the tests. Cementitious seal materials will be placed into boreholes near the heaters, and complementary laboratory tests will be conducted at GRS in Germany. Laboratory tests will investigate the hydraulic-chemical (HC-Test), hydraulic-mechanic-chemical (HMC-Test) and thermal-mechanical (TM-Test) coupled behavior of sealing systems in rock salt, consisting of the seal itself, the DRZ and the contact seam between sealing and DRZ.

Geology Application

Evaporite

Output of Task

The output of the task will be contractor approved reports, papers and modelling experience.

SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6

Further Information

There are other publications relevant to this task [1]–[3]. This task is related to other DECOVALEX tasks (Task 50.3.002, Task 50.3.004 and Task 50.3.006).

1 A. Bond, K. Thatcher, N. Chittenden, C. McDermott, A. Fraser-Harris, and J. Wilson, *Final Report of the Coupled Processes Project: Outcomes from DECOVALEX-2015*, Quintessa and AMEC, Contractor Report 18040-TR-005, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/final-report-of-the-coupled-processes-project-outcomes-from-decovalex-2015/.

2 A. Bond, N. Chittenden, and K. Thatcher, *Rwm coupled processes project – first annual report for decovalex-2019*, Quintessa, Contractor Report QRS-1612D-R1-v1.2, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/rwm-coupled-processes-project-first-annual-report-for-decovalex-2019/.

3 *DECOVALEX website*. [Online]. Available: https://decovalex.org/index.html.

B5.3.4 DECOVALEX 2023: Task G ”Safety Implications of Fluid Flow, Shear, Thermal and Reaction Processes within Crystalline Rock Fracture NETworks (SAFENET)”

Task Number		50.3.004	**Status**	Ongoing	
WBS Level 4		Geosphere			
WBS Level 5		Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)			
Background					
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. Understanding the consequences of shear reactivation in higher strength host rocks of pre-existing discontinuities is an area of potential interest in studies related to radioactive waste management. Existing discontinuities could undergo shear displacement as a result of coupled thermal, mechanical, hydrological and chemical effects, changing host rock permeability and exposed surface mineralogy, and affecting the rate and extent of any groundwater flow and radionuclide transport. The key focus of the experiments within SAFENET is to enhance knowledge and understanding of how the behaviour of discontinuities in higher strength rocks (including mineralogy), with respect to the transport of radionuclides in groundwater, could be modified by shear displacements as could result from GDF-derived THMC processes.					
Research Driver					
To support safety case development by maintaining an understanding of international developments relating to the modelling of THMC processes and their relevance to UK disposal concepts.					
Research Objective					
Systematic and descriptive approach for fracturing processes in crystalline rocks with increasing complexity (from M to THM/HMC).					
Scope					
To further increase our understanding of THMC processes in crystalline rocks, introducing new experimental concepts and modelling approaches, in particular concerning thermo-mechanical processes governing fluid flow through fracture networks under changing mechanical shear, and thermal and geochemical gradients induced by heat generating waste emplacement. To derive better understanding of crystalline systems using multi-scale unique experimental data combined with state-of-the-art numerical modelling techniques and thereby improving environmental safety assessment understanding.					
Geology Application					
HSR					
Output of Task					
Reports and journal publications; beneficial international collaborations and knowledge sharing.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
For more information, see the DECOVALEX website [1]. 1 *DECOVALEX website*. [Online]. Available: https://decovalex.org/index.html.					

B5.3.5 PhD: “Modelling the Behaviour of Compacted Bentonite at High Temperatures”

Task Number	50.3.005	**Status**	Start date in future
WBS Level 4	Geosphere		
WBS Level 5	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)		
Background			
Compacted bentonite clays are envisaged as part of EBS in geological disposal facilities. Placed as a buffer between the nuclear waste container and the host formation, they will be subjected to hydration, at their interface with the latter, and to high temperatures, at their interface with the former. The objective of the EBS design is for hydration to promote the swelling of the bentonite buffer and hence increase its volume to seal construction voids between the container and the host formation, as well as attaining the swelling pressure required to inhibit microbial activity. Pertinent to the modelling of bentonite is the recognition of its double-porosity structure in the as-compacted state, comprising the micro-porosity within the clay aggregates and macro-porosity between the clay aggregates. This structure diminishes with hydration, leading to a single-porosity material at full hydration (saturation). Most of the existing research (experimental, field, and numerical) on the behaviour of compacted bentonite, in relation to nuclear waste disposal, has considered its exposure to temperatures of up to 100ºC. The objective of the proposed research is to explore the behaviour of bentonite buffers at temperatures above 100ºC (see Task 30.3.006 for further ongoing work).			
Research Driver			
By conducting predictive modelling with the software ICFEP, of the thermal, hydraulic and mechanical evolution of the buffer and host rock, associated with the high-temperature bentonite project HotBENT experiment at Grimsel Test Site in Switzerland. The research is aimed at helping optimisation of GDF design in terms of the footprint of the network of underground vaults and deposition holes within a GDF as well as accommodating waste packages with higher thermal output.			
Research Objective			
To explore the behaviour of bentonite buffers at temperatures above 100ºC by conducting predictive modelling with the software ICFEP, of the thermal, hydraulic and mechanical evolution of the buffer and host rock, associated with the HotBENT experiment at Grimsel Test Site in Switzerland.			

Scope					
The scope comprises a PhD to be conducted in conjunction with the EPSRC Centre for Doctoral Training in Nuclear Energy Futures at Imperial College. • The research will first conduct a review of existing experimental evidence on bentonite behaviour under high temperatures, using published literature. Small-scale laboratory experiments will be simulated to verify the performance of the modelling tools at temperatures over 100ºC. • The numerical tools will then be applied to simulations of the large-scale HotBENT experiment. Where possible, the numerical predictions of the bentonite's THM evolution will be compared to field measurements collected from this experiment. • The numerical modelling will further investigate the near-field effects in the host formation. In particular, this will involve quantification of the likely changes, due to temperature, in the permeability and the pore water pressure regime in the ground around the engineered barrier, as well as the extent of these changes in relation to a single deposition hole/vault. A relevant review of the THM characterisation of the host formation will also be conducted and the numerical model verified against existing data. • Thermal dimensioning of a GDF would then be considered by analysing the interaction of two or more vaults/deposition holes in order to quantify the temperature, pore pressure, stress and displacement fields likely to be generated within a GDF. The objective would be to ensure the long-term safety and stability of the GDF.					
Geology Application					
HSR, LSSR					
Output of Task					
The output of the task will be a PhD Thesis and journal papers.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
For further information on the HotBENT experiment: https://www.grimsel.com/gts-phase-vi/hotbent-high-temperature-effects-on-bentonite-buffers/hotbent-introduction There are other publications relevant to this task [1]–[4]. 1 ENRESA, *Febex project: Full-scale engineered barriers experiment for a deep geological repository for high level radioactive waste in crystalline host rock: Final report*, ENRESA Report, 2000. 2 W. Cui, P. D.M., L. Zdravkovic, K. Gawecka, and D. Taborda, *An alternative coupled thermo-hydro-mechanical finite element formulation*. Computers and Geotechnics, vol. 94, pp. 22–30, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0266352X17302203. 3 A. Dueck, R. Goudarzi, and L. Borgesson, *Buffer homogenisation: Status report 2*, SKB, SKB Report TR-14-25, 2014. [Online]. Available: https://www.skb.com/publication/2479764/TR-14-25.pdf. 4 G. Ghiadistri, "Constitutive modelling of compacted clays for applications in nuclear waste disposal," 2019. [Online]. Available: https://spiral.imperial.ac.uk/handle/10044/1/78499.					

B5.3.6 DECOVALEX: Future Phases

Task Number	50.3.006	Status	Start date in future
WBS Level 4	Geosphere		
WBS Level 5	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)		

Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as 'THMC coupled processes' to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems, affecting groundwater movement, the behaviour of any gas present, and by extension – in the scenario of the GDF - how the movement of any GDF-derived species could be affected. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM's geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a UK site-specific level until site-specific and concept-specific information are available.

Given the current unavailability of such UK information, in our current phase of the UK GDF programme RWM is supporting relevant international collaborations and academic studies in this field. THMC coupled processes for higher strength rocks, lower strength sedimentary rocks and evaporites (in particular halite) are extremely complex areas of scientific research, which may have a significant bearing on the potential design and performance of radioactive waste disposal facilities.

The DECOVALEX project is an international research and model comparison collaboration, initiated in 1992, for advancing the understanding and modelling of coupled THM and THMC processes in geological systems. Prediction of these coupled effects is an essential part of the performance and safety assessment of geological disposal systems. Through this collaborative work, in-depth knowledge has been gained of coupled THM and THMC processes, as well as the suitability of numerical simulation models for their quantitative analysis. More recently, DECOVALEX has additionally considered gas issues. DECOVALEX operates in 3.5 year tranches, and the current phase, D-2023, concludes in 2023. Each tranches has its own activities covering the range of THMC-Gas (THMCG) coupled processes of relevance to participating organisations, which includes waste management organisations, technical support organisations, research entities, academia, supply chain organisations, etc. The suite of activities refreshes with every new tranche of DECOVALEX, and hence key current technical issues of interest to participating organisations will always be studied.

This task represents a placeholder for RWM's future participation in DECOVALEX phases after the completion of D-2023 (Task 50.3.002, Task 50.3.003 and Task 50.3.004), with the aim of developing understanding, knowledge and experience relevant to THMC-Gas processes in a range of rocks and in relation to a range of disposal concepts of relevance to the UK GDF programme.

Research Driver

To support safety case development by maintaining an understanding of international developments relating to the modelling of THMCG processes and their relevance to UK disposal concepts.

Research Objective					
The overall objective of DECOVALEX is the development of scientific methodologies for evaluation of coupled THMCG processes in numerical models and to demonstrate how these can be applied to detailed and performance assessment calculations.					
Scope					
Each phase of DECOVALEX (3-4 years), is divided into three or more 'tasks' with each task addressing a particular topic area, often focused around one or more major experiments. DECOVALEX-2019 is now complete and the next phase, DECOVALEX-2023, is ongoing, the scope of future phases will be determined based upon the outcome of D-2023.As a member of the DECOVALEX steering group, RWM maintains its ability to ensure work undertaken in this collaboration is relevant to the UK GDF programme, and that output – reports and journal papers – are published in a timely manner.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Reports, papers and modelling experience.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					

There are other publications relevant to this task [1]–[3].

1 A. Bond, K. Thatcher, N. Chittenden, C. McDermott, A. Fraser-Harris, and J. Wilson, *Final Report of the Coupled Processes Project: Outcomes from DECOVALEX-2015*, Quintessa and AMEC, Contractor Report 18040-TR-005, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/final-report-of-the-coupled-processes-project-outcomes-from-decovalex-2015/.

2 A. Bond, N. Chittenden, and K. Thatcher, *Rwm coupled processes project third annual report for decovalex-2019*, Quintessa, Contractor Report RWM/Contr/20/001, Mar. 2020. [Online]. Available: https://rwm.nda.gov.uk/publication/rwm-coupled-processes-project-third-annual-report-for-decovalex-2019/.

3 *DECOVALEX website*. [Online]. Available: https://decovalex.org/index.html.

B5.4 WBS 50.4 - Preparatory geosphere studies to facilitate site-specific characterisation and investigation (to include thermal, mechanical and chemical, etc processes)

B5.4.1 Review of Understanding and Approach to Modelling Rock Matrix Diffusion (RMD)

Task Number		50.4.001	**Status**	Ongoing	
WBS Level 4		Geosphere			
WBS Level 5		Preparatory Geosphere Studies to Facilitate Site-Specific Characterisation and Investigation (to include Thermal, Mechanical and Chemical, etc processes)			
Background					
Most groundwater flow in higher-strength rocks takes place through a network of inter-connected fractures. The radionuclides are transported ('advected') through these fractures by the flowing groundwater. The fractures provide surfaces on which radionuclides being transported by this flowing groundwater can sorb. However, much of the porosity and mineral surfaces in fractured rocks occur not in the fractures but in the rock between the fractures (the rock 'matrix'). Radionuclide migration through the geosphere would be further slowed if this additional porosity and surface can be accessed. The mechanism by which radionuclides are transported through the pore water into the low permeability rock matrix is diffusion. In the context of diffusive transfer between fracture and rock matrix, the process is termed 'rock-matrix diffusion'.					
Research Driver					
To support the post-closure safety case by ensuring that RWM is aware of the current knowledge base that could be relevant to a GDF in a UK higher-strength rock, drawing learning from SKB and Posiva (in particular) in relation to their respective ongoing studies.					
Research Objective					
To develop a review report that can subsequently underpin the consideration of rock-matrix diffusion in the DSSC.					
Scope					
The scope comprises a desk-based review drawing on the learning from e.g. "SKB Task Force on Modelling of Groundwater Flow and Transport of Solutes Task 9: Increasing the realism in solute transport modelling – Modelling the field experiments of REPRO and LTDE-SD" and other expert sources, as available. To acknowledge that rock-matrix diffusion behaviour *in situ* and in laboratory-based experiments can differ, e.g. due to relaxation of rock cores on extraction, and to consider approaches to dealing with the extrapolation of laboratory-based knowledge to the field-scale at a specific site.					
Geology Application					
HSR					
Output of Task					
Report and papers.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
There are other publications relevant to this task [1]–[3].

1 Nuclear Decommissioning Authority, *Geological Disposal: Radionuclide Behaviour Status Report*, NDA Report NDA/RWMD/034, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-radionuclide-behaviour-status-report-december-2010/.

2 M. Löfgren, *Skb task force on modelling of groundwater flow and transport of solutes, task 9: Increasing the realism in solute transport modelling - modelling the field experiments of repro and ltde-sd. list of scientific challenges*, SKB, SKB Report, Feb. 23, 2015.

3 I. Neretnieks, *Stress-mediated closing of fractures-impact of matrix diffusion*. Journal of Geophysical Research Solid Earth, no. 119, 2014. DOI: 10.1002/2013JB010645.

B5.4.2 Consolidation of Knowledge Gained from Natural Analogue Studies, based on our Natural Analogue Catalogue

<table>
<tr><td colspan="2">Task Number</td><td>50.4.002</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Geosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Preparatory Geosphere Studies to Facilitate Site-Specific Characterisation and Investigation (to include Thermal, Mechanical and Chemical, etc processes)</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In order to validate our understanding of the natural and engineered environments, we complement our laboratory-based modelling and underground research laboratory-based research with studies of natural analogues. Many natural and industrial analogues of relevance to the study of radwaste disposal exist and much information of use in the safety case, both quantitative and qualitative, has been provided to date. However, a large number of these studies were undertaken many years ago and, in the meantime, the relevant disposal concepts and associated needs of the safety case have evolved, as have scientific techniques and modelling toolkits. This task systematically revisits analogue studies undertaken by the radwaste disposal industry in the context of the current regulatory requirements to ascertain if modern ”mining” of earlier studies could, in a cost-effective manner, derive new data and understanding, and hence further enhance confidence in the safety case.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the disposal system safety case by identifying whether existing data from analogue studies could further enhance confidence in the safety case.</td></tr>
<tr><td colspan="6">Research Objective
• To review existing natural and industrial analogue studies in the context of current disposal concepts to provide additional data and understanding in a cost-effective manner that enhances confidence in the safety case.
• To identify opportunities where limited additional natural and industrial analogue research could benefit the safety case.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises a review of analogue studies undertaken for the radwaste industry over approximately the last 30 years in the context of the current disposal concepts and safety case requirements. An example, in the context of analogue studies focussed on bentonite, could include the following:
• Obtaining relevant information by data mining published natural analogue studies with a new focus of current safety case requirements.
• Obtaining relevant information by revisiting known bentonite analogue sites and conducting investigations with modern analytical techniques.
• Identifying novel study sites where, for example, the long-term stability of bentonite in very low salinity groundwaters can be studied.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a contractor approved report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
</table>

Further Information
There are other publications relevant to this task [1]–[6].

1 A. Milodowski, W. Alexander, J. West, R. Shaw, F. McEvoy, J. Scheidegger, and J. Rushton, *A Catalogue of Analogues for Radioactive Waste Management*, British Geological Survey, BGS Report CR/15/106, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/a-catalogue-of-analogues-for-radioactive-waste-management/.

2 W. Miller, W. Alexander, N. Chapman, I. McKinley, and J. Smellie, *Natural Analogue Studies in the Geological Disposal of Radioactive Wastes*. Studies in Environmental Science, vol. 57, 1994. [Online]. Available: https://www.sciencedirect.com/bookseries/studies-in-environmental-science/vol/57.

3 International Atomic Energy Agency, *Natural analogues in repository performance assessments for the disposal of radioactive wastes*, IAEA Report TR 304, 1989. [Online]. Available: https://www.iaea.org/publications/1407/natural-analogues-in-performance-assessments-for-the-disposal-of-long-lived-radioactive-wastes.

4 CSN, *Analogue application to safety assessment and communication of radioactive waste geological disposal: Illustrative synthesis*, DID 11.2004, 2004. [Online]. Available: https://www.csn.es/documents/10182/103228/DID-11-04+Analogue+application+to+safety+assessment+and+communication+of+radioactive+waste+geological+disposal+-+Ilustrative+synthesis.

5 B. Côme and N. (Chapman, *Natural analogue working group; first meeting, brussels, november 1985*, CEC Nuclear Science and Technology, Contractor Report EUR 10315, 1986, Commission of the European Communities, Luxembourg.

6 I. McKinley, "Applying natural analogues in predictive performance assessment," Nagra Report, Unpublished Nagra Internal Report, Nagra, Wettingen, Switzerland, 1989.

B5.4.3 Approaches to Monitoring Relevant to GDF Operational Period, including learning from EC MODERN 2020

Task Number		50.4.003	**Status**	Ongoing	
WBS Level 4		Geosphere			
WBS Level 5		Preparatory Geosphere Studies to Facilitate Site-Specific Characterisation and Investigation (to include Thermal, Mechanical and Chemical, etc processes)			
Background					
The European Commission Modern2020 project, which was led by ANDRA, aimed to provide the means for developing and implementing an effective and efficient repository operational monitoring programme, taking into account the requirements of specific national programmes. The work allowed advanced national radioactive waste disposal programmes to design monitoring systems suitable for deployment when repositories start operating in the next decade and supported less developed programmes and other stakeholders by illustrating how the national context could be taken into account in designing dedicated monitoring programmes tailored to their national needs. The EC Modern2020 project was a successor to the EC MoDeRn (Monitoring Developments for safe Repository project operation), in which RWM also participated. On the basis of learning from Modern2020, and related work, RWM will now commence work on a project "GDF monitoring arrangements for construction and operational phases"; this will report in 2022.					
Research Driver					
To support the operational safety case by ensuring that RWM is informed in relation to approaches to monitoring during the GDF operational period.					
Research Objective					
Modern2020 was established to understand what parameters should be monitored within operational safety cases and to provide methodology on how monitoring information can be used to support decision making and to plan for responding to monitoring results. Output from Modern2020 will now be used by RWM to further consider GDF monitoring arrangements for construction and operational phases.					
Scope					
This task will be undertaken as a multi-year (2015 to 2022) international project, illustrating how a national context can be taken into account in designing dedicated monitoring programmes tailored to national needs.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Reports to be used by RWM to further consider GDF monitoring arrangements for construction and operational phases.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information
There are other publications relevant to this task [1]–[4]. 1 Nirex, *Summary Note for CoRWM on Building Confidence in Repository Long-term Safety Through Monitoring*. 484078, 2005. 2 B. Breen, M. Johnson, H. Maurer, E. Manukyan, M. White, and E. Harvey, *Testing non-intrusive monitoring systems. deliverable D5 of ESDRED Module 1 – WP5*, 2008. 3 Nirex, *Context note 4.2: Monitoring*, 484080, 2005. 4 *MODERN project final report*, 2014. [Online]. Available: http : / / www . modern2020.eu/.

B5.4.4 RWM's Collaboration in Kiruna Natural Analogue Project (KiNa)

Task Number	50.4.004	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Preparatory Geosphere Studies to Facilitate Site-Specific Characterisation and Investigation (to include Thermal, Mechanical and Chemical, etc processes)		

Background

A project between Nagra and SKB, ANDRA, NWMO, POSIVA and RWM on collaboration in the Kiruna Natural Analogue Project. The expected outcome of this project will be an important addition to the safety case as it will provide evidence from a bentonite body under repository-like conditions for several hundred million years. More specifically it will provide the following key information: (i) demonstration of sustainable performance of safety relevant aspects of bentonite such as swelling pressure and low hydraulic conductivity; (ii) a validation of the model for iron and bentonite interaction; (iii) insight into the evolution of the mechanical properties of smectite aged several hundred million years. In the north of Sweden, the up to 50 m thick clay alteration zones have been encountered in the Kiruna-type magnetite(- hematite)-apatite deposits, which are hosted in weakly to strongly metamorphosed intermediate to acid volcanic and subvolcanic rocks. Preliminary data indicates that the clay contains a high amount of montmorillonite and that the swelling pressure and hydraulic conductivity are similar to that of commercial bentonites intended for repository use.

Research Driver

The Kiruna International Natural Analogue Project aims to investigate long-term bentonite behaviour under repository relevant conditions.

Research Objective

- To investigate the durability of the safety-relevant properties of bentonite under repository-like conditions for timescales that exceed the repository timeframe by orders of magnitude.
- To undertake a chemical investigation of the magnetite/hematite-bentonite interface.
- To obtain information on the erosion properties of bentonite.

Scope

The scope comprises the following:

- Investigating a smectite clay body that has been in contact with a magnetite ore body for hundreds of millions of years under repository-like conditions.
- Sampling and *in-situ* characterisation of the alteration zones.
- Physico-chemical and mineralogical analyses of the smectite.
- Age determination of the smectite phase.
- Swelling pressure and hydraulic conductivity tests of smectite.
- Geochemical modelling of the alteration zone.

Geology Application

HSR

Output of Task

The output of the task will result in reports and papers.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					

The KiNa project is an Implementing Geological Disposal of radioactive waste Technology Platform initiative. There are other publications relevant to this task [1], [2].

1 H. Gilgm, P. Rieger, J. Wampler, and U. Andersson, *Origin of Clays in Kiruna-type Iron Ore Deposits, Sweden*. Living Clays: Clay Minerals Society Meeting, p22, 2017. [Online]. Available: https://www.researchgate.net/publication/320586130_Origin_of_clays_in_Kiruna-type_iron_ore_deposits_Sweden.

2 P. Rieger, “Low-temperature Alteration in the Iron Ore Deposits of Norrbotten, Sweden,” 2017.

B5.4.5 Sealing Deep Site Investigation Boreholes: Phase 4

Task Number	50.4.005	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Preparatory Geosphere Studies to Facilitate Site-Specific Characterisation and Investigation (to include Thermal, Mechanical and Chemical, etc processes)		

Background

In the EA Guidance on Requirements for Authorisation for Geological Disposal Facilities on Land for Solid Radioactive Wastes [1] the regulator recognises the potential for deep boreholes, such as those that could be drilled as part of a site investigation process, to affect the integrity of a site. RWM commenced its "Sealing Deep Site Investigation Boreholes" project in 2013. Phase 1 and 2 are now complete ([2, Task 356]). Phase 4 extends Phase 3 ([2, Task 361]) to undertake more field-scale work in pre-existing UK unsealed boreholes in lower strength sedimentary rocks and higher strength rocks, plus overseas work in halite. This task sheet covers Phase 4 of the project.

Research Driver

As part of the process to obtain permission to start surface-based intrusive investigations, RWM will be required to submit an ISE to the EA. To meet the ISE requirement, to demonstrate that the characterisation of the site will not prejudice its future programme, RWM commenced its "Sealing Deep Site Investigation Boreholes" project in 2013.

Research Objective

- To demonstrate RWM's understanding of the requirements relating to the sealing of deep site investigation boreholes in the context of the ISE and long-term performance of the site, such as is considered in the ESC.
- To detail how the practicability of sealing deep site investigation boreholes in a UK context can be demonstrated to meet regulatory requirements.
- To ensure that, if required, a programme of research is developed and undertaken to meet the requirements of the DSSC in consideration of sealing deep site investigation boreholes.
- To inform RWM's overall forward programme.

Scope

The Scope of Phase 4 activities include:

- borehole sealing tests;
- supporting laboratory and numerical modelling studies;
- further research into the impact of the Borehole Damage Zone on borehole seal performance; and
- bentonite natural analogue study (International Bentonite Longevity project).

Geology Application

HSR, LSSR, Evaporite

Output of Task

Completion of Phase 4 will demonstrate RWM's ability to seal deep boreholes in a range of geological environments relevant to the GDF Siting Programme, attaining the project ambition and attaining the project scope expected by EA.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6

Further Information
Task to follow on from [2, Task 361] (Phase 3). RWM is participating in the Mont Terri Project for the hydrogeological, geochemical and geotechnical characterisation of a clay formation, with involvement in the following experiments: "Large-scale Sandwich seal experiment (SW-A)", "Borehole sealing experiment (SB-A)", "Cement-clay interaction (CI)", "Diffusion across 10- year old concrete/claystone interface" and "Well leakage simulation & remediation (CS-A)", in order to benefit the ongoing work at RWM through international collaboration. For more information, see the Mont Terri website. There are other publications relevant to this task [3]–[16].

1 Environment Agency and Northern Ireland Environment Agency, *Geological disposal facilities on land for solid radioactive wastes: Guidance on requirements for authorisation*, Regulation, Feb. 2009.

2 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

3 T. Sandén, K. O., L. Börgesson, U. Nelson, and M. Hedström, *Sealing site investigation boreholes: Phase 2. task 6: Phase 1 laboratory programme*, 202580/05, 2016. [Online]. Available: https://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-stage-1-laboratory-programme/.

4 M. White and M. Crawford, *Sealing site investigation boreholes phase 2: Task 13- evolution of the borehole damage zone*, AFW and Galson Sciences Limited, Contractor Report 202580/08 Issue A, May 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-task-13-evolution-of-the-borehole-damage-zone/.

5 R. Alexander, *Sealing site investigation boreholes phase 2: The use of natural, industrial and archaeological analogues in support of the borehole sealing project*, AFW and Bedrock Geosciences, Contractor Report 202580/07 Issue A, May 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-the-use-of-natural-industrial-and-archaeological-analogues-in-support-of-the-borehole-sealing-project/.

6 M. Crawford, *Sealing site investigation boreholes phase 2: Aspects of long-term performance of borehole seals in halite*, AFW and Galson Sciences Limited, Contractor Report 202580/10 Issue A, 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-aspects-of-long-term-performance-of-borehole-seals-in-halite/.

7 R. Metcalfe and J. Wilson, *Sealing site investigation boreholes phase 2: Support elements*, AFW and Quintessa, Contractor Report 202580/11 Issue A, May 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-support-elements/.

8 B. Frieg, H. Fisch, and S. Vomvoris, *Sealing site investigation boreholes Phase 2: Task 9 - Development of a QA_QC methodology for borehole sealing*, AFW and Nagra, Contractor Report 202580/12 Issue A, Apr. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-task-9-development-of-a-qa%5C_qc-methodology-for-borehole-sealing/.

9 T. Sandén, L. Börgesson, U. Nilsson, and V. Jensen, *Sealing deep site investigation boreholes phase 2: Stage 2 laboratory programme*, AFW and Clay Tech, Contractor Report 202580/13 Issue A, 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-deep-site-investigation-boreholes-phase-2-stage-2-laboratory-programme/.

10 C. Jackson, N. Jefferies, W. Alexander, J. Smith, B. Frieg, I. Gauss, S. Vomvoris, R. Metcalfe, and R. Marsden, *Sealing deep site investigation boreholes: Phase 1 report*, AMEC, Contractor Report 201257/002 Issue B, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-deep-site-investigation-boreholes-phase-1-report-rwmd03042/.

11 N. Jefferies, S. Joyce, V. Tsitsopoulos, W. Alexander, L. Börgesson, O. Karnland, T. Sanden, I. Gaus, S. Vomvoris, R. Metcalfe, F. Groff, and R. Marsden, *Sealing site investigation boreholes: Phase 2. annual report for 2014/2015*, AMEC Foster Wheeler, Contractor Report 202580/001 Issue P1, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-annual-report-for-20142015/.

12 V. Tsitsopoulos, S. Joyce, and N. Jefferies, *Sealing site investigation boreholes: Phase 2. task 2b: Modelling the effects of site investigation boreholes on groundwater flow*, AMEC Foster Wheeler, Contractor Report 202580/02 Issue A, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-task-2b-modelling-the-effects-of-site-investigation-boreholes-on-groundwater-flow/.

13 V. Tsitsopoulos and N. Jefferies, *Sealing site investigation boreholes phase 2. task 11 modelling the effects of different borehole sealing strategies on groundwater flow*, AMEC, Contractor Report 202580/03 Issue A, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-task-11modelling-the-effects-of-different-borehole-sealing-strategies-on-groundwater-flow/.

14 A. Hoch and N. Jefferies, *Sealing site investigation boreholes - phase 2 - impact of gas*, AMEC, Contractor Report 202580/005 Issue A, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-impact-of-gas/.

15 R. Alexander, L. Börgesson, M. Hedström, N. Jefferies, and J. Wilson, *Sealing site investigation boreholes phase 2: Aspects of the evolution and longevity of bentonite seals*, AFW, Bedrock Geosciences, Clay Tech and Quintessa, Contractor Report 202580/09 Issue A, Apr. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-site-investigation-boreholes-phase-2-aspects-of-the-evolution-and-longevity-of-bentonite-seals/.

16 N. Jefferies, A. Hoch, V. Tsitsopoulos, R. Alexander, L. Börgesson, M. Hedström, O. Karnland, T. Sandén, M. Crawford, M. White, B. Frieg, S. Vomvoris, R. Metcalfe, and J. Wilson, *Sealing deep site investigation boreholes: Phase 2. final report*, AFW, Bedrock Geosciences, Clay Tech, Galson Sciences, Nagra and Quintessa, Contractor Report 202580/14 Issue A, Jan. 2018. [Online]. Available: http://rwm.nda.gov.uk/publication/sealing-deep-site-investigation-boreholes-phase-2-final-report/.

B5.5 WBS 50.5 - Groundwater tools, techniques and methods

B5.5.1 Assessment of Repository-induced Effects in a Clay Host Rock: Excavation-disturbed Zone (EdZ) Formation and Impact on Flow (LSSR)

Task Number	50.5.001	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Groundwater Tools, Techniques and Methods		
Background			
The excavation of tunnels and drifts in the host rock causes stress redistribution which results in micro- and macro-scale fractures within an excavation-disturbed zone. The excavation-disturbed zone in LSSR develops during the operational phase of the repository and consolidates after backfilling of the underground structures. The formation and evolution of the excavation-disturbed zone modifies safety-relevant properties of the host rock adjacent to the emplacement vaults, sealing zones and other underground structures, for example damage to the host rock results in an increased porosity. After repository closure, stress redistribution in response to the consolidation process and pore-pressure recovery affect the final properties of the near-field. There is a need to improve understanding of the development of the excavation-disturbed zone around tunnels, emplacement vaults, sealing zones and shafts and to understand its impact on the safety functions of the EBS under repository conditions. The excavation-disturbed zone around backfilled structures represents a viable release path for radionuclides as well as a possible escape route for corrosion and degradation gases. The efficiency of this release pathway depends on the shape and extent of the excavation-disturbed zone and the degree of self-sealing that occurs during resaturation. Knowledge regarding the temporal evolution of rock stress, pore pressure, irreversible strains and hydraulic conductivity in the near-field is required for the entire lifetime of the repository (extending from construction to the late post-closure phase). This information is used to evaluate the effects of the excavation-disturbed zone on groundwater movement and gas migration, which can be represented in numerical models.			
Research Driver			
To support site-characterisation needs and the Environmental Safety Case by improving the understanding of the development of the excavation-disturbed zone around tunnels, emplacement vaults, sealing zones and shafts and to understand its impact on the safety functions of the EBS under repository conditions.			
Research Objective			
To understand how the excavation-disturbed zone develops to ensure that the impact on groundwater movement and gas migration can be included in numerical models developed.			
Scope			
To achieve the objectives the following scope will be undertaken: • Participation in experiments in Underground Research Laboratories that evaluate the temporal evolution of excavation-disturbed zones following construction – RWM participates in the SE-P (Self-sealing processes in old excavation-disturbed zones and breakout zones) experiment at Mont Terri Underground Research Laboratory which evaluates the changes in mechanical and hydraulic properties in tunnels immediately following excavation, and at ten and twenty years post excavation; this experiment concludes in June 2021.			

• To understand which factors have greatest control on the evolution of the excavation-disturbed zone a review of data from Underground Research Laboratory experiments in clay host rock is required (e.g. evaluate the impact in parameters such as the variability and anisotropy of the elastic and plastic rock properties and geochemical conditions) ; this will be delivered as a contractor led project that is planned to start in FY21/22. • Development of an approach/methodology for numerical representation of excavation-disturbed zones. This will be based on results from modelling projects that used state-of-the-art approaches for the simulation of experimental data from *in situ* experiments. This will be a follow-on piece of work to the work that draws on the learning from the activities above; the exact scope and timing is to be determined.					
Geology Application					
LSSR, Cover Rocks					
Output of Task					
• Mont Terri Technical Reports from SE-P experiment. • Contractor and RWM reports presenting the findings of numerical modelling projects.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6

Further Information
For further information of the effect of the EDZ in HSR, LSSR and Evaporite on gas migration, see Task 40.3.005, Task 40.3.006 and Task 40.3.007. There are several publications relevant to this task [1]–[6].

1 Nagra, *Project opalinus clay safety report - demonstration of disposal feasibility of spent fuel, vitrified high-level waste and long-lived intermediate-level waste*, Nagra Report TR-02-05, 2002. [Online]. Available: https://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NTBs%202001-2010/e_ntb02-05.pdf.

2 G. Lanyon, D. Martin, S. Giger, and P. Marschall, *Development and evolution of the Excavation Damaged Zone in the Opalinus Clay – a synopsis of the state of knowledge from Mont Terri*, Nagra, Nagra Report NAB 14-87, 2014. [Online]. Available: https://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NABs%202004%20-%202015/e_nab14-087.pdf.

3 A. Alcolea, U. Kuhlmann, P. Marschall, A. Lisjak, G. Grasselli, O. Mahabadi, R. de La Vaissière, H. Leung, and H. Shao, *A pragmatic approach to abstract the EDZ around tunnels of a geological radioactive waste repository – application to the HG-A experiment in mont terri*. Geological Society, [Online]. Available: https://pubs.geoscienceworld.org/books/book/2089/chapter/114427862/A-pragmatic-approach-to-abstract-the-excavation.

4 Nagra, *Extent and Shape of the EDZ around Underground Structures of a Geological Repository for Radioactive Waste – a Sensitivity Study for the Candidate Host Rocks in the Proposed Siting Regions in Northern Switzerland*, Nagra, Nagra Report NAB 13-78, 2013. [Online]. Available: https://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NABs%202004%20-%202015/e_nab13-078.pdf.

5 MontTerri, *Hg-a experiment: Numerical simulation of the edz formation and mechanical re-compaction process using an fdem approach*, 2014.

6 P. Bossart and M. Thury, *Mont terri rock laboratory project: Programme 1996 to 2007 and results*. Swiss Geological Survey, 2008. [Online]. Available: https://www.worldcat.org/title/mont-terri-rock-laboratory-project-programme-1996-to-2007-and-results/oclc/436787319.

B5.5.2 Tools, Equipment and Techniques for Collecting and Using Groundwater Information to Support GDF Programmes

Task Number	50.5.002	**Status**	Ongoing
WBS Level 4	Groundwater		
WBS Level 5	Groundwater Tools, Techniques and Methods		

Background

Groundwater chemistry and movement information provides a vital understanding to geological disposal facility programmes. It informs decisions regarding the suitability of a site to host a GDF as well as the selection of appropriate designs and disposal concepts. Groundwater knowledge is also required to support permit applications for drilling site-characterisation boreholes and to underpin safety case arguments. International Waste Management Organisations have developed and used tools, equipment and techniques to collect and use groundwater information within their programmes. Additionally, new tools, equipment and techniques are continually emerging or being developed to increase certainty and confidence in the data and interpretations based on them. RWM needs to maintain awareness of the state of the knowledge and to evaluate the use, relevance and value of these tools, equipment and techniques to our programme. RWM also needs to progress the development of tools, equipment and techniques that may not currently be available to our programme, but for which a need has been identified.

Research Driver

To improve the understanding of site characterisation needs and technologies, and to support the environmental safety case.

Research Objective

RWM's objective is to ensure that we have capability to use, and have access to, the most appropriate tools, equipment and techniques for groundwater interpretation relevant to our programme at the point they are needed, as summarised below:

1. To support site evaluation prior to down-selection to two sites.
2. To support site characterisation prior to drilling.
3. To support site characterisation during drilling.
4. To understand the methodologies and work-flows required for the integration of groundwater chemistry data/information to support the different stages of the GDF programme.
5. Capability and resource requirements will be identified and plans put in place to resolve gaps.

Scope

The following scope of works will be undertaken to deliver the objectives (1) and (2) above:

• Identification of emerging tools, equipment and techniques through participation in collaborative UK and international projects.
  • RWM is a partner to Mont Terri Underground Laboratory, participating in ~15 experiments annually. Partnership will continue whilst experiments have relevance to our programme. RWM currently expects to commit to longer term experiments beyond 2025. Each experiment uses a mix of new and emerging GDF relevant science and technology. Outputs are published in technical reports and journal papers.
  • In FY19/20 RWM joined Posiva's knowledge sharing project, Engineered Barrier Behaviour Test, Onkalo (EBBO). This is a demonstration project for the emplacement of waste containers and the subsequent monitoring of the thermal, hydraulic and mechanical evolution of the backfill, buffer and seals. Through workshops and site visits, the science and technology employed will be evaluated, and RWM will take specific learning regarding the industrialisation of techniques (from research designs, to operational designs).
  • In FY18/19 RWM joined the Drilling Fluids experiment at Mont Terri, this project concludes in FY20/21. This experiment tested different drilling fluids to optimise borehole stability and ability to collect groundwater samples with low drilling fluid contamination. The output will be a Nagra (Swiss WMO) project report.
  • Additional opportunities will be kept under review.
• RWM has commissioned research to develop tools, equipment and techniques not currently available to RWM's programme that will be needed to support our site characterisation activities, as follows:
  • High levels of sulphide in groundwater can lead to microbially induced corrosion of waste containers. Accurate measurement of sulphide concentrations is challenged by the sample collection process. In FY17/18 RWM provided industrial funding to an EPSRC studentship at the University of Oxford to deliver the first phase of a project to develop a down-hole sulphide sensor. The output of this phase of the project will be the synthesis of a chemical sensor that utilises molecular recognition to detect the presence of sulphide. In FY19/20 RWM entered the second phase of the project, funding a two-year post-doctorial researcher to develop a prototype sensor that incorporates the synthesised chemical. A follow-on project that will test the sensor in a GDF relevant setting may be scoped depending on the success of the prototype development.
  • Knowledge regarding the composition and nature of the water sources that contribute to the groundwater composition at a GDF site, and along the hydraulic flow-path, is required in order to conceptualise a site. Identification of modern recharge has traditionally used expensive isotope-tracing techniques, however such techniques are becoming less useful, for example due to radioactive decay of weapons-test tritium. RWM is funding a two-year post-doctoral research project at the University of Strathclyde which started in FY19/20. This project will develop a novel tracer technique which can identify surface related/modern recharge using a comparative assessment of organic biomarkers present in surface soils with those identified in groundwater and surface water bodies.

Geology Application
LSSR, HSR, Evaporite, Cover Rocks
Output of Task

• Peer reviewed published reports and journal papers. • A sensor that can detect sulphide in groundwater in GDF relevant conditions. • Validated field and laboratory techniques for identifying modern recharge components within groundwater samples.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5
Further Information					

B5.5.3 Conceptualisation and Numerical Representation of Groundwater Migration in HSR Rocks

Task Number	50.5.003	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Groundwater Tools, Techniques and Methods		
Background			
Groundwater provides a pathway by which radionuclides in a GDF could migrate to the surface environment over long timescales. A robust conceptual understanding of groundwater movement at a catchment and local scale, at all points of the groundwater pathway, is required to support decision making and to underpin safety-case arguments for a GDF. Conceptual models provide visualisations of features and processes that affect groundwater movement in a volume of rock. They draw together lithological information (i.e. rock type/properties, deformation history), structural features (i.e. distribution, intensity and interconnectivity of the fracture network) and hydrogeological and hydrological information (i.e. groundwater and surface water divides, rock hydraulic properties). The conceptual model is used to underpin numerical flow and transport models which represent groundwater migration and chemical evolution in space and time. The groundwater migration mechanism along a flow path between a GDF and the surface environment is dependent upon rock type(s) present. Migration dominantly occurs within fractures in HSR. RWM needs to understand the current state of knowledge regarding how to conceptualise and numerically represent groundwater movement in a range of host and cover rocks. Predecessor programmes for a UK GDF developed conceptual models for a HSR host-rock site, and produced numerical representations of groundwater migration. This work concluded over 20 years ago. There is therefore a need to enhance capability to represent groundwater movement in the current UK GDF programme. A roadmap that is used to inform the development of groundwater conceptual models and groundwater numerical models in HSR is required. Notably, international WMO programmes are currently developing and using tools to conceptualise groundwater movement and represent flow and solute transport in numerical models for GDF sites. Knowledge transfer projects between RWM and advanced programmes will support and enhance capability in this area.			
Research Driver			
To improve the understanding of site characterisation needs and technologies, and to support the environmental safety case.			
Research Objective			
• Raise RWM's awareness of current approaches to delivery of groundwater conceptual and numerical models for potential GDF sites. • Develop capability within RWM and our supply chain, using real-world site data, to conceptualise and numerically represent groundwater movement in a HSR. • Enhance capability within the supply chain (and internally) to use local-scale site data to constrain (reduce uncertainty) probabilistic predictions of flow rates and network connectivity in discrete fracture network models for a HSR.			
Scope			
The following scope will be undertaken:			

- RWM will need to understand the range of conceptual representations that could be adopted for a specific GDF site. An approach to testing, validating and identifying which conceptual model, or models, should be taken forward to represent our GDF site will need to be developed. This scope stems from a regulatory challenge received by the Finnish WMO, Posiva, which required confirmation that the conceptual model chosen for their site was realistic when compared to alternative conceptual models that could also have been developed. The SKB GWTF will start a new five year task in FY20/21 that RWM intends to join. This collaborative forum will use site-specific data to evaluate different alternative conceptual models. An output will be a summary report that synthesises the state of the knowledge, which will act as a reference to underpin decisions by other WMOs and to support regulators in their review of models developed. RWM will join the GWTF partnership and intends to fund a contractor modelling team that will use site-specific data to develop a range of alternative conceptual models. A peer reviewed contractor report will be published, and journal papers are expected.

- Since 2018 RWM has been working in collaboration with Posiva and our contractors to develop a numerical model using site data from an *in situ* experiment, at the tunnel scale. RWM is a partner to Posiva's FISST knowledge share project, from which experimental site data are available to RWM. A spin-off collaborative project, FISST Discrete Fracture Networks between Posiva, RWM and our supply chain gave rise to a series of training workshops for RWM using the FISST experiment as a case study. Monitoring data evaluating the thermal, mechanical and hydraulic evolution of the FISST tunnel in the time since emplacement have been recorded. RWM has joined the follow-on knowledge share project offered by Posiva called EBBO (Engineered Barrier Behaviour Test, Onkalo) which gives RWM access to these data. In FY20/21 RWM will extend the Posiva, RWM and supply chain collaboration to undertake a model validation and verification exercise; this will last one year. A journal paper will be published to showcase the results.

Geology Application

HSR

Output of Task

- A summary report on alternative conceptual models which will be prepared collaboratively by the GWTF.

- Journal paper(s) showcasing the results of the FISST discrete fracture network/Engineered Barrier Behaviour Test, Onkalo experiment participation.

- Enhanced knowledge and capability within RWM and supply chain regarding alternative conceptual models for representing groundwater flow in rock.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information

B5.5.4 Conceptualisation and Numerical Representation of Groundwater Migration in LSSR

Task Number	50.5.004	**Status**	Ongoing
WBS Level 4	Groundwater		
WBS Level 5	Groundwater Tools, Techniques and Methods		
Background			
Groundwater provides a pathway by which radionuclides in a GDF could migrate to the surface environment over long timescales. A robust conceptual understanding of groundwater movement at a catchment and local scale, at all points of the groundwater pathway, is required to support decision making and underpin safety-case arguments for the GDF. Conceptual models provide visualisations of features and processes that affect groundwater movement in a volume of rock. They draw together lithological information (e.g. rock type/properties, deformation history), structural features (e.g. distribution, intensity and interconnectivity of the fracture network) and hydrogeological and hydrological information (e.g. groundwater and surface water divides, rock hydraulic properties). The conceptual model is used to underpin numerical flow and transport models which represent groundwater migration and geochemical evolution in space and time. In LSSR, groundwater migration is dominantly via pore spaces with diffusive transport mechanisms controlling radionuclide migration. Groundwater movement in the transition zone between LSSR (for settings where the LSSR is either the host or a cover rock) and surrounding adventive dominated flow systems is more complex. RWM needs to understand the current state of knowledge regarding the conceptualisation and numerical representation of groundwater in LSSR, and in the surrounding geological environment, and we need to develop capability and capacity where gaps are identified. Advanced International WMO programmes are currently considering this topic and RWM's participation in knowledge transfer and collaboration projects will be central to efficiently progressing this research topic.			
Research Driver			
To improve the understanding of site characterisation needs and technologies, and to support the environmental safety case by developing a robust conceptual understanding of groundwater movement at a catchment and local scale, at all points of the groundwater pathway, is required to support decision making and underpin safety-case arguments for the GDF.			
Research Objective			
• To develop capability within RWM and our supply chain, using real-world site data, to conceptualise and numerically represent groundwater movement in LSSR host rocks/cover rocks, and their surrounding geological environment; and • To raise awareness of current approaches to deliver groundwater conceptual and numerical modelling projects for a potential GDF.			
Scope			
The following scope will be undertaken: • In 2019 RWM commissioned knowledge sharing workshops with Andra (France) and Nagra (Switzerland) to understand the approaches they use to characterise and represent flow in LSSR/the surrounding rocks relevant to their programmes. It is intended that RWM will translate learning from these knowledge sharing projects into production of a technical note on the synthesis of considerations for the characterisation of LSSR settings; this will start in FY20/21.			

• To further understand the role of the transition zone between diffusion dominated LSSR and surrounding advective systems RWM will continue partnership of the Hydrogeological Characterisation experiment at Mont Terri, the output from which will be a published PhD thesis. In FY20/21 RWM will join the Hydrogeological Survey (HS-A) project at Mont Terri which will last for three years. This project will drill a borehole through the LSSR into the underlying aquifer. Micro to macro scale rock testing, and down-hole hydraulic testing will be performed to evaluate the controls on groundwater migration in this transition zone. RWM may seek to commission work-in-kind via laboratory analysis, and this would start in FY21/22. A decision on work-in-kind is deferred until FY21/22 and is dependent upon the work scope planned by other experiment partners. The output from these tasks will be peer reviewed reports, thesis and/or journal papers. • Groundwater migration in LSSR occurs dominantly within pore spaces, however, advective flow will locally occur in bedding plane discontinuities and laminations in the rock strata, as well as within fractures (where fractures may be created during construction, forming part of the engineered disturbed zone, or they relate to persistent geological features). In FY20/21 RWM will join the SKB GWTF Task 10, which will consider alternative conceptual models for representing groundwater flow in advective environments. The output from this task will be a summary report that outlines the state of the knowledge regarding modelling approaches available.					
Geology Application					
LSSR, Cover Rocks					
Output of Task • Internal technical note regarding characterisation of LSSR environments (from a hydrogeological context), • Published, peer reviewed reports and / or journals will be delivered from partners/contributors to the Mont Terri Experiments. • A summary report on alternative conceptual models for groundwater flow in advective settings will be prepared collaboratively by the GWTF.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5
Further Information					

B5.5.5 Site Suitability Considerations

<table>
<tr><td colspan="2">Task Number</td><td>50.5.005</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Geosphere</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Groundwater Tools, Techniques and Methods</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In December 2018 RWM launched its siting programme [1] and we are engaging with communities that have an interest in potentially hosting a GDF. In early discussions with communities RWM will review potential site suitability against a range of criteria, including safety and security, value for money, and environment. The approach to site evaluation to be undertaken during the early phases of community engagement is established in RWM's published documents [2], [3]. Geosphere factors, including rock, groundwater flow and groundwater chemistry will need to be understood in order to evaluate a site's suitability to host a GDF. RWM needs to understand what geosphere factors are relevant and how they can inform our decisions. More progressed GDF programmes, such as in Finland, have established Rock Suitability Criteria which, in some cases, include bounding ranges for some parameters. Since RWM is at the early stage of our programme a quantitative approach is not appropriate and we will seek to evaluate site considerations qualitatively.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support site evaluation, the environmental safety case and to develop an improved understanding of site characterisation needs.</td></tr>
<tr><td colspan="6">Research Objective
• To identify the groundwater flow and groundwater chemistry parameters to be considered as part of site suitability and site-characterisation evaluations.
• To establish an approach for the consistent use of groundwater flow and groundwater chemistry considerations.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">In FY20/21 RWM will consider the role and impact of groundwater flow and groundwater chemistry at all stages of our programme (from site evaluation to post closure). This work will be delivered internally and will bring together our experts who will contribute knowledge and experience from across engineering, site characterisation and technical disciplines.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR, HSR, Evaporite, Surrounding Rocks</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">An internal technical note giving a high level summary of the qualitative considerations relevant to evaluating groundwater flow and chemistry at potential GDF sites will be prepared.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information

1 BEIS, *Implementing geological disposal - working with communities*, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766643/Implementing_Geological_Disposal_-_Working_with_Communities.pdf.

2 Radioactive Waste Management, *Site Evaluation - How We Will Evaluate Sites in Wales*, 2020. [Online]. Available: https://www.gov.uk/government/consultations/site-evaluation-how-we-will-evaluate-sites-in-wales.

3 Radioactive Waste Management, *Site Evaluation - How We Will Evaluate Sites in England*, 2020. [Online]. Available: https://www.gov.uk/government/consultations/site-evaluation-how-we-will-evaluate-sites-in-england.

B5.5.6 Ground Support Methodologies in LSSR

Task Number	50.5.006	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Groundwater Tools, Techniques and Methods		

Background

Globally, a common approach for the support of excavations (e.g. tunnels and vaults) in low strength sedimentary rocks is to provide a fully lined support to the excavation using sprayed concrete. This is required to provide excavation stability and prevent weathering, swelling and loosening of the rock. The NAGRA concept for the disposal of HHGW makes the assumption that, for sealing sections, the lining will not be present in order for the seal to directly interface with the rock. The idea behind this is to prevent a 'fast' groundwater flow path being introduced to the tunnel by directly sealing against the rock in several locations along the disposal tunnel. The requirement for excavation support (an operational requirement) and the requirement for sealing the tunnel (a post-closure requirement) can be seen to be in conflict. RWM hence requires an understanding of feasible means of resolving this conflict.

Research Driver

To identify and develop GDF concepts, to support the disposal system safety case, and to support the GDF design feasibility and development.

Research Objective

The objective is to increase RWM's understanding of the requirements for ground support in LSSR disposal tunnels and understand the implications of using different ground support methodologies. This will inform site-specific design work.

Scope

The scope comprises the following:

- Partnering with the Tunnel Support experiment at the Mont Terri URL.
  - The experiment involves the analysis of two different types of ground support: sprayed concrete lining and steel ribs and mesh.
  - Sections of tunnel constructed as part of the Gallery 18 extension to the Mont Terri URL are monitored to understand behaviour.
- The scope of works for a contractor delivered work-in-kind project to the Tunnel Support experiment is summarised below. This work will conclude in FY20/21.
  - Analysis of tunnel support monitoring data to investigate impacts of construction sequencing, support type, and long-term behaviour.
  - Development of recommendations for the design of disposal tunnels in LSSR based on the analysis of the Tunnel Support experiment.
  - Longer term monitoring and evolution studies of the Tunnel Support experiment, including deformation and investigation of weathering of exposed rock sections.

Geology Application

LSSR

Output of Task

- Published, peer reviewed report on the analysis study of the Tunnel Support experiment data, including recommendations for developing designs of disposal tunnels in LSSR in a UK context.

• Mont Terri monitoring reports (including long term monitoring) for use in underpinning future site-specific design decisions.					
SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 3	**Target SRL/TRL**	TRL 9
Further Information					

B5.5.7 Use of Groundwater Chemistry in GDF Programmes

Task Number	50.5.007	**Status**	Ongoing
WBS Level 4	Geosphere		
WBS Level 5	Groundwater Tools, Techniques and Methods		

Background

RWM needs to understand how to analyse, measure and interpret groundwater chemistry information. We also need to know how to use and integrate knowledge of groundwater chemistry into our decisions for designs and concepts. Information on groundwater flow and groundwater chemistry will be used at all stages of RWM's GDF programme, however in the early stages groundwater chemistry samples will be used to inform site suitability, design and concept selection decisions; data obtained will provide vital underpinning to assumptions regarding the long-term safety of a site. Groundwater chemistry in the near surface is comparatively well understood. Groundwater composition and evolution in the depth range of a GDF is, however, less understood since historically there has not been a reason to investigate it. In developing a GDF RWM will need to collect groundwater samples from depth, potentially from low permeability rocks. We will need to have a mature supply chain that has the capability to deliver the specialist analyses required. We will need expertise to process, use and interpret the chemistry data and will need to understand how this information can be used to benefit our programme.

Research Driver

To deliver groundwater chemistry knowledge, capability and capacity to support RWM's programme at the point it is needed.

Research Objective

To close knowledge gaps/needs relevant to groundwater chemistry at the following times in RWM's programme:

1. to support site evaluation prior to down-selection to two sites;
2. to support site characterisation prior to rock-core drilling;
3. to support site characterisation during rock-core drilling;
4. to understand the methodologies and work flows required for the integration of groundwater chemistry data/information, to support the different stages of the GDF programme; and
5. capability and resource requirements are identified and plans are in place to resolve shortfalls.

Scope

RWM's future groundwater work is underpinned by expert advice received from RWM's Groundwater Review Group. The Groundwater Review Group is formed of internationally renowned external specialists and RWM staff. The work scope is further underpinned by a contractor report [1] which identified a number of knowledge gaps. Our work currently focusses on the near-term objectives, predominantly aligned to objectives (1), (2) and (4) above. Specific ongoing or planned tasks are outlined below.

1. In order to develop understanding of how to characterise water bodies and to identify end-members based on groundwater chemistry data from boreholes a two year contractor project using Andra data, started in February 2020. The output from this project will be a peer reviewed contractor report; information therein will underpin a decision by RWM regarding whether to develop an in-house analytical tool to evaluate groundwater chemistry, or whether to rely on off-the-shelf packages.

2. To understand how pore-water data can be used in GDF programmes a contractor-led project is planned to start in FY20/21. The output will be a peer reviewed contractor report; the information will underpin a strategy for the use of pore water in our programme, which will be subsequently developed by RWM. A follow-on activity will be to evaluate the capacity and capability of our UK and international supply chain to deliver the strategy developed.

3. The use of reference groundwater/porewaters in GDF programmes and the approach needed to derive them will be evaluated via a contractor led piece of work lasting two years. The task will draw on learning from more advanced WMOs' programmes and is planned to start in FY20/21. The arising peer-reviewed contractor report will inform RWM on how to develop reference porewaters so that consistent compositions, accounting for natural variability and evolution of porewaters, can be developed. This will allow the performance of engineering/barrier components to be assessed and the transport and fate of radionuclides in porewater to be evaluated.

4. To maximise the benefit of paleohydrogeological information arising from site investigation activities RWM will undertake a contractor-led project that will consider the range of groundwater and rock-testing techniques and undertake a benefits analysis for their use in RWM's programme. This project will last two years, and is planned to start in FY20/21. A follow-on project will be planned to evaluate the capability and capacity in the UK and international supply chain to deliver paleohydrogeological information. This work will also develop a management plan to address gaps identified. To support this scope, RWM will continue to participate in the Geochemical Data experiment at Mont Terri Underground Rock Laboratory which uses geochemical data to address specific GDF related knowledge gaps.

5. The performance of engineered barrier components and evaluation of the fate and mobility of radionuclides in groundwater will be based on the expected groundwater composition. Over the life of a GDF the composition of recharging water into the system will change, and at points this will be dilute (for example associated with inflow of glacial melt-water). Dilute waters could have an adverse effect on the safety performance of certain engineered barriers. The reality of dilute water reaching GDF depths, when considering water: rock interactions *en route*, has not yet been evaluated. An experimental study of evolution of dilute groundwater compositions by water-rock reaction in HSR and LSSR rocks will be undertaken. This will be delivered potentially via a PhD or through collaboration with a research entity. It will involve experimental work and numerical modelling studies/simulations to evaluate water : rock interactions and the evolution of groundwater composition with time. This project is planned to start in FY21/22 and will last up to four years. Project outputs will include peer reviewed journal papers.

6. Geophysics can supplement information regarding groundwater compositions obtained by water sampling and analyses. Geophysics may be a cost-effective way of obtaining semi-quantitative information on groundwater compositions without the expense and effort of intensive sampling (though it is likely that calibration samples will be required). For example, geophysical resistivity measurements on drill-core samples can be processed to derive a 'formation factor' which is a semi-quantitative measure of rock diffusivity and matrix water conductivity/salinity. RWM needs to understand the current state-of-the-art regarding the integration of geophysics and geochemical data. This topic will initially be explored as a Masters thesis project.

Geology Application					
LSSR, HSR, Evaporite, Cover rocks					
Output of Task • Qualitative outputs of enhanced knowledge and capability within RWM and the UK and international supply chain will be delivered. • Quantitative outputs will include published peer-reviewed contractor reports and journal papers. • Task outputs will inform the scope for future tasks where needed.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	
Further Information					
Needs relating to the development of tools and equipment to test and evaluate groundwater chemistry are outlined in Task Sheet 'Groundwater Tools & Techniques' Task 50.5.002. 1 D. Holton, *State of knowledge review of groundwater movement and ground-water chemistry research*, AMEC, Contractor Report RWM/Contr/19/040, 2018. [Online]. Available: https://rwm.nda.gov.uk/publication/state-of-knowledge-review-of-groundwater-movement-and-groundwater-chemistry-research/.					

B6 WBS 70 - Modelling and Treatment of Uncertainty

The generic research activities to be concluded can be summarised in the following work areas:

- To maintain a watching brief on new and developing methodologies for mathematical modelling and treatment of uncertainty in academic institutions and internationally that may have relevance for RWM's work programme.
- To develop and document our modelling strategy from the start of site-specific work onwards focussing on the selected geological environments.

B6.1 WBS 70.1 - Analytical Advice Provision

B6.1.1 Watching brief on Methodologies for Modelling and Uncertainty

<table>
<tr><td colspan="2">Task Number</td><td>70.1.001</td><td>Status</td><td colspan="2">Start date in FY21/22</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Modelling and Treatment of Uncertainty</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Analytical Advice Provision</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In recent years, RWM has had an ongoing research task to obtain analytical advice relating to mathematical issues across its work programme. The current contract for this will end in 2021. One aspect that has been a part of this advice is the area of developments in academia and elsewhere in mathematical modelling and methods for treatment of uncertainty. These areas are important ones for RWM and therefore there is a need to continue a watching brief beyond 2010.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">RWM needs to maintain an awareness of the state-of-the-art in methodologies for mathematical modelling and treatment of uncertainty. This awareness needs to cover methods that we recommend and advocate the use of, but also needs to cover methods that RWM does not advocate so that RWM is robust to challenge.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To maintain a watching brief on new and developing methodologies for mathematical modelling and treatment of uncertainty in academic institutions and internationally that may have relevance for RWM's work programme.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The envisaged scope of the task is as follows:
Maintain awareness of academic developments in mathematical modelling methods, and determine relevance to geological disposal.
Maintain awareness of approaches to treatment of uncertainty among the radioactive waste community internationally, e.g. through participation in EU projects such as the UMAN network.
Keep a watching brief on developments in all aspects of uncertainty quantification in academia, forming a view on those aspects which are helpful and those which are unhelpful.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Ad-hoc reports as necessary.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B6.2 WBS 70.2 - Modelling and Treatment of Uncertainty

B6.2.1 Modelling Strategy Roadmap

<table>
<tr><td colspan="2">Task Number</td><td>70.2.001</td><td>Status</td><td colspan="2">Start date in FY21/22</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Modelling and Treatment of Uncertainty</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Modelling and Treatment of Uncertainty</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Mathematical modelling is one of the important tools we use to support aspects of our work to assist the development of a GDF for HAW. Modelling is recognised as a powerful tool to test, verify, quantify and predict the outcomes of certain assumptions and scenarios. In our work, models are developed and applied in a range of scientific and technical discipline areas as diverse as: models to quantify doses to non-human biota, to understand the nature of groundwater flow, or to evaluate the consequences of gas generation from waste. In this way they support, supplement and illustrate key arguments underpinning the safety case for transport, operations and post-closure environmental impact of the GDF.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">At the point of developing site-specific models supporting the post-closure safety case for a GDF, RWM will publish an update to the 2013 Modelling Framework report, with fuller detail on the models to be developed as part of the site characterisation programme(s) and our ongoing strategy for delivering modelling work throughout RWM.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop and document our modelling strategy from the start of site-specific work onwards.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The envisaged scope of the task is as follows:
• Develop a roadmap for agreeing RWM's modelling strategy from the start of site-specific work onwards.
• Document our modelling strategy in an accessible report covering an agreed scope for modelling and treatment of uncertainty – this is likely to be an update of report NDA/RWMD/101 (2013) [1], the main difference being the level of detail to which it is possible to include in the models relating to characterising a site(s).
• To agree RWM's commercial strategy for delivering modelling activities across the different areas of the business, and dependent on this, develop our procedures for ensuring quality for modelling work carried out in the supply chain and in-house.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">Targeted at host-rock geologies and geological environments that are to be investigated during site-characterisation.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report on RWM's strategy for mathematical modelling, including treatment of uncertainty appropriate at the start of site-characterisation, and a commercial strategy for procuring modelling activities.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information	
1	Nuclear Decommissioning Authority, *Geological Disposal - Framework for Application of Modelling in the Radioactive Waste Management Directorate*, NDA Report NDA/RWMD/101, 2013. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-framework-for-application-of-modelling-in-the-radioactive-waste-management-directorate/.

B7 WBS 80 - Groundwater Pathway for Radionuclide & Non-radionuclide Species

To demonstrate post-closure safety of the GDF the quantities of radionuclides which may eventually reach the biosphere need to be shown to be sufficiently low that they will not pose an undue risk to living things.

The generic research activities to be concluded can be summarised in the following work areas:

- Development and Maintenance of Thermodynamic Models (**WBS 80.1**)
- Develop Generic Understanding of the Behaviour of Radionuclide and Non-Radionuclide Species in a GDF System (**WBS 80.2**)
- Develop Understanding of Radionuclide Behaviour in the EBS (**WBS 80.3**)
- Develop Understanding of Radionuclide Behaviour in the Geosphere (**WBS 80.4**)
- Develop Understanding of Other Influences on Radionuclide Behaviour (**WBS 80.5**)
- Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-Radionuclide Research **(WBS 80.6)**
- Representation of Radionuclide Behaviour in Assessment Models **(WBS 80.7)**
- Develop Understanding of the Behaviour of Carbon-14 **(WBS 80.8)**

WBS 80.1 will develop and maintain a consistent set of thermodynamic databases to support safety assessments (Task 80.1.001 and Task 80.1.002).

WBS 80.2, 80.3 and 80.4 will provide understanding of the processes by which radionuclides are taken up by backfill materials, EBS components, corrosion products, and the geosphere.

WBS 80.5 will progress the understanding of other influences on radionuclide behaviour, including the role of microbes (Task 80.5.001-Task 80.5.003), the effect of colloids (Task 80.5.004-Task 80.5.008), the potential impact of cement additives (Task 80.5.009-Task 80.5.011), the impact of small quantities of organic/inorganic complexants (Task 80.5.011) and the impact of cellulose degradation products (Task 80.5.013).

WBS 80.6 will ensure RWM has the appropriate level of capability, at the appropriate time, by developing a costed programme of research. This will involve identifying the necessary laboratory capability, capacity and equipment required to begin site-specific research following selection of a candidate geology, to quantify radionuclide transport, retention and retardation in the geosphere.

WBS 80.7 will minimise undue conservatisms in the disposal system specification, design and gDSSC arising from radionuclide behaviour models and consequent experimental programmes.

WBS 80.8 comprises a review of the understanding of C-14 behaviour in the geosphere, and to address to the uncertainties in the safety case surrounding the speciation and mobility of carbon-14 from “cradle to grave”.

B7.1 WBS 80.1 - Development and Maintenance of Thermodynamic Models

B7.1.1 NEA Thermodynamic Database (TDB): Further Development of Internationally Recommended High Quality Thermodynamic Data Parameters (Actinide Update, Cement Phases, High Ionic Strength Media and High Temperature Corrections)

Task Number		80.1.001	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide & Non-radionuclide Species			
WBS Level 5		Development and Maintenance of Thermodynamic Models			
Background					
A database with an enhanced user interface and up-to-date thermodynamic properties is required for key radionuclides and chemotoxic elements in the presence of cement and a variety of rock and mineral surfaces relevant to GDF scenarios (i.e. sorption coefficients, binding constants). The original thermodynamic database, HATCHES, developed by Nirex in the late 1980s, has now been withdrawn after a period of limited maintenance. Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed 'linear sorption', and it is generally argued that the approach is an adequate simplification for use in performance assessments. Thermodynamic modelling is used to build understanding of sorption processes and to confirm the adequacy of the linear sorption approach; the output from such modelling is strongly dependent on the quality of thermodynamic data used to calculate chemical speciation. RWM is currently involved in collaboration with Andra on the development of their Thermodynamic database, ThermoChimie. This task relates to the Nuclear Energy Agency TDB. The first phase of the Nuclear Energy Agency TDB project was initiated in 1984 to fulfil the need for a high quality, internationally recognised and quality assured database for modelling purposes. RWM partially fund this project in collaboration with other international organisations under the auspices of the Nuclear Energy Agency to produce high-quality, peer reviewed and internally consistent datasets for elements of interest in the geological disposal of radioactive waste. Following the completion of Phase V in March 2018, the project is now entering Phase VI.					
Research Driver					
To develop and maintain a consistent set of thermodynamic data to support safety assessments.					
Research Objective					
Continuation of [1, Task 806] (Phase V) with the objective of identifying internationally recommended high quality thermodynamic data parameters for key elements and minerals and providing consistency with other programmes and a robust data trail by gaining international consensus.					
Scope					
The scope is yet to be determined.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Database update and maintenance.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information
Nuclear Energy Agency TDB project website https://www.oecd-nea.org/dbtdb/ .
1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

B7.1.2 ThermoChimie: Further Database Maintenance Including Updates from Reviews and Experiments on Elements of Importance within the Near Field and Geosphere

Task Number		80.1.002	**Status**	Ongoing	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Development and Maintenance of Thermodynamic Models			
Background					
A database with an enhanced user interface and up-to-date thermodynamic properties is required for key radionuclides and chemotoxic elements in the presence of cement and a variety of rock and mineral surfaces relevant to GDF scenarios (i.e. sorption coefficients, binding constants). The original thermodynamic database, HATCHES, developed by Nirex in the late 1980s, has now been withdrawn after a period of limited maintenance. Following a review to identify the best way forward in developing a TDB, RWM is currently involved in collaboration with Andra on the development of their thermodynamic database ThermoChimie. Collaboration with Andra is ongoing to jointly develop ThermoChimie to ensure consistency and validation of the thermodynamic data within the database and provide robust traceability during database development. In addition to funding the development of our thermodynamic dataset, RWM is a part-funder of a multi-national effort under the auspices of the Nuclear Energy Agency to produce high-quality, peer-reviewed, internally consistent datasets for elements of interest in the geological disposal of radioactive waste. The existence of internationally agreed, high quality thermodynamic data is of benefit to RWM as it provides access to internationally recognised, world-class data for the radionuclides which are critical for determining the safety of a GDF.					
Research Driver					
To develop and maintain a consistent set of thermodynamic data to support safety assessments.					
Research Objective					
To identify a consistent set of thermodynamic data to support the RWM programme.					
Scope					
To ensure that the thermodynamic database remains up-to-date and fit for purpose by having a supporting experimental programme.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Database update and maintenance.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are other publications relevant to this task [1].					

1 L. Duro, M. Grive, and E. Giffaut, *ThermoChimie, the ANDRA Thermodynamic Database*. MRS Proceedings, vol. 1475, no. Imrc11-1475-nw35-o71, 2012. [Online]. Available: https://www.cambridge.org/core/journals/mrs-online-proceedings-library-archive/article/div-classtitlethermochimie-the-andra-thermodynamic-databasediv/84065999D2A471F01F0CD05169B873E2.

B7.2 WBS 80.2 - Develop Generic Understanding of the Behaviour of Radionuclide and Non-Radionuclide Species in a GDF System

B7.2.1 International Knowledge Capture and Review of Radionuclide Behaviour in an Evaporite Setting

<table>
<tr><td>Task Number</td><td>80.2.001</td><td>Status</td><td>Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">RWM has developed a range of disposal system concepts and design specifications, and these are used to support our gDSSC (see the [1]). The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. The solubility of key radionuclides and their uptake onto rock surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst other factors). However, until a potential candidate site is identified the deep geological performance cannot be characterised. To aid preliminary assessments, three generic geological settings have previously been developed as examples of approaches that could be applied to post-closure assessments. Evaporite rock is one of the three generic geological settings. To date, significant international effort has focused on understanding the geochemistry of high salinity environments and the behaviour of radionuclides in high ionic strength media, thereby increasing the understanding of evaporitic rock as a potential host geology for a GDF (e.g. WIPP). There is a need, at the generic stage, for RWM to collate and review the state of knowledge regarding the siting of a GDF in an evaporite host rock.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To support the post-closure and disposal system safety cases by ensuring that RWM is aware of the current state of knowledge relevant to siting a GDF in a UK evaporite, drawing from the international community (e.g. WIPP, in particular) in relation to their ongoing studies.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To develop our understanding of radionuclide behaviour in conditions expected in an evaporitic environment based on a review of research completed, in progress or planned by RWM and international WMOs.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">Following a series of workshops and/or knowledge exchange programmes, a contractor report will be prepared to:
• Document and summarise the knowledge gaps and questions being addressed by current research within RWM and international WMOs relating to radionuclide behaviour in evaporitic host rocks;
• Record knowledge gaps and questions closed-out by past research undertaken by RWM and international WMOs; and
• Identify research needs relevant to RWM's programme (at both generic and site specific stages).</td></tr>
</table>

<table>
<tr><td colspan="6">This will be based on:
• A review of recommendations/conclusions in published reports, papers or technical notes by RWM and WMOs;
• Identification of knowledge gaps and outstanding questions not historically considered by RWM, and which are not currently planned to be evaluated; and
• Identification of research activities by WMOs that have advanced the knowledge base beyond RWM’s currently documented understanding.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A contractor report documenting the findings of the knowledge exchange programme, including recommendations for future research.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 2</td><td>SRL/TRL at Task End</td><td>SRL 3</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">For more information, see the WIPP website [2].
1 Radioactive Waste Management, Geological disposal: Overview of the generic disposal system safety case, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.
2 WIPP website. [Online]. Available: https://www.wipp.energy.gov/.</td></tr>
</table>

B7.2.2 Further Experimental/Modelling Study to Understand Radionuclide Behaviour in an Evaporite Setting

Task Number		80.2.002	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System			
Background					
RWM has developed a range of disposal system concepts and design specifications, and these are used to support our gDSSC (see the [1]). The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. The solubility of key radionuclides and their uptake onto rock surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst other factors). However, until a potential candidate site is identified the deep geological performance cannot be characterised. To aid preliminary assessments, three generic geological settings have previously been developed as examples of approaches that could be applied to post-closure assessments. Evaporite rock is one of the three generic geological settings. To date, significant international effort has focused on understanding the geochemistry of high salinity environments and the behaviour of radionuclides in high ionic-strength media, thereby increasing the understanding of evaporitic rock as a potential host geology for a GDF (e.g. WIPP). There is a need, at the generic stage, for RWM to collate and review the state of knowledge regarding the siting of a GDF in an evaporite host rock. This task has been developed to progress the recommendations of Task 80.2.001 (i.e. to address any identified knowledge gaps following the completion of knowledge exchange on evaporite research).					
Research Driver					
To provide further data and thereby increase understanding of individual processes shown to have significant knowledge gaps with respect to the safety case. To use these new data to develop models which more explicitly represent the different types of geological environment, with a view to identifying knowledge gaps in a site-specific scenario.					
Research Objective					
To address outstanding uncertainties in the safety case for a GDF situated in an evaporite host rock by undertaking experimental and modelling studies as defined by Task 80.2.001 and Task 80.2.003.					
Scope					
A detailed experimental and/or modelling programme to address knowledge gaps in data. Scope will be defined based on the outcomes of Task 80.2.001 and Task 80.2.003.					
Geology Application					
Evaporite					
Output of Task					
A detailed experimental and/or modelling programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6

Further Information
For more information, see the WIPP website [2].

1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.

2 *WIPP website*. [Online]. Available: https://www.wipp.energy.gov/.

B7.2.3 Development of Thermodynamic Database Capabilities to Represent Evaporitic Environments

Task Number	80.2.003	Status	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System		

Background

RWM has developed a range of disposal system concepts and design specifications, and these are used to support our gDSSC (see the [1]). The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. The solubility of key radionuclides and their uptake onto rock surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst other factors). However, until a potential candidate site is identified, the deep geological performance cannot be characterised. To aid preliminary assessments, three generic geological settings have previously been developed as examples of approaches that could be applied to post-closure assessments. Evaporite rock is one of the three generic geological settings. Although the base-case assumption in an evaporite safety case is that the host rock is dry, it is necessary to consider variant scenarios including water intrusion into a GDF. A database with an enhanced user interface and up-to-date thermodynamic properties is required for key radionuclides and chemotoxic elements in the presence a variety of rock and mineral surfaces relevant to GDF scenarios (i.e. sorption coefficients, binding constants). The original thermodynamic database, HATCHES, developed by Nirex in the late 1980s, has now been withdrawn after a period of limited maintenance. Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed 'linear sorption', and it is generally argued that the approach is an adequate simplification for use in performance assessments. Thermodynamic modelling is used to build understanding of sorption processes and to confirm the adequacy of the linear sorption approach; the output from such modelling is strongly dependent on the quality of thermodynamic data used to calculate chemical speciation. RWM is currently involved in collaboration with Andra on the development of their Thermodynamic database, ThermoChimie, as well as the Nuclear Energy Agency TDB. However, further work is required to identify a suitable database with up-to-date thermodynamic properties for key radionuclides and chemotoxic elements under conditions relevant to a generic evaporitic setting (i.e. sorption coefficients, binding constants in high ionic strength media).

Research Driver

There is a need to develop thermodynamic models which more explicitly represent the different types of generic geological environment. This task will develop and maintain a consistent set of thermodynamic data for radionuclide behaviour in high ionic strength groundwater to support safety assessments and to provide further data and understanding on individual processes shown to have significant knowledge gaps with respect to the safety case.

Research Objective

To identify and ensure access to a consistent set of thermodynamic data to support RWM's research programme and use this data to undertake modelling studies to address knowledge gaps in the post-closure safety case.

Scope					
This task will seek to develop and maintain a TDB, based on recommendations from other WMOs, for radionuclide behaviour in high ionic-strength media. This will be coupled to a detailed modelling programme, the scope of which will be defined by the recommendations of Task 80.2.001 and Task 80.2.002.					
Geology Application					
Evaporite					
Output of Task					
The development and application of a thermodynamic database for high ionic-strength reaction modelling and a report documenting the applicability of the data with respect to the safety case.					
SRL/TRL at Task Start	SRL 1	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5
Further Information					
For more information on the Thermodynamic Database, see: TDB project website https://www.oecd-nea.org/dbtdb/ and https://www.thermochimie-tdb.com . There are other publications relevant to this task [2].					

1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.

2 L. Duro, M. Grive, and E. Giffaut, *ThermoChimie, the ANDRA Thermodynamic Database*. MRS Proceedings, vol. 1475, no. Imrc11-1475-nw35-o71, 2012. [Online]. Available: https://www.cambridge.org/core/journals/mrs-online-proceedings-library-archive/article/div-classtitlethermochimie-the-andra-thermodynamic-databasediv/84065999D2A471F01F0CD05169B873E2.

B7.2.4 Review of High-solubility Radionuclides in the Inventory

<table>
<tr><td colspan="2">Task Number</td><td>80.2.004</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Quantified estimates of the inventory for geological disposal are needed to support development of the geological disposal system for the UK’s higher activity radioactive wastes. The UKRWI provides the basis for these estimates and contains an extensive amount of data. These data require some modification or enhancement before they can be used in RWM’s generic design and safety assessment at the waste package level. A Derived Inventory has therefore been developed from the UKRWI to provide the required dataset. Radionuclides such as chlorine-36 (Cl-36) and iodine-129 (I-129) present a challenge to the safety case and are generally considered to have unlimited solubility. A minimisation of uncertainty and reduction in conservatisms surrounding the treatment of these radionuclides in the inventory (e.g. location, volume, waste types, packaging) will increase confidence in post-closure assessments.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">Cl-36 and I-129 are expected to be highly soluble and mobile in the geosphere, thus a review of their treatment in the inventory may reduce uncertainties in their impact on a post-closure safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To support safety case development by reducing pessimism in the volumes of chlorine and iodine in the disposal inventory and thereby reduce pessimisms over the mobility of these radionuclides.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">An assessment of the potential for a realistic reduction in conservatisms within the inventory for high solubility radionuclides based on feedback from the gDSSC and waste packaging disposability assessment. The output of this task will support updates to the Derived Inventory.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B7.2.5 Mechanistic Study of Sorption Processes in UK Engineered Barrier System Components: Clays

<table>
<tr><td colspan="2">Task Number</td><td>80.2.005</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">An understanding of radionuclide behaviour in the EBS is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWM's programme has been developed to build confidence in the illustrative concepts adopted. This is being achieved through commissioning dedicated studies or by contributing to international initiatives. RWM considers that the mechanisms of radionuclide transport through engineered barriers are well understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. Whilst bentonite-based materials have not been studied extensively in the UK, data from overseas programmes are considered by RWM to be sufficient for current requirements. As concept development progresses specific details related to UK clay based backfill materials will be required.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support HLW/Spent Fuel concept development by demonstrating understanding of the processes by which radionuclides are taken up by UK clay based backfill materials.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake a focussed mechanistic study on clay mineral phases for a range of radionuclides.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake a step-wise research programme to extend the knowledge base to UK clay based backfill materials and a range of radionuclides. Laboratory-scale experiments may be undertaken at the nanometre scale using the state-of-the-art Science & Technology Facilities Council (STFC) facilities. Experiments may include natural and anthropogenic analogues materials (e.g. naturally occurring bentonite).</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A detailed experimental and/or modelling programme to be undertaken, followed by a report documenting the applicability of the data with respect to the safety case.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B7.2.6 Mechanistic Study of Sorption Processes in UK Engineered Barrier System Components: Corrosion Products

Task Number	80.2.006	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System		

Background

An understanding of radionuclide behaviour in the EBS is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWM's programme has been developed to build confidence in the illustrative concepts adopted. This is being achieved through commissioning dedicated studies or by contributing to international initiatives. RWM considers that the mechanisms of radionuclide transport through engineered barriers are well understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. Whilst bentonite-based materials have not been studied extensively in the UK, data from overseas programmes are considered by RWM to be sufficient for current requirements. As concept development progresses specific details related to UK clay-based backfill materials will be required. In addition, there will be other materials within the EBS which have the potential to sorb radionuclides (e.g. container corrosion products). This task will consider sorption properties of EBS corrosion products.

Research Driver

To support HLW/Spent Fuel concept development by demonstrating understanding of the processes by which radionuclides are taken-up by EBS corrosion products.

Research Objective

- To undertake a focussed mechanistic study for a range of radionuclides.
- To determine whether the distribution coefficient (K_d) approach for sorption processes is an appropriate simplification and also to identify situations where it is inappropriate, including consideration of the presence of container corrosion products.

Scope

To undertake a step-wise research programme to extend the knowledge base to EBS corrosion products using a range of radionuclides. Laboratory-scale experiments may be undertaken at the nanometre scale using the state-of-the-art STFC facilities. Experiments may include natural and anthropogenic analogue materials.

Geology Application

N/A

Output of Task

A detailed experimental and/or modelling programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information
There are other publications relevant to this task [1].

1 T. Marshall, K. Morris, G. Law, J. Frederick, W. Mosselmans, P. Bots, S. Parry, and S. Shaw, *Incorporation and retention of 99-Tc(IV) in Magnetite under High pH conditions*. Environmental Science Technology, no. 48, pp. 11853–11862, 2014.

B7.2.7 Review and Testing of Sorption Processes in Clay Backfills

<table>
<tr><td colspan="2">Task Number</td><td>80.2.007</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">An understanding of radionuclide behaviour in the EBS is important in order for appropriate treatment to be incorporated into performance assessments. During the current preparatory studies phase, RWM's research programme has been developed to build confidence in the feasibility of the GDF. This is being achieved through commissioning dedicated studies or by contributing to international initiatives. RWM considers that the mechanisms of radionuclide transport through engineered barriers are well understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. Whilst not studied extensively in the UK, research into the properties of clays, such as bentonite, has been conducted overseas in support of the development of disposal concepts for spent fuel. In the UK, however, the spent fuel disposal concept has not yet been finalised and further work is required on the sorption properties of possible clay formulations once they have been identified as potentially suitable on the basis of their thermal properties. This task requires input from concept development and the High Heat Integrated Project in order to narrow down which clay minerals to study.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To identify a small range of candidate EBS materials for further evaluation to be used in support of developing the HLW/Spent Fuel disposal concept.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine whether suitable buffer/backfill clay formulations can be identified that provide the necessary safety function of limiting radionuclide mobility and preventing container corrosion, in addition to being resistant to long-term thermal degradation or hydraulic erosion.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">A detailed experimental and/or modelling programme to be undertaken followed by Characterisation of a range of clay-based buffer/backfill formulations and selection of a small range of candidate EBS materials to take forward for further evaluation, with results to be used in support of developing the HLW/Spent Fuel disposal concept.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A contractor report documenting the applicability of the data with respect to the safety case.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task [1].
1 P. Mandaliev, T. Stumpf, J. Tits, R. Dahn, C. Walther, and E. Wieland, *Uptake of Eu(III) by 11 Å Tobermorite and Xonotlite: A TRLFS and EXAFS study*. Geochimica and Cosmochimica Acta, vol. 75, pp. 2017–2029, 2011. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0016703711000159#:~:text=The%20uptake%20of%20Eu%28III%29%20by%20crystalline%20calcium%20silicate,and%20extended%20X-ray%20absorption%20fine%20structure%20%28EXAFS%29%20spectroscopy..

B7.2.8 Data Elicitation for High Priority Radionuclide Sorption Parameters (e.g. Tc, U and other Long-lived HLW Radionuclides)

Task Number		80.2.008	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System			
Background					
To agree the likely range of data required for parameters to be used in the safety case, we use a structured process of data elicitation, whereby a trained team of international experts use a controlled process to derive PDFs for the parameters. A previous task ([1, Task 898]) will have developed an accepted and validated methodology for data elicitation and there is a subsequent need (covered by this task) to apply the methodology to certain key parameters.					
Research Driver					
To support safety assessments by conducting expert data elicitation for high priority sorption parameters (e.g. Tc, U and other long-lived HLW radionuclides) prior to site specific measurements being available.					
Research Objective					
To use data elicitation to support the quantification and treatment of uncertainty for sorption parameters in a manner that feeds effectively into the safety case throughout the siting process.					
Scope					
To elicit from a suitably qualified expert panel and utilising approved methodology, sorption parameters (e.g. Tc, U and other long-lived HLW radionuclides) to feed into the safety case.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Report documenting newly elicited sorption parameters and their applicability in support of performance assessments.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are other publications relevant to this task [2].					

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Nirex, *A procedure for data elicitation in support of performance assessments*, Nirex Report N/132, 2006.

B7.2.9 Data Elicitation for Other Radionuclide Sorption Parameters

Task Number		80.2.009	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System			
Background					
Where international consensus does not exist for data required in the safety case we use a structured process of data elicitation, whereby a trained team of international experts use a controlled process to derive PDFs for the parameters. A previous task ([1, Task 898]) will have developed an accepted and validated methodology for data elicitation and there is a subsequent need (covered by this task) to apply the methodology to certain parameters.					
Research Driver					
To support safety assessments by conducting expert data elicitation for lower priority sorption parameters.					
Research Objective					
Continuation of Task 80.2.008, with the objective of using data elicitation to support the quantification and treatment of uncertainty in a manner that feeds effectively into the safety case throughout the siting process.					
Scope					
To elicit, from a suitably qualified expert panel and utilising approved methodology, sorption parameters for a range of lower priority radionuclides to feed into the safety case.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A report detailing newly elicited sorption parameters and their application in assessment models.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are other publications relevant to this task [2].					

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Nirex, *A procedure for data elicitation in support of performance assessments*, Nirex Report N/132, 2006.

B7.2.10 Development of an Advanced Mechanistic Understanding of Radionuclide Behaviour

<table>
<tr><td>Task Number</td><td colspan="2">80.2.010</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">An understanding of radionuclide behaviour within the EBS as well as in the wider geosphere is important in order for appropriate treatment to be incorporated into performance assessments. Additionally, as RWM's programme progresses, it will be important to build confidence that the individual components of the EBS are appropriately designed so that they work together to provide a system that functions correctly. Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be fully characterised. Nevertheless, advancing our mechanistic understanding of radionuclide interactions in a range of systems is important to fill knowledge gaps in the gDSSC (see the [1]).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the post-closure safety case by improving the mechanistic understanding of radionuclide interactions with EBS and geosphere components and anticipate the knowledge gaps in radionuclide behaviour upon transition to site-specific research.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To advance the mechanistic understanding of radionuclide behaviour using state-of-the-art analytical techniques.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">A range of projects are expected to be proposed for review by RWM. A broad range of projects will be developed in an exploratory bid to bolster a mechanistic understanding of radionuclide behaviour, key areas of research may include the following:
• Actinide (U, Pu) interactions with the EBS and geosphere.
• Uptake of radionuclides onto real-world samples (transitioning to site-specific research).
• Redox cycling and its impact on the long-term fate of radionuclides.
• Intrinsic colloid formation mechanisms.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A range of reports and journal papers, together with a cohort of experienced and capable people who can become involved in the GDF programme.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
This task will utilise the Research Support Office as a platform for university project procurement and development. 1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.

B7.3 WBS 80.3 - Develop Understanding of Radionuclide Behaviour in the EBS

B7.3.1 Further Demonstration of Chemical Containment

Task Number	80.3.001	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Radionuclide Behaviour in the EBS		
Background			
An understanding of radionuclide behaviour in the EBS is important in order for appropriate treatments to be incorporated into performance assessments. During the previous preparatory studies phase, RWM's programme was developed to build confidence in the concepts being considered. This was achieved through commissioning dedicated studies or by contributing to international initiatives. RWM considers that the mechanisms of radionuclide transport through engineered barriers are well understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. For cement-based EBS materials, an extensive dataset exists regarding radionuclide sorption in grouts/backfills (based on UK studies). Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. However, noting the Nirex public enquiry requirement for chemical containment to be an established technology, and an issue recently raised on RWM's Issues Register, radionuclide sorption on potential backfill materials is a topic of continued R&D focus. RWM has established an IPT to identify suitable backfill options. Previous work has been undertaken by RWM towards demonstrating chemical containment from both a mechanistic standpoint and in pilot laboratory studies and a series of final reports which address the issue and prove the concept are undergoing peer review. This is a continuation of this work based on the findings in the report and will act as a pilot study for *in situ* experiments.			
Research Driver			
To further support safety assessments by determining the extent to which backfill material (selection informed by the IPT) will reduce radionuclide mobility in the near field.			
Research Objective			
To determine whether the enhanced retardation and immobilisation of radionuclides by backfill materials means that aqueous radionuclide transport out of the EBS will not challenge the post-closure safety case.			
Scope			
This task will build upon work completed in a prior laboratory study. This is a multi-year project to demonstrate the principle of chemical containment by a cement conditioned near-field environment of a GDF using a range of radionuclides. This study will also seek to identify the effects of additive processes (e.g. microbes, colloids, cellulose degradation products) to investigate whether there are any synergistic effects which lead to a greater cumulative impact than might be expected on a simplistic additive basis.			
Geology Application			
HSR, LSSR			
Output of Task			
Experimental programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.			

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1], [2].					

1 Nirex, *Rock characterisation facility public inquiry - inspector's report*, APP1H09001M9412470 19, 1996.

2 M. Felipe-Sotelo, J. Hinchliff, N. Evans, P. Warwick, and D. Read, *Sorption of radionuclides to a cementitious backfill material under near-field conditions*. Mineralogical Magazine, vol. 76, pp. 3401–3410, Issue 8 2012. [Online]. Available: https://www.researchgate.net/publication/263119459_Sorption_of_radionuclides_to_a_cementitious_backfill_material_under_near-field_conditions.

B7.3.2 Mechanism of Chemical Containment in Aged Cements for a Range of Key Radionuclides

<table>
<tr><td>Task Number</td><td colspan="2">80.3.002</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Understanding of Radionuclide Behaviour in the EBS</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">An understanding of radionuclide behaviour in the EBS is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWM's programme has been developed to build confidence in the feasibility of the GDF. This is being achieved through commissioning dedicated studies or by contributing to international initiatives. RWM considers that the mechanisms of radionuclide transport through engineered barriers are well understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. For cement-based EBS materials an extensive dataset exists regarding radionuclide sorption in grouts/backfills (based on UK studies). Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. However, noting the Nirex public enquiry requirement for chemical containment to be an established technology, radionuclide sorption on potential backfill materials is a topic of continued R&D focus.
Prior work ([1, Task 416]) has employed hydrothermal ageing to accelerate the chemical evolution of NRVB over a 10-year period and understand the consequent changes in cement mineralogy. To date, limited research into radionuclide interactions with aged cements has been undertaken.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support safety assessments by demonstrating a mechanistic understanding of the processes by which radionuclides are taken up by cement phases.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake a focussed mechanistic study on aged cement phases and radionuclides of safety case importance.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To review the comparability of synthetic, aged cements and hydrothermally aged NRVB ([1, Task 416]) and undertake a step-wise research programme (experimental and modelling as appropriate) to extend the knowledge base for radionuclide interactions with aged cements (ageing process to be decided). Laboratory-scale experiments may include materials from natural and anthropogenic analogues (e.g. naturally occurring C-S-H or reinforced concrete) utilising state-of-the-art STFC facilities which allow investigation at a nanometer scale.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A detailed experimental and/or modelling programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [2]–[4]

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 G. Baston, M. Cowper, and T. Marshall, *Sorption of Np, Zr and Sn onto Leached and Hydrothermally-aged NRVB*, Serco, Contractor Report SERCO/TAS/002097/001, 2010.

3 G. Baston, M. Cowper, and T. Marshall, *Sorption of U(VI) onto Leached and Hydrothermally-Aged NRVB*, Serco, Contractor Report SA/ENV-0959, Issue 2, 2010.

4 Radioactive Waste Management, *Geological disposal: Behaviour of radionuclides and non-radiological species in groundwater status report*, RWM Report DSSC/456/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-behaviour-of-radionuclides-and-non-radiological-species-in-groundwater/.

B7.4 WBS 80.4 - Develop Understanding of Radionuclide Behaviour in the Geosphere

B7.4.1 High Solubility Radionuclide Sinks in the Geosphere

Task Number	80.4.001	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Radionuclide Behaviour in the Geosphere		
Background			
Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be fully characterised. Radionuclides such as Cl-36 and I-129 present a challenge to the safety case and are generally considered to have unlimited solubility. However, redox reactions, co-precipitation, sorption and complexation have all been demonstrated to influence the speciation, solubility and transport of these radionuclides under certain conditions. There may be features of I and Cl geochemistry that will retard their transport through the geosphere but are not currently captured in the Environmental Safety Case. In order to limit knowledge gaps in the interactions of these radionuclides in a UK site-specific context, and gain an increased understanding of the rate of transport of these radionuclides, further experimentation is necessary at the generic phase to increase understanding of potential sinks for high solubility species. RWM has recently commissioned a PhD studentship (NDA ICASE) for strategic research into iodine-129 sinks in the geosphere.			
Research Driver			
To support safety case development by building an understanding of high solubility radionuclides (e.g. I-129, Cl-36) in a GDF and their subsequent fate in order to identify consequences that need to be considered in the safety case.			
Research Objective			
To consolidate knowledge and develop a “cradle-to-grave” understanding of the migration and fate of I-129 and Cl-36 from a GDF.			
Scope			
To carry out a review of research into I-129 and Cl-36 interactions in the geosphere and the EBS, followed by execution of an experimental programme, targeting key environmental variables, which control the transport and retardation of these high solubility radionuclides. Examples of research avenues include the following: • Biotransformation and/or incorporation into microbial biomass. • Mineral incorporation (extent, reversibility and susceptibility for competition from major ions). • Speciation analysis (development of tools for determination of different form of I). The task encompasses the systematic evaluation of the results of short-term experimental studies in predicting the long-term biogeochemical behaviour and biological availability of these key radionuclides.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
Review of the literature, execution of experimental programme and a report documenting the applicability of the data with respect to the safety case.			

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					

B7.4.2 Towards a Mechanistic Understanding of the Long Term Mobility and Fate of Technetium-99

Task Number		80.4.002	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Understanding of Radionuclide Behaviour in the Geosphere			
Background					
An understanding of radionuclide behaviour within the EBS as well as the wider geosphere is important in order for appropriate treatment to be incorporated into performance assessments. As RWM's programme progresses, it will be important to build confidence that the individual components of the EBS work together to provide a system that functions correctly. Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be fully characterised. An understanding of the long-term fate of redox-active radionuclides such as technetium-99 (Tc-99) under GDF relevant conditions is important for post-closure safety assessments. This task aims to produce a review of current work in the field of Tc-99 behaviour in the EBS and the geosphere, and instigate an experimental programme to close knowledge gaps and progress the “cradle to grave” understanding of the fate of Tc-99.					
Research Driver					
To review the state of knowledge surrounding the fate of Tc-99 in the EBS and geosphere (concept specific, where appropriate) and support the gDSSC by developing an improved understanding of the long-term fate of Tc-99 in the near and far field.					
Research Objective					
To develop an improved mechanistic and molecular scale understanding of the long-term fate of Tc-99 (e.g. redox cycling, sorption, microbial processes, etc.)					
Scope					
The task will comprise a review of studies undertaken concerning the environmental mobility of Tc-99 and the development and execution of a detailed experimental to address knowledge gaps.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Literature review and experimental programme to be undertaken, followed by a report documenting the applicability of the data with respect to the safety case.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1]. 1 N. Masters-Waage, K. Morris, J. R. Lloyd, S. Shaw, J. F. W. Mosselmans, C. Boothman, P. Bots, A. Rizoulis, F. R. Livens, and G. Law, *Impacts of repeated redox cycling on technetium mobility in the environment*. Environmental Science and Technology, vol. 518, pp. 14301–14310, Issue 24 2017. [Online]. Available: https://pubs.acs.org/doi/10.1021/acs.est.7b02426.					

B7.4.3 Understanding the Impact of Groundwater Chemistry Fluxes on Radionuclide Transport and Sorption

<table>
<tr><td colspan="2">Task Number</td><td colspan="2">80.4.003</td><td>Status</td><td>Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Understanding of Radionuclide Behaviour in the Geosphere</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. To aid preliminary assessments, three generic geological settings have previously been developed as examples of approaches that could be applied to post-closure assessments (LSSR, HSR and Evaporites). Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed ‘linear sorption’, and it is generally argued that it is a valid approximation where the concentration of dissolved contaminant is significantly lower than the concentration of sorption sites. This approach is called the K_d approach with K_d being the distribution ratio. The current working assumption is that the K_d approach is an adequate simplification for use in performance assessment. Over the lifetime of a GDF, groundwater may be subject to chemical fluxes and/or transient chemical disequilibria. An understanding of the impact of changing groundwater chemistry upon radionuclide solubility and sorption/desorption in each of the generic geological settings is important for the post-closure safety assessment.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the post-closure safety case by improving understanding of the long-term fate of radionuclides under a range of dynamic groundwater chemistries and anticipate the knowledge gaps in radionuclide behaviour upon transition to site-specific research.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To gain a mechanistic understanding of the long-term mobility and fate of radionuclides in the geosphere following chemical and/or redox disequilibria in groundwaters.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To develop an experimental and/or modelling programme to determine the impact of transient groundwater chemistries upon radionuclide retention in each of the generic geological settings.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A detailed experimental and/or modelling programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B7.5 WBS 80.5 - Develop Understanding of Other Influences on Radionuclide Behaviour

B7.5.1 The Role of Microbes in Different Disposal Concepts and its Impact on Performance Assessment Modelling

<table>
<tr><td>Task Number</td><td>80.5.001</td><td>Status</td><td>Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Develop Understanding of Other Influences on Radionuclide Behaviour</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Ensuring that an EBS will perform its desired functions requires integration – of an iterative nature – of the following: site-specific information; information on the waste properties; understanding of material properties and performance; and in-situ and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM's programme develops it will be important to build confidence that the individual components within the near field, such as the various waste modules or individual barriers, work together to provide a system that functions correctly. Within this research sub-topic RWM considers additional processes to those already discussed above, which overlap with other key research areas (such as radiation effects, gas generation, waste package longevity, and wasteform degradation) that could impact on near-field evolution.

RWM recognises that microbes could potentially impact upon radionuclide transport in the EBS. Microbes will be present in the GDF environment; some species may be present naturally in the host rock, whilst others may be introduced from the surface during GDF construction and operation. Microbial processes have the potential to alter the near-field chemistry and to promote corrosion and other degradation processes. Internationally, considerable work has been carried out to understand and quantify microbial influences on many near-field evolution processes. The overall influences of microbial activity on the performance of an EBS are complex and dependent (amongst other things) on the disposal concept and geological setting; however, there is still considerable uncertainty concerning the impact of microbial processes on redox-sensitive radionuclides and the impact of microbes at different points and interfaces in different disposal concepts.

Following on from the completion of the EC MIND project, and the review of microbial effects on repository performance [1], this task comprises a review of research into microbial effects on repository performance in order to consolidate RWM's knowledge base in support of the [2]. This project has an emphasis on quantifying specific measurable impacts of microbes on the safety cases under repository conditions to develop understanding of microbes and their representation in safety case performance assessment models.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To support safety assessments by determining the extent to which microbes have the potential to alter the chemical and physical form of radionuclides in concept–specific scenarios (for example, by utilising some elements as nutrient sources and altering the surrounding environment, e.g. redox processes).</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To synthesise knowledge and identify outstanding uncertainties in the safety case surrounding the impact of microbes at different points and interfaces in a range of disposal concepts and couple this understanding to performance assessment modelling.</td></tr>
</table>

<table>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To review knowledge regarding microbial processes in GDF relevant conditions and the controls that these have upon radionuclide behaviour. A 6-part report is envisaged – one section for each disposal concept (i.e. HHGW/LHGW in HSR, LSSR or an Evaporite setting). The review should include, amongst other priority redox-sensitive radionuclides, the role of microbes in the cycling, speciation and transport of C-14.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Generation of a synthesis report in microbial understanding and a proposed experimental programme to feed Task 80.5.002.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">For more information, see https://www.mind15.eu/ . This is a wide-ranging review and experimentation may be brought forward as necessary.

1 P. Humphreys, J. West, and R. Metcalfe, Microbial Effects on Repository Performance, Quintessa, Contractor Report QRS-1378Q-1, Version 3.0, 2010. [Online]. Available: http://eprints.hud.ac.uk/7613/1/Microbial%5C_Effects%5C_on%5C_Repository%5C_Performance.pdf.
2 Radioactive Waste Management, Geological disposal: Overview of the generic disposal system safety case, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.</td></tr>
</table>

B7.5.2 Further Experimental Studies to Understand the Role of Microbes in Different Disposal Concepts

Task Number	80.5.002	**Status**	Start date in the future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		
Background			
Ensuring that an EBS will perform its desired functions requires integration – of an iterative nature – of the following: site-specific information; information on the waste properties; understanding of material properties and performance; and *in-situ* and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM's programme develops it will be important to build confidence that the individual components within the near field, such as the various waste modules or individual barriers, work together to provide a system that functions correctly. Within this research sub-topic RWM considers additional processes to those already discussed above, which overlap with other key research areas (such as radiation effects, gas generation, waste package longevity, and wasteform degradation) that could impact on near-field evolution. RWM recognises that microbes could potentially impact upon radionuclide transport in the EBS. Microbes will be present in the GDF environment; some species may be present naturally in the host rock, whilst others may be introduced from the surface during GDF construction and operation. Microbial processes have the potential to alter the near-field chemistry and to promote corrosion and other degradation processes. Internationally, considerable work has been carried out to understand and quantify microbial influences on many near-field evolution processes. The overall influences of microbial activity on the performance of an EBS are complex and dependent (amongst other things) on the disposal concept and geological setting; however, there is still considerable uncertainty concerning the impact of microbial processes on redox-sensitive radionuclides and the impact of microbes at different points and interfaces in different disposal concepts. Following on from the completion of the EC MIND project, and the review of microbial effects on repository performance [1], this task comprises a review of research into microbial effects on repository performance in order to consolidate RWM's knowledge base in support of the [2]. This project has an emphasis on quantifying specific measurable impacts of microbes on the safety case under repository conditions to develop understanding of microbes and their representation in safety case performance assessment models.			
Research Driver			
To support safety assessments by determining the extent to which microbes have the potential to alter the chemical and physical form of radionuclides in concept–specific scenarios (for example, by utilising some elements as nutrient sources and altering the surrounding environment, e.g. redox processes).			
Research Objective			
To address outstanding uncertainties surrounding the impact of microbes at different points and interfaces in a range of disposal concepts and couple this understanding to performance assessment modelling.			

Scope

A detailed experimental and/or modelling programme to address gaps in data. Scope will be defined based on the outcomes of Task 80.5.001. Informed by the EC MIND project, experimental work could include (but is not limited to) studies to widen the understanding of microbial activity within bentonites; the impact of microbial sulfidation/sulfate-reducing bacteria on corrosion processes, radionuclide behaviour, mineral transformations and pathways to immobilisation; as well as organic degradation pathways and consequent impacts on radionuclide mobility. Dedicated work on scale-up experiments that mimic repository conditions and/or *in-situ* experiments at URLs may also fall under the scope of additional experimentation.

Geology Application

HSR, LSSR, Evaporite

Output of Task

A report documenting the applicability of the data with respect to the safety case.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information

Experimentation may be brought forward depending on the outcomes of Task 80.5.001.

1 P. Humphreys, J. West, and R. Metcalfe, *Microbial Effects on Repository Performance*, Quintessa, Contractor Report QRS-1378Q-1, Version 3.0, 2010. [Online]. Available: http://eprints.hud.ac.uk/7613/1/Microbial%5C_Effects%5C_on%5C_Repository%5C_Performance.pdf.

2 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.

B7.5.3 Determine the pH Limit for the Methanogenesis of Calcite

Task Number	80.5.003	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		

Background

A key component of the safety case for the disposal of radioactive waste is an understanding of radionuclide behaviour under a range of relevant conditions. Carbon-14, likely existing as carbonate in EBS-conditioned groundwater, is expected to precipitate as calcite due to the high calcium concentration in the near-field. Therefore, the mobility of carbonate (and thereby carbon-14) will be reduced in a cementitious engineered barrier system (see the Behaviour of Radionuclide and Non-radiological Species in Groundwater Report [1])Recent work [2] has provided some evidence that microbes may be able to utilise calcite as a carbon source for methanogenesis at or near pH 10. By the time the pH within the engineered barrier drops this low, it is expected that the majority of the carbon-14 will have undergone radioactive decay (although this will depend on the specific site, design and groundwater flow).

However, if microbes are able to utilise calcite for methanogenesis at higher pH values, this could potentially re-mobilise trapped carbon-14 before sufficient decay time has elapsed. This task therefore aims to follow up on the findings of recent work [2] and investigate the potential for microbes to utilise calcite in methanogenesis at relevant pH.

Research Driver

Carbon-14 is an important radionuclide for post-closure safety. Therefore, understanding its behaviour in the engineered barrier system is vital, particularly mechanisms which could reduce its migration.

Research Objective

The objective of this research programme is to understand whether there is a route for carbon-14 immobilised as calcite to be re-mobilised by microbial methanogenesis under relevant pH conditions.

Scope

The scope of work is to determine the conditions relevant to geological disposal under which calcite can be used for biotic methanogenesis.

Geology Application

LSSR, HSR

Output of Task

Contractor reports to which RWM contributed to.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6

Further Information

1 Radioactive Waste Management, *Geological Disposal: Behaviour of Radionuclides and Non-radiological Species in Groundwater*, RWM Report DSSC/456/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-behaviour-of-radionuclides-and-non-radiological-species-in-groundwater/.

2 R. Wormald, *Environmental limits of methanogenesis and sulphate reduction*, 2019. [Online]. Available: http://eprints.hud.ac.uk/id/eprint/35063/.

B7.5.4 Synthesis Report on Colloidal Understanding

Task Number	80.5.004	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		

Background

An understanding of radionuclide behaviour in the EBS and the geosphere is important in order for appropriate treatments to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by WMOs in other countries, as well as by our own work. This work area also includes R&D on the impact of colloids on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they could affect the migration of radionuclides in different disposal concepts.

Research Driver

To support safety assessments by developing an improved understanding of whether colloids will significantly affect radionuclide mobility in either the near field or the geosphere.

Research Objective

To compile a summary of research to determine the following:

- A conceptual basis (including tools and techniques) to represent colloids in the gDSSC (see the [1]).
- Whether or not colloidal processes present a significant challenge to disposal concepts (for example, due to the low rate of colloid formation and slow migration from bentonite).
- If the stability of complexes formed between repository-relevant radionuclides and colloids is sufficient to significantly enhance radionuclide transport through the geosphere.
- Whether reversibility in the binding of radionuclides by colloids lessens concerns over their enhanced migration through the geosphere.
- A methodology for the sampling and characterisation of colloids that will be beneficial during the site characterisation phase of the UK geological disposal programme.

Scope

To produce a summary report consolidating understanding gained from a variety of projects involving RWM regarding colloids and their potential impact on radionuclide behaviour (including the EC BELBaR project [2, Task 754], the Grimsel-based Colloid Formation and Migration experiment [2, Task 755] and related studies ([2, Task 753] and [2, Task 756]). Other international work will also be included. This will inform the experimental programme proposed by Task 80.5.005.

Geology Application

HSR, LSSR, Evaporite

Output of Task

A report documenting the summary of understanding and a review of relevant literature/projects.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					

There are other publications relevant to this task [3], [4]. For more information, see: http://www.grimsel.com/gts-phase-vi/cfm-section/cfm-introduction .

1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.

2 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

3 BELBaR, *Bentonite Erosion: Effects on the Long-term Performance of the Engineered Barrier and Radionuclide Transport (BELBaR)*, 2016. [Online]. Available: https://cordis.europa.eu/project/id/295487/reporting.

4 M. Kelly, F. Hunter, and S. Swanton, *Treatment of colloids in post-closure safety assessment*, SERCO / TAS / 002924 / 02, 2012.

B7.5.5 Further Understanding of the Effect of Colloids on Radionuclide Mobility

Task Number	80.5.005	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		
Background			
An understanding of radionuclide behaviour in the EBS and the geosphere is important in order for appropriate treatments to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by WMOs in other countries, as well as by our own work. This work area also includes R&D on the impact of colloids on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they could affect the migration of radionuclides. To date, considerable international effort has focussed on understanding the impact of colloids derived from clay-based EBS materials such as bentonite. RWM has had significant involvement in the Colloid Formation and Migration experiment in the URL at Grimsel and the (now complete) EC BELBaR project. However, colloids may originate from other materials that might be present in the disposal system (the wasteform, cementitious backfill, crushed rock, sand, iron corrosion products, etc.) or from the geosphere (e.g. humic acids). Knowledge gaps also exist surrounding the formation and stability of 'intrinsic' rather than 'carrier' colloids.			
Research Driver			
To further our understanding of whether: • Colloids generated within the disposal system (including the wasteform) will significantly increase radionuclide mobility through the EBS for the range of RWM concepts; • Colloids generated within the disposal system, or carried within natural groundwaters, will significantly increase radionuclide mobility through the geosphere for the range of RWM concepts.			
Research Objective			
To address outstanding uncertainties in the safety case regarding colloidal effects on radionuclide mobility in different disposal concepts.			
Scope			
Informed by the review undertaken in Task 80.5.004, this task will comprise laboratory-scale experimental work to further understand the interactions between colloids and radionuclides, the mechanisms of sorption and de-sorption of radionuclides on the colloids and determination of sorption and de-sorption rates. The effect of chemical conditions and colloid size will be studied, with a view to applying the data to concept-specific and/or site-specific scenarios.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
A report documenting the applicability of the data with respect to the safety case.			

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1]. For more information, see: http://www.grimsel.com/gts-phase-vi/cfm-section/cfm-introduction 1 BELBaR, *Bentonite Erosion: Effects on the Long-term Performance of the Engineered Barrier and Radionuclide Transport (BELBaR)*, 2016. [Online]. Available: https://cordis.europa.eu/project/id/295487/reporting.					

B7.5.6 Update Synthesis Report on Colloidal Understanding

Task Number	80.5.006	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		
Background			
An understanding of radionuclide behaviour in the EBS and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by WMOs in other countries, as well as by our own work. This work area also includes R&D on the impact of colloids on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they could interact with radionuclides originating from evolving wasteforms and how they would affect the migration of radionuclides. This task is an update of a previous review, Task 80.5.004 following additional experimental and modelling programmes in Task 80.5.005.			
Research Driver			
To support safety assessments by developing an improved understanding of whether colloids will significantly affect radionuclide mobility in either the near field or the geosphere.			
Research Objective			
To update the prior summary of research to determine/expand the following: • A conceptual basis (including tools and techniques) to represent colloids in the gDSSC (see the [1]). • Whether or not colloidal processes present a significant challenge to disposal concepts (for example, due to the low rate of colloid formation and slow migration from bentonite). • If the stability of complexes formed between repository-relevant radionuclides and colloids is sufficient to significantly enhance radionuclide transport through the geosphere. • Whether reversibility in the binding of radionuclides by colloids lessens concerns over their enhanced migration through the geosphere. • A methodology for the sampling and characterisation of colloids that will be beneficial during the site characterisation phase of the UK geological disposal programme.			
Scope			
A revision of the summary report generated in Task 80.5.004 to pull together the understanding gained through a variety of projects focussed on colloids and their potential impact on radionuclide behaviour. This update is to incorporate understanding gained from completion of BELBaR, the current phase of the Colloid Formation and Migration experiment and understanding gained from multi-component large-scale experiments.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

An update to the synthesis report generated by Task 80.5.004 based on new experimental and/or modelling data.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [2]. For more information, see the BELBaR website [3] and the Grimsel Test Site website [4].					

1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.

2 M. Kelly, F. Hunter, and S. Swanton, *Treatment of colloids in post-closure safety assessment*, SERCO / TAS / 002924 / 02, 2012.

3 *BELBaR website*. [Online]. Available: https://www.skb.se/belbar/.

4 *Grimsel website*. [Online]. Available: https://grimsel.com/.

B7.5.7 Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour

<table>
<tr><td>Task Number</td><td>80.5.007</td><td>Status</td><td colspan="3">Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Develop Understanding of Other Influences on Radionuclide Behaviour</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The development of models to interpret experimental data is important to provide understanding of the processes which control radionuclide behaviour in the various barriers of a GDF and to support the GDF post-closure safety assessment. Thermodynamic models are important for the interpretation of experimental observations of radionuclide behaviour and prediction of behaviour over the long timescales relevant to a GDF (e.g. ~1 million years).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the safety case by developing a suite of detailed mechanistic models for the processes that control sorption and solubility.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To represent radionuclide sorption to a range of surfaces, and partitioning between phases, using detailed mechanistic models.
To develop modelling tools to represent the processes of sorption and solubility of radionuclides appropriately in the near and far-fields of a GDF.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To develop detailed mechanistic models for the processes controlling sorption and solubility using outputs and knowledge gained from experimental programmes of work, e.g. completed [1, Task 736], [1, Task 737], [1, Task 740], [1, Task 741], Task 80.5.005, Task 80.5.006 and Task 80.5.007</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Development of a process model and a report documenting its application.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [2]. For more information, see: http://hatches-database.com/ and http://www.thermochimie-tdb.com/ .

1 Nuclear Decommissioning Authority, Geological Disposal: Science and Technology Plan, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.
2 L. Duro, M. Grive, and E. Giffaut, ThermoChimie, the ANDRA Thermodynamic Database. MRS Proceedings, vol. 1475, no. Imrc11-1475-nw35-o71, 2012. [Online]. Available: https://www.cambridge.org/core/journals/mrs-online-proceedings-library-archive/article/div-classtitlethermochimie-the-andra-thermodynamic-databasediv/84065999D2A471F01F0CD05169B873E2.</td></tr>
</table>

B7.5.8 Update to Process Model for Colloidal / Microbial Processes

Task Number		80.5.008	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Understanding of Other Influences on Radionuclide Behaviour			
Background					
The development of models to interpret experimental data is important to provide understanding of the processes which control radionuclide behaviour in the various barriers of a GDF and to support the GDF post closure safety assessment. Thermodynamic models are important for the interpretation of experimental observations of radionuclide behaviour and prediction of behaviour over the long timescales relevant to a GDF (e.g. ~1 million years).					
Research Driver					
To support the safety case by developing a suite of detailed mechanistic models for the processes that control sorption and solubility.					
Research Objective					
To represent radionuclide uptake and partitioning in models to take account of colloidal and microbial affects.					
Scope					
Update to the mechanistic models of sorption and solubility controlling processes, developed in [1, Task 816], to incorporate microbial- and colloidal-mediated processes using knowledge gained from experimental programmes of work e.g. Tasks 383, [1, Task 754], 80.5.016, [1, Task 756]. Depending on the timing of this task the update may be based on site-specific data.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Updated process models and reports detailing their applications.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
This work follows on from that completed as part of Tasks 383, [1, Task 754], [1, Task 756].					

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

B7.5.9 Review of Superplasticisers for GDF Construction

<table>
<tr><td colspan="2">Task Number</td><td>80.5.009</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Understanding of Other Influences on Radionuclide Behaviour</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">An understanding of radionuclide behaviour in the EBS and geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex or ongoing works by WMOs in other countries, as well as by our recent work. A yet to be specified superplasticiser may be necessary for construction of the GDF, for example in shotcrete. Potential issues exist regarding organic superplasticisers, or their breakdown products, by enhancing radionuclide solubility in the near-field and potentially in the geosphere. Improved formulations and characterisation of their effect on radionuclide sorption and transport are required. Based on a previous task ([1, Task 764]) it is assumed that successful laboratory-scale trials will have been completed and an experiment in an Underground Research Laboratory will have been started on a newly formulated superplasticiser.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support safety assessments by determining the potential impact of superplasticisers in GDF construction upon radionuclide mobility.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To identify whether a different superplasticiser will be required during construction than any identified for use in waste encapsulation (through outputs of [1, Task 757] and [1, Task 761]).</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To identify functional requirements for superplasticisers required during construction and to review the results from [1, Task 757] and [1, Task 761] to determine whether any superplasticiser identified during these tasks will meet construction requirements.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report documenting a review of outputs from prior tasks and recommendations for GDF construction.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [2], [3].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 M. Hayes, M. Angus, and R. Garland, *Current Status Paper on the Potential use of Superplasticisers in a Geological Disposal Facility*, NNL, Contractor Report (12) 11905, Issue 4, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/superplasticiser-position-paper-rwmd-comments-issue-4-approved.

3 A. Clacher, G. Baston, F. Glasser, G. Jauffret, and S. Swanton, *Effects of superplasticiser on radionuclide solubility*, AMEC 006180, 2013.

B7.5.10 Review of Organic Additives to Cement Powders (e.g. Grinding Agents)

Task Number		80.5.010	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Understanding of Other Influences on Radionuclide Behaviour			
Background					
An understanding of radionuclide behaviour in the EBS and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by WMOs in other countries, as well as by our own work. Considerable effort has focussed on the potential role of organic superplasticisers as additives to grout formulations and their potential role in radionuclide mobilisation in the near-field and the geosphere. However, commercial cement powders contain other proprietary materials for which there is little understanding of their ability to interact with radionuclides. Potential issues exist regarding these materials and this task will investigate whether further work is required. In addition, other potential complexants may be present in decommissioning wastes deriving from, for example, chemical decontaminants (e.g. citrate) and strippable coatings.					
Research Driver					
To support safety assessments by determining the potential impact of non-cellulosic organic materials and inorganic decontamination agents on radionuclide mobility in the near field and to establish whether these effects could challenge the safety case.					
Research Objective					
To identify the composition and inventory of small quantities of organic/inorganic components of wastes which may have a significant impact on radionuclide mobility in a GDF.					
Scope					
To review previous and ongoing LoC assessments to determine if any experimental work is required on additional organic components of wasteforms (these are likely to include decontamination agents, cement additives/grinding aids, etc.).					
Geology Application					
N/A					
Output of Task					
Review report including recommendations for further work.					
SRL/TRL at Task Start	SRL 1	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 4
Further Information					
There are other publications relevant to this task [1]. 1 Nuclear Decommissioning Authority, *Geological Disposal: Radionuclide Behaviour Status Report*, NDA Report NDA/RWMD/034, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-radionuclide-behaviour-status-report-december-2010/.					

B7.5.11 Experimental Screening Study of Radionuclide Behaviour in the Presence of Potential Complexants

Task Number		80.5.011	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Understanding of Other Influences on Radionuclide Behaviour			
Background					
An understanding of radionuclide behaviour in the EBS and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by WMOs in other countries, as well as by our own work. Considerable effort has focussed on the potential role of organic superplasticisers as additives to grout formulations and their potential role in radionuclide mobilisation in the near-field and the geosphere. However, commercial cement powders contain other proprietary materials for which there is little understanding of their ability to interact with radionuclides (e.g. C-14, U/Ra, Cs-137, Am-241, Pu, Sr-90 and I-129). Potential issues exist regarding these materials and this task will investigate whether further work is required. In addition, other potential complexants may be present in decommissioning wastes deriving from, for example, chemical decontaminants (e.g. citrate) and strippable coatings. This task follows an initial review of the potential inventory and composition of such materials [1, Task 763].					
Research Driver					
To support safety assessments by determining the potential impact of non-cellulosic organic materials and inorganic decontamination agents on radionuclide mobility in the near field and to establish whether these effects could challenge the post-closure safety case.					
Research Objective					
To determine whether small quantities of organic/inorganic components of wastes have a significant impact on radionuclide mobility under representative near-field conditions of a GDF.					
Scope					
Scope will be determined by the output of Task 80.5.010 (Review of organic additives). An experimental research programme to assess the likely impact on radionuclide behaviour is anticipated.					
Geology Application					
N/A					
Output of Task					
Report.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4

Further Information
Further research would be necessary if results indicate that CDP are not a bounding case for organic influence on radionuclide behaviour, in which case an SRL of 5 will be required.

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

B7.5.12 Development of Process Model for Cellulose Degradation Product (CDP) Behaviour in the Near Field

Task Number	80.5.012	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		
Background			
An understanding of radionuclide behaviour in the EBS and the geosphere is important in order for appropriate treatments to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. RWM has a good understanding of the processes occurring within the EBS leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by WMOs in other countries, as well as by our recent work. This work area also includes R&D on the impact of organic complexants in order for RWM to decide whether there are processes which need to be represented in the performance assessment (and whether to gather additional data). Large UK and overseas R&D programmes have been investigating cellulose degradation under cementitious conditions and the consequential effects of CDP on radionuclide behaviour. Previous work by RWM has identified that for representative trivalent and tetravalent species their behaviour is bounded by the CDP isosaccharinic acid and that at levels likely to be present in the GDF there will be negligible enhancement of radionuclide transport. This task will identify the need for any further work, such as studies on key radionuclides (such as Pu and U) and will facilitate a more accurate representation of the processes of cellulose degradation, and subsequent migration and interaction behaviour of the CDP with radionuclides.			
Research Driver			
To support safety assessments by determining the potential impact of CDP on radionuclide mobility and to accurately represent these effects within the safety case.			
Research Objective			
• To determine whether isosaccharinic acid is a suitable model compound for cellulose degradation product complexation behaviour with key radionuclides. • To develop a suitably validated model to represent CDP behaviour in the EBS.			
Scope			
This project will: • Capture knowledge from ongoing projects looking at CDP and previous work programmes; and • Develop a process model to simulate cellulose degradation and subsequent interaction with radionuclides within the near-field. Model uncertainties and sensitive input parameters will be evaluated.			
Geology Application			

<table>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A literature review, followed by a detailed experimental and/or modelling programme to be undertaken and a report documenting the applicability of the data with respect to the safety case.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 3</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1], [2].
1 M. Randall, B. Rigby, O. Thompson, and D. Trivedi, Assessment of the Effects of Cellulose Degradation Products on the Behaviour of Europium and Thorium, Parts A and B, National Nuclear Laboratory, Contractor Report NNL (12) 12239, 2013.
2 G. Kuippers, C. Boothman, H. Bagshaw, M. Ward, R. Beard, N. Bryan, and J. R. Lloyd, The biogeochemical fate of nickel during microbial ISA degradation: Implications for nuclear waste disposal. Scientific Reports, vol. 8, p. 8753, 2018. [Online]. Available: https://www.nature.com/articles/s41598-018-26963-8.</td></tr>
</table>

B7.5.13 Update Process Model - Understanding of Cellulose Degradation Product (CDP) Metabolism

<table>
<tr><td>Task Number</td><td colspan="2">80.5.013</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Develop Understanding of Other Influences on Radionuclide Behaviour</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">An understanding of radionuclide behaviour in the EBS and geosphere is important in order for appropriate treatments to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. RWM has a good understanding of the processes occurring within the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by WMOs in other countries, as well as by our recent work.UK and overseas R&D programmes have been undertaken investigating cellulose degradation under cementitious conditions and the consequential effects of cellulose degradation products on radionuclide behaviour. RWM has developed a near-field component model which enables us to examine the effects of various parameters within an abstracted representation of the cementitious near-field of the ILW disposal concept. To date however, this model does not include representation CDP.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support safety assessments by developing the cementitious near-field component model to include the effects of CDP on radionuclide mobility and establishing whether these effects could challenge the safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine whether microbes can actively respire utilising CDP within the wasteform, thus having a beneficial impact by reducing radionuclide mobility by rapidly reducing available organic complexants.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Undertake an update to the process model generated in [1, Task 758] utilising the knowledge gained in [1, Task 751].</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Model update and supporting documentation.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">1 Nuclear Decommissioning Authority, Geological Disposal: Science and Technology Plan, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.</td></tr>
</table>

B7.5.14 NERC RATE Lo-RISE: Review of Findings

<table>
<tr><td>Task Number</td><td>80.5.014</td><td>Status</td><td colspan="3">Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Develop Understanding of Other Influences on Radionuclide Behaviour</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. Nevertheless, it is possible to study a range of near-surface environments which have been contaminated by natural and anthropogenic radionuclides in order to understand the speciation, transport and mobility of these radionuclides as they enter the food web. The project was established to determine whether the study of four near-surface UK sites would allow the key environmental and biological processes which control the movement of C-14, U/Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 to be understood and modelled. With the aim of facilitating the following:

• The development of reactive transport modelling for soils and sediments.
• Mechanistic modelling of plant uptake.
• An understanding of C-14 transport and food-web modelling in the marine environment.
• Reactive transport modelling in soils and sediments.
• An understanding of C-14 transport and food web modelling in the marine environment.

This task is a review of the outputs from the radionuclide behaviour aspects of the RATE Lo-RISE programme ([1, Task 786] - [1, Task 788]), which ran from 2014–2019.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support safety assessments by developing a mechanistic understanding of the effects of biogeochemical processes on radionuclide behaviour.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To further determine whether the understanding of the key environmental and biological processes which control the movement of C-14, U/Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 in the near-surface are the same as those at depth.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To assess outputs from the Lo-RISE programme of work and to incorporate these into process models.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Synthesis report contextualising the results of the Lo-RISE programme of work and a determination of the need for further work.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 2</td><td>SRL/TRL at Task End</td><td>SRL 3</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
This is an internal review of the outputs of a RWM/NERC/EA/STFC co-funded project, managed on behalf of NERC under the Radioactivity and the Environment programme by the British Geological Survey [2].

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 *NERC RATE website*. [Online]. Available: https://nerc.ukri.org/research/funded/programmes/rate/.

B7.5.15 Follow on from NERC RATE Lo-RISE: Review of Findings

Task Number	80.5.015	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		

Background

Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. Nevertheless, it is possible to study a range of near-surface environments which have been contaminated by natural and anthropogenic radionuclides in order to understand the speciation, transport and mobility of these radionuclides as they enter the food web. The project was established to determine whether the study of four near-surface UK sites would allow the key environmental and biological processes which control the movement of C-14, U/Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 to be understood and modelled. With the aim of facilitating the following:

- The development of reactive transport modelling for soils and sediments.
- Mechanistic modelling of plant uptake.
- An understanding of C-14 transport and food-web modelling in the marine environment.
- Reactive transport modelling in soils and sediments.
- An understanding of C-14 transport and food web modelling in the marine environment.

Following a review of the outputs from the radionuclide behaviour aspects of the RATE Lo-RISE programme ([1, Task 786] - [1, Task 788]), which ran from 2014–2019, this task will address outstanding knowledge gaps identified by Task 80.5.014.

Research Driver

To support safety assessments by developing a mechanistic understanding of the effects of biogeochemical processes on radionuclide behaviour.

Research Objective

To determine whether the understanding of the key environmental and biological processes which control the movement of C-14, U/Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 in the near surface are the same as those at depth.

Scope

The scope of this task will be defined by the outputs of Task 80.5.014. Further experimentation and/or modelling studies are anticipated.

Geology Application

HSR, LSSR, Evaporite

Output of Task

A detailed experimental and/or modelling programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5

Further Information
This is a follow-on project based on the outputs of a RWM/NERC/EA co-funded project, managed on behalf of NERC under the Radioactivity and the Environment programme by the British Geological Survey. In addition to the scientific objectives, the RATE programme had an objective of capacity building in the UK's academic institutions [2]. 1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/. 2 *NERC RATE website*. [Online]. Available: https://nerc.ukri.org/research/funded/programmes/rate/.

B7.5.16 Colloids: Colloid Formation and Migration (CFM) Experiment – Underground Rock Laboratory (URL) Hot Migration Study on the Effect of Bentonite Colloids on Radionuclide Mobility

Task Number	80.5.016	**Status**	Ongoing
WBS Level 4	Radionuclide Behaviour		
WBS Level 5	Develop Understanding of Other Influences on Radionuclide Behaviour		

Background

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. This work area includes research on the impact of naturally occurring colloids (microscopic particles with the potential to complex with radionuclides) on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they would affect the migration of radionuclides. A key area of international interest and effort is on understanding the impact of colloids derived from clay-based EBS materials such as bentonite due to its importance in applications such as the Swedish KBS-3 spent fuel disposal concept. This task investigates the formation of bentonite-derived colloids and their binding to a range of radionuclides in a real, fractured host-rock environment, followed by investigation of their migration and their subsequent collection and characterisation. The experiment is underway at the Grimsel Test Site in Switzerland.

Research Driver

To support safety assessments by developing an improved understanding of whether colloids will significantly affect radionuclide mobility in either the near-field or the geosphere.

Research Objective

- To understand whether colloidal processes present a significant challenge to bentonite-based disposal concepts (for example due to the rate of colloid formation and transport from bentonite).
- To investigate whether the stability of complexes formed between repository-relevant radionuclides and bentonite colloids, demonstrated in a realistic geological environment, is sufficient to significantly enhance radionuclide transport through the geosphere.
- To investigate whether reversibility in the binding of radionuclides by colloids lessens concerns over their potential to enhance radionuclide migration through the geosphere (for example whether, over the timescales relevant to radionuclide return to surface via groundwater, the radionuclides will partition with the aqueous phase and sorb onto geological materials, thereby becoming dissociated from the mobile colloidal phase).
- To utilise the ColloidFormation and Migration (CFM) experiment to provide methodology and expertise in the sampling and characterisation of colloids such as to be beneficial during site characterisation.

<table>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">RWM is participating in the 10-year, multi-partner CFM experiment at the Grimsel Test Site. The CFM project is dedicated to the study of: colloid formation / bentonite erosion, the groundwater / pore water mixing zone, colloid migration (filtration) and colloid-associated radionuclide transport. CFM is a well-established experiment with a proven track record of success in studying radionuclide behaviour in a well characterised shear zone under repository-relevant boundary conditions. The CFM project entered Phase 4 in 2019, comprising two discrete-borehole projects: the Long Term in-situ Test (LIT) and the In-situ Bentonite Erosion Test (i-BET). For LIT, the focus of Phase 4 is on the over-coring and sampling process. The i-BET study is now 500 days from emplacement with sampling and analysis ongoing.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Numerous reports and publications</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">For further information see: http://www.grimsel.com/gts-phase-vi/cfm-section/cfm-introduction.</td></tr>
</table>

B7.6 WBS 80.6 - Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-Radionuclide Research

B7.6.1 Understanding the Laboratory Capacity and Methodologies Required for Site Characterisation

Task Number	80.6.001	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research		
Background			
RWM has developed a range of disposal system concepts and design specifications, and these are used to support our gDSSC (see the [1]). The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. In the generic phase of the research programme, underpinning knowledge is limited by a lack of site-specific data. Following selection of candidate sites for a GDF, a programme of site-specific research will be needed to provide robust assurance of radionuclide behaviour and transport mechanisms for comparison against RWMs current knowledge base and assumptions. RWM is currently funding an ongoing programme of research in the development of experimental methodologies for measurement of site-specific and other safety-relevant radionuclide parameters. Following selection of candidate sites, adequate laboratory capacity and a detailed process understanding will be required to execute the next phase of the research programme.			
Research Driver			
To understand the experimental needs and laboratory capacity required to move beyond the generic phase following the selection of candidate sites and exploratory borehole drilling.			
Research Objective			
To develop a costed programme of research, including identifying the necessary laboratory capacity and equipment required to begin site-specific research following selection of a candidate geology.			
Scope			
To design an experimental programme that will provide data to underpin key assumptions in radionuclide behaviour that have been made at the generic stage. This will take the form of a high-level experimental workflow that will be executed following the initiation of sampling at a selected site. There is a need to identify whether a dedicated laboratory will be required to commence site-specific research, as well as how laboratory programme costs might vary between different siting scenarios (e.g. number of boreholes required, extent of study, etc.).			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			
Report documenting recommendations for the proposed laboratory capacity and experimental programme required for site characterisation based on prior proof of concept methodologies.			

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					

1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.

B7.6.2 Development of a Gated Workflow for Site-Specific Radionuclide Behaviour Analysis

Task Number		80.6.002	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research			
Background					
RWM has developed a range of disposal system concepts and design specifications, and these are used to support our gDSSC (see the [1]). The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. In the generic phase of the research programme, underpinning knowledge is limited by a lack of site-specific data. RWM is undertaking a medium-term programme of work to develop the methodologies that will be applied in a future site-specific programme to provide data to input into the safety case and to carry out measurements to fill data gaps of underpin safety arguments. Both modelling and experimental work are underway for priority safety radionuclides and non-radiological species where there are current data needs. Appropriate decision making, based on periodic influxes of site-specific data, will be necessary to efficiently drive a site-specific research programme.					
Research Driver					
To understand the decision-making process necessary following transition to a site-specific scenario and development of a high-level experimental programme in underpinning radionuclide behaviour.					
Research Objective					
Development of a gated, time-scaled work flow to aid experimental decision making, containing data freeze and or hold points as necessary.					
Scope					
Production of a work-flow diagram, containing hold-points and a decision making process to inform experimentation and sampling decisions following commencement of a site-specific research programme. Data quality objectives, outlining the type, quality and quantity of data to make strategic decisions should also be considered. This task should incorporate learning from overseas WMOs.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of the task will result in a report.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.					

B7.6.3 Procurement of Laboratory Equipment and Execution of a Site-Specific Experimental Programme

Task Number	80.6.003	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research		

Background

RWM has developed a range of disposal system concepts and design specifications, and these are used to support our gDSSC (see the [1]). The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. In the generic phase of the research programme, underpinning knowledge is limited by a lack of site-specific data. Following selection of candidate sites for a GDF, a programme of site-specific research will be needed to provide robust assurance of radionuclide behaviour and transport mechanisms for comparison against RWMs current knowledge base and assumptions.

RWM is currently funding an ongoing programme of research in the development of experimental methodologies for measurement of site-specific and other safety-relevant radionuclide parameters (Task 80.6.004) . Following selection of candidate sites, adequate laboratory capacity and a detailed process understanding will be required to execute the next phase of the research programme. This task follows on from Task 80.6.002, to initiate the procurement of adequate laboratory capacity in order to begin a site-specific programme of research.

Research Driver

To procure appropriate laboratory capacity/equipment in order to deliver upon RWM's site-specific programme of work to underpin key assumptions in radionuclide behaviour that have been made at the generic stage.

Research Objective

The initiation of site-specific experimental research into radionuclide behaviour following establishment of appropriate laboratory capacity and a detailed experimental programme.

Scope

This is a follow-on task from Task 80.6.002, once a site has been selected and borehole drilling planned:

- Development of commercial strategy, business case and associated procurement activities.
- Acquisition of laboratory space and equipment in line with the proposed experimental programme.
- Execution of the proposed experimental programme once a site has been selected and borehole drilling underway.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Experimental programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					
1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.					

B7.6.4 Development of Experimental Methodologies for the Measurement of Site-specific and other Safety Relevant Radionuclide Behaviour Parameters

Task Number	80.6.004	**Status**	Ongoing
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research		

Background

A key component of the safety case for the disposal of radioactive waste is an understanding of radionuclide behaviour under a range of relevant conditions. RWM, its predecessors and its supply chain have many years of experience in running research programmes to develop our understanding of radionuclide behaviour and to measure parameters used to underpin the numerical safety case. Our understanding at the generic phase is captured in the [1], its accompanying [2] and references therein. To date, a good understanding of the key processes that are likely to control the behaviour and transport of radionuclides and non-radiological species in groundwater has been developed. This understanding has been used both in the generic safety case and to underpin assessments of the disposability of proposed waste packaging solutions. An important aspect of the total system model used in the numerical assessment is the representation of uncertainty [3]. RWM uses a process of elicitation to develop PDFs, which are used in the probabilistic total system model.

Given the site-specific nature of groundwater species behaviour, it is anticipated that, in future, significant work will be required to underpin any site-specific safety case. This task aims to develop a programme of work to underpin the methodologies and approaches required in a site-specific evaluation, so that knowledge and understanding can be developed in a timely and cost-effective manner. The scope includes developing methodologies for acquiring site-specific radionuclide behaviour parameters, and may also include measurements to fill data gaps or to underpin safety arguments.

Research Driver

During site characterisation, RWM will need to investigate the behaviour of radionuclides under site-specific conditions and input tailored datasets into the environmental safety case and total system model. There is a need to understand the methodology and capability required for site-specific research.

Research Objective

To develop a medium-term programme of work, which will establish the methodologies that will be applied in a future site-specific experimental programme. Work will provide data to input into the safety case and carry out measurements to fill data gaps or underpin safety arguments. The overarching aim is to prepare RWM strategically for experiments that may be required to investigate radionuclide behaviour during site characterisation.

Scope

The scope of work could include, but should not necessarily be limited to the following:

- Identifying parameters that may be required in a future safety case to demonstrate understanding of radionuclide behaviour and how these parameters would be acquired.

- Methodologies for acquiring design and site-specific radionuclide behaviour parameters:
  - Development of techniques and approaches for measuring the sorption of key radionuclides to bentonite.
  - Development of through-diffusion techniques for measuring the key parameters that will be used to describe the migration of radionuclides through both lower strength sedimentary rocks and higher strength rock.
  - Development of methodologies for undertaking sorption measurements on site-specific geological materials.
  - Development of techniques for characterising samples from a drill-core, such as that might be acquired through a site characterisation programme.
  - Development of techniques to visualise porosity and relate this to a conceptual model for radionuclide transport.
- Measurements to fill data gaps or to underpin safety arguments:
  - Carrying out targeted sorption measurements on a broad range of cements, including encapsulation grouts and example backfill materials.
  - Carrying out sorption measurements on corrosion products.
  - The potential use of radionuclides to measure sorption behaviour of species which are hazardous in non-radiological form.

Geology Application					
LSSR, HSR					
Output of Task					
Contractor reports presenting the findings of project to which RWM contributed.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					

1 Radioactive Waste Management, *Geological Disposal: Behaviour of Radionuclides and Non-radiological Species in Groundwater*, RWM Report DSSC/456/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-behaviour-of-radionuclides-and-non-radiological-species-in-groundwater/.

2 Radioactive Waste Management, *Disposal system safety case: Data report*, RWM Report DSSC/422/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-disposal-system-safety-case-data-report/.

3 Radioactive Waste Management, *Methods for management and quantification of uncertainty*, RWM Report NDA/RWM/153, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/methods-for-management-and-quantification-of-uncertainty/.

B7.6.5 Further Development of Methodologies for Measurement of Site Specific and other Safety Relevant Radionuclide Behaviour Parameters

Task Number		80.6.005	**Status**	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research			
Background					
RWM has developed a range of disposal system concepts and design specifications, and these are used to support our gDSSC (see the [1]). The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. In the generic phase of the research programme, underpinning knowledge is limited by a lack of site-specific data. RWM is undertaking a medium-term programme of work to develop the methodologies that will be applied in a future site-specific programme to provide data to input into the safety case and to carry out measurements to fill data gaps in safety arguments. Both modelling and experimental work are underway for priority safety-related radionuclides and non-radiological species where there are current data needs. Following site-selection, further refinement of the proposed methodologies will be possible.					
Research Driver					
To support the post-closure safety case by developing methodologies for the measurement of site-specific behaviour parameters.					
Research Objective					
Further development of the proposed experimental methodologies to fill generic knowledge gaps following site-selection.					
Scope					
This task involves the design and execution of experimental methods for the measurement of site-specific radionuclide behaviour parameters. The scope of the task will be informed by the outputs of ongoing work and is yet to be determined.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Experimental programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
1 Radioactive Waste Management, *Geological disposal: Overview of the generic disposal system safety case*, RWM Report DSSC/101/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-overview-of-the-generic-disposal-system-safety-case/.					

B7.6.6 Develop Capability to Perform In-situ Experiments on Strongly Sorbing Elements

<table>
<tr><td colspan="2">Task Number</td><td>80.6.006</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In-situ experiments, which determine the rate of radionuclide migration through a host rock, are important to underpin laboratory experiments and build confidence in an environmental safety case. However, due to the low mobility of strongly-sorbing elements, their migration rate is often difficult to determine. This is a consequence of both a long travel time, meaning experiments must run for an extended duration, and high sorption propensity, meaning low concentrations in groundwater can often challenge detection limits. This problem is exacerbated in LSSR where diffusion rates are characteristically low. International WMOs are developing tools, equipment and techniques to improve the design and sensitivity of these experiments. RWM needs to maintain awareness of these developments and evaluate the use, relevance and value of these tools, equipment and techniques for its own future programme.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">Studying strongly-sorbing radionuclides in-situ, especially in LSSR, is challenging. The development of more sensitive equipment, tools and techniques will save time and money, as well as improve the data generated by these experiments.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To ensure that RWM has the capability/knowledge to perform in-situ diffusion experiments on strongly-sorbing elements in LSSR if/when required.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Maintain a watching brief on emerging tools, equipment and techniques. In particular, the DR-B experiment at the Mont Terri URL features a bespoke, in-situ XRF probe being deployed in observation boreholes to investigate long-term diffusion of iodide (non-sorbing tracer) in Opalinus clay. Long-term experiments using high sensitivity equipment are important for knowledge capture.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR</td></tr>
<tr><td colspan="6">Output of Task
Journal papers detailing novel/emerging techniques from projects led/funded by RWM.
Contractor reports presenting the findings of projects to which RWM has contributed.
Learning will be captured in the [1] and via internal knowledge capture processes.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>TRL 5</td><td>SRL/TRL at Task End</td><td>TRL 6</td><td>Target SRL/TRL</td><td>TRL 7</td></tr>
</table>

Further Information
There are other publications relevant to this task [2] 1 Radioactive Waste Management, *Geological Disposal: Behaviour of Radionuclides and Non-radiological Species in Groundwater*, RWM Report DSSC/456/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-behaviour-of-radionuclides-and-non-radiological-species-in-groundwater/. 2 M. Jaquenoud, “Diffusion of Iodide in Opalinus Clay: In-situ X-ray Fluorescence Measurements, Visualization & interpretation.,” 2019.

B7.7 WBS 80.7 - Representation of Radionuclide Behaviour in Assessment Models

B7.7.1 Holistic Review of Assumptions Pertinent to Radionuclide Behaviour in Post-Closure Models

<table>
<tr><td>Task Number</td><td colspan="2">80.7.001</td><td colspan="2">Status</td><td>Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Representation of Radionuclide Behaviour in Assessment Models</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Our understanding of radionuclide transport mechanisms and their representation in thermodynamic models is considered to be mature. An understanding of the release, transport and uptake mechanisms of radionuclides in the geosphere is vital to the safety case and is influenced by a number of factors (e.g. groundwater geochemistry, geology, microbial influences, colloidal mobility, etc.). However, until a potential candidate site is identified the deep geological performance cannot be fully characterised. At the generic stage, our understanding of these processes and their representation in models relies upon a number of assumptions necessarily taken when there is a lack of data in key areas. The resultant uncertainties have often been taken into account through conservative approaches which may tend to overestimated risk. Indeed, many assumptions may now have been superseded by/require revision due to new experimental data. Examples of conservatisms pertinent to radionuclide behaviour include the use of beta factors, incorporation of anion exclusion parameters and applicability of rock matrix diffusion (Task 50.4.001). This task therefore comprises a review of existing assumptions in radionuclide behaviour with a view to minimising conservatisms by using more appropriate, relevant or updated parameters.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the post-closure safety assessment by:
• Understanding the applicability of current assumptions and the associated conservatisms that currently underpin radionuclide behaviour models and consequent experimental programmes; and
• Identifying areas in which parameters may require an update or the need for assumptions have been negated by experimental data.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To minimise undue conservatisms in RWM's modelling and experimental programmes.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task comprises a holistic review of current radionuclide behaviour-related assumptions or conservative parameters used by RWM (i.e. in the disposal system specification, design and gDSSC).</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report reviewing the applicability of assumptions in radionuclide behaviour.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B7.7.2 Site-specific Review of Assumptions Pertinent to Radionuclide Behaviour in Post-Closure Models

<table>
<tr><td colspan="2">Task Number</td><td>80.7.002</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Representation of Radionuclide Behaviour in Assessment Models</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Our understanding of radionuclide transport mechanisms and their representation in thermodynamic models is considered to be mature. An understanding of the release, transport and uptake mechanisms of radionuclides in the geosphere is vital to the safety case and is influenced by a number of factors (e.g. groundwater geochemistry, geology, microbial influences, colloidal mobility, etc.). However, until a potential candidate site is identified the deep geological performance cannot be fully characterised. At the generic stage, our understanding of these processes and their representation in models relies upon a number of assumptions necessarily taken when there is a lack of data in key areas. The resultant uncertainties have often been taken into account through conservative approaches which may tend to overestimate risk. Indeed, many assumptions may now have been superseded by/require revision due to new experimental data. Examples of conservatisms pertinent to radionuclide behaviour include the use of beta factors, incorporation of anion exclusion parameters and applicability of rock matrix diffusion. This task therefore comprises a review of assumptions at 2-site stage, following on from the output of Task 80.7.001, with a view to minimising conservatisms by using more appropriate or updated parameters once RWM moves beyond the generic phase.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the post-closure safety assessment by:
Understanding the applicability of current assumptions and the associated conservatisms that currently underpin radionuclide behaviour models and consequent experimental programmes;
Identifying areas in which parameters may require an update or the need for assumptions have been negated by experimental data; and
Reviewing the above at a site-specific stage.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To minimise conservatisms in RWM's modelling and experimental programmes at a site-specific stage.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task comprises a review of radionuclide behaviour-related assumptions or conservative parameters used by RWM (i.e. in the disposal system specification, design and gDSSC) and their applicability at two-site stage (planning assumption).</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report reviewing the applicability of assumptions in radionuclide behaviour at a site-specific stage.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B7.7.3 Update to Model of C-14 Transport in Gas Pathways

<table>
<tr><td colspan="2">Task Number</td><td>80.7.003</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Representation of Radionuclide Behaviour in Assessment Models</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM previously established an integrated project team to develop an holistic approach to C-14 management in the disposal system and there is now a better understanding of the processes involved. RWM also co-led a collaborative EC-funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

The current modelling basis largely ignores any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, and more information is needed surrounding the form of C-14 released from different waste types. Recent work has shown that a better understanding of the speciation and rate of source term corrosion could reduce the calculated radiological consequences for these wastes.

This task will assess whether knowledge gained from Task 80.8.004 and Task 80.8.005 can be fed into gas transport models as RWM moves into site-specific research.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To update groundwater transport models as applicable depending on the results generated in Task 80.8.004 and Task 80.8.005.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To use new experimental data to understand if there are any potential benefits from the geosphere in retarding or preventing gaseous C-14 from reaching the surface. This task acts to maintain knowledge for longevity and will capture new assumptions as required.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Review of modelling parameters based on new experimental data. This task may not be required, depending on the importance of the related uncertainties in the safety case.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Updates to the gas pathway transport model.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [1], [2]. This task may not be required, depending on the importance of the related uncertainties in the safety case. 1 A. Hoch, C. Rochelle, P. Humphreys, J. Lloyd, T. Heath, and K. Thatcher, *Carbon-14 Project Phase 2, Formation of a Gas Phase and its Migration, Near-field and Far-field Processes Influencing 14C-bearing Gases*, AMEC, Contractor Report AMEC/200047/007, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-2-formation-of-a-gas-phase-and-its-migration/. 2 D. Lever and S. Vines, *The Carbon-14 IPT: An Integrated Approach to Geological Disposal of UK Wastes Containing Carbon-14*. Mineralogical Magazine, vol. 79, pp. 1641–1650, Issue 6 2015. [Online]. Available: https://pubs.geoscienceworld.org/minmag/article/79/6/1641/301187/the-carbon-14-ipt-an-integrated-approach-to.

B7.7.4 Update to Model of C-14 Transport in Groundwater

Task Number	80.7.004	**Status**	Start date in future
WBS Level 4	Groundwater Pathway for Radionuclide and Non-radionuclide Species		
WBS Level 5	Representation of Radionuclide Behaviour in Assessment Models		

Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM previously established an integrated project team to develop an holistic approach to C-14 management in the disposal system and there is now a better understanding of the processes involved. RWM also co-led a collaborative EC-funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

The current modelling basis largely ignores any potential benefits from the geosphere in retarding or preventing C-14 containing groundwater from reaching the surface, and more information is needed surrounding the form of C-14 released from different waste types. Recent work has shown that a better understanding of the speciation and rate of source-term corrosion could reduce the calculated radiological consequences for these wastes.

This task will assess whether knowledge gained from Task 80.8.004 and Task 80.8.005 can be fed into groundwater transport models as RWM moves into site-specific research.

Research Driver

To update groundwater transport models as applicable depending on the results generated in Task 80.8.004 and Task 80.8.005.

Research Objective

To use new experimental data to understand if there are any potential benefits from the geosphere in retarding or preventing C-14 in groundwater from reaching the surface. This task acts to maintain knowledge for longevity and will capture new assumptions as required.

Scope

Review of modelling parameters based on new experimental data. This task may not be required, depending on the importance of the related uncertainties in the safety case.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Updates to the groundwater transport model.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information

There are other publications relevant to this task [1]. This task may not be required, depending on the importance of the related uncertainties in the safety case.

1 D. Lever and S. Vines, *The Carbon-14 IPT: An Integrated Approach to Geological Disposal of UK Wastes Containing Carbon-14*. Mineralogical Magazine, vol. 79, pp. 1641–1650, Issue 6 2015. [Online]. Available: https://pubs.geoscienceworld.org/minmag/article/79/6/1641/301187/the-carbon-14-ipt-an-integrated-approach-to.

B7.7.5 Review of the Use of Beta Values

<table>
<tr><td>Task Number</td><td colspan="2">80.7.005</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Radionuclide Behaviour</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Representation of Radionuclide Behaviour in Assessment Models</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Data parameters for the sorption to the geosphere bulk rock are determined largely from laboratory experiments on crushed rock samples equilibrated with various radionuclides in appropriate groundwater or near-field simulant solutions. Laboratory measurements made on crushed rock are likely to have different surface areas to intact rock samples. In order to derive values of sorption distribution coefficients that are appropriate for sorption to intact rock from values obtained in batch laboratory experiments the crushed rock K_d values are multiplied by a factor called the ’beta factor’. The beta parameters reflect an understanding of the relative surface areas of crushed and intact rock samples and have been derived by comparison of the results of batch and intact rock sorption experiments through the application of this correction factor. The beta values were elicited as part of the Nirex programme using experimental sorption measurements on crushed and intact rock for a selection of radionuclides. The beta values are used for species in addition to these; therefore, a review of the applicability of the beta values is appropriate.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the integrity of the post-closure safety case by reviewing the validity of our use of beta values to correct batch-derived sorption data for a realistic scenario of contacting intact rock.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To substantiate the use of beta values.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following elements:
• To review the use of beta values for scaling crushed rock experiments to bulk intact rock values required as part of the total system model.
• To specify the appropriateness of the values (e.g. for which rock / mineral types, radionuclides, etc).
• To consider whether one beta value set is required for all radionuclides or whether they should be radionuclide-specific.
• A review of how other organisations deal with scaling will also be undertaken to ensure RWM are using best practice.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, cover rocks.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A contractor report making recommendations for the future use of Beta values.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>4</td><td>SRL/TRL at Task End</td><td>4</td><td>Target SRL/TRL</td><td>4</td></tr>
</table>

Further Information
[1], [2]

1 A. Chambers and S. Williams, *The Basis for Cumulative Distribution Functions Used in the Groundwater Pathway Calculations of the Nirex Generic Post-closure Performance Assessment*, SA/ENV-0740, 2010, Query - Institution and Type. [Online]. Available: http://rwm.nda.gov.uk/publication/the-basis-for-cumulative-distribution-functions-used-in-the-groundwater-pathway-calculations-of-the-nirex-generic-post-closure-performance-assessment/.

2 *Nirex Safety Assessment Research Programme: Nirex Near-Field Research; Report on Current Status in 1994*. S/95/011, 1995.

B7.8 WBS 80.8 - Understanding the Behaviour of Carbon-14

B7.8.1 Review of potential C-14 Release from Irradiated Graphite from Whole Inventory

<table>
<tr><td colspan="2">Task Number</td><td>80.8.001</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Understanding of the Behaviour of Carbon-14</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 contains a significant contribution from the leaching of irradiated graphite. RWM has previously conducted work on the rate and speciation of C-14 from a range of materials, including graphite. This has included the recently completed collaborative EC-funded project CAST.
Irradiated graphite provides the largest inventory of C-14 associated with irradiated material in ILW, and recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. Only limited work has been undertaken on a small range of samples from WAGR, BEPO and Oldbury Magnox reactors. Graphite from AGR reactors represents a significant proportion of the total graphite inventory and will be studied in Task 80.8.002. Following this a review of all sources of graphite and current knowledge of the rate and speciation of C-14 from all graphite would enable RWM to better parameterise assessment models and identify future research needs.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the post-closure safety case by better underpinned parameterisation of the model of carbon-14 release from irradiated graphite through review of available information from previous studies.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review state-of-the-art knowledge and identify any future research needs.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">A review of all available information from previous studies and inventory data to capture the state-of-the-art knowledge of C-14 release from irradiated graphite. The scope will also include capturing future research needs, either in terms of further leaching studies on new or previously studied graphite or on inventory data and uncertainty.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">This task will follow the completion of Task 80.8.002 and will feed into Task 80.8.003.</td></tr>
</table>

B7.8.2 Study of C-14 Release from Irradiated, Advanced Gas-cooled Reactor Graphite

<table>
<tr><td>Task Number</td><td colspan="2">80.8.002</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Understanding of the Behaviour of Carbon-14</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste due to the calculated assessment of the radiological consequences of gaseous C-14 bearing species. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 includes a significant contribution from the leaching of irradiated graphite. RWM has previously conducted work on the release rate and chemical speciation of C-14 liberated from a range of materials, including graphite. This has included the recently completed collaborative EC-funded project CAST.Irradiated graphite provides the largest inventory of C-14 associated with irradiated material in ILW, and recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. Only limited work has been undertaken on a small range of samples from WAGR, BEP0 and Oldbury Magnox reactors. Graphite from AGR reactors represents a significant proportion of the total graphite inventory and an understanding of the release rate and speciation of C-14 from this type of graphite would enable RWM to better parameterise assessment models.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the post-closure safety case by better underpinned parameterisation of the model of C-14 release from irradiated graphite through investigation of the behaviour of irradiated graphite from an AGR.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop an improved understanding of the behaviour of irradiated graphites in a GDF by carrying out experiments on AGR irradiated graphite samples.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">An experimental study to measure dissolved and gaseous C-14 releases from AGR graphite samples and compare to those previously recorded from prior studies</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are other publications relevant to this task [1]–[3]. 1 G. Baston, R. Preston S. Otlet, A. Walker, A. Clacher, M. Kirkham, and B. Swift, *Carbon-14 Release from Oldbury Graphite*, AMEC, Contractor Report AMEC Report AMEC/5352/002 Issue 3, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-release-from-oldbury-graphite-npo004819/. 2 T. Marshall, G. Baston, R. Otlett, A. Walker, and I. Mather, *Longer-term release of carbon-14 from irradiated graphite*. SERCO/TAS/001190/001 Issue 2, SERCO, 2011. 3 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 project - Phase 1 report*, NDA Report NDA/RWMD/092, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-1-report/.

B7.8.3 Studies of C-14 Release from Irradiated Graphite from Other Sources

<table>
<tr><td colspan="2">Task Number</td><td>80.8.003</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Understanding of the Behaviour of Carbon-14</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 contains a significant contribution from the leaching of irradiated graphite. RWM has previously conducted work on the release rate and chemical speciation of C-14 liberated from a range of materials, including graphite. This has included the recently completed collaborative EC-funded project CAST.Irradiated graphite contains the largest inventory of C-14 associated with irradiated material in LLW/ILW, and recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. Only limited work has been undertaken on a small range of samples from WAGR, BEP0 and Oldbury Magnox reactors. Graphite from AGR reactors represents a significant proportion of the total graphite inventory and will be studied in Task 80.8.002. Following this, a review of all sources of graphite and current knowledge of the rate and speciation of C-14 from all graphite would be captured in Task 80.8.001, which would also identify any future research needs.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the post-closure safety case by better underpinned parameterisation of the model of C-14 release from irradiated graphite through investigation of the behaviour of irradiated graphites with a wider range of characteristics and irradiation histories than previously studied.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop an improved understanding of the behaviour of irradiated graphites in a GDF by carrying out experiments on a AGR irradiated graphite samples.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope is dependent on the output of Task 80.8.002, it is envisaged that this task will undertake experimental work to measure dissolved and gaseous C-14 releases from UK graphite samples with different characteristics and irradiation histories than those sampled previously. This could be from different types of graphite and/or additional samples of previously studied graphite types. The work may also involve studies to underpin the inventory of C-14 in irradiated graphite.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">This task may not be required, depending on the output of Task 80.8.002.</td></tr>
</table>

B7.8.4 C-14 Treatment and Representation in Models: A Review of Understanding of C-14 Behaviour in the Geosphere

<table>
<tr><td>Task Number</td><td colspan="2">80.8.004</td><td colspan="2">Status</td><td>Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Groundwater Pathway for Radionuclide and Non-radionuclide Species</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Understanding of the Behaviour of Carbon-14</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM previously established an IPT to develop an holistic approach to C-14 management in the disposal system and there is now a better understanding of the processes involved. RWM also co-led a collaborative EC-funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.
The current modelling basis largely ignores any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, and more information is needed surrounding the form of C-14 released from different waste types. Recent work has shown that a better understanding of the speciation and rate of source-term corrosion could reduce the calculated radiological consequences for these wastes. An improved understanding of the assumptions used in reactive transport models in the context of C-14 would enable us to better parameterise and contextualise these models and reveal key knowledge gaps in C-14 behaviour in the geosphere. This includes an understanding of the representation of C-14 mobility and speciation from variant source terms, packaging types and backfill, and the role of microbes in C-14 behaviour from source to release.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To determine the applicability of current modelling approaches towards representing new experimental data and collate assumptions surrounding the treatment of C-14 in models in order to identify knowledge gaps and over-conservatisms.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To synthesise current knowledge and identify outstanding uncertainties in the safety case surrounding the representation of C-14 behaviour in models.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of work includes the collation of data and relevant underpinning science from existing and prior work (including output from the recent C-14 IPT) to generate a high level report on the current knowledge of C-14 behaviour and the parameters used for its treatment in transport models.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report documenting the current understanding of C-14 representation in models and recommendations for future research.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
This is a wide review and experimentation may be brought forward as necessary. There are other publications relevant to this task [1].   1 D. Lever and S. Vines, *The Carbon-14 IPT: An Integrated Approach to Geological Disposal of UK Wastes Containing Carbon-14*. Mineralogical Magazine, vol. 79, pp. 1641–1650, Issue 6 2015. [Online]. Available: https://pubs.geoscienceworld.org/minmag/article/79/6/1641/301187/the-carbon-14-ipt-an-integrated-approach-to.

B7.8.5 Further Understanding of C-14 Speciation and Mobility from Source to Release

Task Number		80.8.005	Status	Start date in future	
WBS Level 4		Groundwater Pathway for Radionuclide and Non-radionuclide Species			
WBS Level 5		Develop Understanding of the Behaviour of Carbon-14			
Background					
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM previously established an IPT to develop an holistic approach to C-14 management in the disposal system and there is now a better understanding of the processes involved. RWM also co-led a collaborative EC-funded project, CAST, which included experimental programmes to fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. The current modelling basis largely ignores any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, and more information is needed surrounding the form of C-14 released from different waste types. Recent work has shown that a better understanding of the speciation and rate of source term corrosion could reduce the calculated radiological consequences for these wastes. This task has been developed to progress the recommendations of Task 80.8.004 (i.e. to address any identified knowledge gaps and generate data to minimise conservatisms following the completion of a review of understanding).					
Research Driver					
A need to provide further data and understanding on individual processes shown to have significant knowledge gaps with respect to the safety case.					
Research Objective					
To address outstanding uncertainties in the safety case surrounding the speciation and mobility of C-14 from “cradle to grave” and couple this understanding to performance assessment modelling.					
Scope					
The development and execution of a detailed experimental and/or modelling programme to address knowledge gaps identified by Task 80.8.004.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A detailed experimental and/or modelling programme to be undertaken followed by a report documenting the applicability of the data with respect to the safety case.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1]. 1 D. Lever and S. Vines, *The Carbon-14 IPT: An Integrated Approach to Geological Disposal of UK Wastes Containing Carbon-14*. Mineralogical Magazine, vol. 79, pp. 1641–1650, Issue 6 2015. [Online]. Available: https://pubs.geoscienceworld.org/minmag/article/79/6/1641/301187/the-carbon-14-ipt-an-integrated-approach-to.					

B8 WBS 90 - Waste Container Evolution

Waste container materials have already been selected for much of the ILW destined for the GDF and many thousands of packages are stored awaiting disposal. The primary research need for these stainless steel and cast iron containers is to understand their likely degradation prior to transport to the GDF and backfilling of the vaults. For HHGW the container material has not yet been selected and will be dependent upon the site-specific conditions. The minimum (IAEA) requirement for a HHGW container in a highly diffusive geological environment which provides very long return time to the surface is for containment throughout the thermal period; in more advective environments high durability containers are required, with lifetimes of over 100,000 years. **WBS 90** therefore develops RWM's understanding of the evolution of a range of container materials:

- Material Science Studies in Support of Waste Container Development (Spent Fuel, HLW, ILW, LLW) (**WBS 90.1**). This research will develop understanding of mechanisms of degradation (Task 90.1.001-Task 90.1.002, Task 90.1.004-90.1.010) and feasibility of manufacture for conceptual designs (Task 90.1.003). The evolution of waste containers is strongly influenced by the environment surrounding the containers. In a GDF, the environment is influenced by the near-field barriers, the radiogenic dose / dose-rate, the presence of hydrogen gas and by the chemistry of inflowing groundwater from the surrounding rocks. Therefore, at the site-specific stage, the key information that will be required will be related to the groundwater chemistry at the site in order to consolidate the generic understanding of LHGW containers and optimise and underpin the design of HHGW containers.
- Development of Models for LHGW and HHGW Container Evolution Using Data Derived from Generic Stage Work Scope (**WBS 90.2**).

B8.1 WBS 90.1 - Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)

B8.1.1 Studies of Container Durability During Prolonged Exposure to Elevated Temperatures and Atmospheric Conditions

Task Number	90.1.001	**Status**	Start date in future
WBS Level 4	Waste Container Evolution		
WBS Level 5	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)		

Background

The UK does not have a long history of research into the evolution of candidate container designs for HHGW. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally. Although most information produced in waste management programmes has been focused on materials behaviour during the post-closure period, there is also a good understanding of the corrosion performance of candidate container designs in conditions relevant to the periods that may precede closure of a GDF, including potentially long periods of exposure to atmospheric or oxic conditions (e.g. interim storage). The UK has one of the largest and most complex waste inventories within the nuclear community and, as a result of this, not all wastes will be suitable for disposal in the container designs developed by other countries; it is likely that bespoke solutions will be required for some wastes (e.g. bulk plutonium). Some of these containers will be subject to significant and sustained thermal outputs for periods of surface/underground storage, which may affect the durability of container materials before and after closure of a GDF. This task considers the current illustrative designs and potential bespoke disposal containers; it aims to evaluate their evolution and pre/post-closure durability on the basis of models and information available in the technical literature.

Research Driver

To develop a mechanistic understanding of the durability of HHGW disposal containers during periods preceding closure of a GDF (e.g. dry interim storage, buffer underground 'storage' at a GDF, and reversible/retrievable disposal periods), and of the potential for operational factors to affect the durability of containers during the post-closure period. This work will support strategic decisions on HHGW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels) and the development of the safety case.

Research Objective

To underpin the evaluation of the durability of HHGW containers in conditions of prolonged exposure to high-temperature atmospheric conditions. In particular:

- To develop an initial understanding of the deliquescence properties of aerosols and contaminants likely to be present in underground environments;
- To model the likely occurrence of surface wetting based on expected conditions of power output, air relative humidity and surface contaminants;
- To evaluate the corrosion behaviour (both aqueous corrosion and dry oxidation) of candidate materials in the environmental conditions and timescales of interest; and

- To consider the potential coupling between mechanical and corrosion effects in representative scenarios, including effects associated with internal pressurisation, hydrogen embrittlement and stress corrosion.

Scope

The scope comprises the following:

- To gather additional information on the likely contaminants present in underground excavations based on existing information and field measurements.
- To assess if current models of deliquescence behaviour of contaminants could be suitably adapted to examine the behaviour of HHGW container materials.
- To evaluate expected corrosion mechanisms and relative rates for candidate materials.
- To carry out a coupled chemical-mechanical analysis in specific scenarios using methodologies previously developed (i.e. Failure Assessment Diagrams).

Geology Application

HSR, LSSR and Evaporite.

Output of Task

Reports that support the knowledge base underpinning the GDF DSSC, including, but not limited to, the Waste Package Evolution Status Report [1]. Provide information to support strategic decisions relating to the management of HAW and the UK nuclear materials inventory.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information

'Corrosion allowance' is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a GDF. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. There are several publications relevant to this task [2], [3]. This task will be carried out by our contractors.

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

2 F. King, J. Wilson, and J. Mackenzie, *Corrosion of Candidate HLW/Spent Fuel Container Materials in Generic Environments – Operational Aspects*, Quintessa, Contractor Report QRS-1525A-R1, 2011. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20150806132355/http://www.nda.gov.uk/publication/corrosion-of-candidate-hlw-spent-fuel-container-materials-in-generic-environments-operational-aspect-october-2011/.

3 J. Tani, M. Mayuzumi, and N. Hara, *Stress corrosion cracking of stainless steel canisters for concrete cask storage of spent fuel*, 2008, pp. 42–47. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0022311508003243.

B8.1.2 Further Studies of Internal Corrosion / Pressurisation, Including Considerations of Accident Scenarios

Task Number	90.1.002	**Status**	Start date in future
WBS Level 4	Waste Container Evolution		
WBS Level 5	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)		

Background

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally. Previous studies indicate a very limited extent of structural damage, but some potential for hydrogen pressurisation, in scenarios of storage and disposal of waterlogged AGR fuel elements. Based on previous studies, this work will consider the potential for internal corrosion and pressurisation in a variety of storage and disposal systems, including packages featuring different designs, different wasteforms (e.g. fuels generating higher amounts of heat), and disposal scenarios (including packaging dates and assumed water content of the wasteform). Considerations will be extended to the case of fire accidents.

Research Driver

To develop an understanding of the potential for significant internal corrosion and pressurisation of a variety of spent fuels and container designs to storage and disposal scenarios. This work will underpin the safety case, the disposability assessment process, upstream waste management strategies and the development of suitable disposal concepts for spent fuels.

Research Objective

To determine the following:

- Whether the amount of water carried over in spent fuel containers could result in internal corrosion of structural elements (steel/cast iron) to an extent which affects their ability to provide structural strength (i.e. providing containment) and maintaining the designed configuration (criticality safety), if no action (draining/drying) was undertaken.
- The dryness level required to ensure that fuel will produce insufficient internal pressurisation to require the container to be treated as a pressurised vessel and whether this is compatible with the levels that can be achieved with deployable drying technologies and/or waste management strategies (e.g. selective loading of fuel into waste containers to ensure spreading of water-logged fuel).
- Whether the expected levels of pressurisation in the case of water-logged fuel could be reduced through engineering design of the waste container (e.g. by controlling thermal conductivity and free volume).
- The expected level of pressurisation from other sources, particularly helium.

Scope

Based on previous studies on AGR fuel, through a combination of new calculations, additional sensitivity analysis and qualitative considerations, this study should form a view of the potential for internal corrosion and pressurisation of a disposal container for a variety of other types of spent fuel, container designs and storage/disposal scenarios. The scope comprises the following:

• Consideration of the effect of other spent fuels (e.g. PWR and new build fuel), including anticipated higher power output. • Consideration of the effect of a variety of relevant container designs, including previously considered designs (e.g. the Variant 1 as bounding case) as well as designs not previously assessed, considering differences in heat density, efficiency of heat dissipation, and internal volume. • Consideration of the likely effect of a variety of relevant packaging, storage and disposal scenarios, including scenarios of good or incomplete dryness, timing of packing and disposal, and thermal properties associated with boundary conditions (e.g. thermal conductivity of buffer materials and host rock after disposal). • Specific consideration of the expected level of pressurisation in a fire accident scenario of both dry and waterlogged fuel, including consideration of any expected contribution from fissile gases/helium and on the release of volatile radionuclides in the container.					
Geology Application					
N/A					
Output of Task					
Reports to support the development of the knowledge base that underpins the GDF Disposal System Safety Case, including, but not limited to, the Waste Package Evolution Status Report [1]. Support to disposability assessments.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
'Corrosion allowance' is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. There are several completed deliverables for this task [2], [3]. 1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/. 2 D. Burt, S. Massey, A. Horvat, and F. King, *Impact of water carry over on the extent of structural damage and pressurisation on a Variant 1 AGR spent fuel disposal container*, AMEC, Contractor Report 17697/TR/06, issue 1, 2014. 3 D. Burt, J. Ganeshalingam, S. Massey, A. Horvat, and F. King, *Impact of water carry over on the extent of structural damage and pressurisation on a Variant 2 AGR spent fuel disposal container*, AMEC, Contractor Report 17697/TR/04, issue 2, 2014. [Online]. Available: http://rwm.nda.gov.uk/publication/impact-of-water-carry-over-on-the-extent-of-structural-damage-and-pressurisation-on-a-variant-2-agr-spent-fuel-disposal-container/.					

B8.1.3 Considerations on the Feasibility and Quality of Manufacture of Containers for HLW and Spent Fuel

Task Number	90.1.003	**Status**	Start date in future
WBS Level 4	Waste Container Evolution		
WBS Level 5	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)		

Background

The UK does not have a long history of research into the evolution of candidate container designs for HHGW. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally. Existing information indicates that the manufacture of corrosion-allowance container designs based on the use of carbon steel or copper is feasible, as demonstrated by large-scale prototypes developed in a variety of national programmes (e.g. in Sweden and Switzerland). Information produced in the past in other programmes (e.g. in the USA), indicates that it may be also feasible to manufacture containers with corrosion-resistant materials (e.g. titanium, stainless steel or nickel alloys), although less work is available to evaluate the feasibility and resulting quality of this type of operations. There has also been a body of work carried out by the international community on other container and concept designs (e.g. coated containers and ceramics). Based on existing information (desk-based study), this task will explore the feasibility of manufacturing and the anticipated quality of a variety of container designs, including designs based on the use of corrosion-resistant materials and other lower TRL designs. Information will include available manufacturing techniques, their maturity (e.g. TRL levels), anticipated characteristics (e.g. nature, size and frequency of expected defects) and consideration of costs.

Research Driver

To support concept development by underpinning the feasibility of manufacture of HHGW containers and the quality of the resulting designs.

Research Objective

Based on existing information, to evaluate the feasibility of manufacture and anticipated quality of a variety of container designs, including those based on the use of corrosion-resistant materials and those with lower TRLs.

Scope

The work will present a desk-based study considering all HHGW container materials and designs. The information presented will consider specific design and manufacturing studies previously carried out in the radioactive waste industry, as well as experiences in the manufacture of similar components in other industries. The scope will include the following:

- A description of the type of designs considered so far for HLW and spent fuel containers (e.g. single shell, dual shell) and of the type of materials considered in different designs.
- A review of manufacturing techniques for the manufacture of large-scale, critical components in the materials of interest, including techniques considered in the radioactive waste industry and elsewhere.

- Consideration of the anticipated wall thickness of relevant components, including thick-walled components (e.g. any mechanical inserts for dual-shell containers) and thin-walled components (e.g. the external corrosion barrier in dual-shell designs).
- Consideration of the manufacturing of components in a non-radioactive environment and final welding in the presence of a radioactive wasteform.
- Consideration of the anticipated quality achieved with different types of design and manufacturing techniques, including nature, frequency and typical size of expected defects and resulting inspection regimes.
- High-level consideration of the cost of different options to inform a comparative analysis.

Geology Application

N/A

Output of Task

Reports to support the development of the knowledge base that underpins the GDF Disposal System Safety Case, including, but not limited to, the Waste Package Evolution Status Report [1] would also provide support to concept development and disposability assessments.

SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 3	**Target SRL/TRL**	TRL 6

Further Information

'Corrosion allowance' is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. There are other publications relevant to this task [2], [3]. This work will be carried out by our contractors.

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

2 SKB, *Design, production and initial state of the canister*, SKB Report TR-10-14, 2010. [Online]. Available: http://www.skb.com/publication/2151522/TR-10-14.pdf.

3 L. Nolvi, *Manufacture of disposal canisters*, Posiva Oy, Contractor Report POSIVA 2009-03, 2009. [Online]. Available: http://www.posiva.fi/files/1056/POSIVA%5C_2009-03web.pdf.

B8.1.4 Corrosion Studies of Carbon Steel / Cast Iron in Cyclic Conditions and Salt Mixtures

Task Number	90.1.004	**Status**	Ongoing
WBS Level 4	Waste Container Evolution		
WBS Level 5	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)		

Background

Previously, Nirex carried out a limited amount of research relating to the use of carbon steel to dispose of ILW in anoxic, alkaline environments. Research evaluating the use of this and other relevant materials (e.g. cast iron) for the management and disposal of ILW or other radioactive wastes (e.g. HLW and spent fuel) has also been carried out internationally. RWM places a significant emphasis on evaluating the durability of container materials during periods of atmospheric exposure likely to precede the closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities. Building on previous reviews of the atmospheric corrosion of cast iron, of the durability of paint systems and work carried out on stainless steel (ACSIS), this task will carry out a targeted experimental programme on both painted and bare samples of carbon steel and cast iron to provide data needed to extend ACSIS to carbon steel and cast iron containers.

Research Driver

To develop a mechanistic understanding of the durability of ILW corrosion-allowance (carbon steel, cast iron) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible/retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period. This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

Research Objective

To evaluate whether, on the basis of existing mechanistic understanding and any new data generated in this task, predictive models of degradation of ILW containers manufactured in painted carbon steel or cast iron can be developed. In particular, to determine the following:

- Whether relevant paint systems are likely to suffer environmental degradation in static conditions of temperature, relative humidity and surface contamination expected in interim stores and during the operational period of a GDF.
- The typical timescales of water transport and subsequent corrosion of the substrate, including the effect of cyclic conditions of temperature and relative humidity and increases in the deposition of surface contaminants, on them.
- The corrosion rate of the substrate under painted areas which have been accessed by moisture, the nature of corrosion products formed and their effect on the kinetics of paint spalling.
- The corrosion rate of the substrate in conditions of paint spalling.

Scope

The scope comprises the following:

• Experimental studies of water absorption and resulting paint degradation in selected conditions of surface contamination and in constant/cyclic conditions of temperature and relative humidity. • Experimental studies of carbon steel/cast iron corrosion in selected conditions of surface contamination and in constant / cyclic conditions of temperature and relative humidity with, and without paint, systems.					
Geology Application					
HSR, LSSR and Evaporite.					
Output of Task					
Reports to support the knowledge base that underpins the GDF Disposal System Safety case, including, but not limited to, the Waste Package Evolution Status Report [1]. Support to disposability assessments and development of interim storage guidance.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [2]. This task will be procured through our contractors with input from academic partners. 1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/. 2 J. Morris and D. Winpenny, *Review of atmospheric corrosion of Ductile Cast Iron*. 17391-TR-003.					

B8.1.5 Studies of Stainless Steel Corrosion in Cement in the Presence of Radiation and Thiosulphate

Task Number	90.1.005	**Status**	Start date in future
WBS Level 4	Waste Container Evolution		
WBS Level 5	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)		
Background			
Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities. Work carried out by Nirex investigating the corrosion behaviour of stainless steel in conditions simulating disposal of ILW in a cement-based near-field indicated that corrosion can only occur if groundwaters containing sufficiently high levels of chloride were to come into contact with waste containers whilst relatively high temperatures (from curing of the backfill) and relatively high redox conditions (e.g. due to any unreacted oxygen) are still present in the near field. Limited tests on the potential effect of thiosulphate (a known corrosive agent that may be produced in a GDF by microbial activity or by the oxidation of pyrite minerals) were also carried out. Building on work carried out by Nirex, this experimental and modelling task considers outstanding uncertainties associated with the effects on stainless steel of radiation and specific chemical species (thiosulphate) that may be present in the disposal environment.			
Research Driver			
To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods following closure of a GDF. This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels) and safety case development.			
Research Objective			
To evaluate outstanding uncertainties relative to the corrosion behaviour of stainless steel in contact with a cement backfill. In particular, the following: • To identify the effect of ionising radiation (if any) on the likelihood of localised corrosion (due to an increase in redox potential) in a cement backfill at the dose rates expected in thin-walled ILW containers and, if any effect is observed, to identify any dose rates at which corrosion is not observed. • To test whether the high alkalinity of cement backfills is able to inhibit the potential for localised corrosion (and SCC) in mixtures of chloride and thiosulphate previously observed to induce corrosion (up to pH 11). • To evaluate whether the typical resistivity of cement backfills is likely to stifle localised corrosion, resulting in limited depth of propagation.			
Scope			
The scope comprises the following:			

- Experimental studies on the effect of ionising radiation on the corrosion potential and overall susceptibility to localised corrosion at high pH and at relevant dose rates.
- Experimental studies of localised corrosion initiation and propagation in the presence of chloride/thiosulphate at high pH.
- Development of models of localised corrosion propagation in cement considering kinetic parameters relevant to cement systems (i.e. resistivity).

Geology Application

HSR, LSSR and Evaporite.

Output of Task

Data quantifying when and how radiation dose affects corrosion rates for ILW packages and data on whether thiosuphate is significant in affecting ILW package corrosion rates. This will support the knowledge base which underpins the GDF Disposal System Safety Case and provide support to disposability assessments.

SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information

There are several publications relevant to this task [1]–[3]. This task will be procured through our contractors with input from academic partners.

1 N. Smart, D. Blackwood, A. Graham, F. Porter, A. Rance, and M. Thomas, *Stress Corrosion Cracking of Stainless Steels in Simulated Blast Furnace Slag Porewaters*. AEAT/ERRA-0319, AEA Technology, 2002.

2 C. Naish, S. Sharland, and K. Taylor, *The initiation of crevice corrosion in stainless steel: A combined modelling and experimental approach*, AEAT, Contractor Report AEAT/ERRA-0268, 2000.

3 C. Donohoe, *The effect of ionizing radiation on the corrosion resistance of ILW containers*. NNL (08) 9544 Issue 3, National Nuclear Laboratory, 2009.

B8.1.6 The Effect of Gamma Radiation on the Corrosion Behaviour of Container Materials

<table>
<tr><td>Task Number</td><td>90.1.006</td><td>Status</td><td>Start date in the future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Waste Container Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">The UK does not have a long history of research into the evolution of candidate container designs for HHGW. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider waste-forms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally. Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure period is generally well understood and is underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in-situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including consideration of the potential coupling between chemical and mechanical effects. This task will focus on copper and carbon steel, the behaviour of which will be evaluated on the basis of a collaborative project.</td></tr>
<tr><td colspan="4">Research Driver
• To develop a mechanistic understanding of the durability of HLW/spent fuel containers in periods following closure of a GDF in a variety of relevant disposal scenarios.
• To support the assessment of packaging solutions, the development of suitable disposal concepts for these wastes and the development of the safety case.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">The work is designed to take a first, but substantial, step towards addressing questions around the potential effect of radiation on containers made from primary candidate materials, by taking into account relevant chemical conditions, dose rates and total doses.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">To experimentally evaluate the effect of gamma radiation on the corrosion behaviour of carbon steel, and optionally copper, in conditions of interest to the disposal of high HLW and spent fuel. Dose rates proposed range from levels similar to that expected during the early lifetime of a disposal canister (0.1-0.2 Gy h-1) to much higher levels. This will help to identify threshold conditions (if any) below which radiation may stop playing a role in corrosion phenomena. The duration of different experiments is designed to cover, at the highest dose rates tested, the total doses expected during disposal. In general, the matrix of experiments is designed to achieve the same total dose at different dose rates, so that a direct comparison between the behaviour observed in different experiments should yield information on whether dose rates, total doses, or both, control the behaviour of the system.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR and Evaporite.</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
</table>

Improved understanding of the effects of levels of radiation on the corrosion process for copper and carbon steel and data that can be used to inform corrosion rates used in material assessments.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
This task is intended for collaborative funding under the Nagra ISCO programme. Co-funded project (Nagra, NWMO, RWM). This task will be carried out by our contractors.					

B8.1.7 Corrosion of High Heat Generating Waste (HHGW) Materials in Bentonite Saturated with Groundwater

Task Number	90.1.007	**Status**	Ongoing
WBS Level 4	Waste Container Evolution		
WBS Level 5	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)		

Background

The waste container is one component of the engineered barrier system within the multi-barrier system adopted at a GDF. It contributes to safety by delaying the release of radionuclides. The performance of the container is influenced by the material and method of construction in combination with the geological, hydrogeological and micro-biological conditions prevailing. To support a safety case for a GDF, knowledge regarding the expected lifetime of the waste container is needed. To enhance and validate our existing knowledge on container performance, RWM is participating in a number of international projects. Historically our research efforts have focussed on HSR environments, namely involvement in the MaCoTe experiment at the Grimsel Test Site. There is a need for RWM to extend our knowledge regarding container performance to include LSSR and the materials used in these environments, experiments analogous to those at Grimsel Test Site are being performed at the Mont-Terri underground research laboratory which is constructed in LSSR.

Research Driver

- Disposal System Safety Case – Environmental Safety Case.
- Identification and development of GDF concepts.
- Disposal System Specification.

Research Objective

To determine whether the corrosion behaviour of candidate container materials (carbon steel and copper) in contact with saturated clay (bentonite) in small-scale *in situ* experiments planned at Grimsel Test Site and Mont-Terri Underground Laboratory is consistent with the expected behaviour. In particular to determine:

• whether any formation of microbial biofilm on container materials is inhibited if sufficiently compacted (i.e.dense) bentonite is used;

• the (general) corrosion rate of coupons, including whether the effect of microbial activity on container materials can be estimated on the basis of the concentration of any aggressive by-products (e.g. sulphide) produced 'far' from the container-buffer interface; and

• whether any localised corrosion is observed and, if so, whether this is consistent with current estimates (e.g. based on the previously evaluated 'pitting factor').

Scope

In-situ experiments focusing on the exposure of coupons of candidate materials (carbon steel and copper) to groundwater-saturated (chloride-containing) anoxic bentonite at different levels of compaction. The experiments will specifically observe the effect of this parameter on the ability of naturally-occurring microbes to affect the behaviour of the engineered barrier system. RWM will participate in both the MaCoTe experiment at Grimsel Test Site (HSR environment) and the IC-A experiment at Mont-Terri (LSSR environment) and will compare the outcome of both experiments against current knowledge from laboratory experiments and natural analogue behaviour to both enhance and validate our understanding of materials behaviour.

Geology Application

LSSR, HSR

Output of Task					
• Mont Terri technical reports from the IC-A experiment. • NAGRA technical reports from the MaCoTe experiment. • A synthesis report which compares the outputs of the experiments with current knowledge and identifies any safety significant gaps in understanding. • Learning from the experiment will be captured in the next iteration of the Waste Package Evolution Status Report [1].					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
For more information, see the Grimsel website [2].					

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

2 *Grimsel website*. [Online]. Available: https://grimsel.com/.

B8.1.8 State of the Art Review of ILW Container Evolution under Atmospheric Conditions and Identification of Further Research Needs

<table>
<tr><td>Task Number</td><td colspan="2">90.1.008</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Waste Container Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has historically conducted extensive research into the impact of exposure of ILW container materials to atmospheric conditions. This includes whilst the containers are in storage and in the operational periods of the GDF. Stainless steels can be susceptible to certain degradation mechanisms if conditions move outside of those which are considered ideal for its preservation. This task aims to assess the state of knowledge on ILW container materials under atmospheric conditions, specifically those relevant to a GDF environment, and assess it against the requirements of the current GDF safety cases and disposability assessments, identifying significant gaps in knowledge and paths to closure (which may include information from operational experience).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To update and validate our understanding of the evolution of containers for ILW under atmospheric conditions to support the assessment of packaging solutions and the development of the safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review the current knowledge on ILW container evolution in atmospheric conditions (specifically those relevant to a GDF environment) against the newly developed claims, arguments and evidence hierarchy and other RWM safety cases. Identify any knowledge gaps and path to closure. Identify where operational experience could be used to support claims, arguments and evidence.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To conduct a review of the status of knowledge and research needs for ILW containers in atmospheric conditions (specifically those applicable to the GDF environment) utilising non-nuclear related research, RWM reports, LoC submissions, waste owner liaison, the scientific literature and liaison with SLCs regarding operational experience.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report detailing the status of RWM's knowledge on ILW containers under atmospheric conditions (specifically those relevant to a GDF environment) against the appropriate safety case documents, identification of any gaps and a path to closure.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">Further information can be found in the following reference [1].
1 Radioactive Waste Management, Geological disposal: Waste package evolution status report, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.</td></tr>
</table>

B8.1.9 Studies of Stress Corrosion Cracking Initiation and Propagation

Task Number	90.1.009	**Status**	Start date in future
WBS Level 4	Waste Container Evolution		
WBS Level 5	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)		
Background			
Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities. Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor and operational GDF environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term. This task continues work to investigate the kinetics of stress corrosion cracking in both austenitic stainless steel grades (304/316) and duplex grades in conditions relevant to interim storage facilities.			
Research Driver			
To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible/retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period. This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.			
Research Objective			
To determine whether: • Cycling of relative humidity in controlled exposure tests has an impact on the initiation of SCC (i.e. incubation time) such that typical variations expected in the natural environment are likely to accelerate or inhibit initiation; • Controlled tests in salt mixtures representative of contamination in relevant facilities, as opposed to pure chloride salts, affect the likelihood of SCC (by either inhibiting chloride-induced corrosion and/or by affecting the deliquescence properties of contaminated surfaces); and • The data produced, applied in the parametric model (ACSIS) aimed at evaluating the development of corrosion, indicate that the development of pitting and stress corrosion is unlikely to lead to substantial damage in the long-term.			

Scope					
• Experimental studies of SCC in realistic atmospheric conditions in the presence of relative humidity cycles (relatively aggressive conditions of temperature and chloride contamination). • Experimental studies of SCC in atmospheric conditions in the presence of mixed salts of composition relevant to that found in typical ILW stores. • Development of parametric models of the wetting behaviour of stainless steel surfaces in relevant environmental conditions and of the likely initiation and propagation of corrosion.					
Geology Application					
HSR, LSSR and Evaporite.					
Output of Task					
Data on the environmental conditions where SCC is a threat and the rates of initiation and propagation.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
Stainless steels are potentially susceptible to in storage environments; SCC, should it occur, represents the greatest threat to container integrity. This task will be carried out by our contractors.					

B8.1.10 Studies of Internal Pressurisation and Hydrogen Embrittlement on Carbon Steel / Cast Iron Containers

<table>
<tr><td>Task Number</td><td>90.1.010</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Waste Container Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Previously, Nirex carried out a limited amount of research relating to the use of carbon steel to dispose of ILW in anoxic, alkaline environments. Research evaluating the use of this and other relevant materials (e.g. cast iron) for the management and disposal of ILW or other radioactive wastes (e.g. HLW and spent fuel) has also been carried out internationally. RWM places a significant emphasis on evaluating the durability of container materials during periods of atmospheric exposure so as to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (and including a long GDF operational period and possible reversible / retrievable periods) and the design of suitable storage and disposal facilities. Building on the approach employed in similar studies for HLW / spent fuel containers, this task focuses on the potential for corrosion processes to induce a significant degradation of the structural performance of carbon steel and cast iron waste containers (such as ductile cast iron containers (DCICs)), including effects associated with hydrogen embrittlement.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts (in particular, concepts envisaging long underground periods in un-backfilled tunnels), GDF design, and the development of the post-closure safety case by gaining a mechanistic understanding of the durability of ILW corrosion-allowance (carbon steel, cast iron) containers in periods preceding closure of the GDF.</td></tr>
<tr><td colspan="4">Research Objective
To evaluate the expected extent of general corrosion on the basis of realistic assumptions of the amount and distribution of water in the system, the effectiveness of environmental control in interim stores and a GDF, and expected post-closure conditions.
To evaluate whether localised corrosion, stress corrosion cracking and / or microbially-influenced corrosion can be expected on the inside or on the outside of the waste container.
To evaluate the extent of internal pressurisation likely to be associated with hydrogen generation inside and outside the container and any resulting embrittlement of the waste container.
To evaluate the impact of the expected level of embrittlement on the ability of the container to withstand expected loads during periods preceding and following closure.
To evaluate the overall durability of the container in relevant scenarios.</td></tr>
</table>

<table>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises a desk-based study to determine the degree of internal corrosion, pressurisation and hydrogen embrittlement of carbon steel / cast iron ILW container designs during periods preceding and following closure of a GDF. It includes the calculation of the likely amount of general corrosion and discussion of the potential for localised corrosion, stress corrosion and microbial corrosion on the basis of existing information. It also includes an assessment of the expected pressurisation and associated hydrogen embrittlement, the effect of hydrogen embrittlement on the fracture toughness in relevant loading conditions and the durability of waste containers based on assumed system evolution, including sensitivity analysis.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR and Evaporite.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A technical report which details the corrosion behaviour of cast iron/carbon steel under the specific conditions mentioned above, the impact of the nature and extent of corrosion on the integrity of the container and impact on its required safety functions. Will also include an assessment of the potential and extent for internal pressurisation.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B8.1.11 Studies of Stainless Steel Corrosion in Relevant Storage Conditions - Chloride Deposition Measurement Methods

<table>
<tr><td>Task Number</td><td>90.1.011</td><td>Status</td><td>Start date in the future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Waste Container Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities. Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term. This task focuses on the practical measurement of chloride species deposition.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">Chloride deposition and its role in initiating and propagating all forms of localised corrosion; pitting, crevice and stress corrosion cracking, is the main threat to stainless steel waste package integrity during surface storage and the GDF operational phase. A range of techniques are used and being developed for measurement of chloride species on surfaces.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To determine:
The range of practically applicable techniques available to measure chloride species deposition on stainless steel surfaces in storage environments, both in-situ and by subsequent analysis of test samples exposed in the storage environment and subsequently recovered for analysis;
The reproducibility and levels of detection offered by the various techniques; and
Guidance on the application of the measurement techniques and their advantages and disadvantages.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">The scope of this task is to carry out a desk based review of relevant chloride measuring methods, interviews and correspondence with waste producers who have practical experience and discussions with academics working in the field of developing methods e.g. hyperspectral imaging.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR and Evaporite.</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
<tr><td colspan="4">Improved chloride measurement methods and data reproducibility. Improved confidence in assurance of packages.</td></tr>
</table>

SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
This task will be carried out in collaboration between NDA estate Site Licence Companies and will be funded through NDA's Direct Research Portfolio.					

B8.2 WBS 90.2 - Develop Models for LHGW and HHGW Container Evolution Using Data Derived from Generic Stage Work Scope

B8.2.1 Development of Component Models for HLW / SF containers

<table>
<tr><td>Task Number</td><td colspan="2">90.2.001</td><td>Status</td><td colspan="2">Completed, undergoing review</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Container Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Develop Models for LHGW and HHGW Container Evolution Using Data Derived from Generic Stage Work Scope</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally. Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure period is generally well understood and underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including considerations of the potential coupling between chemical and mechanical effects. This task considers the development of component models for the treatment of radionuclide containment in HLW/spent fuel containers during the post-closure period of a GDF.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the development of the post-closure safety case by refining the treatment of radionuclide release from waste containers.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop component models for the treatment of radionuclide containment in the engineered barrier system in periods following closure of a GDF for specific disposal concepts based on expected corrosion mechanisms.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following:
Based on previously developed information, evaluate degradation mechanisms of selected concepts for which component models could be meaningfully developed (covering a range of geologies) in a variety of thermal, chemical and mechanical conditions.
If appropriate, develop parametric models yielding expected containment timescales, including uncertainty ranges.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report and software tool (PackET).</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
'Corrosion allowance' is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. In our modelling hierarchy we define a component model as a collection of process models that use multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development, some representation of uncertainty is usually required. There are previous publications relevant to this task [1].   1 D. Sanderson D, P. Gardner, F. King, and S. Watson, *The use of failure assessment diagrams to evaluate the durability of HLW and spent fuel waste containers*, AMEC, Contractor Report 17697/TR/05 (MMI report MMU298-P01-R-02, Quintessa report QRS-1589A-R1.2), Issue 2.1, 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/the-use-of-failure-assessment-diagrams-to-evaluate-the-durability-of-hlw-and-spent-fuel-waste-containers/.

B8.2.2 Development of Component Models for ILW Containers

Task Number	90.2.002	**Status**	Completed, undergoing review
WBS Level 4	Waste Container Evolution		
WBS Level 5	Develop Models for LHGW and HHGW Container Evolution Using Data Derived from Generic Stage Work Scope		
Background			
Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex, but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities. Work carried out by Nirex investigating the corrosion behaviour of stainless steel in conditions simulating disposal of ILW in a cement-based near field indicated that corrosion can only occur if groundwaters containing sufficiently high levels of chloride were to come into contact with waste containers whilst relatively high temperatures (from curing of the backfill) and relatively high redox conditions (e.g. due to any unreacted oxygen) are still present in the near-field. Limited tests on the potential effect of thiosulphate (a known corrosive agent that may be produced in a GDF by microbial activity or by the oxidation of pyrite minerals) were also carried out. Building on work carried out by Nirex, this task comprises the development of a parametric model able to estimate the likely release of radionuclides from initially vented/sealed stainless steel, carbon steel and cast iron containers following their eventual post-closure degradation. To date, the post-closure safety case takes no credit for the presence of the waste container.			
Research Driver			
To develop an understanding of the ability of ILW containers to retain radionuclides in periods following closure of a GDF. This work will support the development of the safety case.			
Research Objective			
To develop a parametric model able to evaluate the evolution of ILW containers in the post-closure period and the subsequent rate of radionuclide release from both stainless steel and carbon steel/cast iron containers (vented or sealed) in relevant hydrogeochemical conditions in order to: • Underpin any contribution of the waste package in achieving containment of radionuclides; and • Understand to what extent the development of corrosion may impact on the rate of radionuclide release.			
Scope			
The scope comprises the development of parametric models of the flow of radionuclides from both intact (vented) and corroded ILW containers in assumed geochemical and hydrogeological conditions and considering an assumed size distribution and surface density of corroded areas (i.e. pits), including sensitivity analysis.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

Report and software tool (PackET).					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1]. 1 A. Chambers, C. Jackson, C. Wilding, and B. Swift, *Data for a representation of physical containment in a repository-scale model*, SERCO, SA/ENV-0658, 2008.					

B8.2.3 Studies of Stainless Steel Corrosion in relevant storage conditions

Task Number	90.2.003	**Status**	Ongoing
WBS Level 4	Waste Container Evolution		
WBS Level 5	Develop Models for LHGW and HHGW Container Evolution Using Data Derived from Generic Stage Work Scope		

Background

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities. Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term. This task focuses on the monitoring/demonstration of the corrosion behaviour of both austenitic stainless steel grades (304/316) and relevant duplex grades (e.g. 2101/2205) in conditions relevant to interim storage facilities for which relevant data can be obtained.

Research Driver

To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible/retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period. This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

Research Objective

To determine:

- Typical environmental conditions (e.g. temperature and relative humidity fluctuations, type and nature of contaminants) present in interim stores and anticipated in the operational period of a GDF;
- Whether practical experience with the use of stainless steel under prolonged atmospheric exposure in relevant conditions indicates evidence of deep pits and stress corrosion cracks;
- Whether any signs of corrosion, as observed by routine waste package monitoring, can be correlated with environmental conditions expected to yield pitting and stress corrosion on the basis of laboratory experiments and models; and
- Whether previously developed parametric models (ACSIS) are able to reproduce the behaviour observed in real conditions.

Scope					
The scope comprises a continuation of data collection on environmental conditions and the level of corrosion found on relevant materials, in indoor (inland) locations previously used, in more aggressive (i.e.coastal) locations and/or in underground environments.					
Geology Application					
HSR, LSSR and Evaporite.					
Output of Task					
Data on environmental conditions and contaminant deposition rates in real storage conditions.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are several publications relevant to this task [1]–[3]. This task will be procured through our contractors with input from academic partners.					

1 N. Smart, D. Blackwood, A. Graham, F. Porter, A. Rance, and M. Thomas, *Stress Corrosion Cracking of Stainless Steels in Simulated Blast Furnace Slag Porewaters*. AEAT/ERRA-0319, AEA Technology, 2002.

2 C. Naish, S. Sharland, and K. Taylor, *The initiation of crevice corrosion in stainless steel: A combined modelling and experimental approach*, AEAT, Contractor Report AEAT/ERRA-0268, 2000.

3 C. Donohoe, *The effect of ionizing radiation on the corrosion resistance of ILW containers*. NNL (08) 9544 Issue 3, National Nuclear Laboratory, 2009.

B9 WBS 100 - Waste Package Accident Performance

The WPAP work area provides accident scenario data for the Transport and Operational Safety Cases. This in turn sets requirements in the waste package specifications for waste producers, enabling them to meet RWM's safety case requirements when packaging wastes. The research activities within **WBS 100** can be summarised in the following work areas:

- Impact Accident Performance (**WBS 100.1**)
- Fire Accident Performance (**WBS 100.2**)
- Combined Fault Accident Performance (**WBS 100.3**)

Following a review of research needs in 2014, RWM has undertaken a large project covering research tasks in support of the Waste Package Accident Performance needs of the Operational Safety Case, Transport Safety Case, and Waste Management directorate. This work provides understanding and data on how waste packages provide the necessary physical and chemical robustness against fires and impact accidents in support of the transport and operational safety cases.

For this research area, it is considered that site-specific impact accident research will not be required as waste package impact accident scenarios are geosphere-specific; the drop height is dependent on the dimensions of the underground openings (inlet cell, transfer tunnel, disposal vault) through which the waste package is moved. RWM has defined impact accident drop heights for the GDF constructed in a HSR and a LSSR; site-specific research would only be required if there is a change in the future in these design parameters.

Waste package fire accident scenarios are the same for all three geological environments. There will, therefore, be no requirements for site-specific research based on the waste package fire accident scenario. Following the completion of the ongoing and planned tasks within the WPAP area, Task 100.3.002 will form a review of the waste package accident performance knowledge base, resulting in the closure of arising WPAP knowledge gaps and maintaining a watching brief on any arising needs from novel packaging proposals.

B9.1 WBS 100.1 - Impact Accident Performance

B9.1.1 Performance of Aged Packages - Effect of Ageing

<table>
<tr><td colspan="2">Task Number</td><td colspan="2">100.1.001</td><td>Status</td><td>Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Impact Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. One area of uncertainty pertains to the impact performance of waste packages many decades after their manufacture and this task further develops research, initiated in 2001, into this aspect. The current state of knowledge is that there are no known factors likely to lead to detrimental ageing of cementitious materials over the timescales considered, but no work has been undertaken on alternative encapsulants.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the operational and transport safety cases and waste package disposability assessments by addressing our knowledge gap in the impact performance of aged cementitious waste packages.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To quantify the variation of break-up properties of wasteforms due to ageing.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope includes the following activities:
To undertake a desk study to develop the ageing study carried out in 2001, in order to consider the likely effect of ageing on stress-strain properties and breakup properties of wasteforms other than cement encapsulated wasteforms.
To develop a long-term test strategy and test programme to allow the effects of ageing to be studied and to procure test samples (as defined above) and put them into storage.
To carry out break-up and compression tests to assess the ageing of a simulated wasteform that was prepared in 1985, and subsequently tested in 1992. Following which, a comparison will be undertaken between the two sets of test results.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing the proposed experimental programme for underpinning the impact accident performance of aged waste packages.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are several publications pertinent to this task [1]–[4].

1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

2 Nirex, *The Effect of Ageing on the Impact Performance of Unshielded Nirex Standard Packages for ILW*, Nirex Report 57718/05, Issue A, 2001.

3 P. Donelan, *Activity Release from ILW Packages under Impact Accident Conditions*. 761, Ove Arup and Partners, 1995.

4 R. Bush, A. Fenton, A. Harris, and R. Simmons, *Mechanisms of ageing for cemented ILW wasteforms*, AEA Technology, Contractor Report AEAT/R/NS/0469 Issue 3, 2003.

B9.1.2 Develop Methodologies for Scaling Release Fraction Data for Varying Drop Heights

Task Number	100.1.002	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		
Background			
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. In reality, the impact release fraction (RF) will differ for each combination of, for example, container, waste inventory, wasteform, drop height, drop orientation, target type and package age. The Waste Package Accident Performance (WPAP) status report adopts standard impact RFs for ten generic waste package types and a range of specified drops, identifying the respirable fraction to be utilised in accident scenario studies. Research is required in order to develop methodologies for scaling release fraction data in order for RWM to provide appropriate performance data for each current scenario and any future requirements. This task comprises the development of methodologies for scaling impact release fraction data appropriate to the updated impact scenarios described in the GDF fault and hazard schedule. Influences on impact performance include drop heights, orientations, target types, break-up of the wasteform and the particulate size(s) of concern for the inhalation dose pathway.			
Research Driver			
To support the operational and transport safety cases and waste package disposability assessments by developing methodologies for the scaling of impact release fraction data to alternative drop heights and the particulate size(s) of concern for the inhalation dose pathway.			
Research Objective			
To extend existing RWM work that investigated the scaling of RFs from 25 m to 15 m for particulates smaller than 100 μm to 40 and 10 μm, to evaluate other drop heights and particulate sizes; the results will lead to less pessimistic dose estimates to workers and the public.			
Scope			
The scope is to apply the methodology established in the scoping report to derive the scaling factor for alternative drop heights and particle sizes. Two approaches for scaling test data are needed: • A method to scale drop test data at 25 m down to 15 m needs to be extended to other drop heights. • A method to scale the predicted airborne particle size released (100 μm) from a waste package to the inhalation particle size that could be inhaled and retained in the lungs (~10 μm) may need to be extended to smaller particle sizes; possibly 1 μm for some public dose calculations.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

Report detailing scaling methodologies for impact drop heights and particle-size distribution.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					
Relevant publications include: [1] 1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.					

B9.1.3 Develop, Refine and Document Holistic Impact Methodology

Task Number	100.1.003	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		
Background			
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target. In reality, the impact release fraction will differ for each combination of, for example, container, waste inventory, wasteform, drop height, drop orientation, target type and package age. The Waste Package Accident Performance status report [1] adopts standard impact RFs for ten generic waste package types and a range of specified drops, identifying the respirable fraction to be utilised in accident scenario studies. The Letter of Compliance disposability assessment process applied by RWM evaluates the disposability of a waste package by adopting a holistic methodology to estimate the amount of particulate that could be generated based on data on the total amount of energy absorbed from the wasteform and results of computational modelling combined with small-scale wasteform break-up tests. However, this holistic methodology requires refinement since it is believed that the current approach over-predicts (by approximately 10 times) the levels of particulate generated and released, compared to full-scale test data.			
Research Driver			
To support the operational and transport safety cases and waste package disposability assessments by addressing the potential over-estimate in the impact RF from cementitious waste packages.			
Research Objective • To determine whether an accurate, systematic and transparent methodology can be developed (based on existing partially-developed approaches and currently available data) to estimate impact RFs for a variety of packaging approaches and drop scenarios. • To quantify any possible reduction in the quantity of particulate generated from impact accidents because the wasteform will be 'confined' within the container and may 'flow' rather than become airborne.			
Scope			
This task comprises the following scope: • Undertaking a test programme to understand the mechanics of grout flow versus grout break-up during a package impact accident and revising and validating the holistic impact methodology such that flow behaviour can be taken into account. • Arranging and facilitating independent expert peer review of the proposed revised holistic impact methodology. • Publishing the revised holistic impact methodology in peer-reviewed journals and at conferences.			
Geology Application			
HSR, LSSR, Evaporite			

<table>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing the refined holistic impact methodology, together with publication in the academic literature.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are several publications pertinent to this task [2]–[4].
1 Radioactive Waste Management, Geological disposal: Waste package accident performance status report issue 2, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.
2 C. Tso, Proposed holistic methodology for assessing waste package impact performance, ARUP, Contractor Report 69760-15-01, 2009. [Online]. Available: http://rwm.nda.gov.uk/publication/proposed-holistic-methodology-for-assessing-waste-package-impact-performance/.
3 C. Tso and S. Shah, Validation of the holistic impact methodology for 500 litre drum: Stage 1 validation of the modelling of waste package behaviour, ARUP, Contractor Report 118366-08-01, Issue 1, 2009. [Online]. Available: http://rwm.nda.gov.uk/publication/validation-of-the-holistic-impact-methodology-for-500-litre-drum-stage-1-validation-of-the-modelling-of-waste-package-behaviour/.
4 C. Tso, Validation of the Holistic Impact Methodology for 500 litre Drum: Stage 2 Validation of the Calculation of Breakup and Release. 118366-08-01, Arup, 2009.</td></tr>
</table>

B9.1.4 Develop Improved ILW Package Models (Finite Element Analysis, FEA)

Task Number		100.1.004	**Status**	Ongoing	
WBS Level 4		Waste Package Accident Performance			
WBS Level 5		Impact Accident Performance			
Background					
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. Based on consideration of the likely design and layout of a GDF, we wish to transform the safety case from the current bounding criteria towards a range of more realistic accident scenarios. In some cases it may be possible to eliminate or reduce the assessed effect of an impact accident. RWM will then be better placed by focusing on addressing impact scenarios important to the safety of the facility.					
Research Driver					
To support the operational and transport safety cases, waste package disposability assessments and upstream waste processing at decommissioning sites by eliminating potential over-conservatisms which have led to onerous constraints at the GDF, during transport from waste producers' sites and during decommissioning operations at those sites.					
Research Objective					
To extend the understanding of the impact performance of the 2 metre and 4 metre boxes.					
Scope					
The scope comprises the following elements: • To analyse an existing finite element model of the generic 3 cubic metre box for a 9 metre drop in lid-edge, lid-corner, lid-down and side-drop orientations onto a flat unyielding target. This task may include creation of a new box model if required. • To develop a detailed model of the 2 and 4 metre boxes with shielding thicknesses of 0 mm, 100 mm and 200 mm. The model results will be analysed for a 10 metre drop in the worst orientation onto a flat target and its behaviour evaluated to derive release fraction values. Following this, comparison will be made with the RF from the designs with different shielding thickness.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Report detailing finite element modelling of the 2 metre and 4 metre boxes.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information
For further information, see the Waste Package Accident Performance Status Report [1]. 1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

B9.1.5 Impact Accident - Behaviour and Properties of Containers and Wasteforms

<table>
<tr><td>Task Number</td><td colspan="2">100.1.005</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Impact Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. Finite element modelling is used extensively in order to evaluate the performance of waste packages in accident scenarios in the most efficient and safe, yet robust, manner. Such modelling requires data parameters gained in laboratory stress-strain experiments and drop-test experiments on real packages. There is a need to compile a reference data-set of agreed and consistent data of stress-strain and break-up properties to support these modelling studies. Currently, such data are disseminated over a range of data sources and reports. This task comprises the collation of this data-set in order to improve the efficiency and consistency of FE evaluations.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the operational and transport safety cases and waste package disposability assessments by improving the efficiency and consistency of FE input parameters.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To compile an agreed and consistent reference stress-strain and break-up data-set to support the modelling of packages in impact accident scenarios.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of work includes the collation of data and relevant underpinning from existing work carried out by RWM and its predecessor companies, regarding stress-strain and break-up behaviour of wasteforms and encapsulants.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing the collation of data required for impact accident modelling.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 6</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">For further information, see the Waste Package Accident Performance Status Report [1].

1 Radioactive Waste Management, Geological disposal: Waste package accident performance status report issue 2, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.</td></tr>
</table>

B9.1.6 Validation and Update of the Impact Performance Methodology for the 500 Litre Robust Shielded Drum and the 3 Cubic Metre Robust Shielded Drum

Task Number	100.1.006	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		

Background

A methodology for evaluating Release Fractions (RFs) from Robust Shielded Containers (RSCs) following an impact fault and subsequent seal failure was developed by RWM for a recent packaging proposal. This methodology was adopted by the waste producers and has yet to be assessed for continued suitability for the final LoC stage where a higher level of scrutiny is appropriate.

Research Driver

To support the disposability assessment of RSCs, a validated methodology for predicting any possible release fraction from pressurised RSCs following an impact fault which results in lid-seal failure is required.

Research Objective

To evaluate the current methodology for provision of RFs for RSCs resulting from a sudden seal failure from a maximally pressurised RSC following a GDF fault which leads to an impact accident and subsequent seal failure within the RSC. This evaluation is to assess the suitability of the methodology for use in the final stage Letter of Compliance process.

Scope

The scope comprises consideration of the 500 litre robust shielded drum and the 3 cubic metre robust shielded drum containers under maximum pressurisation with fault conditions as appropriate for the RSC vault. The output is to be a reasoned recommendation, with evidence wherever possible, as to whether the current methodology is suitable or not. The evaluation shall contain at least (but not be limited to) consideration of the following:

- The relevance of breakup data used.
- The RSC cavity airborne release fraction used.
- The current methodology as defined in the RWM technical note.
- The height scaling factor.

In addition:

- Consideration of the likely effect of the vent orifice size on the result (this is not considered at all in the current methodology).
- Should the evaluation recommend that the current methodology is suitable, this should be presented in a report.
- Should the evaluation recommend that the current methodology is unsuitable then suggestions for further work (both desk-based and/or experimental) to improve or replace the current methodology and the data on which it relies are to be made to ensure it is suitable for use in final stage LoC assessments.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report detailing the documentation, validation and refinement to the robust shielded intermediate level waste container impact methodology.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					

B9.1.7 Develop Improved ILW Package Models - Including Credit for Design Features (e.g. Capping Grout)

Task Number	100.1.007	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		

Background

RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. Based on consideration of the likely design and layout of a GDF, we wish to transform the safety case from the current bounding criteria towards a range of more realistic accident scenarios. In some cases, it may be possible to eliminate or reduce the assessed effect of an impact accident. RWM will then be better placed by focusing on addressing impact scenarios important to the safety of the facility.

Research Driver

To support the operational and transport safety cases, waste package disposability assessments and upstream waste processing at decommissioning sites by eliminating potential over-conservatisms which have led to onerous constraints.

Research Objective

- To define the benefits to impact performance of having an annulus and capping grout in unshielded intermediate-level waste and shielded intermediate-level waste package designs. In addition, to give guidance on the design of the annulus, including material type, strength and thickness for the 500 litre drum, 3 cubic metre box, 2 metre box and 4 metre box packages.
- To give an indicative understanding of the performance of waste packages in a standard waste transport container in order to reduce over-conservatism in the RF.
- To estimate the RF from four drums in a SWTC in an International Atomic Energy Authority transport accident scenario, taking into account the realistic boundary conditions, as defined for the SWTC.
- To extend the understanding of the impact performance of the 2 metre and 4 metre boxes.

Scope

The scope comprises the following elements:

- To carry out finite element analysis on models of a 3 cubic metre box design, a 500 litre drum design, a 2 metre box design and a 4 metre box design.
- To give guidance to disposability assessments for waste producers on the recommended design of annulus and capping grout.
- To give guidance to disposability assessments regarding whether the annulus or capping grout can be considered uncontaminated and under what conditions they can be considered uncontaminated.

<table>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing an investigation into the effects of annulus and capping on impact performance.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are several publications pertinent to this task [1], [2] .
1 Radioactive Waste Management, Geological disposal: Waste package accident performance status report issue 2, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.
2 C. Tso and S. Owen, Evaluation of the Benefit of an Annulus. 69760/17, Ove Arup and Partners Limited, 2006.</td></tr>
</table>

B9.1.8 Package Decontamination Factors - Part 1 – Selecting Appropriate Analogues

<table>
<tr><td colspan="2">Task Number</td><td>100.1.008</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Impact Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Within the Letter of Compliance process, there is a long history of the use of analogues to support package accident performance submissions; see example reports given under ‘Further Information’. The basis is that the understanding of the performance of a package that has been extensively analysed, either by physical testing or by Finite Element Analysis, can be applied to other packages that have similar design, construction and materials properties. The comparison needs to be made by an appropriately qualified and experienced person and that expected divergence in performance due to differences in the packages being compared should be explored. RWM is receiving an increased number of Letter of Compliance submissions attributing performance benefits for specific package features which reduce predicted releases by a specified fraction (called a Decontamination Factor). Submissions may be supported by offering performance data from an analogous package.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop the principles of what constitutes an appropriately analogous package or container feature when used to support a performance submission for another package or container feature.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">Provision of a document clearly defining the principles to be followed to identify appropriate analogues used to support assessments of package or container feature performance. This document should allow consistent selection of appropriate analogues by well-informed technical persons. If possible, some guidance should be provided on how to identify if a proposed analogue has diverged too far from the package or container feature being considered to be valid.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">A desk-based study of previously accepted analogues and an analysis of what divergences in packaging and container features have been accepted between proposed package and analogue. This will be coupled with elicitation from a variety of experts on the guidelines for what should be considered when choosing an analogue.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing a desk study of relevant underpinning to support the use of decontamination factors in impact accident assessments.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
There are several publications pertinent to this task [1]–[3].

1. Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.
2. Tso, C.S., *Waste package impact release fraction data report*, ARUP, Contractor Report 124857-14-01, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/waste-package-impact-release-fraction-data-report/.
3. Serco, *Release fractions from waste packages exposed to fire*, SERCO/TCS/6663/01, 2010.

B9.1.9 Package Decontamination Factors - Part 2 – Accounting for Multiple Barriers

Task Number		100.1.009	**Status**	Start date in future	
WBS Level 4		Waste Package Accident Performance			
WBS Level 5		Impact Accident Performance			
Background					
Within the safety assessment process, there are some examples of the use of multiple barriers to improve accident performance; see example reports given under 'Further Information'. RWM is receiving some Letter of Compliance submissions which attribute performance benefits for multiple barriers, some sealed and some unsealed, which reduce predicted releases by a specified fraction (called a Decontamination Factor).					
Research Driver					
To support waste package disposability assessments by the quantification of the likely benefits of a range of multiple barriers of containment within waste packages.					
Research Objective					
To quantify, to orders of magnitude, the likely benefits of multiple layers of containment within a package. Specifically, the predicted benefit of a steel liner grouted within a 3 cubic metre box, both with a sealed lid and without a lid. Also, a paint tin containing waste encapsulated in cementitious grout with a sealed lid and with a loosely fitting lid. The wastes to be considered are: powders, grouted solids, ungrouted solids and liquids.					
Scope					
This is a desk-based study that will review previous work on packages with multiple containment barriers, the available literature on this topic and the Sellafield Release Fraction Database. The task may include an element of Finite Element modelling with recently developed package models to assess the benefit of the various extra barriers.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Report detailing an review of the effect of multiple barriers on impact accident performance.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are several publications relevant to this task [1]–[3].					

1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

2 *TN International, Multiple Water Barriers: An Alternative to the Assessment of the Fuel Assemblies During Accident Conditions of Transport, PATRAM*. Presented at the The 15th International Symposium on the Packaging and Transport of Radioactive Materials, 2007.

3 International Nuclear Services, *Disposal container transport container - (DCTC): Generic design development*, INS Report TD/ETS/R/12/282, 2013.

B9.1.10 Effect of Cracked Wasteform on Impact Performance

Task Number	100.1.010	**Status**	Start date in future
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		

Background

It is understood that as cementitious wasteforms cure and age they may undergo some cracking. It is also known that some wastes which undergo expansive corrosion, such as Magnox metal, can contribute to any cracking of the wasteform. The RWM position, arrived at via elicitation, is that moderate cracking of a wasteform which leaves largely monolithic pieces of wasteform is unlikely to be detrimental to the impact performance of the package. Uncertainty arises when cracking of the wasteform is extensive.

Research Driver

To support the wasteform disposability assessments process, the operational safety case and the transport safety case, it is necessary to understand whether cracking of cementitious wasteforms leads to reduced package impact performance, specifically whether any 'cliff-edge effects' exist as the degree of cracking increases beyond the level at which cracking may become problematic. Additionally, how might the degree of cracking be quantified?

Research Objective

Quantification of what level of cracking, if any, reduces the impact performance of a package to a degree where its presence must be taken into consideration for transport or operational safety. Guidance is to be provided as to the effect on package release fraction given various levels of wasteform cracking. Information will be required for standard wasteform types in standard packages. Additionally, if required by the operational safety case at the time of commencement, information on any increase in particulate present in a cracked cementitious wasteform over an un-cracked wasteform prior to any impact fault should be provided.

Scope

This task will begin with a literature survey of waste producers' research and also that of general industry (specifically construction) to determine what information is already available. Following this, small-scale experimental trials may be conducted to determine the effect of a cracked wasteform on impact performance.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report detailing the effect of wasteform cracking on the potential release of radionuclides in an impact accident scenario.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4

Further Information
There are several publications pertinent to this task [1]–[3].

1 B. Swift, J. Babington, and C. Jackson, *Calculations of times to wasteform cracking and container rupture for packages containing metal waste*, Serco, Contractor Report SERCO/TAS/000755/001, 2008.

2 M. Constable, A. Craven, and S. Dickinson, *Review of wasteform ageing up to repository resaturation, part 2*, Other Technical Report WMT(07)P052, 2010.

3 Nuclear Decommissioning Authority and Department of Energy and Climate Change, *Radioactive wastes in the UK: A Summary of the 2013 Inventory*, URN 14D039, 2014.

B9.1.11 Update to the Holistic Impact Methodology Following Breakup Versus Flow Tests

<table>
<tr><td colspan="2">Task Number</td><td>100.1.011</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Impact Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The holistic impact methodology [1]–[3] is being updated to incorporate the effect of breakup versus flow on impact (Task 100.1.003), the effect of wasteform ageing on impact performance (Task 100.1.001) and the effect of wasteform cracking on impact performance (Task 100.1.010). There will be a need to update the impact methodology to incorporate the output from these tasks.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the wasteform disposability assessments process, the operational safety case and the transport safety case, a methodology for assessing the impact performance of waste packages that reduces conservatisms and areas of uncertainty is required.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To provide a single methodology synthesising the work that has been performed in this area.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This desk-based task will review the research tasks performed since the last update to the holistic impact methodology and detail an approach to incorporate any advancements to reduce pessimisms and uncertainty into an updated methodology.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing an experimental investigation into the behaviour of cementitious grout in a container during an impact accident scenario.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
For further information, see the Waste Package Accident Performance Status Report [4].

1 C. Tso, *Proposed holistic methodology for assessing waste package impact performance*, ARUP, Contractor Report 69760-15-01, 2009. [Online]. Available: http://rwm.nda.gov.uk/publication/proposed-holistic-methodology-for-assessing-waste-package-impact-performance/.

2 C. Tso and S. Shah, *Validation of the holistic impact methodology for 500 litre drum: Stage 1 validation of the modelling of waste package behaviour*, ARUP, Contractor Report 118366-08-01, Issue 1, 2009. [Online]. Available: http://rwm.nda.gov.uk/publication/validation-of-the-holistic-impact-methodology-for-500-litre-drum-stage-1-validation-of-the-modelling-of-waste-package-behaviour/.

3 S. Shah, *Validation of the holistic impact methodology for 500 litre drum stage 2 validation of the calculation of breakup and release*, ARUP, Contractor Report 118366-08, Issue 1, 2009. [Online]. Available: http://rwm.nda.gov.uk/publication/validation-of-the-holistic-impact-methodology-for-500-litre-drum-stage-2-validation-of-the-calculation-of-breakup-and-release/.

4 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

B9.1.12 Group Various Package Types

Task Number	100.1.012	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		

Background

In support of fire and impact accident performance evaluation, RWM has defined a set of generic package type groupings (encompassing minor design modifications such as bolting arrangements and closure types) to enable extrapolation from well characterised packages to those which are similarly configured, but which have not been subject to extensive experimental or modelling studies. For each waste package type, small-scale test data have been grouped according to what is considered to be representative of the likely simulated wasteforms or plain grout formulations that could be present. Generic release fraction values for each waste package type are given in the Waste Package Accident Performance Status Report [1] and the derivations are discussed in detail in the Arup report “Waste Package Impact Release Fraction Data Report” [2]. This grouping is based on expert judgement and has been done in order to narrow the range of values where possible. This task considers the revision of the ten current waste package type groups:

- Expanding the waste package type groups to account for variations in waste package design.
- Differentiating between packages of the same design but with different annulus/shielding thickness.
- Expanding the groups to account for different wasteform types.

Research Driver

To support the operational and transport safety cases and waste package disposability assessments by reviewing whether less pessimistic generic RFs can be assigned to a particular package in the absence of a specific RF based on experiment or computational analysis.

Research Objective

To re-define the waste package type groups in the WPAP Status Report to account for variations in waste package design within each waste package type; new bounding waste stream definitions and new package types.

Scope

The waste package type groups will consider sub-types; to include, but not be limited to the following:

- Wasteform types (e.g., heterogeneous, homogeneous).
- Encapsulant types (e.g., polymer, cement).
- Package design elements (e.g., engineered annulus, grouted annulus, double-lid with anti-floatation plate) - essentially, the features that provide a distinct step-change in RF.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report proposing new waste package sub-groups for impact accident performance assessment.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					

1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

2 Tso, C.S., *Waste package impact release fraction data report*, ARUP, Contractor Report 124857-14-01, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/waste-package-impact-release-fraction-data-report/.

B9.1.13 Impact Thresholds Below Which Releases Will Not Occur

<table>
<tr><td colspan="2">Task Number</td><td>100.1.013</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Impact Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. In reality, the impact release fraction will differ for each combination of, for example, container, waste inventory, wasteform, drop height, drop orientation, target type and package age. Currently, the Generic Waste Package Specification identifies impact accident performance requirements for a 0.3m drop without ‘loss or dispersal of the radioactive contents’ for Shielded ILW waste packages. There is clearly benefit to the Transport and Operational safety cases if drop heights can be identified below which no release could occur, since this may allow consideration of the small drop-height impact accidents to be eliminated.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the operational and transport safety cases and waste package disposability assessments by identifying whether threshold drop heights can be derived for waste packages, below which consideration of radionuclide release can be neglected.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To establish a threshold drop height below which there is no release of contents, for representative Unshielded Intermediate Level Waste and SILW packages.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope for this task is to model one design of each UILW and SILW package type (i.e. the 2 metre box, 4 metre cubed box, 500 litre drum, corner stacking 3 cubic metre box, mid-side stacking 3 cubic metre box, 3 cubic metre drum, Miscellaneous Beta Gamma Waste Store box and 6 cubic metre box) in the orientation most vulnerable to release in an impact, from a drop height of 0.3 m and increasing the height at 1 m intervals until there is release of radioactive particulates or until the drop height reaches 10 m.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report to identify whether threshold drop heights can be derived for waste packages, below which consideration of radionuclide release can be neglected.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [1].

1 Nuclear Decommissioning Authority, *Geological Disposal: Generic Specification for Waste Packages Containing Low Heat Generating Waste*, NDA Report NDA/RWMD/068, 2012. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-specification-for-waste-packages-containing-low-heat-generating-waste-august-2012/.

B9.1.14 Derivation of ab initio Release Fraction Values for the 6 Cubic Metre Box; Revised 3 Cubic Metre Drum; MBGWS Box and Corner Lifting 3 Cubic Metre Box

Task Number	100.1.014	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		

Background

RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of 'release fractions' for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. In reality, the impact RF will differ for each combination of, for example, container, waste inventory, wasteform, drop height, drop orientation, target type and package age. The WPAP status report [1] adopts standard impact RFs for ten generic waste package types and a range of specified drops, identifying the respirable fraction to be utilised in accident scenario studies. The RFs for the revised 3 cubic metre drum, the corner-lifting 3 cubic metre box, the MBGWS box and the 6 cubic metre box (previously known as the WAGR box) were based on analogy to other waste packages for which an RF based upon experiment or modelling already exists. To improve the robustness of the RF data and for consistency with other package types, this task comprises the *ab initio*FE analysis calculation of these data.

Research Driver

To support the operational and transport safety cases and waste package disposability assessments by deriving more robust RF data (*ab initio*, rather than by analogy) for use in impact accident assessments.

Research Objective

To derive new RF values to replace the existing values for the following package types: 6 cubic metre box; revised 3 cubic metre drum; MBGWS box; and corner-lifting 3 cubic metre box.

Scope

The scope comprises the following activities:

- Undertaking a review of the RF values from the RWM commissioned detailed FE analyses recently completed for the 6 cubic metre box.
- Detailed FE analysis to derive RF values for the revised 3 cubic metre drum and the MBGWS box.
- Review of Sellafield Ltd drop test and FE analysis data for the corner-lifting 3 cubic metre box.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Reports detailing the development and analysis of improved impact accident performance models.

SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6

Further Information
There are other publications pertinent to this task [2].

1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

2 Tso, C.S., *Waste package impact release fraction data report*, ARUP, Contractor Report 124857-14-01, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/waste-package-impact-release-fraction-data-report/.

B9.1.15 Prepare Impact Performance Data Set

<table>
<tr><td>Task Number</td><td>100.1.015</td><td>Status</td><td colspan="3">Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Waste Package Accident Performance</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Impact Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. Following completion of a number of impact accident work activities in previous tasks, the impact accident standard release fractions (RFs) will need to be revised. The revisions, in particular, need to reflect a change to more realistic accident scenarios currently being introduced by RWM, revised scaling factors 100.1.002, impact threshold work (Task 100.1.013) and improved models (Task 100.1.003, Task 100.1.004 and Task 100.1.014).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the operational and transport safety cases and waste package disposability assessments by collating the state of knowledge on impact accident RFs.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To collate impact RF data from existing work currently used in support of packaging assessments and from the output of tasks in the Waste Package Accident Performance research programme, to identify additional tests and analyses which may need to be carried out and to prepare a new impact RF report (replacing the existing “Waste Package Impact Release Fraction Data Report” [1]) as a key input to a future WPAP Status Report.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of work for this task includes the following:
• Collating impact RF data from existing work and from other tasks in the WPAP research programme.
• Identifying additional tests and analyses which may need to be carried out.
• Preparing a new impact RF report to replace the existing Waste Package Impact Release Fraction Data Report [1]. The RFs will be based on the package type groups defined in Task 100.1.012.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a contractor approved report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">1 Tso, C.S., Waste package impact release fraction data report, ARUP, Contractor Report 124857-14-01, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/waste-package-impact-release-fraction-data-report/.</td></tr>
</table>

B9.1.16 Data Requirements for Updated Operational Safety Case Approach

<table>
<tr><td colspan="2">Task Number</td><td>100.1.016</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Impact Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The operational safety case is updating the methodology used both for identification of bounding waste streams and for fault analysis. This updated methodology proposes additional factors for use in calculating potential releases for fire and impact faults. At the time of writing, the updated methodology is being refined. This task sheet therefore provides only an outline of the work that may be required.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the operational safety case by supplying suitable data to allow assessment of predicted radiation doses to workers and the public in the event of fire or impact faults using the updated methodology.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">Exact requirements are to be confirmed by the operational safety case. The outline objectives comprise a review of available data for the following new input requirements:
• Inherent wasteform factors. What fraction of activity is already in a form available for release from a package prior to any accident, for radionuclides of interest when the following in physical forms?
    • Activated object.
    • Gross contamination.
    • Surface contamination.
    • Liquid.
    • Gas.
• Containment factors (also known as decontamination factors). What fraction of the releasable material which becomes available following a fire or impact accident is withheld by the various container layers?</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This is a desk-based study comprising literature review and data evaluation. Data will be required for radionuclides of radiological dose consequence significance and for packages identified using the new bounding wastestream methodology. Data for all bounding wastestreams will be located from suitable sources, evaluated for validity and confidence. Where data are not available, data elicitation supported by analogous data are to be used where possible.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing literature review and data evaluation.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B9.1.17 Performance of Generic Waste Package Types in Aggressive Feature Impacts

Task Number	100.1.017	Status	Start date in future
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		

Background

RWM has previously undertaken research to understand the performance of waste packages in impact accident scenarios in which the package impacts directly onto the vault floor. The RFs that have been calculated from this work can be used to inform the operational and transport safety cases and they can be used as part of the evaluation of waste packaging proposals. These activities did not include the consideration of aggressive feature impact accident scenarios, and so at present RWM does not have a reference set of RFs and performance expectations for these scenarios.

Evaluation of aggressive feature scenarios is required [1] in order to enable the assessment of waste packaging proposals and provide advice to waste producers. Furthermore, regulators have recommended that RWM provide more information about the performance of waste packages impacting on an aggressive feature. As such, there is a need for current knowledge in this area to be improved. RWM has no current basis to assess whether, according to their impact performance, waste package types should be isolated in separate vaults or mixed. An understanding of the differences in impact performance for different aggressive features would support future decisions on waste package placement, as these aggressive features may be other waste packages.

Research Driver

To enable the assessment of waste packaging proposals and provide advice to waste producers and to address recommendations from the regulators, an understanding of the performance of waste packages in an aggressive feature impact accident scenario is sought.

Research Objective

To improve the current understanding of the behaviour of RWM's suite of generic waste packages in aggressive feature impact scenarios.

Scope

In order to have sufficient understanding of the performance of the waste packages, this work will need to provide:

- release fractions;
- knockback / penetration depth; and
- description of the condition of the waste packages.

This information should be obtained through reviews of existing literature and FE modelling, as appropriate, depending on the available information. Those packages that were previously modelled for flat-surface impact as part of RWM's research activities should be modelled in this work for consistency. The suite of generic waste packages includes the following:

- 500 litre drum*
- 3 cubic metre side-lifting box*
- 3 cubic metre corner-lifting box
- 3 cubic metre drum
- MBGWS box

• 2 metre box • 4 metre box (* Literature review may be sufficient) The drop heights should be confirmed at task start up. These are currently expected to be: • 10 metres for UILW waste packages; and • 7 metres for SILW waste packages. The choice of aggressive target should consider: • The most onerous aggressive feature, assuming that different waste package types are mixed within a single vault (such as all types of UILW package in one vault). This feature might be expected to be the corner of another waste package.
Geology Application
HSR, LSSR, Evaporite
Output of Task
A report describing the performance of the generic waste package types under aggressive target impact accident conditions.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4

Further Information
1 Radioactive Waste Management, *Work instruction: Impact accident performance evaluation*, 2018.

B9.1.18 Evidence to Underpin SWTC Containment Argument in the Transport Safety Case

Task Number	100.1.018	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		
Background			
RWM has developed a family of transport packages known as the SWTCs to demonstrate feasibility. To ensure containment of the radioactive contents is maintained during transport, there are allowable release limits specified in the Transport Regulations for accident conditions of transport. RWM in conjunction with International Nuclear Services has developed a computer program called ARC (Activity Release Calculator). ARC takes account of gravitational settling and coagulation of airborne particulate that reduce the amount of material available for release. In doing so ARC demonstrates that the SWTC activity release post-Accident Conditions of Transport (ACT) satisfies regulatory limits. To support the argument, the fluid mechanics principles in the model will need experimental evidence to confirm that these principles are applicable to the conditions within the SWTC during accident conditions of transport. Wastes have already been assessed as part of the disposability process using the SWTC containment argument. If the SWTC containment argument based on the additional mechanisms of gravitational settling and coagulation of airborne particulate is not accepted then there is a risk that some wastes may not be transportable in the SWTC.			
Research Driver			
To demonstrate that only a limited amount of material is available to leak from a transport package.			
Research Objective			
The objective is to develop an understanding of the impact of coagulation and gravitational settling on the safety of transport containers			
Scope			
The validation gap can be addressed by developing a (analogy, test and experimental) programme to provide the assurance in the components of the activity release calculator model. This argument of gravitational settling and coagulation of airborne particulate is novel and has not been directly validated by experiment. Therefore in order to validate the model a specific literature review and experimental programme will be undertaken to provide evidence to support the application of the model to SWTC and strengthen this key step in the arguments for a limited release of activity past the SWTC seals. The proposed option is a programme led by RWM's Research Support Office with its links to academic institutions. Imperial College has been selected to conduct the project. International Nuclear Services has the specific transport expertise to support this task and provide Industrial supervisor oversight to Imperial College to ensure that the programme deliverables will build the underlying evidence for the activity release calculator model. International Nuclear Services will also realise the benefits in understanding of aerosols through updates to the ARC model. The scope comprises the following activities: • Literature review to identify relevant sampling and test work in the field of aerosol research. • Develop and implement analogy, test and experimental programme to underpin the ARC model.			
Geology Application			
N/A			

Output of Task					
A PhD thesis and academic journal publications describing the extent to which gravitational settling and coagulation of airborne particulate can be claimed.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 5
Further Information					
There are other publications relevant to this task [1]. 1 Radioactive Waste Management, *Geological Disposal: Transport Package Safety Report*, RWM Report DSSC/302/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-transport-package-safety/.					

B9.1.19 The Effect of Voidage on Waste Package Accident Performance

Task Number	100.1.019	**Status**	Start date in future
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Impact Accident Performance		

Background

It is accepted that the placement of waste packages within a GDF will result in a level of voidage present within the disposal system. Such voidage could be inherently (mechanically) unstable in the longer term. The extent of in-package voidage is therefore an important factor to be controlled within the GDF disposal environment. RWM has undertaken a review of its current position relating to in-package voidage. This review identified how to best capture and reflect this new knowledge within RWM's controlled documentation. The review resulted in a number of changes to requirements within the RWM Disposal System Specification and Level 2 and Level 3 WPSGD being proposed in order to clarify RWM's position. In particular, the following explicit voidage requirements have been proposed:

- An overarching 5% in-package voidage screening level would be introduced in the Level 2 generic waste package specification for LHGW.
- An 8% in-package screening level for RSCs would be introduced into the Level 3 WPS/300 specifications series.

These voidage screening levels originate from post-closure safety, however they must also allow for acceptable performance under accident conditions for transport and operational safety. The acceptance of a waste package, from a waste package accident performance perspective, is not always trivial. A waste package with poor performance could be redesigned, or the total activity within reduced. As such, voidage is not the sole variable responsible for controlling the acceptance of a waste package. As a first step towards underpinning these screening levels, RWM has produced five hypotheses detailing how changes in voidage might be expected to affect the container performance and the deduced RF of a waste package under accident conditions:

- Increased ullage space reduces mechanical support of the wasteform. Knock-back distances are larger, increasing the probability of the container tearing (no increase to calculated RF expected).
- Increased ullage space causes more impact energy to be deposited in the container, rather than the active wasteform (potential RF decrease).
- Loose items, such as wastes or inner containers, may behave as an internal battering ram, potentially damaging the container (no increase in calculated RF increase expected).
- Greater void spaces introduced by entombed inner containers could potentially be breached by an aggressive feature (potential RF increase).
- Increasing voidage over cementitious grout will reduce heat capacity of the wasteform, increasing the temperature of the wastes (potential RF increase).

These hypotheses have been made using expert judgement but supporting scientific underpinning has not yet been sought, either from existing literature or detailed modelling.

Research Driver

To simplify waste packaging operations, a better understanding of the implications of voidage in waste package accidents during transport and operations is necessary.

Research Objective					
The objective of this work is to quantify the consequences of the voidage screening levels specified in the proposed WPSGD on the accident performance of waste packages, and to determine the variation of accident performance for different amounts of voidage.					
Scope					
The following aspects of accident performance shall be considered in terms of the effect that the voidage screening levels will have on them: • Energy deposition and breakup of the wasteform (Impact). • Damage to the container (Impact). • Extent of the battering ram effect (Impact). • Penetration of aggressive feature into an entombed void (Impact). • Maximum temperatures reached in a fire (Fire). In order to understand the extent to which the RF is affected, variations in the quantity of voidage beyond the screening level should also be considered to enable the effects of different levels of voidage to be investigated. Waste packages of interest for this work include UILW packages, SILW packages and robust-shielded intermediate level waste packages, as follows: • 500 litre drum. • 3 cubic metre box (side lifting). • 3 cubic metre box (corner lifting). • 3 cubic metre drum. • 2 metre box. • 4 metre box. • 6 cubic metre concrete box. • 500 litre robust-shielded drum. • 3 cubic metre robust-shielded box.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A report detailing the consequences of the voidage screening limits on waste package accident performance.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4
Further Information					

B9.2 WBS 100.2 - Fire Accident Performance

B9.2.1 Development of Fire Release Fractions

Task Number	100.2.001	**Status**	Complete, pending publication
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Fire Accident Performance		

Background

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. The safety case currently uses highly conservative bounding assumptions of radionuclide release from a fire accident. However, by considering more realistic accident scenarios, in some cases it will be possible to eliminate or reduce the effect of a fire accident; the current bounding approach for assessing fire performance assumes a fully engulfing fire of one hour duration. We are improving our understanding of the underlying mechanisms for the release of radioactivity in fire accidents and have developed a dedicated furnace rig to test small-scale active samples of simulant wasteforms under controlled conditions. This facility is able to test a range of radionuclides, including volatile species such as compounds containing radioactive hydrogen-3 (tritium) and carbon-14, for which RWM currently makes pessimistic assumptions about their release. This task comprises a review of previous work in order to determine the likely level of pessimism in the currently recommended release fractions.

Research Driver

To support the operational and transport safety cases and waste package disposability assessments by reviewing the findings of release fraction experiments in order to identify potential over-conservatisms and, where possible, derive more appropriate RF data.

Research Objective

- To understand data reliability by reviewing the findings of current and previous Activity Release in Fire Accident Conditions and ILW RF measurement tests carried out on samples of encapsulated floc, Magnox sludges and encapsulated fuel hulls.
- To compare older and more recent results to show the effect of sample composition/preparation and/or the effect of the inert gas flow-rate on the release fraction results obtained, thus highlighting any pessimisms in the data.
- To provide input to the proposed new ARFAC work within the current Waste Package Accident Performance research programme (Task 100.2.008 and Task 100.2.009).

Scope

The scope comprises the following:

- Reviewing the ARFAC and more recent ILW test results and comparing these measured release fractions against those in the contractor report "Release Fractions from Waste Packages Exposed to Fire" [1] to determine the likely level of pessimism in the currently recommended release fractions.

- Identifying and obtaining reports on relevant ARFAC and ILW tests carried out by NIREX and more recent test data.
- Developing an analysis and interpretation strategy that fulfils the research objectives.
- Evaluating test results to determine, based on these data, if it is possible to assess the effect of differing sample composition/preparation and/or the radionuclide transfer enhancement arising from the inert gas flow-rate used to move volatilised material from the sample to the measurement apparatus.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report collating and reviewing past fire testing work.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information

There are several publications pertinent to this task [2], [3].

1 C. Fry, *Release fractions from waste packages exposed to fire*, SERCO, Contractor Report SERCO/TCS/6663/01 Issue 1, 2010.

2 Nirex, *ILW fire programme, wasteform performance and activity release under fire conditions*, 320573, 2000.

3 *Activity Release from Immobilised ILW under Fire Accident Conditions: Large-Scale Inactive Fire Testing*. 121, 1992.

B9.2.2 Methodology for Use of Analogy to Other Waste Package Types

Task Number	100.2.002	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Fire Accident Performance		

Background

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 're-lease fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. The WPAP status report [1] adopts standard fire RFs for radionuclides grouped by volatility. The RFs for the revised 3 cubic metre drum, the corner-lifting 3 cubic metre box, all variants of the 500 litre drum (with both homogeneous and heterogeneous wastes) and the 6 cubic metre box (previously known as the WAGR box) were based on analogy to other waste packages for which a release fraction, based upon experiment or modelling, already exists. To improve the robustness of the RF data and for consistency with other package types, this task comprises production of a justification for this practice and the delivery of any further FE analysis that is required.

Research Driver

To support the operational and transport safety cases and waste package disposability assessments by producing a justification for the practice of determining the RF for some waste packages by analogy to others which have been subject to experimental or modelling studies. Where this is not possible further FE analysis is needed.

Research Objective

- To produce a justification on a package-by-package basis, for the practice of determining the RF by analogy to other package types which have been subject to experimental or modelling studies.
- To conduct any further FE modelling shown to be required to validate the fire accident RFs employed by RWM in its safety cases and waste package disposability assessments.

Scope

The scope comprises the following:

- Confirmation of the list of package types for which RFs are derived by analogy with similar designs of package. The differences between each of these packages and the package with which it is assumed to be analogous will be considered and the significance of each difference to the overall package RF judged on the basis of experience (supported by calculations where necessary).
- Production of a report considering the extent to which the analogy approach can be applied to different wasteforms in the same package type. The report will also include advice on when the analogy cannot be used and delivery of any further FE modelling.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report detailing a methodology for use of analogy in fire accident performance evaluations.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					
1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.					

B9.2.3 Development of Improved ILW Package Models for Fire Analysis

<table>
<tr><td colspan="2">Task Number</td><td>100.2.003</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Fire Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. The current bounding approach for assessing fire performance assumes a fully engulfing fire of one hour duration. Finite Element modelling is used extensively in order to evaluate the performance of waste packages in accident scenarios in the most efficient and safe, yet robust, manner. Modelling of the 6 cubic metre box (previously known as the WAGR box), the 2 metre box with 0, 100mm or 200mm shielding and the 4 metre box with 0 and 100mm shielding is yet to be carried out.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the operational and transport safety cases, waste package disposability assessments and upstream waste processing at decommissioning sites by undertaking FE modelling on those waste packages which have not yet been modelled for fire accident RF.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To undertake 3-dimensional fire modelling of the 6 cubic metre box and the 2 metre and 4 metre boxes (with requisite shielding) to provide supporting data for the DSSC and waste package disposability assessments. This includes ungrouted/unshielded packages.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following:
Agreement between RWM and the contractor of a standardised group of a ‘typical’ 6 cubic metre box, 2 metre box and 4 metre box waste package representative of those in the derived inventory and development of models of the 2 and 4 metre box with different thicknesses of concrete (0 mm, 100 mm and 200 mm).
Development of ABAQUS thermal models of these waste packages to simulate the effect of fires with temperatures and durations suitable for use in support of the Disposal System Safety Case.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing the development of improved ILW packaged models.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1].
1 Nirex, Modelling of Unshielded ILW Packages Under Fire Conditions. N/073, 2003.</td></tr>
</table>

B9.2.4 Derivations of Temperature Thresholds Below Which Release Will Not Occur

Task Number	100.2.004	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Fire Accident Performance		

Background

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. The current bounding approach for assessing fire performance assumes a fully engulfing fire of duration one hour. The Disposal System Safety Case suite of documents includes illustrative generic designs for a GDF in three generic geological settings. We are now able to analyse these designs to develop a more realistic set of fire accident scenarios. For example, it may be possible to reduce the duration of the reference fire, and hence the maximum temperature reached by much of the package, in the identified accident scenario. We are improving our understanding of the underlying mechanisms for release of radioactivity in fire accidents and have developed a dedicated furnace rig to test small-scale active samples of simulant wasteforms under controlled conditions. This facility is able to test a range of radionuclides, including volatile species such as radioactive hydrogen-3 (tritium) and carbon-14 (C-14), for which RWM currently makes pessimistic release fraction assumptions. In order to reduce conservatisms in the transport and operational safety cases, there is a need to define, by package and waste type, a minimum temperature below which there is no predicted release during a fire. It is currently assumed for all packages that there is no release below 50°C; this value is, however, considered to be conservative for many wastes and package types. A large proportion of the wasteform in a fire is at a relatively low temperature, i.e. <100°C. Below approximately 80°C there would be less release of radionuclides through entrainment in rapidly evaporating pore water. Due to the limited test data currently available, the same RFs are applied to waste between 50°C and either 300°C or 700°C, depending on the wasteform type.

Research Driver

To support the operational safety case by reducing the pessimisms associated with a lack of data on temperatures below which there is no release of volatile radionuclides.

Research Objective

- To determine whether the current assumptions regarding thermal release fractions are over-conservative.
- To determine whether the threshold temperatures for releases can be raised for many wastes and packages and whether large proportions of the wasteform in a fire may not exceed these thresholds.

Scope

The scope comprises the following:

- Planning a test programme, specifying test conditions, sample types and numbers, the type of test and the isotopes to be tested. The objective for the testing programme will be to maximise learning and data from a minimum number of samples and analyses.

<table>
<tr><td colspan="6">• Definition of procedures for work involving the ’hot rig’ - an existing piece of experimental equipment designed and built for investigating radionuclide release from heated wasteform materials. The following waste types will be considered: mild steel, graphite, floc, sludge.
• Undertaking the experimental programme utilising the ’hot rig’.
• Additional samples may also be produced for storage and later testing to allow them to age significantly.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing results of experimental work.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">See the Waste Package Accident Performance Status Report for more information [1].
1 Radioactive Waste Management, Geological disposal: Waste package accident performance status report issue 2, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.</td></tr>
</table>

B9.2.5 Revise Volatility Groups

Task Number	100.2.005	**Status**	Complete, pending publication
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Fire Accident Performance		
Background			
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. For simplicity, fire accident scenarios consider radionuclides in six 'volatility groups' and wasteforms in a small number of generic waste package types. All the elements are currently categorised into six groups based on the volatility of the chemical form of the element when in equilibrium with steam and air up to 1000°C. Volatility Group I has the highest volatility, where all the elements have one or more chemical forms that are gases. It is assumed that the more volatile the chemical, the greater the fire RF of the associated radionuclide. In fact, Group I volatiles are always given an RF of 1 (i.e. a 100% release). Volatility Group I nuclides can be in different chemical forms, rather than those which are readily mobile as gases, but this is not currently considered and is a likely over-conservatism.			
Research Driver			
To support the operational and transport safety cases and waste package disposability assessments by reviewing whether less pessimistic fire RFs can be assigned to a particular package by the use of volatility assignments that more accurately reflect the true release of radionuclides.			
Research Objective			
To review the six volatility groups, possibly recommending sub-division of the groups or individual RFs for key nuclides (or a reduction in the number of groups), although the focus should be on those radionuclides and groups that are challenging the safety case, e.g. the Group I radionuclides (i.e. H-3, C-14, Cl-36, Se-79, I-129) and key Group II to VI radionuclides (i.e. Sr-90 and isotopes of Am, U and Pu). This assessment will be based on whether the activity is fixed or mobile and a consideration of the chemical form of the elements.			
Scope			
The work scope is broken down by grouping, as follows: • Obtain data for radionuclides that are most challenging to the Operational Safety Case and Transport Safety Case regarding package type and chemical form (e.g. based on the bounding waste streams). • Consider the volatility of each radionuclide (along with modification of the volatility groups to account for the different releases from different elements and chemical forms). • Review the availability of suitable test data to support volatility-specific RFs for a range of chemical forms.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

Report detailing proposed revisions to the volatility groups.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					

There are several publications relevant to this task [1], [2].

1 S. Dickinson, M. Mignanelli, and M. Newland, *Review of volatility and solubility categorisations*, AEA Technology, AEAT/R/NS/0710 Issue 2, 2004.

2 Nirex, *Categorisation of radionuclides into volatility groups for release calculations*, Nirex Report AEAT/R/NT/0306, 2000.

B9.2.6 Revision of Release Fractions for Volatility Group I Radionuclides

Task Number		100.2.006	**Status**	Complete, pending publication	
WBS Level 4		Waste Package Accident Performance			
WBS Level 5		Fire Accident Performance			
Background					
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. For simplicity, fire accident scenarios consider radionuclides in six 'volatility groups'. All the elements are currently categorised into these six groups based on the volatility of the chemical form of the element when in equilibrium with steam and air up to 1000°C. We have developed a dedicated furnace rig to test small-scale active samples of simulant wasteforms under controlled conditions. This facility is able to test a range of radionuclides, including the Volatility Group I species such as radioactive hydrogen-3 (tritium) and carbon-14 (C-14), for which we currently make pessimistic release fraction assumptions. The package Release Fractions (RFs) calculated in the disposability assessment process and used in the operational safety case and transport safety case use the 2001 Bush and Harris report [1] on recommended release fractions as a key reference. However, this report has not been updated to reflect more recent experimental data such as were obtained from the fire test-rig commissioning tests. This is particularly relevant to radionuclides in Volatility Group I, which are currently all assumed to be fully liberated at temperatures above 50°C.					
Research Driver					
To support the operational and transport safety cases and waste package disposability assessments by eliminating over-conservatisms in the fire accident RFs for the Volatility Group I radionuclides.					
Research Objective					
To update RF data for Volatility Group I radionuclides as a function of temperature in light of recent fire test-rig data.					
Scope					
The scope comprises the following: • Comparing RFs for Volatility Group I as reported in the Bush & Harris report and the results of the fire rig commissioning tests. • Development of RFs for Volatility Group I, as a function of temperature, with these values presented in a peer reviewed report.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Report detailing the proposed revisions to the Volatility Group I release fractions.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6

Further Information
There are several publications pertinent to this task [2]. 1 A. Bush and R. Harris, *Recommended release fractions for intermediate and low level waste packages*, AEA Technology, AEAT/R/NT/0288, 2001. 2 J. Meadows, *Design, Fabricate and Demonstrate a Rig to Measure Radioactive Releases from Simulants of Nuclear Waste Materials. Final Report*. 14609/TR/011, AMEC, 2011.

B9.2.7 Derivation of a Reference Data Set for Fire Accident Scenarios

<table>
<tr><td colspan="2">Task Number</td><td>100.2.007</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Fire Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. RWM also needs to assess the performance of waste container materials and different simulant wasteforms for which there are gaps in understanding, such as C50 shield concrete and graphite. Finite Element analysis is a key tool for determining the fire accident performance of waste packages, however this relies on consistent and robust data. This task comprises the compilation of an agreed, consistent reference data set of thermal properties for polymers and concretes at temperatures up to 1000°C. Relevant data are either not currently recognised by RWM (currently, we treat polymerised wastes as unconditioned wastes due to insufficient supporting data), or are dispersed over a range of data sources and reports.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the operational and transport safety cases and waste package disposability assessments by improving the efficiency and consistency of fire-impact modelling via production of a reference data set of thermal properties.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To document and collate thermal property data for polymers and concretes at temperatures up to 1000°C. Thermal properties of an encapsulation polymer, concrete (including C50) and graphite, within each waste package type, are to be determined.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following:
Identification and review of the thermal performance data currently utilised in the Letter of Compliance process for polymers and concrete at temperatures up to 1000°C.
Identification of data from other assessments and research programmes (including historical Central Electricity Generating Board research), polymer trials with fuel element debris (FED) and the RWM fire-rig commissioning tests.
Preparation of a report in which a consistent set of materials properties data are reported and their source appropriately referenced.
Identification of data gaps for concrete and polymer material types.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing materials properties data and sources for fire accident performance.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 6</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
For further information, see the Waste Package Accident Performance Status Report [1].   1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

B9.2.8 Fire Performance of Aged Packages

Task Number		100.2.008	**Status**	Ongoing	
WBS Level 4		Waste Package Accident Performance			
WBS Level 5		Fire Accident Performance			
Background					
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. One area of uncertainty pertains to the fire performance of waste packages many decades after their manufacture. Currently, RFs are calculated based on “as-made” materials. The assumption that the RF evaluated for ‘pristine’ packages can be safely assumed for ‘aged’ packages depends both on the evolution of the wasteform and the waste container. The current understanding of the mechanisms of ageing is that the waste containers are unlikely to be affected significantly during interim storage at waste packaging sites or during GDF operations, with very low general corrosion rates of 0.01-0.1 μm per year. The effect of ageing becomes more of an issue as the wasteform ages further. This task comprises research to confirm the activity releases from aged wasteforms compared to tested simulant wasteforms by testing historical samples, accelerated aged samples and/or coupons. Understanding of the properties of evolved packages is also needed in order to assess the viability of waste retrievability.					
Research Driver					
To support the transport and operational safety cases by determining fire-accident release fractions for aged waste packages.					
Research Objective					
To develop a strategy for obtaining an understanding of the effect of ageing upon the thermal performance of different wasteforms and the release of radionuclides in a fire.					
Scope					
The scope comprises the following: • A desk study to review possible mechanisms and properties that might be affected by ageing. • The development of a long-term test strategy and programme that could be performed on aged samples, the findings of which will inform what current samples need to be collected and laid down for future testing.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Report detailing the strategy for underpinning the performance of aged waste packages in a fire accident scenario.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 6

Further Information
Relevant further information can be found in reports on wasteform ageing [1]. 1 M. Constable, A. Craven, and S. Dickinson, *Review of wasteform ageing up to repository resaturation, part 1*, WMT(06)P118, 2010.

B9.2.9 Evaluation of Fire Release Fractions from Aged Samples

<table>
<tr><td>Task Number</td><td colspan="2">100.2.009</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Waste Package Accident Performance</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Fire Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. One area of uncertainty pertains to the fire performance of waste packages many decades after their manufacture. Currently, RFs are calculated based on “as-made” materials. The assumption that the RF evaluated for ‘pristine’ packages can be safely assumed for ‘aged’ packages depends both on the evolution of the wasteform and the waste container. The current understanding of the mechanisms of ageing is that the waste containers are unlikely to be affected significantly during interim storage at waste packaging sites or during GDF operations, with very low general corrosion rates of 0.01-0.1 μm per year. The effect of ageing becomes more of an issue as the wasteform ages. This task, following on from Task 100.2.008 comprises research to confirm the activity releases from aged wasteforms compared to tested simulant wasteforms by testing historical samples, accelerated aged samples and/or coupons. Understanding of the properties of evolved packages is also needed in order to assess the viability of waste retrievability.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the transport and operational safety cases by determining fire-accident release fractions (RFs) for aged waste packages.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To obtain an understanding of the effect of ageing upon the thermal performance of different wasteforms and the release of radionuclides in a fire through experimental testing of historical samples, artificially aged samples, or through future testing of samples to be laid down as part of this task.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following:
Performing the testing programme developed in Task 100.2.008
Testing of historic or artificially aged samples as identified duringTask 100.2.008
Laying down of samples for future testing as outlined in the programme.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing the results of experimental fire aging tests.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
Relevant further information can be found in reports of wasteform ageing [1]. 1 M. Constable, A. Craven, and S. Dickinson, *Review of wasteform ageing up to repository resaturation, part 1*, WMT(06)P118, 2010.

B9.2.10 Scaling Release Fraction Data for Different Fire Scenarios

Task Number	100.2.010	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Fire Accident Performance		
Background			
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 're-lease fractions' (RFs) for use in safety assessments. For ILW packages, extensive mod-elling has been conducted, which provides a good knowledge of the expected heat en-ergy absorbed by the waste container. Most of the energy will be absorbed by the im-mobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste pack-ages. The current bounding approach for assessing fire performance assumes a fully-engulfing fire of duration one hour. The recent Disposal System Safety Case suite of documents includes illustrative generic designs for a GDF in three generic geological settings. We are now able to analyse these designs to develop a more realistic set of fire-accident scenarios. The influences on fire performance that need to be considered include the location of the fire, any protection provided by the transport container, avail-ability of combustible material, degradation of the wasteform and associated release of activity. Work has been undertaken in support of the Operational Safety Case in justify-ing a reduction in the duration of the reference fires, and hence the maximum temper-atures reached by much of the package in these identified scenarios. The heat load-ing into waste packages is dependent on the temperature difference between the flame temperature and the surface temperature of the waste package. Hence, release frac-tions (RFs) for package fire assessment do not simply scale with flame temperature or duration; therefore, the RFs previously determined for a one hour, 1000°C fire cannot simply be scaled to represent those relating to the more realistic fire accident scenar-ios. Hence, modelling needs to be performed to derive the RFs appropriate to the new, shorter, fire scenarios. The intention is to provide an improved dataset that can be inter-polated and applied to different scenarios. In the future, the fire accident performance data will then be flexible and remain appropriate even if there are further changes to some of the scenarios as the design develops.			
Research Driver			
To support the operational safety case by deriving an improved dataset that, based on more a realistic (shorter duration) reference fire(s), reduces conservatisms in the fire fault release fractions.			
Research Objective			
To obtain a set of RFs relevant to the set of realistic fire-accident scenarios which are currently being developed by RWM. The dataset can then be interpolated and applied to different scenarios.			
Scope			
The scope comprises the development of thermal models and RFs for each of the 'stan-dard' types of waste package (as listed below) with revised boundary conditions corre-sponding to the appropriate 'realistic fire-accident scenarios'. The standard packages are:			

<table>
<tr><td colspan="6">

Unshielded ILW packages:

500 litre drum (homogeneous, heterogeneous and annular grouted)
3 cubic metre box
3 cubic metre drum
Miscellaneous Beta-Gamma Waste Store box

Shielded ILW packages:

2 metre box (with both 100mm and 200mm of concrete)
4 metre box (with both 100mm and 200mm of concrete)
6 cubic metre box

</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing an investigation of scaling methodologies for fire release fractions.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are several publications pertinent to this task [1], [2].
1 S. Dickinson, M. Mignanelli, and M. Newland, Review of volatility and solubility categorisations, AEA Technology, AEAT/R/NS/0710 Issue 2, 2004.
2 Nirex, Categorisation of radionuclides into volatility groups for release calculations, Nirex Report AEAT/R/NT/0306, 2000.</td></tr>
</table>

B9.2.11 Effect of Re-Heating on Vitrified Waste

<table>
<tr><td colspan="2">Task Number</td><td>100.2.011</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Package Accident Performance</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Fire Accident Performance</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. For simplicity, fire accident scenarios consider radionuclides in 6 ‘volatility groups’ and wasteforms in a small number of generic waste package types. The ‘vitrification’ of ILW has been proposed by some waste producers, whereby a glass wasteform is formed at temperatures of over 1000°C; there is however currently no information on radionuclide release fractions (RFs) for this material when re-heated. This task will underpin the assumption that the RF for this material is expected to be low.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support the transport and operational safety cases by demonstrating that thermally treated ILW (vitrified ILW) poses no challenge to a fire accident scenario (since it has already been heated to over 1000°C).</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To underpin the assumption that the RF for vitrified ILW is expected to be low; this work should include consideration of aged or re-wetted wasteforms.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the thermal modelling of ‘vitrified’ ILW in a fire scenario so as to derive RFs. This study will include an understanding of the manufacture of the wasteform in order to:
• Identify and evaluate the appropriateness of currently available data; and
• Prepare a report which identifies any research needs in order for this wasteform to be acceptable to RWM.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Report detailing a study of existing knowledge on thermally treated wasteforms.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications pertinent to this task [1].
1 M. Kelly, D. Lever, C. Wilding, D. Applegate, and R. Hand, Consideration of Vitrified ILW in a Geological Disposal Facility. Serco/TAS/003061/Final Report June 2009, Serco, 2009.</td></tr>
</table>

B9.2.12 Derivation of Fire Release Fractions for Packages Within the Standard Waste Transport Container (SWTC)

Task Number	100.2.012	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Fire Accident Performance		

Background

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 're-lease fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. The current bounding approach for assessing fire performance assumes a fully-engulfing fire of duration one hour. The presence of the Standard Waste Transport Container around the waste package will result, in the event of a fire, in the waste package experiencing lower temperatures, but over a longer period of time. Even under normal conditions of transport, some waste packages may experience temperatures above the 50°C limit at which radionuclide releases are currently assumed by RWM to occur. To support transport assessments, information is needed on the impact of longer heating and cooling times for packages inside a Standard Waste Transport Container, taking consideration of the effect of the SWTC in reducing the temperature to which wasteforms may be exposed in a fire-accident.

Research Driver

To support the transport safety case by understanding the impact of the presence of the SWTC on the fire performance of waste packages.

Research Objective

To provide radionuclide RF data for different types of waste package inside a Standardised Waste Transport Container.

Scope

The scope comprises the following:

- Determination of temperatures which waste packages inside the SWTC might experience - both under fire-accident conditions as a function of time and under normal conditions of transport. These temperatures will be based on calculations and will be compared against those which a 'bare' waste package might experience in a fire-accident.
- Undertaking a review of findings/results of previous experimental research regarding radionuclide RFs (both small-scale and full-scale) to evaluate the effects of duration upon release fractions.
- Consideration on the need to include some longer duration tests in the fire-rig test programme.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report detailing modelling work to determine the temperatures that a waste package would expect to experience in transport configuration when subjected to a fire-accident scenario.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					
For further information, see the Waste Package Accident Performance Status Report [1]. 1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.					

B9.2.13 Update to Standard Reference Report for Fire Release Fractions

Task Number	100.2.013	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Fire Accident Performance		

Background

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages. Following RWM and international research in the Waste Package Accident Performance work area (Task 100.2.014, Task 100.1.001, Task 100.1.003, Task 100.1.008 and Task 100.1.009), a revised version of the AEAT (2001) fire-accident release fraction report [1] (known as the 'Bush and Harris' report) is required, including the following updates:

- New fire rig commissioning data.
- International package release data.
- Better substantiation.
- More package types and waste forms.

There may also be a need to revise the solubility data that underpins the Bush and Harris report. It is expected that the new data will enable the recommended RFs at low temperatures (50°C to 150°C) to be significantly reduced, which will have a notable impact upon the predicted releases from many waste packages under fire-accident scenarios.

Research Driver

To support the operational and transport safety cases and waste package disposability assessments by consolidating recent RWM and international improvements in fire-accident RF data in a new standard RWM reference.

Research Objective

To update the 'Bush and Harris' recommended fire-accident radionuclide RF report using data from the fire-rig commissioning tests, data generated as part of the Waste Package Accident Performance work programme and any available international RF data.

Scope

The scope comprises a review of international data on fire-accident radionuclide RFs and data from the fire-rig commissioning tests and any further tests. The deliverable for this task is an update of the 'Bush and Harris' recommended RF report.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report detailing revised fire release fractions based on recent work.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6

Further Information
There are various publications pertinent to this task [2].

1 A. Bush and R. Harris, *Recommended release fractions for intermediate and low level waste packages*, AEA Technology, AEAT/R/NT/0288, 2001.

2 J. Meadows, *Design, Fabricate and Demonstrate a Rig to Measure Radioactive Releases from Simulants of Nuclear Waste Materials. Final Report*. 14609/TR/011, AMEC, 2011.

B9.2.14 Mixed Oxide Spent Fuel (MOX SF) - Thermal Properties for Use in Fire Fault Modelling

Task Number		100.2.014	**Status**	Start date in future	
WBS Level 4		Waste Package Accident Performance			
WBS Level 5		Fire Accident Performance			
Background					
Safety assessments require thermal modelling for fire-accident performance. These models require relevant and accurate input data in order to produce robust results. This task relates to the derivation of fire-accident performance data for MOX SF, should new-nuclear build operators pursue its use.					
Research Driver					
MOX SF has been identified as requiring identification of its thermal properties in order for thermal fault assessments to be carried out.					
Research Objective					
A set of agreed thermal properties data for MOX SF suitable as input to the finite element modelling codes in use at the time of the task.					
Scope					
A review of the available thermal properties data for MOX SF and selection of a representative dataset for performing safety evaluations.					
Geology Application					
HSR, LSSR, Evaporite.					
Output of Task					
A report detailing an investigation to determine materials properties data for MOX SF to be used in thermal modelling.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are several publications pertinent to this task [1], [2].					

1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

2 Radioactive Waste Management, *Geological disposal: Implications of the 2013 derived inventory on the generic disposal system safety case*, RWM Report NDA/RWM/129, Jul. 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/implications-of-2013-derived-inventory-on-gdssc/.

B9.3 WBS 100.3 - Combined Fault Accident Performance

B9.3.1 Methodology for Determining Release Fractions in Combined Fault Accidents and Identification of Modifying Mechanisms

Task Number	100.3.001	**Status**	Ongoing
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Combined Fault Accident Performance		

Background

The current approach for assessing combined impact and fire performance is to assume that the two events are independent and can be assessed separately. Further work is required to understand the fire performance following an impact and whether there are any new mechanisms that could give rise to an enhanced release of radioactivity. The current approach may be appropriate if the waste container is intact following the initial impact. However, if a waste container is breached in the initial impact, there will no longer be a complete barrier to prevent free air ingress. Chemical reactions can proceed faster when there is a supply of oxygen. Hence, compared to the pyrolysis mechanisms considered for an unbreached waste package in a fire-only accident (as considered in Task 100.2.001), there could be stronger degradation mechanisms acting on the wasteform. This task considers such mechanisms and evaluates whether there are further research needs in this area.

Research Driver

To support the transport and operational safety cases by providing the required technical arguments and underpinning data for combined impact and fire accidents.

Research Objective

For each of the combined impact and fire accident scenarios and/or for each of the associated package types:

- To document the rationale for considering the impact and fire components of a fault separately and additively (if possible).
- To evaluate whether our current practice of considering impact followed by fire, rather than the reverse scenario, is justified.
- To evaluate whether there are any combined fault mechanisms that could give rise to additional release of radioactivity.
- To identify further work required to understand the fire performance following an impact.

Scope

The scope comprises consideration of each of the combined accident scenarios identified by RWM and each package type which may be involved in such an accident. The effect of the impact damage upon the fire performance (or vice-versa) will be considered and, for each case, the argument as to why it is acceptable to simply add the separate impact and fire RFs will be documented. Cases in which the addition of the separate RFs cannot be justified will be identified. In the event that findings of activities above suggest an accident scenario in which the simple addition approach cannot be justified, the mechanisms that may enhance the combined RFs will be identified and considered, together with any further research requirements.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Report detailing an investigation into the limitations of the current combined fault methodology.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
For further information, see the Waste Package Accident Performance Status Report [1].					

1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.

B9.3.2 Review of the Waste Package Accident Performance Knowledge Base

Task Number	100.3.002	**Status**	Start date in future
WBS Level 4	Waste Package Accident Performance		
WBS Level 5	Combined Fault Accident Performance		

Background

In order for a safety case to be made for the GDF, scientific underpinning is needed for a wide range of topics. This includes WPAP, which is concerned with the understanding of releases of radioactive material from a waste package in the event that it is subject to an impact accident or a fire accident. Following a review of research needs in 2014, RWM has undertaken a large project covering approximately thirty research tasks in support of the WPAP needs of the Operational Safety Case, Transport Safety Case, and Waste Management directorate.

Upon completion of this work, it will be necessary to summarise the learning in the WPAP Status Report in order to ensure that a holistic understanding of the state of knowledge for this topic is understood and can be effectively communicated.

Recent research will have improved our knowledge; however, there may be aspects of those needs that require further attention following these activities. Additionally, since the previous review of research needs, new needs may have arisen. As such, there is a need to determine the research needs according to the up-to-date knowledge base and latest internal customer needs.

Research Driver

To ensure that the current state of knowledge is understood and further research needs are captured, a review of the knowledge base is required following significant research by RWM.

Research Objective

The objective of this work is to review the current state of knowledge in the field of WPAP and summarise this in an update to the WPAP Status Report. Knowledge gaps are to be identified and task sheets for the Science and Technology plan generated.

Scope

Knowledge pertaining to the topic of WPAP as it is relevant to RWM's mission shall be considered. The extent of the knowledge to be considered in this review is as follows:

- Recent research undertaken by RWM as part of a large solution-based contract.
- Other recent research undertaken by RWM.
- Recent research undertaken by the wider nuclear industry, including waste packagers and the NDA.
- The knowledge base as summarised in the 2010 and 2016 versions of the WPAP Status Report.

The identification of further research shall consider the needs of the following RWM customers:

- Operational Safety.
- Transport Safety.
- Waste Management.

Geology Application

HSR, LSSR, Evaporite

Output of Task

An updated WPAP Status Report detailing the current knowledge base. Science and Technology Plan task sheets detailing identified knowledge gaps.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					
Relevant publications include: [1] 1 Radioactive Waste Management, *Geological disposal: Waste package accident performance status report issue 2*, RWM Report DSSC/457/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-accident-performance-status-report/.					

B10 WBS 110 - Wasteform Evolution

The UK Inventory for Disposal comprises one of the broadest ranges of wasteforms any Waste Management Organisation is seeking to dispose of. Outstanding research needs exist in the following sub-topic areas:

- Non-cementitious ILW/LLW Wasteforms (**WBS 110.1**)
- HLW Glass (**WBS 110.2**)
- Plutonium, Uranium and other Wasteforms (**WBS 110.3**)
- Spent Fuel (**WBS 110.4**)
- Graphite (**WBS 110.5**)

WBS 110.1 aims to review the planned use of polymeric materials for the immobilisation of ILW to identify any additional research needs; to identify gaps in the current knowledge around thermally treated wasteforms with respect to their long-term evolution and suitability for disposal and to define a future research programme to assess the durability of ILW wasteforms in UK-specific groundwaters and host geologies.

HLW glass is the focus of **WBS 110.2**. Recent work funded by RWM has aimed to benchmark the disposability performance of UK HLW glasses against the well characterised international glasses. This work has shown a limited degradation in performance of high magnesium-content glasses and so further work is planned to improve our mechanistic understanding of the dissolution process, extend our understanding to other UK HLW glasses, investigate interactions of iron (from containers) with glasses and to investigate the effects of radiation and cracking on performance. Then as we move into the site-specific phase we will seek to extend this understanding to site-specific groundwaters and pore-waters.

In support of the need to dispose of waste plutonium materials, **WBS 110.3** includes studies on simulant and real plutonium wasteforms and development of a preferred disposal concept for these wasteforms. it also includes work to review the status of knowledge for cementitious ILW wasteforms and reduce conservatisms associated with reactive metals encapsulated in cement.

WBS 110.4 encompasses a broad range of studies on UK fuels and simulant materials aimed at gaining sufficient mechanistic understanding of the ‘instant release’ (actually a short-term release over 2-3 years) and the long-term matrix dissolution rate in order to underpin the Environmental Safety Case. This work initially focusses on AGR spent fuel, but progresses to PWR, Magnox, MOX and Ministry of Defence owned fuels.

WBS 110.5 focusses on understanding the performance of irradiated graphite in terms of its release of radionuclides into groundwater or gaseous phases (Task 110.5.001) and on the likelihood and consequences of a Wigner energy release (Task 110.5.002-Task 110.5.003).

B10.1 WBS 110.1 - Non-cementitious ILW/LLW Wasteforms

B10.1.1 Review Research Needs for Polymeric Wasteforms

<table>
<tr><td colspan="2">Task Number</td><td>110.1.001</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Non-cementitious ILW/LLW Wasteforms</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In the past, in the UK, Nirex and others have commissioned extensive programmes of R&D to demonstrate the effectiveness of cement in immobilising a variety of ILW/LLW in wasteforms suitable for disposal in a GDF. R&D has also considered some alternative wasteforms. A number of organic polymers have been used as encapsulants for radioactive wastes around the world and they have possible advantages over cement-based encapsulants in some applications. Recent work in the UK has shown that, under simulated disposal conditions, some epoxy resin formulations have properties and stability that may make them suitable for encapsulation of ILW and LLW. However, the evolution of organic systems over the very long timescales considered in post-closure performance assessments has not been extensively studied. At this stage of the programme, depending on the drive to employ this type of encapsulant, RWM may continue to undertake experiments to improve its understanding of the long-term stability of possible organic polymeric encapsulants in representative conditions expected in a GDF. We plan to evaluate whether the formation of degradation products from these materials has any potential impact on transport, operational or post-closure safety. We may need to undertake work to examine alternative disposal options for this type of wasteform. This task will focus on candidate polymeric wasteforms emerging in the industry for which research needs will be identified on the basis of a desk-based study.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop a mechanistic understanding of the evolution of polymeric wasteforms for ILW to support the assessment of packaging solutions, the development of disposal concepts for these wasteforms and the development of the safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review the planned use of polymeric materials for the immobilisation of ILW to identify any additional research needs.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To conduct a review of the research needs for polymeric waste encapsulants utilising international Waste Management Organisation resources, RWM reports, LoC submissions, waste owner liaison, the scientific literature, etc.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A clear understanding of the research requirements for polymeric encapsulants informed by the future waste packaging plans of waste producers.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
There are other reports relevant to this task [1]. This task will be carried out by our contractors and/or RWM internal resources. 1 J. Dawson, G. Baston, M. Cowper, and T. Marshall, *The effects of gamma irradiation and thermal ageing on the stability of candidate polymer encapsulants*, SERCO, Contractor Report SERCO/TAS/002008/001 Issue 02, 2010.

B10.1.2 Knowledge Capture Exercise on Progress in Thermally Treated ILW

Task Number	110.1.002	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	Non-cementitious ILW/LLW Wasteforms		
Background			
The UK has a significant volume of ILW destined for disposal in a future GDF. Immobilisation through various thermal treatment technologies has been suggested as an alternative to grout encapsulation for certain types of ILW [1] as it may provide advantages of volume reduction and greater wasteform durability compared to cement encapsulation under some conditions. Another potential advantage is that the thermal treatment process would also destroy organic waste components, reducing the chemical reactivity of some types of ILW. In most cases, the technology is at an early stage of development and the formulations have not been optimised for disposal.			
Research Driver			
To understand the current status of thermal treatment of ILW research, develop an understanding of its disposability in a GDF under relevant conditions and identify gaps which will need to be addressed for ILW to be considered optimised considering a balance of process and disposability constraints.			
Research Objective			
• To identify gaps in the current knowledge around thermally treated wasteforms with respect to its long-term evolution and suitability for disposal against a set of requirements. • To define a future research programme to assess durability of ILW wasteforms in UK-specific groundwaters and host geologies.			
Scope			
The scope comprises the following: • Define what the requirements are for an optimised vitrified ILW wasteform in RWM's ILW vault concept. • Understand the vitrified ILW formulation envelope and whether wasteforms in it meet the requirements (i.e. are there compositions that can be considered to be "optimised"). • Understand recent advances in ILW vitrification (e.g. the output of the EU THERAMIN programme and NDA's Thermal Treatment IPT). • Produce a research programme that will provide underpinning for the disposability of thermally treated ILW wasteforms in applicable concepts and groundwaters.			
Geology Application			
HSR, LSSR, Evaporite.			
Output of Task			
• A list of requirements for disposal of vitrified ILW wasteforms. • A compositional envelope for vitrified ILW formulations which can be considered to be optimised for disposal to the GDF. • A report outlining the current status of international R&D on vitrified ILW.			

• Outlines of an experimental programme to understand the durability of optimised vitrified ILW formulations.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
This task is intended for procurement through our contractors with significant input from academic partners (e.g. through the RWM University Research Support Office). Further information can be found at: http://www.theramin-h2020.eu/ and https://ecosystem.org.uk/groups/thermal-treatment-ipt-18-19-slnnl. There are other publications relevant to this task [2].					
1 K. Witwer, E. Dysland, M. James, and C. Mounsey, *Thermal Treatment of UK Intermediate and Low-level Radioactive Waste: A Demonstration of the GeoMelt Process Towards Treatment of Sellafield Waste*. Waste Management Conference, no. Paper 10507, 2010. [Online]. Available: http://www.wmsym.org/app/2010cd/wm2010/pdfs/10507.pdf. 2 J. Schofield, S. Swanton, B. Farahani, B. Myatt, and S. Burrows, *Experimental Studies of the Chemical Durability of UK HLW and ILW Glasses: Final Report on Simulant ILW Glasses*, Wood/103498/05, 2019.					

B10.2 WBS 110.2 - HLW Glass

B10.2.1 Understanding the Relationship Between the Durability of Simplified and Complex UK HLW Glasses

Task Number	110.2.001	**Status**	Ongoing
WBS Level 4	Wasteform Evolution		
WBS Level 5	HLW Glass		

Background

There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the gDSSC to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, in the future, glasses arising from Post-Operational Clean Out. Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors, including the effects of elevated temperature and groundwater composition, controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. This task will focus on Magnox and blend HLW glasses, and aims to evaluate the applicability of tests carried out to support the development of vitrified products at Sellafield to understand the broad process envelope, as well as the effect of high temperature and cracking, on the dissolution behaviour of suitable glass simulants.

Research Driver

To develop a mechanistic understanding of the dissolution behaviours of HLW glasses, including the effect of elevated temperature on the evolution and dissolution rates (short and long-term), in near-neutral and, to a lesser degree, alkaline groundwater. This is to support the following:

- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
- The development of the safety case.

Research Objective

To further evaluate the use of inactive simplified glass formulations to develop a mechanistic understanding of the behaviour of more complex inactive HLW glass simulants and to correlate the aqueous durability of simplified glass formulations to HLW glass simulants to leverage the existing aqueous durability database produced at Sellafield for disposability assessments.

Scope

The scope comprises the following:

- Identify suitable compositional simplification protocols for present (MW25 and blend glasses) and potential future (higher waste loaded) borosilicate glasses in close collaboration with Sellafield Ltd.
- Determine initial, residual rate and any resumption of alteration in both complex and simplified analogue glasses under identical experimental conditions using Product Consistency Test-B and initial rate tests.

• Use the results to inform a mechanistic understanding of UK glass durability. • Compare results in deionised water with simulant groundwaters. • Compare temperature effects on glass dissolution (40°C vs 90°C).					
Geology Application					
N/A					
Output of Task					
Reports and publications that will expand the knowledge base supporting the GDF DSSC suite of reports, including but not limited to, the Waste Package Evolution Status Report [1].					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [2]–[6].					

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

2 J. Schofield, A. Clacher, C. Utton, S. Swanton, and R. Hand, *Initial Dissolution Rate Measurements for 25 wt % simulant waste-loaded Magnox VTR product in simulated groundwaters*. SERCO/004844/02, 2012.

3 S. Gin, A. Abdelouas, L. Criscenti, W. Ebert, K. Ferrand, T. Geisler, M. Harrison, Y. Inagaki, S. Mitsui, K. Mueller, J. Marra, C. Pantano, E. Pierce, J. Ryan, J. Schofield, C. Steefel, and J. Vienna, *An international initiative on the long-term behaviour of high-level nuclear waste glass*. Materials Today, no. 16, pp. 243–248, 2013.

4 C. Utton, R. Hand, P. Bingham, N. Hyatt, S. Swanton, and S. Williams, *Dissolution of vitrified wastes in a high pH calcium-rich solution*. Journal of Nuclear Materials, vol. 435, pp. 112–122, Issues 1-3 2013. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0022311512006897.

5 T. Gout, M. Harrison, and I. Farnan, *Evaluating the temperature dependence of Magnox waste glass dissolution*. Journal of Non-Crystalline Solids, vol. 518, pp. 75–84, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0022309319302947.

6 T. Gout, M. Harrison, and I. Farnan, *Relating Magnox and international waste glasses*. Journal of Non-Crystalline Solids, vol. 524, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0022309319305186.

B10.2.2 Further Groundwater Dissolution Studies on Simulant Magnox, Blend and Post-Operational Clean Out (POCO) Glasses

Task Number	110.2.002	**Status**	Ongoing
WBS Level 4	Wasteform Evolution		
WBS Level 5	HLW Glass		

Background

There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the gDSSC to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and glasses that are expected to arise from POCO of the HALES facility. Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors, including the effects of elevated temperature and groundwater composition controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. This task will focus on Magnox, Blend, POCO (and other) glasses, the behaviour of which will be evaluated on the basis of dissolution/leaching experiments of suitable simulants and mechanistic modelling.

Research Driver

To develop a mechanistic understanding of the evolution and dissolution rates (short- and long-term) of vitrified Magnox, Blend and POCO glasses in near-neutral and, to a lesser degree, alkaline groundwater. This work also aims to develop an understanding of the glass formulation dissolution behaviour relative to each other and in relation to glasses from other international research programmes. This is to support the following:

- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
- The development of the safety case.

Research Objective

To determine the effect of a number of variables on the dissolution behaviour of simulants of HLW waste streams expected to arise from future Sellafield operations (e.g. POCO glasses). In particular, to determine whether:

- Differences in groundwater composition (near-neutral pH) significantly affect the dissolution behaviour of the glass;
- The presence of calcium-rich alkaline plumes that may be generated in the presence of cement-based buffers or due to a co-located, cement-based ILW module affect the long-term dissolution behaviour of the glass in a way which negatively affects the safety case;
- Differences in the dissolution behaviour of UK HLW glass simulants of key waste streams (Magnox/Blend glass), other waste streams (e.g. POCO glass) and French HLW glass simulants can be interpreted on the basis of differences in their chemical composition. In particular, if any 'fast' leaching that may be observed in short-term experiments (if any) can be correlated to the formation of soluble (e.g. molybdenum-rich) phases;

- The long-term evolution of the glass in the absence of other EBS components (in particular iron-based materials) is such that thermodynamically-stable phases formed in the long-term are unlikely to induce dissolution rates significantly faster than those estimated from short-term experiments;
- Results from samples with a low surface area/volume ratio (e.g. monoliths) are consistent with those of high surface area/volume ratio (powder) and can be used to scope the initial and long-term dissolution rate; and
- The behaviour of POCO-derived glasses can be interpreted on the basis of suitably modified models already available for other glasses (e.g. GRAAL).

Scope

The scope comprises the following:

- Identification, sourcing and archiving of a variety of vitrified HLW products from Sellafield Vitrification Test Rig that are representative of Magnox, Blend and POCO glasses.
- Characterisation of relevant materials.
- Experimental measurements (40°C) of the glass simulants in near-neutral groundwater simulants (deionised water and two near-neutral groundwaters) with high surface area/volume ratio (powders).
- Experimental measurements (40°C) of the dissolution behaviour of glass simulants in alkaline groundwater simulants (three hyperalkaline solutions
- NaOH, $Ca(OH)_2$, and chloride-rich $Ca(OH)_2$ with high surface area/volume ratio (powders).
- Experimental measurements (40°C) of the dissolution behaviour of glass simulants in groundwater with low surface area/volume ratio (e.g. monoliths).
- Experimental measurements of the dissolution behaviour of French (SON64) and other simulant glasses (e.g. Ca-common glass) to allow comparison.
- Review of existing mechanistic/parametric models developed internationally (e.g. GRAAL model) to evaluate their applicability to the behaviour of glasses.

Geology Application

HSR, LSSR, Evaporite.

Output of Task

Reports and publications that will contribute to the knowledge base supporting the GDF DSSC suite of reports, including, but not limited to, the Waste Package Evolution Status Report [1].

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6

Further Information
There are other publications relevant to this task [2]–[6]. This task is ongoing via procurement through our contractors and collaboration with academic research institutions.

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

2 J. Schofield, A. Clacher, C. Utton, S. Swanton, and R. Hand, *Initial Dissolution Rate Measurements for 25 wt % simulant waste-loaded Magnox VTR product in simulated groundwaters*. SERCO/004844/02, 2012.

3 C. Utton, R. Hand, P. Bingham, N. Hyatt, S. Swanton, and S. Williams, *Dissolution of vitrified wastes in a high pH calcium-rich solution*. Journal of Nuclear Materials, vol. 435, pp. 112–122, Issues 1-3 2013. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0022311512006897.

4 C. Mann, T. Le Hoh, C. Thorpe, and C. Corkhill, *Dissolution of glass in cementitious solutions: An analogue study for vitrified waste disposal*. MRS Advances, vol. 3, pp. 1147–1154, Issue 21 2018. [Online]. Available: http://eprints.whiterose.ac.uk/131719/.

5 A. Fisher, M. Harrison, N. Hyatt, R. Hand, and C. Corkhill, *The dissolution of simulant uk Ca/Zn-modified nuclear waste glass: Insight into stage III behaviour*. MRS Advances, vol. 5, pp. 103–109, Issue 3-4 2020. [Online]. Available: https://www.cambridge.org/core/journals/mrs-advances/article/dissolution-of-simulant-uk-caznmodified-nuclear-waste-glass-insight-into-stage-iii-behavior/6B22F1290B82C2747E0C887D4EF87589.

6 S. Gin, A. Abdelouas, L. Criscenti, W. Ebert, K. Ferrand, T. Geisler, M. Harrison, Y. Inagaki, S. Mitsui, K. Mueller, J. Marra, C. Pantano, E. Pierce, J. Ryan, J. Schofield, C. Steefel, and J. Vienna, *An international initiative on the long-term behaviour of high-level nuclear waste glass*. Materials Today, no. 16, pp. 243–248, 2013.

B10.2.3 Effect of Iron-based Materials and Radiation Damage on the Dissolution Behaviour of Simulant HLW Glasses

Task Number	110.2.003	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	HLW Glass		

Background

There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the generic Disposal System Safety Case to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, in the future, glasses arising from Post-Operational Clean Out. Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. These studies include the influence of iron-based materials present elsewhere in the disposal system and are aimed at developing underpinning data for use in safety assessments. This task will cover a variety of HLW glasses expected within the UK inventory, the behaviour of which needs to be evaluated on the basis of dissolution/leaching experiments of suitable simulants and mechanistic modelling in groundwater containing iron (arising from container degradation), both excluding and including the presence of radiation.

Research Driver

To develop a mechanistic understanding of the evolution and dissolution rates (short- and long-term) of vitrified HLW glasses in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions;
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed); and
- The development of the safety case.

Research Objective

To determine the effect of a number of variables on the dissolution behaviour of HLW simulants of selected waste streams (Magnox, blend, POCO, etc.). In particular, to determine whether:

- The presence of iron-based materials (e.g. container/structural inserts) in contact with HLW glass affects the evolution and dissolution rates of the glass in a way which is predictable and does not prejudice the safety case (i.e. to determine whether the presence of iron leads to the formation of phases that do not lead to dissolution rates faster than those estimated from short-term experiments);
- The effect of radiation fields has an impact on the dissolution behaviour of the glass and can be interpreted on the basis of available knowledge on radiation chemistry and radiation damage;
- Fracturing and cracking have any significant effect on the dissolution rate of HLW products in relevant conditions and whether any effect is predictable; and

- Previously developed models can be successfully refined to take these effects into account.

Scope

The scope comprises the following:

- Sourcing and archiving of samples from large-scale simulants (i.e. from Sellafield Vitrification Test Rig) and/or active samples (if available) to support the experimental R&D programme.
- Characterisation of relevant materials.
- Experimental measurements on specific glass compositions in the presence of iron in selected groundwater simulants to investigate the effect of the presence of iron-based materials in contact with the glass under realistic dose-rate conditions.
- Experimental measurements on specific glass compositions in the presence of radiation fields in selected groundwater simulants to investigate the effect of radiation-damage and radiolysis under realistic dose-rate conditions.
- Review/refinement of glass dissolution models to consider the effect of radiation-fields and iron-based materials.

Geology Application

HSR, LSSR, Evaporite.

Output of Task

Reports and publications that contribute to the knowledge base supporting the GDF Disposal System Safety Case suite of documents, including, but not limited to, the Waste Package Evolution Status Report [1].

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6

Further Information

This task is intended for procurement through our contractors with potential input from academic partners. There are other publications relevant to this task [2].

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

2 B. Grambow, K. Lemmens, Y. Minet, C. Poinssot, K. Spahiu, D. Bosbach, I. Casas, J. de Pablo, J. Giménez, S. Gin, J. Glatz, N. Hyatt, E. Iglesias, B. Kienzler, B. Luckscheiter, A. Martinez-Esparza, V. Metz, A. Ödegaard-Jensen, K. Ollila, J. Quiñones, A. Rey, S. Ribet, N. Rodriguez, G. Skarnemark, D. Wegen, F. Clarens, E. Gonzalez-Robles, and D. Serrano-Purroy, *Final Synthesis Report RTD Component 1: Dissolution and release from the waste matrix, NF-PRO Report European Commission*, European Commission, European Commission Report 2008.

B10.2.4 Review of Microstructural Evolution of Glassy and Ceramic Wasteforms and their Impact on Leaching Properties

<table>
<tr><td>Task Number</td><td>110.2.004</td><td>Status</td><td colspan="3">Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Wasteform Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">HLW Glass</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">There is a good general understanding of the long-term evolution and leaching behaviour of HLW glasses and spent fuels in a GDF, as these have been studied in other international programmes. There is also limited information about the evolution/leaching behaviour of other glassy or ceramic wasteforms (e.g. for the immobilisation of ILW) from the UK and other programmes. This work will focus on testing of UK-specific materials so that they can be compared with those of products tested in other programmes. Leaching studies, however, do not inherently consider the potential for long-term microstructural evolution processes to affect the behaviour of the wasteform. Relevant long-term evolution processes include the potential for thermal effects (e.g. devitrification), radiation-assisted effects, alpha-decay and mechanical damage to change the surface area and chemical characteristics of the wasteform, affecting its dissolution/leaching behaviour. This task will focus on HLW glasses, but will also consider the potential for relevant effects to occur in any thermally treated ILW which could potentially be produced through future UK waste management programmes.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop a mechanistic understanding of the likely long-term evolution behaviour of wasteforms. This is to support the following:
The assessment of packaging solutions.
The development of suitable disposal concepts for these wastes.
The development of the safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine the likely extent of microstructural evolution processes and their impact on the expected dissolution/leaching of relevant wasteforms as well as, in the case of any gas-generating processes, the potential for internal pressurisation of the waste container.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">A desk-based study reviewing existing information is envisaged. The scope comprises review and discussion in the UK context of likelihood and potential effects of microstructural evolution processes expected in HLW and thermally treated ILW. Processes should include thermal effects due to high processing/storage temperatures (e.g. devitrification of HLW), radiation-induced effects (e.g. effect on extent of micro-segregation or amorphisation), gas generation due to alpha-decay and its effect on the amount of cracking (available surface area) and any cracking introduced by (accidental) mechanical damage.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Reports to support the ongoing development of a knowledge base to support the GDF Disposal System Safety Case suite of reports, including, but not limited to, the Waste Package Evolution Status Report [1].</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information

There are other publications relevant to this task [2]–[6]. This task will be procured through our supply chain partners and may have input from the academic community.

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

2 S. Peuget, J.-M. Delaye, and C. Jégou, *Specific outcomes of the research on the radiation stability of the french nuclear glass towards alpha decay*. Journal of Nuclear Materials, no. 444, pp. 76–91, 2014.

3 C. Ferry, P. Lovera, C. Poinssot, and L. Johnson, *Quantitative Assessment of the Instant Release Fraction (IRF) for Fission gases and Volatile Elements as a Function of Burn-up and Time under Geological Disposal Conditions*. Materials Research Society Symposium Proceedings, no. 807, pp. 35–40, 2004.

4 A. Gandy, M. Stennett, and N. Hyatt, *Surface-sensitive spectroscopic study of ion beam irradiation-induced structural modifications in borosilicate glasses*. MRS Proceedings, vol. 1514, pp. 75–80, 2013. [Online]. Available: https://www.researchgate.net/publication/271677498_Surface_Sensitive_Spectroscopy_Study_of_Ion_Beam_Irradiation_Induced_Structural_Modifications_in_Borosilicate_Glasses.

5 M. Ojovan, B. Burakov, and W. Lee, *Radiation-induced microcrystal shape change as a mechanism of wasteform degradation*. Journal of Nuclear Materials, vol. 501, pp. 162–171, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0022311517310772.

6 N. Hyatt and M. Ojovan, *Special issue: Materials for nuclear waste immobilisation*. Materials, vol. 12, Issue 21 2019. [Online]. Available: https://www.mdpi.com/journal/materials/special_issues/MNWI.

B10.2.5 State of the art review of UK HLW glass dissolution research and development of future research strategy

<table>
<tr><td colspan="2">Task Number</td><td>110.2.005</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">HLW Glass</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has carried out a number of experimental studies on UK HLW formulations including Blend [1], Magnox [1], POCO and Butex Glasses. UK HLW glasses differ from overseas HLW glasses and attempts have been made to benchmark data from RWM programmes against overseas programmes by use of the ISG. A number of models have been developed to describe the behaviour of overseas glass formulations including the GRAAL model [2]. The applicability of these models to UK HLW glasses has recently been assessed [2]. The knowledge base on HLW glasses and their behaviour is extensive, however gaps still remain.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To gain a holistic view of the long-term evolution behaviour of UK HLW glasses in conditions relevant to disposal in a GDF. To develop a strategy for site-specific research and identify where gaps exist within the claims, arguments and evidence hierarchy and the means by which these gaps could potentially be addressed.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop a mechanistic understanding of the evolution and dissolution rates (short and long-term) of vitrified HLW glasses in simulant groundwaters applicable to RWM's three generic concepts (HSR, LSSR and evaporite). This is to support the following:
• The assessment of packaging solutions.
• The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
• To robustly underpin the claims, arguments and evidence that form the basis of RWM's safety case.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task is to carry out a desk-based review of the results from RWM's two large experimental programmes carried out on UK HLW glasses (2012-2023), plus additional information where published (e.g. work done/being carried out by the Universities of Cambridge and Sheffield). The aim of this is to develop a holistic view of the status of UK glass research which will form the basis upon which to assess knowledge gaps and the means by which to close them through an expert workshop(s).</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report describing the detailed understanding of UK HLW glass behaviour in a GDF environment and an assessment of the status of knowledge against the requirements of the GDF safety case. A research roadmap that identifies tasks to address knowledge gaps.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 3</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
This task is intended for procurement through our contractors, with significant input from academia. 1 J. Schofield, S. Swanton, B. Farahani, B. Myatt, and S. Burrows, *Experimental Studies of the Chemical Durability of UK HLW and ILW Glasses. final Report on Studies of Simulant HLW Glasses*, AMEC/103498/04, 2017. 2 D. Trivedi, K. Fritsch, B. Hodgson, and A. Fuller, *Application of International Glass Dissolution Models to UK Nuclear Waste Glasses: A Review*, NNL Report 14914, 2019.

B10.2.6 Further Groundwater Dissolution Studies on Simulant Magnox, Blend and Post-Operational Clean Out (POCO) HLW Glasses Using Site-Specific Groundwaters

<table>
<tr><td colspan="2">Task Number</td><td colspan="1">110.2.006</td><td>Status</td><td colspan="2">Start date in the future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level</td><td colspan="4">HLW Glass</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations with their own HLW glass products. RWM has studied a variety of HLW glass compositions representative of the likely products arising from the WVP at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, glasses arising from POCO in simulant groundwaters based on the three RWM generic concepts (HSR, LSSR and evaporite) [1]. These initial studies were aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour, as well as establishing a mechanistic understanding and knowledge of modelling of glass evolution achieved internationally and its applicability to UK glasses.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">During the site-specific phase of the GDF, a more detailed understanding and input data on the dissolution rates of UK HLW glass products are required to support the site-specific DSSC.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To assess the durability of UK HLW glasses under site-specific conditions.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following:
Experimental measurements (40^{o}C) of the same well-characterised HLW glass products archived from the studies in site-specific groundwater [1] (or simulants) with high surface area/volume ratio (powders) and low surface area/volume ratio (e.g. monoliths).
Experimental measurements of the dissolution behaviour of French (SON64) and other simulant glasses in the same groundwaters (e.g. the International Standard Glass) to allow comparison with overseas data.
Review of existing mechanistic/parametric models developed internationally (e.g. GRAAL model) to evaluate their applicability to the behaviour of UK HLW glasses in this study.
The methodology will be as developed and used in other studies [1].</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Dissolution data and mechanistic understanding of UK HLW glasses in site-specific groundwaters. These data can be used to inform the ESC and PCSA modelling of that site.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
Task to follow on from Task 110.2.002. This task is intended for procurement through our contractors, with significant input from academia (e.g. through the RWM University Research Support Office). 1 J. Schofield, S. Swanton, B. Farahani, B. Myatt, and S. Burrows, *Experimental Studies of the Chemical Durability of UK HLW and ILW Glasses. final Report on Studies of Simulant HLW Glasses*, AMEC/103498/04, 2017.

B10.3 WBS 110.3 - Plutonium, Uranium and other Wasteforms

B10.3.1 Scoping Investigations on the Suitability of Simulants to Study the Dissolution Behaviour of Glass-Ceramic Wasteforms for Plutonium Immobilisation

Task Number	110.3.001	**Status**	Ongoing
WBS Level 4	Wasteform Evolution		
WBS Level 5	Plutonium, Uranium and other Wasteforms		
Background			
For wastes, and materials which may be declared as wastes, where disposal concept development is at its earlier stages, current and future work is aimed at developing our understanding of the available options to support the NDA nuclear materials management strategy. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. By the completion of reprocessing operations in the UK there will be approximately 140 tonnes of civil separated plutonium, a small proportion of this material will be unsuitable for reuse and will be disposed of in a GDF. It is therefore necessary to research potential wasteforms for these materials that will provide long-term integrity and criticality safety and in turn understand their evolution and behaviours. A number of potential immobilisation options are currently being considered, with immobilisation in a glass-ceramic wasteform being the leading option for the plutonium that is not suitable for reuse. Past reviews on the expected evolution and leaching behaviour of such wasteforms indicated that there is only a limited amount of information available from historic experimental programmes and that further work is likely to be required to fully underpin the disposal of these materials. This is one of a number of studies that RWM plans to carry out to support NDA in providing advice to HMG on the options for plutonium management.			
Research Driver			
To support NDA in providing advice to HMG on the options for plutonium management.			
Research Objective			
To determine whether it is possible to manufacture inactive simulants of plutonium glass-ceramic wasteforms with chemical composition, characteristics (with the exception of self-irradiation) and leaching behaviour which are sufficiently representative of realistic wasteforms. To validate the use of simulant wasteforms in leaching experiments aimed at evaluating their evolution behaviour in simulated GDF environments. In particular, to determine whether: • The morphology of the simulants is similar enough to that observed in the real materials; • The partitioning of radionuclides or chemical simulants in the microstructure is consistent with experimental observations on the real materials; • The dissolution behaviour of the simulants is similar to that of real plutonium wasteforms, including sensitivity to the groundwater chemistry, temperature, composition and redox conditions, including tests to specifically document the effect of alkaline groundwater; • The presence of radiation damage induced ex-situ has an effect on the ensuing dissolution behaviour; • The presence of the cladding materials in leaching experiments affects the dissolution behaviour; and • Secondary minerals form upon leaching, that are similar to those expected in the wasteform.			

Scope					
To develop an understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of plutonium glass-ceramic wasteforms in near-neutral and, to a lesser degree, alkaline groundwater on the basis of dissolution/leaching experiments of suitable simulants and mechanistic modelling. The task will comprise the following: • To identify and archive relevant samples, underpinning information and suitable simulants. • To undertake macroscopic and microscopic characterisation. • To perform dissolution/leaching measurements in controlled chemical conditions. • To undertake modelling of phase segregation and dissolution processes.					
Geology Application					
HSR, LSSR, Evaporite.					
Output of Task					
Reports, Publications, data and models to support the knowledge base underpinning the GDF DSSC suite of reports, including, but not limited to the [1]. The outputs may also provide supporting information to the NDA and wider nuclear estate on milestones and deliverables relating to the management strategy for nuclear materials.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [2].This work will be carried out in the academic sector. 1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/. 2 Nuclear Decommissioning Authority, *Progress on plutonium consolidation, storage and disposition*, 2019. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/791046/Progress_on_Plutonium.pdf.					

B10.3.2 State-of-the-art Review of Cementitious ILW Wasteforms and Identification of Further Research Needs

<table>
<tr><td colspan="2">Task Number</td><td>110.3.002</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Plutonium, Uranium and other Wasteforms</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In the past, in the UK, Nirex and others have commissioned extensive programmes of R&D to demonstrate the effectiveness of cement in immobilising a variety of ILW/LLW in wasteforms suitable for disposal in a GDF. This area is considered to be relatively well understood but has not been reviewed in some time in the context of the safety case claims, arguments and evidence approach. This task will review our current knowledge base on ILW wasteforms against the claims and arguments within the RWM safety case and aim to identify any knowledge gaps and how they might be addressed. It will also aim to identify any opportunities where operational experience could be used to provide supporting evidence in the safety case.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To update and develop our understanding of the evolution of wasteforms for ILW to support the assessment of packaging solutions, the development of site-specific disposal concepts for these wasteforms and the development of the site-specific safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To review the current knowledge on ILW wasteforms against the newly developed safety case claims, arguments and evidence hierarchy.
Work with waste management specialists to identify any significant areas or uncertainty or concern that may require further R&D to enable disposability assessments to be effectively carried out.
Identify any knowledge gaps and path to closure.
Identify where operational experience could be used to support claims arguments and evidence.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To conduct a review of the status of knowledge and research needs for cementitious ILW wasteforms, in the context of site-specific conditions, utilising international WMO resources, RWM reports, LoC submissions, waste owner liaison, the scientific literature and liaison with SLC’s regarding operational experience relating to wasteform evolution in storage.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A report detailing the status of RWM’s knowledge on cementitious wasteforms against the claims and arguments in the safety case, waste management concerns, identification of any gaps and a path to closure.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
Relevant publications include the [1].

1 Radioactive Waste Management, *Geological disposal: Waste package evolution status report*, RWM Report DSSC/451/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-waste-package-evolution-status-report/.

B10.3.3 Further Development of RWM's Immobilised Plutonium Disposal Concepts

Task Number	110.3.003	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	Plutonium, Uranium and other Wasteforms		

Background

RWM is progressing the development of potential candidate concepts for immobilised plutonium based upon disposal MOX or Zirconolite wasteforms.The NDA is considering alternative approaches to putting the majority of the plutonium stockpile (140 tonnes of civil grade plutonium) 'beyond reach'. A part of these considerations is the development of options for the final disposition of plutonium, and one alternative being explored, in addition to the base case of re-use as MOX, is immobilisation of un-irradiated plutonium followed by a period of interim surface storage, before final disposal to a GDF [1].

In RWM's Inventory for Disposal, plutonium is identified as a potential waste requiring disposal, subject to UK Government policy. The UK Government's "Consultation response on the long-term management of UK owned separated civil plutonium" [2] sets out that the UK's preferred policy for the management of plutonium stockpiles is reuse as MOX fuel in civil nuclear reactors. Spent MOX would likely eventually be declared as waste and therefore the plutonium would still be destined for the GDF; the main difference to RWM is that it would then be hotter and contain fission products, but less fissile plutonium/uranium. However, the strategy also recognises that the portion of the plutonium which cannot be converted to MOX will be immobilised and treated for disposal, at the very least this amounts to 5% of the current inventory.

Research Driver

Further work needs to be undertaken to develop more fit-for-purpose disposal concepts and, specifically, to support the NDA estate in taking the process technologies for wasteform production to TRL 6 through production of a wasteform specification and associated programme. This requires sufficient underpinning understanding of the disposability of preferred wasteforms (zirconolite and 'disposal MOX').

Research Objective

Overall objective:

- To evaluate the disposability of the preferred wasteforms (on the basis of criticality safety, thermal properties, leachability, radiation damage, etc) and develop initial considerations for the disposal concept (i.e the overall multi-barrier system employed) for separated plutonium built upon zirconolite or 'disposal MOX' wasteforms.
- To develop a preferred disposal concept for zirconolite and disposal MOX wasteforms and their associated safety case arguments (claims, arguments and evidence).

Scope

The scope includes: Phase 1: Initial desk-based studies and a review that will inform the research activities needed to be conducted within Phase 2.

- Undertake desk-based studies to understand the current baseline for plutonium disposal, including a detailed definition of the plutonium inventory and consider the implications of wasteforms on disposal concepts together with associated criticality, thermal, dose, containment, etc. studies.

• In parallel with the desk-based work, a programme of experimental work will investigate immobilised plutonium wasteform evolution and dissolution (leaching) behaviour. This work will be conducted by our supply chain and selected academic institutions.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The output of the task will be a series of reports which will be used to support NDA in increasing the TRL of selected technologies.					
SRL at Task Start	TRL 2	**SRL at Task End**	TRL 5	**Target SRL**	TRL 6
Further Information					
For further information, see the 2016 DSSC. 1 Radioactive Waste Management, *Immobilised plutonium options study (pre-conceptual stage)*, 2019. 2 Department of Energy and Climate Change, *Management of the UK's plutonium stocks: A consultation response on the long-term management of UK-owned separated civil plutonium*, 2011.					

B10.3.4 Further Development of RWM's Immobilised Plutonium Disposal Concepts (follow on)

Task Number		110.3.004	**Status**	Start date in future	
WBS Level 4		Wasteform Evolution			
WBS Level 5		Plutonium, Uranium and other Wasteforms			
Background					
RWM is progressing the development of potential candidate concepts for immobilised plutonium. The NDA is considering alternative approaches to putting the majority of this plutonium stockpile 'beyond reach'. A part of these considerations is the development of options for the final disposition of plutonium, and one alternative being explored, in addition to the base case of re-use as MOX, is immobilisation of un-irradiated plutonium followed by a period of interim surface storage, before final disposal to a GDF [1]. In RWM's Inventory for Disposal, plutonium is identified as a potential waste requiring management, subject to UK Government policy. The UK Government's "Consultation response on the long-term management of UK owned separated civil plutonium" [2] sets out that the UK's preferred policy for the management of plutonium stockpiles is reuse as MOX fuel in civil nuclear reactors. Spent MOX would likely be declared as waste and therefore the plutonium would still be destined for the GDF; the main difference to RWM is that it would then be hotter and contain fission products, but less fissile plutonium/uranium. However, the strategy also recognises that the portion of the plutonium which cannot be converted to MOX will be immobilised and treated for disposal, at the very least this amounts to 5% of the current inventory.					
Research Driver					
There will be a need to build upon the outcomes of Task 110.3.003 as it matures towards completion, as there will be a greater understanding for the subsequent development phase of the disposability of both zirconolite and 'disposal MOX'.					
Research Objective					
To develop the preferred disposal concept to a point that enables a robust safety case to be made and the waste to be packaged in accordance with the requirements of the disposal concept.					
Scope					
The scope will be determined following the outcome of Task 110.3.003.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A plutonium disposal system specification.					
SRL/TRL at Task Start	TRL 5	**SRL/TRL at Task End**	TRL 6	**Target SRL/TRL**	TRL 6
Further Information					
For further information, see the 2016 DSSC. 1 Radioactive Waste Management, *Immobilised plutonium options study (pre-conceptual stage)*, 2019. 2 Department of Energy and Climate Change, *Management of the UK's plutonium stocks: A consultation response on the long-term management of UK-owned separated civil plutonium*, 2011.					

B10.3.5 Studies on the Impact of Reactive Metal Corrosion in Cement

Task Number	110.3.005	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	Plutonium, Uranium and other Wasteforms		

Background

A large body of information based on over 20 years of R&D in the UK and overseas shows cement to be an effective encapsulant for many types of ILW and LLW. Based on this experience, the majority of cement-based wasteforms that have been, or would be, produced are expected to perform satisfactorily. However, the long-term reactions of certain wastes may have consequences for wasteform properties and container integrity. For example, grouted reactive metals, particularly Magnox cladding and uranium metal, undergo expansive corrosion. In some cases such processes could have an effect on the physical integrity of the wasteform, or in the extreme, the waste container, prior to closure of a GDF. In these cases there is risk that re-working of waste packages could be required and appropriate provision would need to be made for this. RWM plans to carry out specific experimental and modelling work to understand the likely evolution of cross-industry waste-streams for which specific technical issues have been identified or observed. This work will be co-ordinated with that of waste producers, who undertake R&D on specific wasteform issues associated with the packaging of individual waste streams (e.g. grout formulation, wasteform stability). This task will focus on the evolution of wasteforms containing reactive metals (magnesium, aluminium and uranium), the behaviour of which will be evaluated on the basis of experimental and modelling studies.

Research Driver

To develop a mechanistic understanding of the evolution of cement-based wasteforms for ILW to support the assessment of packaging solutions and the development of the safety case.

Research Objective

To determine whether significant cracking of the wasteform due to expansive corrosion processes can take place in cement-based wasteforms containing reactive metals, particularly uranium-containing wasteforms. In particular, the following:

- To determine what is a significant / ”extensive” degree of cracking in terms of wasteform behaviour.
- To evaluate whether the chronic corrosion rate of uranium in cement is sufficient to induce extensive cracking of the wasteform considering the availability of water and the transport properties of the wasteform and the mechanical properties of the waste container.
- To supplement previous work evaluating whether the chronic corrosion rate of aluminium and Magnox in cement is sufficient to induce extensive cracking of the wasteform if limited quantities of these materials were present in the wasteform, considering the availability of water and the transport properties of the wasteform and the mechanical properties of the waste container.

Scope

To undertake desk-based and modelling studies of reactive metal corrosion and expansion in cement.

Geology Application

N/A

Output of Task

A technical report detailing the current understanding of expansive corrosion processes in cementitious wasteforms including assessment of likelihood and extent of wasteform cracking and impact on the physical integrity of the wasteform. The report should also assess the impact of the loss of wasteform integrity on the relevant GDF safety cases.					
SRL/TRL at Task Start	SRL 5	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					

There are other publications relevant to this task [1]–[4].

1 N. Hoch A.R.and Smart and B. Reddy, *A survey of reactive metal corrosion data for use in the SMOGG gas generation model*, SERCO, Contractor Report Serco Report SA/ENV-0896, issue 2, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/a-survey-of-reactive-metal-corrosion-data-for-use-in-the-smogg-gas-generation-model/.

2 C. Stitt, M. Hart, N. Harker, K. Hallam, J. MacFarlane, A. Banos, C. Paraskevoulakos, E. Butcher, C. Padovani, and T. Scott, *Nuclear waste viewed in a new light; a synchrotron study of uranium encapsulated in grout*. Journal of Hazardous Materials, no. 285, pp. 221–227, 2015.

3 J. Cronin and N. Collier, *Corrosion and expansion of grouted magnox*, NNL, Contractor Report NNL (11) 11524, issue 3, 2011. [Online]. Available: http://rwm.nda.gov.uk/publication/corrosion-and-expansion-of-grouted-magnox-november-2011/.

4 D. Lever, B. Swift, A. Hoch, K. Thatcher, G. Towler, S. Watson, M. Wellstead, and A. Carter, *Carbon-14 project phase 2: Irradiated reactive metal wastes*, AMEC, Contractor Report AMEC/2000047/006 issue 1, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/carbon-14-project-phase-2-irradiated-reactive-metal-wastes/.

B10.4 WBS 110.4 - Spent Fuel

B10.4.1 Scoping Dissolution Studies of Historical Fuels (Windscale AGR: WAGR)

Task Number	110.4.001	**Status**	Ongoing
WBS Level 4	Wasteform Evolution		
WBS Level 5	Spent Fuel		
Background			
Based on extensive international research there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example AGR fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, PWR fuels). Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory. Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ('further') studies aimed at providing additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task will focus on AGR fuel, the behaviour of which will be evaluated on the basis of scoping experiments on historic fuels (WAGR) in oxic conditions.			
Research Driver			
To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support: • The assessment of packaging solutions; • The development of suitable disposal concepts; and • The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.			
Research Objective			
To scope whether the characteristics and leaching behaviour of historical fuels being retrieved as part of Sellafield clean-up (in particular WAGR fuel) are sufficiently similar to those of recently discharged AGR fuel to justify their use in AGR fuel dissolution/leaching studies, particularly for fuel elements with cladding that may have degraded during interim storage. In particular, to evaluate whether: • Sufficiently detailed records of the characteristics (e.g. burn up, chemical composition, initial enrichment) of 'historical' fuels (particularly the prototype WAGR fuel) and of their storage environment(s) exist to indicate that the type of fuel and the environment in which it has been stored is relevant enough to justify experimental studies on these materials as analogues to support the disposal of modern AGR fuel;			

- The dissolution behaviour of historical fuel (IRF and long-term dissolution rate) for which cladding has retained its integrity over extended periods of pond storage is similar enough to that observed for modern AGR fuels to give confidence in the relevance of any studies carried out on these materials to underpin the disposal of AGR fuel;
- The dissolution rate of water-logged fuels showing significant oxidation is either similar to that estimated in short-term experiments on irradiated AGR fuel (in oxic conditions) or, if higher, shows a correlation with the extent of oxidation observed;
- The cladding of the majority of historical fuel elements shows signs of degradation after prolonged contact with any pond water that may have leaked (if any) inside cans employed during interim storage;
- The condition of any water-logged prototype AGR fuel retrieved from Sellafield legacy ponds after storage shows that dissolution processes have led to the formation of phases which impact on the ability to retain radionuclides relevant to the safety case;
- The extent of oxidation in any fuel with cladding that was perforated during storage (as opposed to purposely cut during PIE) is limited to a localised area or to a superficial layer;
- The concentration of radionuclides relevant to the safety case in any water in contact with waterlogged fuel (if any) is compatible with (or lower than) that estimated from the IRF and long-term release rate estimated for AGR/LWR fuels over relevant periods (corrected for radionuclide decay). If significant differences are observed the objective includes determination as to whether these differences can be interpreted on the basis of the likely exchange of solutes with the external environment.

Scope

The scope comprises the following:

- Evaluation of records and PIE data of relevant materials, samples and storage conditions to establish whether any work carried out on retrieved materials is likely to be sufficiently relevant to the study of commercial AGR fuels.
- Depending on information available (records) and decommissioning constraints, inspection of historical fuels (particularly WAGR) to evaluate the condition of the cladding.
- Depending on information available (records) and decommissioning constraints, undertake characterisation of fuel samples and radiochemical analysis of water in contact with water-logged fuel and dissolution/leaching experiments of intact fuel samples in fresh (oxic) solutions.

Geology Application

HSR, LSSR, Evaporite

Output of Task

A report to develop and explore WAGR leaching rates.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	SRL 4

Further Information
There are other publications relevant to this task [1]. Information is also available at: http://www.firstnuclides.eu/.This task is currently being carried out by contractors that have access to specialist facilities; the feasibility and method development work has been successful and is now complete. 1 L. Johnson, I. Günther-Leopold, J. Kobler Waldis, H. Linder, J. Low, D. Cui, E. Ekeroth, K. Spahiu, and L. Evins, *Rapid aqueous release of fission products from high burn-up LWR fuel: Experimental results and correlations with fission gas release*. Journal of Nuclear Materials, no. 420, pp. 54–62, 2012.

B10.4.2 Further Work on SimFuel to Understand Dissolution Behaviour of Spent Fuel

Task Number	110.4.002	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	Spent Fuel		

Background

Based on extensive international research there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example AGR fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, PWR fuels). Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory. Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ('further') studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task comprises further work on SimFuel (following on from Task 547), manufactured to replicate relevant spent fuel, whose behaviour will be evaluated on the basis of a variety of scoping experiments and atomistic models. SimFuel is made by doping UO_2 with non-radioactive isotopes as surrogates of the fission products expected to form in spent fuels.

Research Driver

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- the assessment of packaging solutions;
- the development of suitable disposal concepts; and
- the development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

Research Objective

To determine whether it is possible to manufacture inactive simulants of spent fuel (SimFuel) with chemical composition, characteristics (with the exception of self-irradiation) and leaching behaviour which are sufficiently representative of UK spent fuels (e.g. AGR, LWR or MOX) to justify their use in leaching experiments aimed at evaluating the leaching behaviour of the fuel. In particular to determine whether:

- The morphology of SimFuel is similar enough to that observed in spent fuel;
- The partitioning of fission product surrogates in the UO_2 microstructure and the resulting oxidation state of the fuel is consistent with experimental observations on spent fuels;

- The dissolution behaviour of SimFuel is similar to that of spent fuels, including sensitivity to the groundwater chemistry, temperature, fuel composition (representing the post-discharge 'age' of the fuel) and redox conditions, including tests to specifically document the effect of alkaline groundwater;
- The presence of radiation damage induced *ex-situ* has an effect on the ensuing dissolution behaviour of SimFuel;
- The presence of the stainless steel/Zircaloy representative of fuel cladding in leaching experiments affects the dissolution behaviour of the SimFuel; and
- Secondary uranium minerals form on SimFuel upon leaching, which are similar to those expected in UO_2 spent fuels (which would indicate retention of uranium and non-radioactive isotopes or surrogates of some important radionuclides).

Scope

To compare leaching behaviour of SimFuel with UK spent fuels (e.g. AGR, PWR or MOX) to determine whether these are sufficiently similar to be used in leaching experiments and evaluate and understand differences in behaviour.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Comparison of SimFuel with real UK spent fuel and understanding of the differences.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4

Further Information

There are other publications relevant to this task [1]. This task will be carried out through academic partners. The opportunity for co-funding from the relevant research council may be investigated.

1 N. Rauff-Nisthar, C. Boxall, I. Farnan, Z. Hiezl, W. Lee, C. Perkins, and R. Wilbraham, *Corrosion behaviour of AGR simulated fuels – evolution of the fuel surface*. ECS Transactions, vol. 53, pp. 95–104, 2013. [Online]. Available: https://www.researchgate.net/publication/268113592_Corrosion_Behavior_of_AGR_Simulated_Fuels_-_Evolution_of_the_Fuel_Surface.

B10.4.3 Scoping Studies on Dissolution Behaviour of Exotic and High Pu-bearing Spent Fuels

Task Number	110.4.003	**Status**	Ongoing
WBS Level 4	Wasteform Evolution		
WBS Level 5	Spent Fuel		

Background

Based on extensive international research there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example experimental legacy fuels that are likely to be disposed of in smaller quantities. These are known as exotic fuels and include metallic, oxide and carbide materials. These fuels are a legacy from earlier nuclear industry activities such as the development of research, experimental or prototype reactors. Although exotics often share the physical characteristics and properties of Magnox and oxide fuel, their composition and enrichment are varied, with a substantial number containing plutonium. Furthermore, by the completion of reprocessing operations, current estimates indicate that there will be approximately 140 tonnes of civil separated plutonium (Pu) in the UK. Little work has to date been undertaken on the disposability of the exotic fuels and high Pu-bearing fuels (e.g. MOX fuel) as we have focussed our efforts on the large quantities of AGR and PWR fuel that dominate the UK inventory. This task therefore comprises an assumed set of short-term scoping experiments, on real samples of exotic and/or high Pu-bearing fuels or simulants, based on a previous desk-based analysis of research needs for exotic fuels ([1, Task 550]).

Research Driver

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions;
- The development of suitable disposal concepts; and
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

Research Objective

Depending on type of fuel and disposal concept, to scope the dissolution/corrosion behaviour of unirradiated/irradiated exotic fuels as measured in a set of short-term experiments. In particular, the following:

- To measure the dissolution/corrosion behaviour of selected samples in groundwater simulants (including any conditioning from immobilisation/buffering media) to scope expected long-term rate.
- Where appropriate, to determine whether the dissolution/corrosion rates are similar enough to those of other fuels (for oxide fuels) or uranium metal (for metallic fuels) to indicate that further measurements are likely to be successful in providing confidence in their behaviour in our standard disposal concepts.
- To scope whether there are any detrimental effects on the dissolution behaviour of the fuel at the levels of burn-up and power history expected.
- To scope whether the presence of cladding in the proximity of exotic fuels exposed to oxic groundwater results in effects which are detrimental to the leaching behaviour of the fuel.

- To evaluate whether the results of scoping measurements are consistent with the expected inventory and partitioning/segregation of radionuclides in fuel elements.
- To evaluate whether, where appropriate (e.g. oxic fuels) the dissolution / leaching of safety-relevant radionuclides can be correlated with any more easily measurable quantities (e.g. FGR).

Scope

The scope comprises the following:

- To identify and access relevant fuel samples and underpinning information (e.g. inventory, burn-up, FGR) or suitable simulants (e.g. SimFuel).
- Macroscopic and microscopic characterisation of the fuel samples.
- Dissolution/leaching measurements of relevant fuel samples in controlled chemical conditions.
- Thermodynamic modelling of phase segregation.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Theses and peer reviewed journal publications.

SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 3	**Target SRL/TRL**	TBA

Further Information

There are other publications relevant to this task [2]–[4]. This task will be carried out through contractors and academic partners. Opportunities for co-funding from the relevant research council may be sought.

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Nuclear Decommissioning Authority, *Progress on approaches to the management of separated plutonium*, NDA Report SMS/TS/B1-PLUT/002/A, 2014.

3 Nuclear Decommissioning Authority, *Exotic fuels: Dounreay fast reactor (DFR) breeder - credible options*. [Online]. Available: https://www.nda.gov.uk/strategy/spentfuelsmgmt/exoticfuel/.

4 L. Johnson, I. Günther-Leopold, J. Kobler Waldis, H. Linder, J. Low, D. Cui, E. Ekeroth, K. Spahiu, and L. Evins, *Rapid aqueous release of fission products from high burn-up LWR fuel: Experimental results and correlations with fission gas release*. Journal of Nuclear Materials, no. 420, pp. 54–62, 2012.

B10.4.4 Further Dissolution Studies on Advanced Gas-cooled Reactor (AGR) Fuel

Task Number	110.4.004	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	Spent Fuel		

Background

Based on extensive international research there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example AGR fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, PWR fuels). Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory. Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ('further') studies aimed at providing additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. Following on from previous work ([1, Task 546], [1, Task 547], Task 110.4.001, [1, Task 551], Task 110.4.002), this task will focus on AGR fuel, whose behaviour will be evaluated on the basis of experiments on fuels with differing characteristics.

Research Driver

To further develop our mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support the following:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

Research Objective

To extend the applicability of the results of previous leaching measurements on UK AGR fuels to a broader envelope of spent AGR fuels and to document the effects of alkaline groundwater on the dissolution behaviour. In particular, the following:

- To identify and gain access to specific samples which can be studied to test the applicability of previously estimated IRF and long-term dissolution rates to fuels with different power history, burn-up and fission gas release.
- To carry out leaching studies in controlled chemical conditions to compare with results of previous tests on UK AGR fuels as well as international studies on LWR fuels.
- To rationalise dissolution behaviour of the AGR fuel envelope in the context of the mechanistic understanding being developed in the UK and internationally.

Scope

The scope comprises the following:

• Identification and access to relevant fuel samples and underpinning information (e.g. inventory, power history, burn-up, FGR). • Macroscopic (e.g. optical) and microscopic (e.g. Scanning Electron Microscopy) characterisation of relevant fuel samples. • Dissolution/leaching measurements of relevant fuel samples in controlled chemical conditions.
Geology Application
HSR, LSSR, Evaporite
Output of Task
Leaching data on UK AGR spent fuels published in contractor reports and peer-reviewed publications.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5

Further Information

The IRF is that fraction of fission products associated with grain boundaries and areas of macroscopic accumulation of segregated phases, as opposed to the fuel matrix. Operationally, AGR fuel is exposed to different temperature profiles than LWR fuel, hence a different degree of partitioning of the more volatile fission product may have occurred, potentially leading to different leaching behaviour. There are other publications relevant to this task [2].

Information is also available at: http://www.firstnuclides.eu/.This task is will be carried out by contractors that have access to specialist facilities.

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 L. Johnson, I. Günther-Leopold, J. Kobler Waldis, H. Linder, J. Low, D. Cui, E. Ekeroth, K. Spahiu, and L. Evins, *Rapid aqueous release of fission products from high burn-up LWR fuel: Experimental results and correlations with fission gas release*. Journal of Nuclear Materials, no. 420, pp. 54–62, 2012.

B10.4.5 Dissolution Studies on UK Pressurised Water Reactor (PWR) Fuel

<table>
<tr><td>Task Number</td><td colspan="2">110.4.005</td><td colspan="2">Status</td><td>Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">There is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. RWM plans to build on this international understanding, however it is first necessary to validate the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent PWR fuel against this understanding. This task will focus on PWR fuel, the behaviour of which will be evaluated based on experiments on fuels with a range of characteristics. RWM's spent fuel strategy is currently being reviewed (Task 110.4.012) which will define the work required in this task.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent PWR fuel in near-neutral and, to a lesser degree, alkaline groundwater on the basis of dissolution/leaching experiments of suitable samples.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To extend the applicability of the results of previous leaching measurements obtained internationally on LWR fuels (including PWR) to UK PWR fuel. In particular, the following:
• To identify and gain access to specific samples which can be studied to test the applicability of previously estimated IRF and long-term dissolution rates to fuels with UK-specific power history, burn-up and FGR.
• To carry out leaching studies in controlled chemical conditions to compare with the results of international studies on LWR fuels.
• To rationalise the dissolution behaviour of the PWR fuel envelope in the context of the mechanistic understanding being developed in the UK and internationally.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following:
• To identify and access relevant fuel samples and underpinning information (e.g. inventory, power history, burn-up and FGR).
• To undertake macroscopic and microscopic characterisation.
• To undertake dissolution/leaching measurements in controlled chemical conditions.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Contractor approved reports and peer reviewed publications.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
</table>

Further Information
The IRF is that fraction of fission products associated with grain boundaries, as opposed to the fuel matrix. There are other publications relevant to this task [1]. Information is also available at: http://www.firstnuclides.eu/. This task is will be carried out by contractors that have access to specialist facilities and, potentially, in the context of, or in collaboration with, ongoing international studies on LWR fuels. 1 L. Johnson, I. Günther-Leopold, J. Kobler Waldis, H. Linder, J. Low, D. Cui, E. Ekeroth, K. Spahiu, and L. Evins, *Rapid aqueous release of fission products from high burn-up LWR fuel: Experimental results and correlations with fission gas release*. Journal of Nuclear Materials, no. 420, pp. 54–62, 2012.

B10.4.6 Further Studies on Dissolution Behaviour of Exotic and High Pu-bearing Fuels

Task Number	110.4.006	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	Spent Fuel		
Background			
Based on extensive international research there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example experimental legacy fuels that are likely to be disposed in smaller quantities. These are known as exotic fuels and include metallic, oxide and carbide materials. These fuels are a legacy from earlier nuclear industry activities such as the development of research, experimental or prototype reactors. Although exotics often share the physical characteristics and properties of metallic and oxide fuel, their composition and enrichment are varied, with a substantial number containing plutonium. Nevertheless, by the completion of reprocessing operations, current estimates indicate that there will be approximately 140 tonnes of civil separated plutonium in the UK. The NDA has concluded that reuse remains the preferred option although little work has to date been undertaken on the disposability of these exotic and high plutonium-bearing (e.g. MOX) fuels as we have focussed our efforts on the large quantities of AGR and PWR fuel that dominate the UK inventory. This task therefore comprises an assumed set of dissolution/leaching experiments, on real samples or simulants, based on a previous desk-based analysis of research needs for exotic fuels and high plutonium-bearing ([1, Task 550]) and subsequent scoping experiments ([1, Task 553]).			
Research Driver			
To develop a mechanistic understanding of the evolution and dissolution behaviour of UK exotic fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater. This is to support: • The assessment of packaging solutions; • The development of suitable disposal concepts; and • The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.			
Research Objective			
Depending on type of fuel and disposal concept, to determine the dissolution/corrosion behaviour of unirradiated/irradiated exotic fuels as measured in a set of short-term experiments. In particular, the following: • To measure the dissolution/corrosion behaviour of selected samples in groundwater simulants (including any conditioning from immobilisation/buffering media) to scope the expected long-term dissolution rate. • Where appropriate, to determine whether the dissolution/corrosion rates are similar enough to those of other fuels (for oxide fuels) or uranium metal (for metallic fuels) to indicate that further measurements are likely to be successful in providing confidence in their behaviour in our standard disposal concepts. • To scope whether there are any detrimental effects on the dissolution behaviour of the fuel at the levels of burn-up and power history expected.			

• To scope whether the presence of cladding in the proximity of exotic fuels exposed to oxic groundwater results in effects which are detrimental to the leaching behaviour of the fuel. • To evaluate whether the results of scoping measurements are consistent with the expected inventory and partitioning/segregation of radionuclides in fuel elements. • To evaluate whether, where appropriate (e.g. oxic fuels) the dissolution / leaching of safety-relevant radionuclides can be correlated with any more easily measurable quantities (e.g. the FGR).					
Scope					
To be developed on the basis of the outcome of Task 110.4.003.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Understanding of the evolution and dissolution behaviour of UK exotic fuels instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	TBA
Further Information					
There are other publications relevant to this task [2]–[5]. This task will be carried out through contractors and academic partners. Opportunities for co-funding from the relevant research council may be sought.					

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Radioactive Waste Management, *Geological disposal: The 2013 derived inventory*, RWM Report NDA/RWM/120, Jul. 2015. [Online]. Available: http://rwm.nda.gov.uk/publication/2013-derived-inventory/.

3 Nuclear Decommissioning Authority, *Exotic fuels: Dounreay fast reactor (DFR) breeder - credible options*. [Online]. Available: https://www.nda.gov.uk/strategy/spentfuelsmgmt/exoticfuel/.

4 Nuclear Decommissioning Authority, *Progress on approaches to the management of separated plutonium*, NDA Report SMS/TS/B1-PLUT/002/A, 2014.

5 L. Johnson, I. Günther-Leopold, J. Kobler Waldis, H. Linder, J. Low, D. Cui, E. Ekeroth, K. Spahiu, and L. Evins, *Rapid aqueous release of fission products from high burn-up LWR fuel: Experimental results and correlations with fission gas release*. Journal of Nuclear Materials, no. 420, pp. 54–62, 2012.

B10.4.7 Scoping Studies on Dissolution Behaviour of Un-reprocessed Metallic Fuel

Task Number	110.4.007	**Status**	Ongoing
WBS Level 4	Wasteform Evolution		
WBS Level 5	Spent Fuel		

Background

Based on extensive international research there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique or very specific to the UK, among these is metallic fuel irradiated in Magnox reactors. The NDA's baseline plan is for all metallic fuel to be reprocessed at Sellafield, however this plan is dependent upon the efficiency of ongoing reprocessing operations and it is therefore possible that RWM may be required to consider the disposal of un-reprocessed metallic fuel. Research may therefore be required on the disposal of irradiated metallic fuel, depending on the progress of reprocessing operations. Following the review undertaken in [1, Task 554], this task comprises a possible scoping study on the behaviour of un-reprocessed metallic fuel, based on dissolution/leaching experiments of real spent fuel samples or suitable simulants.

Research Driver

To develop a mechanistic understanding of the evolution and dissolution behaviour of UK spent fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater. This is to support the following:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

Research Objective

To scope the IRF and long-term dissolution rate of metallic fuels and/or high plutonium-bearing fuels (and any relevant wasteform). In particular the following:

- To measure the dissolution behaviour of selected samples in groundwater simulants and to determine whether the rates are similar enough to those of other fuels to provide confidence in their behaviour.
- To evaluate whether there are detrimental effects on the dissolution behaviour at the levels of burn-up and power history expected.
- To evaluate whether the presence of cladding in the proximity of fuel exposed to oxic groundwater results in effects that are detrimental to the leaching behaviour of the fuel.
- To evaluate whether the results of scoping measurements are consistent with the expected inventory and partitioning/segregation of radionuclides in fuel elements and with the likely oxidation state of the fuel matrix.
- To evaluate whether the dissolution/leaching of safety-relevant radionuclides can be correlated with any more easily measurable quantity (e.g. the FGR).

Scope

Following on from the previous review task this scope comprises the following:

- Identification and gaining access to relevant fuel samples, underpinning information and suitable simulants.

- Macroscopic and microscopic characterisation of relevant fuel samples.
- Dissolution/leaching measurements of relevant fuel samples in controlled chemical conditions.
- Thermodynamic modelling of phase segregation.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Contractor approved reports. It is assumed that these scoping studies will be sufficient to demonstrate that these materials perform within the envelope of other ILW in post-closure assessments, hence only SRL 4 would be required.

SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 4

Further Information

There are several publications relevant to this task [2]. This task will be carried out by contractors and academic partners. Opportunities for co-funding from the relevant research council may be sought.

1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.

2 Nuclear Decommissioning Authority, *Magnox fuel, strategy position paper - magnox fuel*, NDA Report issue 1, Jul. 2012.

B10.4.8 Further Studies on Dissolution Behaviour of Un-Reprocessed Metallic Fuel

<table>
<tr><td>Task Number</td><td colspan="2">110.4.008</td><td colspan="2">Status</td><td>Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Based on extensive international research there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique or very specific to the UK, among these is metallic fuel irradiated in Magnox reactors. The NDA's baseline plan is for all metallic fuel to be reprocessed at Sellafield, however this plan is dependent upon the efficiency of ongoing reprocessing operations and it is therefore possible that RWM may be required to consider the disposal of un-reprocessed metallic fuel. Research may therefore be required on the disposal of irradiated metallic fuels, depending on the progress of reprocessing operations. Following the previous work undertaken in [1, Task 554] and Task 110.4.007, this task comprises further evaluation of the dissolution/leaching behaviour of real metallic spent fuel samples or suitable simulants.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop a mechanistic understanding of the evolution and dissolution behaviour of UK spent fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
• The assessment of packaging solutions;
• The development of suitable disposal concepts; and
• The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To be developed on the basis of the outcome of Task 110.4.007.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To be developed on the basis of the outcome of Task 110.4.007.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Understanding of the evolution and dissolution behaviour of un-reprocessed metallic spent fuel. It is assumed that these scoping studies will be sufficient to demonstrate that these materials perform within the envelope of other ILW in post-closure assessments, hence only SRL 4 would be required.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
</table>

Further Information
There are several publications relevant to this task [2].   1 Nuclear Decommissioning Authority, *Geological Disposal: Science and Technology Plan*, NDA Report NDA/RWMD/121, 2016. [Online]. Available: https://webarchive.nationalarchives.gov.uk/20181001115909/https://rwm.nda.gov.uk/publication/science-and-technology-plan-ndarwm121/.   2 Nuclear Decommissioning Authority, *Magnox fuel, strategy position paper - magnox fuel*, NDA Report issue 1, Jul. 2012.

B10.4.9 Scoping Studies to Assess the Behaviour of Metallic Uranic Fuel in Self-shielded Boxes

<table>
<tr><td colspan="2">Task Number</td><td>110.4.009</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Based on extensive international research, there is good understanding of the behaviour of LWR spent fuel under conditions relevant to geological disposal. Alongside this, the UK work to date has primarily focused on AGR spent fuel. However, the inventory for disposal will also contain metallic, carbide and unconventional oxide fuel types. These fuels, grouped for the purposes of this work as exotics, represent a number of spent fuels from research, experimental and other reactors, typically of low volume and with varied, currently unstudied disposal characteristics.The exotics can be further broken down into other groupings, including metallic uranic fuel (as used in Magnox reactors), that has not been reprocessed, that has a low initial enrichment and therefore alternative methods for treatment and disposal are being investigated, which is the focus of this task.

There have been proposals to package spent Magnox fuel into Self-Shielding Boxes (SSBs) to assist in decommissioning activities, and therefore work is proposed to identify any challenges related to the disposability of such packages.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support concept development by developing understanding of the disposability of Magnox spent fuel in SSBs.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop to understanding of Magnox spent fuel behaviour, particularly its leaching and dissolution, and the impact of this on the post-closure performance safety case to identify any challenges associated with its disposal in SSBs.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To undertake post-closure performance scoping calculations to understand the key parameters affecting the disposability of Magnox spent fuel in SSBs.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a report (or reports) detailing the likely impact of disposing of Magnox in SSBs on the post-closure performance in a range of scenarios. As this work is at a scoping level the report(s) will also detail potential areas of uncertainty which may be further reduced if required.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 1</td><td>SRL/TRL at Task End</td><td>SRL 2</td><td>Target SRL/TRL</td><td></td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1], [2].
1 Nuclear Decommissioning Authority, Magnox fuel, strategy position paper - magnox fuel, NDA Report issue 1, Jul. 2012.
2 Nuclear Decommissioning Authority, Magnox fuel strategy: Contingency options, 21167690, 2014. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/457813/Magnox_Fuel_Strategy_-_Contingency_Options.pdf.</td></tr>
</table>

B10.4.10 Processing, Characterisation and Corrosion/Leaching Behaviour of Simulated MOX Spent Fuel

<table>
<tr><td>Task Number</td><td>110.4.010</td><td>Status</td><td colspan="3">Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Wasteform Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In 2011, the UK government proposed a preliminary policy view to re-use the UK's stockpile of separated plutonium as Mixed Oxide fuel. This would see the vast majority of UK plutonium (95% of civil) converted into fuel for irradiation in civil nuclear reactors. A significant quantity of MOX has already been produced and some of this has been irradiated in experimental research reactors. Therefore, there is a need to study these materials to understand how they will behave in a geological disposal facility. However, irradiated MOX is extremely radioactive, making it difficult to handle and study in detail.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop simulant fuels to enable the safe study of spent MOX fuels, since the reduced activity of these samples will both reduce the demand on complex and expensive handing facilities and allow more detailed analysis and techniques to be used.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop a spent MOX simulant, which can be used to study leaching and dissolution behaviour. Such SIMFUELs contain inactive isotopes of the radionuclides, or chemically similar elements, to those that will be present in irradiated fuels. These materials will be studied in simulant deep groundwater representing the chemical composition that may be encountered in the GDF environment.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To develop and characterise simulant MOX fuel materials.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be a PhD thesis and peer reviewed journal papers.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1], [2].
1 Nuclear Decommissioning Authority, Magnox fuel, strategy position paper - magnox fuel, NDA Report issue 1, Jul. 2012.
2 Nuclear Decommissioning Authority, Magnox fuel strategy: Contingency options, 21167690, 2014. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/457813/Magnox_Fuel_Strategy_-_Contingency_Options.pdf.</td></tr>
</table>

B10.4.11 DISCO: Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions

<table>
<tr><td>Task Number</td><td colspan="2">110.4.011</td><td colspan="2">Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Wasteform Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The development of robust safety cases for geological disposal of spent nuclear fuel requires a solid understanding of its dissolution over very long timescales (up to a million years). The Spent Fuel dissolution is the main source term for the release of radionuclides under repository conditions, and it will control the release of radioactivity in the environment surrounding the engineered barriers (the near field) of a disposal facility once the EBS has degraded and groundwater comes into contact with the spent fuel.There is good understanding of the behaviour of conventional LWR spent fuel under conditions relevant to geological disposal. However, novel fuel types are being developed, offering improved in-reactor properties (such as Cr-doping) or burning different fuels (such as MOX). DISCO is a collaborative project funded by the European Commission under the Horizon 2020 Research and Training Programme of the European Atomic Energy Community, which aims to investigate their effect on the behaviour of spent fuel in a repository environment.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To improve understanding of the effect of novel fuel types (Cr-doping and MOX) on spent fuel dissolution.</td></tr>
<tr><td colspan="6">Research Objective
• To enhance understanding of Spent Fuel matrix dissolution under conditions representative of failed containers in reducing repository environments.
• To assess whether novel fuel types behave like conventional ones.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To assess the effect of dopants in novel fuel types on their dissolution properties under conditions relevant to deep geological disposal.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The task will output reports and academic papers in peer reviewed journals.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3</td><td>SRL/TRL at Task End</td><td>SRL 4</td><td>Target SRL/TRL</td><td></td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">For further information, see: [1]
1 DISCO - Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions. [Online]. Available: https://disco-h2020.eu/Home/.</td></tr>
</table>

B10.4.12 Spent Fuel Strategy

Task Number		110.4.012	**Status**	Ongoing	
WBS Level 4		Wasteform Evolution			
WBS Level 5		Spent Fuel			
Background					
The vast majority of spent fuels likely to require disposal in the GDF are ceramic oxide (UO_2-based) fuels, arising from the fleet of commercial Advanced Gas-cooled Reactors and a PWR currently operating in the UK. UO_2-based fuels requiring disposal may also arise from the operation of new commercial reactors that may be built in the future (e.g. New Build fuels such as LWR, BWR and MOX). Research and development underpinning the disposability of such fuels (mainly focusing on their expected GDF dissolution and leaching behaviour) is ongoing both in the UK and internationally. In general, given the very limited chemical reactivity of their UO_2 matrix, these materials are likely to provide additional confidence in the safety of the GDF during periods preceding closure of the facility (i.e. the GDF operational period) and after the facility is sealed and closed (the post-closure phase). Safety cases for the disposal of oxide fuels are being successfully progressed in a number of countries. Beyond this relatively large inventory of more conventional UO_2-based fuels (1,000s of tonnes), the UK disposal inventory also includes a more modest inventory of metallic, non-conventional oxide and carbide fuels. This is likely to include several 100 tonnes of non-reprocessed Magnox spent fuel once the Magnox reprocessing plant closes, some of which may be proposed for disposal in Self-Shielded Boxes which would require assessing. Work, aimed at identifying the key characteristics of these fuels and evaluating their likely disposability, has been carried out in past disposability assessments. Furthermore, a recent study sought to further describe (in more detail) the physical, chemical and radiological properties of these fuels that are relevant to disposal and to document some of these data for these lesser studied/considered UK fuels. RWM has recently developed a research programme which includes the spent fuel research area. However, this task seeks independent advice to ensure the proposed forward programme is technically accurate and appropriate.					
Research Driver					
To ensure that the needs of the post-closure safety case are well understood, in order to inform decommissioning across the wider NDA estate and to capitalise on any opportunities arising during decommissioning.					
Research Objective					
To ensure the forward work programme in Spent Fuel evolution is appropriate.					
Scope					
To investigate, for each fuel type, how different inventories and different dissolution behaviours would affect post-closure performance and to use this to inform the development of the forward work programme. This work programme will be used to update RWM's research plans following review by invited experts from across the industry.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
The task will output a report, roadmap and any updated S&T plan task sheets.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					

B10.4.13 Review of Irradiated MOX for Disposal

<table>
<tr><td>Task Number</td><td colspan="2">110.4.013</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Wasteform Evolution</td></tr>
<tr><td>WBS Level 5</td><td colspan="5">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In 2011, the UK Government proposed a preliminary policy view to re-use the UK’s stockpile of separated plutonium as Mixed Oxide fuel. This would see the vast majority of UK plutonium (95% of civil) converted into fuel for irradiation in civil nuclear reactors. A significant quantity of MOX has already been produced and some of this has been irradiated in experimental research reactors. However, a review of what irradiated MOX has currently been produced and is destined for disposal is required.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To better define the inventory of irradiated MOX for disposal to understand how this can be accommodated within a geological disposal facility and the research required to achieve this.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine the inventory of irradiated MOX for disposal and relevant history of this material.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To determine the inventory of irradiated MOX for disposal and its irradiation history. This will then be used to understand whether these spent fuels are compatible with those disposal concepts that RWM will use for the remainder of the waste inventory.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The task will output a report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 1</td><td>SRL/TRL at Task End</td><td>SRL 2</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">[1]

1 Nuclear Decommissioning Authority, Plutonium Strategy - Current Position Paper, SMS/TS/B1-PLUT/001/A v2.0, 2011. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/457864/Plutonium_position_paper_February_2011.pdf.</td></tr>
</table>

B10.4.14 Confirm PWR Spent Fuel Behaviour

<table>
<tr><td colspan="2">Task Number</td><td>110.4.014</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Based on extensive international research, there is good understanding of the behaviour of LWR spent fuel, similar to that used at Sizewell B Power Station, under conditions relevant to geological disposal. However, the UK work to date has primarily focused on AGR spent fuel. This task aims to confirm that this understanding is applicable to UK PWR spent fuel in site-specific groundwater.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">Confirm that international research on spent light-water reactor fuel is applicable to UK PWR spent fuel.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To determine leaching and dissolution behaviour of UK PWR spent fuel and determine how this fits with international data and understanding.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Perform leaching studies in site-specific groundwater using internationally recognised methodologies on UK PWR spent fuel.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The task will output a report containing leaching data.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B10.4.15 Assess the Nature and Quantity of MoD Owned Wastes

<table>
<tr><td colspan="2">Task Number</td><td>110.4.015</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">A number of MoD-owned wastes are expected to be destined for geological disposal. However, very little is currently known within the GDF programme about the nature or quantity of these wastes.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">It is important to identify whether any of the MoD-owned wastes differ significantly from those currently included in the UK Radioactive Waste Inventory to ensure that the designed geological disposal facility can accommodate these wastes.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To understand whether MoD wastes are compatible with those disposal concepts that RWM will use for the remainder of the waste inventory.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To develop an understanding of the characteristics of MoD wastes relevant to deep geological disposal. This will include wasteform evolution and dissolution, criticality safety, waste package accident performance, gas generation, etc.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The task will output a report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 2</td><td>SRL/TRL at Task End</td><td>SRL 3</td><td>Target SRL/TRL</td><td>TBA</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task: [1]
1 Ministry of Defence, Nuclear Liabilities Management Strategy, 2011. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/27391/nuclear_strategy_final.pdf.</td></tr>
</table>

B10.4.16 Review the Understanding of the Effect of Hydrogen on Spent Fuel Matrix Dissolution

<table>
<tr><td colspan="2">Task Number</td><td>110.4.016</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Spent Fuel</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The topic of spent fuel dissolution has been studied for many years and there is significant knowledge and experience available in this field. However, there remain areas which require further investigation, such as the mechanism behind the hydrogen effect (i.e. the activation of hydrogen to suppress fuel oxidation at the fuel surface). This task comprises a review of current understanding and the identification of any future research needs in this area.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop an improved mechanistic understanding of the effect of hydrogen in spent fuel dissolution to potentially facilitate its inclusion in spent fuel dissolution models.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To improve understanding of spent fuel matrix dissolution mechanisms in the presence of hydrogen.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">A desk-based review of the current understanding of spent fuel dissolution mechanisms in the presence of hydrogen and to determine any further experiments required to delineate relevant mechanistic understanding in the context of the long-term performance and leaching properties of spent fuel.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Review report and details of any future experimental programme.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 2</td><td>SRL/TRL at Task End</td><td>SRL 3</td><td>Target SRL/TRL</td><td>SRL 4</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1].
1 A. Barreiro-Fidalgo, Y. Kumagai, and M. Jonsson, 2, O2 and UO2. Journal of Coordination Chemistry, vol. 71, pp. 1799–1807, Issue 11-13 2018.</td></tr>
</table>

B10.5 WBS 110.5 - Graphite

B10.5.1 Review of CAST WP5 in UK Context

<table>
<tr><td colspan="2">Task Number</td><td colspan="2">110.5.001</td><td>Status</td><td>Completed, undergoing review</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Graphite</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">For wastes such as graphite arising from the dismantling of the Magnox and AGR fleets, where the disposal concept is at an early stage of development, current and future work is aimed at developing our understanding of the available options to support future decisions. Nevertheless, we are confident, based on work conducted in programmes such as the EC CARBOWASTE [1] programme that the UK graphite inventory is disposable. If disposed of in a GDF, commercial reactor core graphite is likely to be packaged without encapsulation. This material is likely to be stable and unlikely to evolve in a way which affects the performance of the waste packages. However, the release of carbon-14 from graphite is an important aspect of RWM's R&D. Relevant research was carried out through a UK-coordinated EC project (CAST WP5). The disposal behaviour of graphite will be evaluated in this task on the basis of the CAST WP5 experiments with irradiated samples and model development.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop a mechanistic understanding of the leaching behaviour of other graphite wasteforms to support strategic decisions, the disposability assessment process, the development of disposal concepts for these wasteforms and the safety case.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To evaluate the output of the CAST EU project in the UK context.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises a desk-based review of the output of CAST and discussion in the context of the disposal of the UK graphite inventory and, in particular, the large quantities which will arise during dismantling of the Magnox and AGR reactor fleets.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of the task will result in a report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
</table>

Further Information
This will be used to support strategic decisions on the management of these waste-forms, the assessment of packing solutions, the safety case and the development of disposal concepts for these wasteforms. There are other publications relevant to this task [2]–[4].

1 A. Wareing, L. Abrahamsen, A. Banford, M. Metcalfe, and W. von Lensa, *Final publishable carbowaste report*, EC Project CARBOWASTE report Deliverable D-0.3.12, Jun. 7, 2013.

2 S. Norris and M. Capouet, *Overview of CAST project*. Radiocarbon, vol. 60, pp. 1649–1656, Special Issue 6 2018. [Online]. Available: https://doi.org/10.1017/RDC.2018.142.

3 Nuclear Decommissioning Authority, *Geological Disposal: Carbon-14 Project - Phase 1 Report*, NDA/RWM/092, 2012.

4 Radioactive Waste Management, *Geological disposal: Carbon-14 project phase 2: Overview report*, RWM Report NDA/RWM/137, Issue 1, Mar. 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-carbon-14-project-phase-2-overview-report/.

B10.5.2 Understanding the Potential Impact of Wigner Energy

Task Number	110.5.002	**Status**	Start date in future
WBS Level 4	Wasteform Evolution		
WBS Level 5	Graphite		
Background			
Graphite irradiated at low temperatures may have Wigner energy associated with it. For clarity, Wigner energy is an effect which arises due to stored energy from defects in the graphite lattice. It is more important for low-temperature graphite irradiation (<~250°C), resulting from the small number of experimental reactors in the UK, because the type of defects that store high levels of energy and can release it over a narrow temperature range are produced and survive at low irradiation temperatures. This effect leads to the storage of an unquantified but potentially large amount of energy within the irradiated graphite structures which is capable of being released if the graphite is exposed to an input of energy. Absence of Wigner energy is very difficult to demonstrate robustly, however this does not necessarily mean it is likely to be released. The mechanistic understanding of Wigner energy and its release are reasonably well documented, and have been the focus of previous work undertaken by RWM (as Nirex) and other nuclear industry organisations. However, the potential initiating events and consequences of Wigner energy release on post-closure performance have only received limited attention.			
Research Driver			
Release of Wigner energy could impact on the post-closure safety case if there was a substantial release of energy that impacted the multi-barrier system and therefore an understanding of the likelihood and consequences of such an event is required.			
Research Objective			
To understand and document the state-of-the-art knowledge on Wigner energy impacts of the operational and post-closure phases of the GDF.			
Scope			
To review and document the necessary steps that would be required for Wigner energy to be released (event tree), establish the inventory of material that may pose a challenge and the broad range of energy that would be released (likelihood). It will also develop a methodology for understanding the consequences of a hypothetical 'what-if' Wigner energy release event. The study into the consequences can be broken down into the following categories: • The release and speciation of radionuclides and non-radiological pollutants from the waste (the source term). • The transport of radionuclides in groundwater (the groundwater pathway). • The transport of radioactive gas and other potential effects of GDF-derived gas on post-closure performance (consequences of gas). • The consequences of inadvertent human intrusion (the human intrusion pathway). • The transport of non-radiological pollutants in groundwater (chemotoxic assessment). • The effect on the engineered barriers and geosphere.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

The output of this task would be a report (or reports) detailing the state-of-the-art knowledge of the likelihood and consequences of a potential Wigner energy release event. It will also detail any future research needs required to underpin the understanding and/or address any identified gaps.					
SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1] 1 Environment Agency, *Wigner energy in irradiated graphite and post-closure safety*, P3—80/TR, 2002. [Online]. Available: https://www.gov.uk/government/publications/wigner-energy-in-irradiated-graphite-and-post-closure-safety.					

B10.5.3 Addressing Identified Gaps to Understand the Potential Impact of Wigner Energy

<table>
<tr><td colspan="2">Task Number</td><td>110.5.003</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Wasteform Evolution</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4">Graphite</td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Graphite irradiated at low temperatures may have Wigner energy associated with it. For clarity, Wigner energy is an effect which arises due to stored energy from defects in the graphite lattice. It is more important for low-temperature graphite irradiation (<~250°C), resulting from the small number of experimental reactors in the UK, because the type of defects that store high levels of energy and can release it over a narrow temperature range are produced and survive at low irradiation temperatures. This effect leads to the storage of an unquantified but potentially large amount of energy within the irradiated graphite structures which is capable of being released if the graphite is exposed to an input of energy. Absence of Wigner energy is very difficult to robustly demonstrate, however this does not necessarily mean it is likely to be released. The mechanistic understanding of Wigner energy and its release are reasonably well documented, and have been the focus of previous work undertaken by RWM (as Nirex) and other nuclear industry organisations. The potential initiating events and consequences of Wigner energy release on post-closure performance will have been documented as part of Task 110.5.002, and this task aims to complete any identified research gaps.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">Release of Wigner energy could impact on the post-closure safety case and therefore an understanding of the likelihood and consequences of such an event is required.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To complete any identified work to address identified research gaps from Task 110.5.002 to underpin the knowledge of the impacts of potential Wigner energy release on post-closure performance.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The exact scope of this task will be developed as part of Task 110.5.002.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">The output of this task will be determined by the scope developed as part of Task 110.5.002.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 5</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">This task will only be required if Task 110.5.002 identifies a need to perform further work. There are other publications relevant to this task [1].
1 Environment Agency, Wigner energy in irradiated graphite and post-closure safety, P3—80/TR, 2002. [Online]. Available: https://www.gov.uk/government/publications/wigner-energy-in-irradiated-graphite-and-post-closure-safety.</td></tr>
</table>

B11 WBS 210 - Social Science

In collaboration with participating communities RWM aims to develop an approach to measuring and tracking community well-being (Task 210.001) during the GDF siting process and subsequent GDF implementation. Further tasks may be developed in collaboration once community partnerships are formed.

B11.1 Assessing Community Well-being

<table>
<tr><td colspan="2">Task Number</td><td>210.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Social Science</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Both Government policy and RWM’s proposals for implementing geological disposal aim to improve the well-being of communities participating in the GDF siting process and to support sustainable community development. However, concepts such as ‘well-being’ and ‘sustainable community development’ are difficult to define and measure. Several different approaches to measuring community well-being have been developed over recent years. Examples include the Happy City Index, What Works Well-being, Well-being Wales, the Well-being Resilience Measure, the Wheel of Well-being and the Co-op Community Well-being Index. Drawing on such approaches, RWM is aiming to develop an approach to assessing and tracking community well-being during the GDF siting process.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support community engagement during the GDF siting process RWM needs to demonstrate how GDF implementation can improve community well-being and support sustainable community development.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">In collaboration with participating communities, develop an approach to measuring and tracking community well-being during the GDF siting process and subsequent GDF implementation.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Review different approaches which have been used to measure community well-being and evaluate their relative success in supporting project implementation, effective community engagement and demonstrating positive outcomes. Consider the applicability of these approaches to GDF implementation and develop a tailored approach to assessing and tracking community well-being in collaboration with participating communities.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task
Periodic literature reviews of different approaches to assessing community well-being.
Test reports assessing the applicability of these different approaches to the GDF siting process.
Proposals for tailored approaches in a specific community (or communities).</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 3-4</td><td>SRL/TRL at Task End</td><td>SRL 5</td><td>Target SRL/TRL</td><td>SRL 5</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B12 WBS 220 - Environmental Safety Case (ESC)

The generic Environmental Safety Case will be maintained until RWM has sufficient confidence in site-specific safety cases and decides that generic work is no longer necessary. Therefore, generic work will be progressed up until the point at which site-specific safety reports are produced. The generic work comprises the following areas:

- Post-Closure Safety Production **(WBS 220.1)**
- Operational Environmental Safety Assessment **(WBS 220.2)**

WBS 220.1 will further develop and document RWM's environmental safety case capability through the creation of improved arguments and methodologies (220.1.001-220.1.003). Within **WBS 220.2**, RWM's will develop its capability to undertake comprehensive numerical assessments of post-closure safety, with appropriate assessment methodologies and models available and incorporating aqueous and gaseous pathways, non-radiological contaminants, environmental radioactivity and human intrusion scenarios (220.2.001). These models can be used for research purposes and as a basis for further development as site-specific models are required. These models will be coupled to data produced by groundwater flow models, with a full consideration of uncertainty and correlation between geological layers in doing so. **WBS 220.2** will outline the tasks needed for the future development of the generic and future site-specific OESAs during the period between now and the application for a nuclear site licence (220.2.001).

B12.1 WBS 220.1 - Post-closure Safety Production

B12.1.1 Understanding the Implications of Voidage for the Disposal System Safety Case

Task Number	220.1.001	**Status**	Ongoing
WBS Level 4	Environmental Safety Case		
WBS Level 5	Post-closure Safety Production		
Background			
The illustrative disposal concept for ILW in higher strength rock requires the backfilling of disposal vaults with an ultra-high pH cement, such as the Nirex Reference Vault Backfill, so as to provide conditions which minimise the mobility of radionuclides; this is termed the chemical barrier. RWM recognises that some degree of voidage within a GDF is inevitable and could be present, for example, through the inclusion of waste packages containing voidage, decisions regarding the disposal concept design and the practicalities of backfilling. Recent waste packaging proposals for non-encapsulated wastes have highlighted the potential for the introduction of larger amounts of in-package voidage in a GDF than previously considered. This has led to the need to develop and substantiate appropriate safety arguments in order to ascertain the implications of introducing such voidage within a GDF. The aim of this task is to provide guidance to waste producers regarding the maximum allowable voidage within waste packages. The outputs of Task 30.1.008 and Task 100.1.019 will support the progress of this task.			
Research Driver			
To support the Disposability Assessment process by determining whether it is possible, or not, to provide guidance on acceptable levels of voidage within waste packages and within the GDF near-field with respect to post-closure safety in the absence of site-specific information.			
Research Objective			
To consider and develop safety arguments in relation to voidage to inform RWM decision making related to concept option selection, waste packaging guidance and safety case development.			
Scope			
To produce a clear summary of RWM's position on voidage by: • Undertaking a focussed literature review of the conceptualised mechanical, hydrogeological, and possibly, chemical evolution of a GDF; • Further developing, and subsequently assessing, RWM's conceptual models of the mechanical evolution of a GDF (also considering other coupled thermal, hydrogeological and chemical processes), for the illustrative host rocks and concepts considered by RWM; • Developing safety arguments for relevant evolution scenarios and determining the limitations of what can be meaningfully inferred on the topic of voidage at a generic stage; and • If necessary, undertaking a simple analysis to determine the practicalities and implications (safety and indicative costs) of void-filling of packages prior to disposal in a GDF but after they have been packaged by waste producers.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

The output of the task will result in a contractor approved report.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 5
Further Information					
There are several publications relevant to this task [1]–[3].					

1 G. Towler, T. Baldwin, A. Paulley, and J. Wilson, *An Initial Evaluation of the Nature and Amount of Voidage Associated with an ILW GDF*, ASSIST, Contractor Report ASSIST-1547B-R1, 2012.

2 *Managing voidage in a GDF - towards a methodology for evaluating voidage in waste packaging proposals*, Quintessa, Galson, Geo-Design, Nucleus and Orchid, Contractor Report QRS-1698F-R1-V3, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/managing-voidage-in-a-gdf-towards-a-methodology-for-evaluating-voidage-in-waste-packaging-proposals/.

3 G. Towler, S. Watson, T. Hicks, J. Hunter, R. Shaw, A. Paulley, J. Penfold, A. Bond, J. Wilson, and C. Jones, *Implications of voidage for post-closure safety of a GDF*, Quintessa, Contractor Report QRS_1698A-1, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/implications-of-voidage-for-post-closure-safety-of-a-gdf/.

B12.1.2 Total System Model Development

Task Number	220.1.002	Status	Ongoing
WBS Level 4	Environmental Safety Case		
WBS Level 5	Post-closure Safety Production		

Background

In the post-closure safety case the risk to future populations from the groundwater pathway is carried out by a probabilistic Total System Model which comprises representation of the packages, wasteforms, engineered barrier systems, geosphere and biosphere, with uncertainty explicitly included by means of parameters being assigned probability density functions (PDFs) representing the uncertainty in each value. Such a model was produced for the 2016 Environmental Safety Case for GDFs for LHGW and HHGW in HSR and LSSR. This model, whilst wholly appropriate for calculating illustrative results for the current ESC, has some shortcomings and limitations, some of which came to light when an attempt was made to use the model to compute concentrations on non-radiological contaminants.

Research Driver

At the outset of developing a site-specific ESC, RWM needs to have available a consistent set of Total System Models that are fully capable of producing a range of required outputs such as risk in the biosphere, and non-radiological impacts at a range of points in the geosphere.

Research Objective

To develop a consistent set of Total System Models that can be used for research purposes and as a basis for further development as site-specific models are required, to inform research activates in the meantime and to form the basis of models used for a future ESC. These models will be coupled to data produced by groundwater flow models with a full consideration of uncertainty and correlation between geological layers in doing so.

Scope

The envisaged scope of the task is as follows:

- Agreement on which pathways in the base scenario and relevant variant scenarios the model needs to cover.
- Production of Model Risk Assessment and Quality Plan, in line with RWM's quality management system's requirements.
- Development of conceptual model and representation of geology(ies).
- Agree approach to data input.
- Model development.
- User interface for research application, and script interface for assessment application.
- Checking and verification.
- Report production.

Geology Application

HSR, LSSR, evaporite

Output of Task

New GoldSim Total System Model(s) and associated reports.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 5	**Target SRL/TRL**	SRL 6
Further Information					

B12.1.3 Post Closure Safety Assessment Development

Task Number	220.1.003	**Status**	Ongoing
WBS Level 4	Environmental Safety Case		
WBS Level 5	Post-Closure Safety Production		

Background

A UK GDF will only be built if RWM can demonstrate that members of the public and the surrounding environment will be adequately protected, both at the time of waste disposal and in the long term (hundreds of thousands of years) after disposal facility closure. This demonstration will be documented through an ESC. ESCs will be produced to support applications for environmental permits as development of the disposal facility progresses. Each ESC will consider environmental safety during both the operational period of a GDF and after closure of that facility. During the post-closure period assessments will be carried out to demonstrate that the GDF is consistent with the environmental safety principles and requirements set out in the regulators' guidance [1]. An understanding of the initial state of the GDF system, together with the processes which may lead to its evolution (as derived through RWM's site characterisation, engineering and research programmes), are key to this and must be carried out with an appropriate management of uncertainty, to ensure the safety case is robust. A separate task sheet considers environmental safety during the operational period.

Research Driver

The 2016 gDSSC considered all of the GRA requirements, but both safety arguments and numerical assessments against the various radiological and technical requirements are at different stages of technical maturity. Illustrative calculations were presented to assess the potential impact of radiological contaminants in groundwater, gas generation and migration, and work on the likelihood and consequence of criticality, with scoping calculations or qualitative arguments presented for the potential impacts of future unintentional human intrusion and the impact of non-radiological contaminants in groundwater. As the process to identify and investigate potential GDF sites progresses, RWM will need to develop its capability to undertake comprehensive assessments of post-closure safety, with appropriate assessment methodologies and models available.

Research Objective

This task will further develop and document RWM's PCSA capability through the creation of improved methodologies, models, data and understanding, ensuring this knowledge is embedded in RWM's safety case team and its supply chain.

Scope

This PCSA development task will be split into a number of activities, which will be informed by the scenario identification work carried out under the ESC Development S&T task (Task 220.1.001):

- Groundwater flow modelling – this activity will develop three-dimensional groundwater flow and radionuclide transport models for the illustrative disposal concepts and generic geological environments considered in the 2016 gDSSC. Results will be abstracted from these models for use in RWM's total system Performance Assessment models to explore significance with a full treatment of uncertainty.
- Assess non-radiological contaminants – this activity will build upon the work of the non-radiological contaminants Integrated Project (see Task 10.5.002) to develop a comprehensive approach to assessing the hazard associated with non-radiological contaminants in radioactive waste.

- Gas pathway – this activity will develop an approach to assessing base and variant scenarios in the gas phase. It is composed of the following subcomponents:
  - Develop understanding of the uncertainties in gas generation;
  - Develop a treatment for gas generation that takes account of the identified uncertainties, potentially based on the existing SMOGG process model for gas generation; and
  - Review existing models for gas migration in illustrative environments (building upon work in the Gas and Geosphere research areas - task sheets starting at Task 40.1.001 and 50.001 onwards, respectively), with the view of assessing whether these need updating and how they might be applied in a site-specific scenario.

  At the current generic stage, for safety case performance assessment, the migration of gas will be treated using a series of scenarios for release area and migration time informed by the review of the models of gas migration in illustrative environments.

- Human intrusion – this activity will develop a methodology based on that developed in the IAEA Hydra project, for assessing human intrusion, including any data and models needed to perform illustrative calculations.

- Environmental radioactivity – this activity will build upon the work in the Biosphere research area (task sheets Task 10.1.001 to Task 10.8.001) to develop a methodology for assessing the impacts of environmental radioactivity (i.e. the radiological effects of a disposal facility on the accessible environment as described in Requirement R9 of the GRA [1]) to humans, non-human biota and the environment after GDF closure.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Outputs of activities will be captured in RWM reports or technical notes and integrated into RWM's safety case management system VISI. Associated guidance, procedures, documentation and code will be produced as needed.

SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A

Further Information

For further information see the HIDRA website [2].

1 Environment Agency and Northern Ireland Environment Agency, *Geological disposal facilities on land for solid radioactive wastes: Guidance on requirements for authorisation*, Regulation, Feb. 2009.

2 *HIDRA website*. [Online]. Available: https://www.iaea.org/topics/disposal/human-intrusion-in-the-context-of-disposal-of-radioactive-waste-hidra.

B12.2 WBS 220.2 - Operational Environment Safety Assessment

B12.2.1 OESA Roadmap

<table>
<tr><td>Task Number</td><td>220.2.001</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Environmental Safety Case</td></tr>
<tr><td>WBS Level 5</td><td colspan="3">Operational Environment Safety Assessment</td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">The gOESA [1] was published in 2016 as part of the 2016 gDSSC. Its main focus was a quantitative assessment of doses to humans and non-human biota from aerial discharge of any significant radioactive gases during the operational period. Other potential environmental impacts, such as those from non-radioactive releases, radioactive liquid and solid releases were assessed qualitatively, considered in the generic Environmental Assessment report [2], or justifiably excluded. The EA and ONR reviewed the 2016 gOESA.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">To meet RWM's needs as the primary user and address regulatory actions relevant to the gOESA.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To set out the tasks needed for the future development of the generic and future site-specific OESAs during the period between now and the application for a nuclear site licence.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">To define a work programme comprising three sequential groups of tasks: Scoping and Enabling tasks, Planning tasks and Assessment tasks. The titles below represent the tasks currently identified. Planning tasks will be informed by the Scoping and Enabling tasks and therefore may change as earlier tasks are completed. In the meantime they represent the current expectation of the topics that will need to be addressed. Assessment tasks will be informed by planning tasks following an integration task. At this stage, they have not yet been defined.
Scoping and Enabling Tasks:
• Gather user and permitting requirements.
• Develop Claim-Argument-Evidence thread.
• Develop internal competence.
• Update modelling approach (see Task 10.1.002).
Planning Tasks:
• Define approach to assessment of LSSR and Evaporite illustrative designs.
• Define updated baseline and variant scenarios.
• Develop strategy for assessing effects of non-radiological pollutants.
• Define approach for input into disposability assessments.
• Define approach to assessing fault conditions and external hazards
• Define approach for assessing dose from liquid discharges.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
</table>

<table>
<tr><td colspan="6">An OESA Roadmap will lay out a series of tasks required to address regulatory issues and RWM's own needs in operational environmental safety. Work on Scoping and Enabling tasks and Planning tasks will take place into 2022. During this time, the roadmap will continue to be updated to reflect changes to the tasks and scope. By the end of FY 2021/2022, an integration task will collate the outputs of the planning tasks and determine how they will inform the assessments needed for input into safety reports at each stage towards the eventual licensing of a GDF.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>N/A</td><td>SRL/TRL at Task End</td><td>N/A</td><td>Target SRL/TRL</td><td>N/A</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">1 Radioactive Waste Management, Geological Disposal: Generic Operational Environmental Safety Assessment, RWM Report DSSC/315/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-operational-environmental-safety-assessment/.
2 Radioactive Waste Management, Geological disposal: Generic environmental assessment report, RWM Report DSSC/331/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-environmental-assessment-report/.</td></tr>
</table>

B12.3 Environmental Safety Case Development

Task Number	220.001	**Status**	Ongoing
WBS Level 4	Environmental Safety Case		
WBS Level 5			

Background

A UK GDF will only be built if RWM can demonstrate that members of the public and the surrounding environment will be adequately protected, both at the time of waste disposal and in the long term (hundreds of thousands of years) after disposal facility closure. This demonstration will be documented through an Environmental Safety Case. ESCs will be produced to support applications for environmental permits as development of the disposal facility progresses.The ESCs will present a series of claims about the environmental safety of geological disposal in the context of the environmental safety principles and requirements set out in the regulators' Guidance on Requirements for Authorisation of geological disposal facilities for radioactive wastes [1]. The environmental safety claims will be justified by environmental safety arguments linked to underpinning scientific evidence, relating to how the barrier system will contain potential contaminants (radiological and non-radiological), preventing them from reaching the accessible environment in harmful quantities.

Research Driver

The 2016 generic [2] considered all of the GRA requirements, but both safety arguments and numerical assessments against the various radiological and technical requirements are at different stages of technical maturity. As the process to identify and investigate potential GDF sites progresses, RWM will need to develop its capability to undertake comprehensive assessments of environmental safety, with appropriate assessment methodologies and models available. Prior to that, ISEs will be required in support of applications for the drilling of boreholes in the site characterisation phase and will need to include a description of how an ESC might be constructed for the potential disposal site(s). This will include key safety claims and information to support assurances that proposed intrusive investigations will not have unacceptable impacts on the environmental safety of the site.

Research Objective

This task will further develop and document RWM's environmental safety case capability through the creation of improved arguments and methodologies, ensuring this knowledge is embedded in RWM's safety case team and its supply chain.

Scope

This ESC development task will be split into a number of activities:

- Claims, Arguments, Evidence collation – this activity will review RWM's knowledge base and systematically document the Claims, Arguments and Evidence which may be used to underpin its environmental safety case, during both the operational and post-closure periods.
- Scenario identification methodology – this activity will update RWM's existing methodology for scenario identification and apply this, using the NEA's latest international Feature, Event and Process list, to the 2016 gDSSC disposal concepts (HHGW and LHGW) and host environments (LSSR, HSR and evaporite), leading to a set (base and variants) of scenarios for assessment.
- Alternative inventories and disposal concepts – this activity will extend the outputs of the scenario identification activity to explore sensitivity by considering alternative inventories and disposal concepts (i.e. outside the illustrative concepts in the 2016 gDSSC), again leading to a set of scenarios for assessment.

<table>
<tr><td colspan="6">

- Updating the ESC – this activity will continue the development of RWM's digital safety case management system (VISI) and update its content (including associated procedures and the Environmental Safety Manual) in light of the output from the activities above and those elsewhere in the S&T plan.
- Updating the waste package post-closure safety assessment – this activity will update the waste package post-closure safety assessment as part of RWM's Disposability Assessment process in light of the output from the activities above and those elsewhere in the S&T plan.

This task will be supported by the modelling and assessment activities described in the 'Post-closure Safety Assessment' task sheet (Task 220.2.001) and 'Operational Environmental Safety Assessment' task sheet (220.2.001).</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSR, HSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Outputs of activities will be captured in RWM reports or technical notes and integrated into RWM's safety case management system VISI. Associated guidance, procedures, documentation and code will be produced as needed.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>N/A</td><td>SRL/TRL at Task End</td><td>N/A</td><td>Target SRL/TRL</td><td>N/A</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">

1 Environment Agency and Northern Ireland Environment Agency, *Geological disposal facilities on land for solid radioactive wastes: Guidance on requirements for authorisation*, Regulation, Feb. 2009.

2 Radioactive Waste Management, *Geological disposal: Generic environmental safety case - main report*, RWM Report DSSC/203/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-environmental-safety-case-main-report/.

</td></tr>
</table>

B13 WBS 310 - Concept Options and Alternatives

The Concepts Integrated Project concluded in 2017 and further work is being progressed addressing the outcomes [2]. Maintaining and further developing the range of geological disposal concept options will allow RWM to select and develop appropriate concepts for the UK wastes requiring disposal when the geological environment for the GDF is known.

- To develop an underpinned range of packaging solutions and associated geological disposal concept options suitable for materials including MoD irradiated fuel.
- To develop our understanding of the constraints and opportunities presented by less mature disposal concepts such as the use of silos in horizontally space-constrained rock formations and construction of engineered barriers off-site and in alternative geographical locations.
- To keep alternatives in radioactive waste management under review, including alternatives to geological disposal.
- To maintain a watching brief on national and international developments in alternative radioactive waste management options, including those that may influence the nature and quantity of waste requiring geological disposal.

B13.1 Develop Disposal Options for MoD Irradiated Fuel

Task Number	310.001	**Status**	Start date in future
WBS Level 4	Concept Options and Alternatives		
WBS Level 5			
Background			
A geological disposal concept is the EBS and its geometry (layout) required to deliver the safety functions and requirements defined in the DSS in a particular geological environment. A geological disposal concept is developed for a particular inventory or a particular type or group of waste and geological setting. A GDF for all UK higher activity waste will combine a number of geological disposal concepts for specific types of waste and will function as one integrated system. A key feature of a geological disposal concept is that it must be tailored to site-specific characteristics. Disposability advice has been requested by the Ministry of Defence to support the strategy for long-term management of its irradiated fuel. This task comprises the assessment of disposal concepts against these materials so as to support RWM's advice and evaluation to the MoD in the development of potential conditioning and packaging solutions for them.			
Research Driver			
To support the waste disposability assessment process by developing an underpinned range of packaging solutions and associated geological disposal concept options suitable for materials including MoD irradiated fuel.			
Research Objective • To develop a geological disposal concept description for the MoD irradiated fuel that may require geological disposal to a sufficient level to understand the constraints and potential benefits of the existing concepts. • To identify what issues must be addressed to achieve operational and post-closure safety for this defined waste group in our three generic host geological environments and other environments currently under investigation utilising existing concepts. • To ensure that the parameters that might be used in Level 2 specifications take account of any disposal concept that could be suitable for implementation in the UK. • To specify any geological environments that would be unsuitable for this concept.			
Scope • To identify what issues must be addressed to achieve operational and post-closure safety for this defined waste group in our three generic host geological environments and other environments currently under investigation utilising existing concepts. • To ensure that the parameters that might be used in Level 2 specifications take account of any disposal concept that could be suitable for implementation in the UK. • To specify any geological environments that would be unsuitable for this concept. • Development of bounding parameters underpinning a Level 2 waste packaging specification.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

Update to Concept Status Report and identification of further research and development required to address issues identified.					
SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 3	**Target SRL/TRL**	TRL 9
Further Information					
For further information, see the Concept Status Report [1].					

1 Radioactive Waste Management, *Geological disposal: Concept status report*, RWM Report NDA/RWM/155 Issue 1, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-concept-status-report/.

B13.2 Further Develop Understanding of Disposal Concept Options

Task Number		310.002	**Status**	Ongoing	
WBS Level 4		Concept Options and Alternatives			
WBS Level 5					
Background					
A geological disposal concept is the engineered barrier system and its geometry (layout) required to deliver the safety functions and requirements defined in the disposal system specification, in a particular geological environment. A geological disposal concept is developed for a particular inventory or a particular type or group of waste and geological setting. A geological disposal facility for all UK higher activity waste will combine a number of geological disposal concepts for specific types of waste and function as one integrated system. A key feature of a geological disposal concept is that it must be tailored to site-specific characteristics. Having developed concepts for three rock types assuming an onshore disposal facility using traditional construction methods a need has been identified to better understand the constraints and opportunities presented by alternative siting concepts such as: off-site construction of engineered barriers (referred to as super-containers); concepts permitting use of a site which is constrained in size horizontally but provides vertical space (silos) or utilising a coastal site.					
Research Driver					
To support the GDF siting process and the provision of packaging advice for all waste groups in the inventory that may require geological disposal.					
Research Objective					
The development of our understanding of the constraints and opportunities presented by less mature disposal concepts such as the use of silos in horizontally space constrained rock formations, construction of engineered barriers offsite and in alternative geographical locations.					
Scope					
Factors requiring consideration include: review of international precedent, identification of engineered barrier systems and their associated operational and post-closure safety functions, engineering practicality and layout, criticality safety, thermal impacts, radiological impacts, operational safety, cost-estimation and scheduling and environmental impacts. The output of this task will be an update to the Concept Status Report [1] that describes the range of disposal concepts.					
Geology Application					
HSR, LSSR and Evaporite.					
Output of Task					
The output of the task will result in an update to Concept Status Report.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					
1 Radioactive Waste Management, *Geological disposal: Concept status report*, RWM Report NDA/RWM/155 Issue 1, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-concept-status-report/.					

B13.3 Review of Alternative Waste Management Options (Watching Brief)

Task Number	310.003	**Status**	Ongoing
WBS Level 4	Concept Options and Alternatives		
WBS Level 5			
Background			
Government policy for the management of radioactive waste in the long-term is through geological disposal as described in its policy document was published in 2018 [1]. Meanwhile, safe and secure interim storage is maintained as ongoing R&D supports the optimised implementation of the geological disposal solution. The policy document also notes that for some wastes other long-term management options could emerge as practical alternatives to geological disposal in the future. The NDA and RWM will therefore continue to review alternative solutions that may be appropriate for UK wastes by learning from, and engaging with, overseas programmes. This task supports RWM's commitment to monitor alternatives to geological disposal.			
Research Driver			
In support of Government policy, RWM needs to periodically review alternative radioactive waste management options to report relevant developments and, as required, align with specific activities or decision points in the GDF siting process.			
Research Objective			
To keep alternatives in radioactive waste management under review, including alternatives to geological disposal.			
Scope			
The scope will address the following aspects: • Identification and explanation of recent, relevant developments in radioactive waste management options. • Explanation of the significance of these developments for the UK inventory of Higher Activity Waste. • Discussion of any developments that merit more detailed attention. • The findings from RWM's reviews of options will be published periodically; these publications will provide the basis for communicating developments in radioactive waste management options with Government and stakeholders. If an alternative disposal option is identified as sufficiently developed that the option potentially requires consideration relative to geological disposal, then RWM will provide this information to Government. It will then be the responsibility of Government to take such a decision and make any necessary changes to policy. The scope of RWM's review of alternatives to geological disposal (recognising that many of these alternatives do not offer complete solutions) includes the following: • Long-term interim storage options (although research and consideration of interim storage prior to waste disposal is the responsibility of the wider NDA and nuclear site operators). • Waste treatment techniques (e.g. partitioning and transmutation). • Near-surface disposal (tens of metres to around 150 metres deep) for short-lived waste. • Deep borehole disposal.			
Geology Application			
N/A			

Output of Task					
The output of the task will result in a published Alternative Disposal Concepts Report.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					

Note: RWM's methods for keeping waste management options under review are:

- reviews of technology and status updates for specific options;
- dialogue with the wider NDA and nuclear site operators on developments in disposal options, waste management options, technologies and solutions. This includes engagement through the Direct Research Portfolio programme, through the disposability assessment process and through participation in the Nuclear Waste Decommissioning Research Forum;
- discussions with overseas waste management organisations, facilitated by the NDA's bilateral agreements with such organisations and participation in international initiatives;
- participation in international expert groups, studies and reviews; and
- participation in targeted international conferences.

There are other publications relevant to this task [2].

1 BEIS, *Implementing geological disposal - working with communities*, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766643/Implementing_Geological_Disposal_-_Working_with_Communities.pdf.

2 *Geological disposal: Review of alternative radioactive waste management options*, 2017.

B14 WBS 320 - Waste Inventory Characterisation

RWM maintains and further develops the UK's Inventory for Geological Disposal and this provides a key input to understanding UK-viable disposal concepts that form a planning basis for the GDF with sufficient flexibility to accommodate the inventory for geological disposal in a range of prospective geological environments.

B14.1 Further Development of the Inventory for Geological Disposal

<table>
<tr><td colspan="2">Task Number</td><td>320.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Waste Inventory Characterisation</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Quantified estimates of the inventory for geological disposal are needed to support development of the geological disposal system for the UK’s higher activity radioactive wastes. The UK Radioactive Waste Inventory provides the basis for these estimates and contains an extensive amount of data. These data require some modification or enhancement before they can be used in RWM’s generic designs and safety assessments. An Inventory for Geological Disposal has therefore been developed from the UKRWI to provide the required dataset. This task involves further development of the methodologies and tools used to prepare the Inventory for Geological Disposal to ensure it remains fit for purpose, and to improve and expand the data as required by RWM’s designs and safety assessments (e.g. addition of data on non-radiological species).</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To support disposal system development and communication of inventory to stakeholders.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To maintain and further develop the Inventory for Geological Disposal.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope of this task will include the following:
Maintenance of the methodology and tools used to prepare the Inventory for Geological Disposal.
Ongoing review of the nuclear data used to support the Inventory for Geological Disposal.
Reducing the inventory uncertainty in priority areas based on feedback from the generic DSSC and future site-specific safety case development, as well as from waste packaging disposability assessments.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">N/A</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Up-to-date Inventory for Geological Disposal</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>N/A</td><td>SRL/TRL at Task End</td><td>N/A</td><td>Target SRL/TRL</td><td>N/A</td></tr>
</table>

Further Information
There are several publications relevant to this task [1]–[4].

1 Radioactive Waste Management, *2016 inventory for geological disposal - main report*, RWM Report DSSC/403/02, 2018. [Online]. Available: https://www.gov.uk/government/publications/2016-inventory-for-geological-disposal.

2 Radioactive Waste Management, *Inventory for geological disposal: Method report*, RWM Report DSSC/405/01, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/835815/Inventory_for_geological_disposal_Proof_Method_report_a.pdf.

3 Radioactive Waste Management, *Inventory for geological disposal: Differences report*, RWM Report DSSC/406/01, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/835816/Inventory_for_geological_disposal_differences_report_a.pdf.

4 Radioactive Waste Management, *Inventory for geological disposal: Implications of the 2016 IGD for the generic Disposal System Safety Case*, RWM Report DSSC/407/01, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/835818/Implications_of_the_2016_Inventory_for_geological_disposal_for_the_generic_Disposal_System_Safety_Case_a.pdf.

B15 WBS 410 - Sub-surface Facilities Design and Operational Safety

Early tasks focus on further developing confidence and capability following previous proof of feasibility work that enabled the generic DSSC. Tasks relate to the following objectives:

- To maintain and develop understanding of nuclear safeguards technology and techniques (Task 410.001) to geological disposal facilities enable the efficient application of nuclear safeguards to the design, operation and closure of a GDF.
- To provide continued confidence in the feasibility to construct, operate, maintain, backfill and close disposal vaults and tunnels (Task 410.003) as well as to inform site-specific design decision-making.
- To understand the package handling and throughput capacity (Task 410.004), including any associated activities, for a GDF in different host geological environments and to understand the impacts on the operational programme.
- To investigate the potential provided by the adoption of digital twins (Task 410.005) within the GDF siting process to facilitate improved communication and public/stakeholder confidence.
- To develop LHGW and HHGW disposal concept options applicable to a UK evaporite context (Task 410.006) in order to provide support to site selection.
- To develop RWM's capability to deliver safety-integrated conceptual designs (Task 410.006-Task 410.008); testing RWM's procedures to give confidence that site-specific conceptual designs can be developed efficiently once site(s) for a GDF are identified.
- To develop understanding of the potential post-closure safety impacts of construction materials (Task 410.009) to inform site-specific design decisions.

B15.1 Watching Brief on Technology and Techniques for Safeguards Verification

Task Number	410.001	**Status**	Ongoing
WBS Level 4	Sub-surface Facilities Design and Operational Safety		
WBS Level 5			

Background

Nuclear safeguards are measures to verify that countries comply with their international obligations to use nuclear materials (plutonium, uranium and thorium) from their civil nuclear programmes for peaceful uses. These measures will apply to the disposal of safeguarded material within the GDF. Work is continuing internationally on the application of safeguards to GDFs. As in other areas of safeguards, the technology and techniques that are used to verify the contents of waste packages, the as-built condition of facilities and to detect attempted diversion are subject to continued development.

Research Driver

To maintain and develop understanding of technology and techniques for the application of nuclear safeguards to geological disposal facilities with input of this knowledge and understanding into:

- The development of RWM's approach to safeguards and discussions with key stakeholders; and
- Application of knowledge to inform the design, operation and closure of the GDF.

Research Objective

To ensure that techniques and technology are available for the efficient application of nuclear safeguards to the design, operation and closure of the GDF.

Scope

To maintain an understanding of available data acquisition techniques through liaison with ONR Safeguards, Euratom, overseas sister organisations and involvement in international fora such as the IAEA expert group on the Application of Safeguards to Geological Repositories.

Geology Application

HSR, LSSR and Evaporite.

Output of Task

The task will ensure that the principles of Safeguards by Design are built into the GDF programme. This will include liaising with all key stakeholders, both national and international, in order to ensure that their requirements are captured and managed via the overall GDF Requirements Management Framework.

SRL/TRL at Task Start	SRL 4	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6

Further Information

There are other publications relevant to this task [1].

1 International Atomic Energy Agency, *Technological Implications of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste*, NW-T-1.21, 2010. [Online]. Available: https://www.iaea.org/publications/8185/technological-implications-of-international-safeguards-for-geological-disposal-of-spent-fuel-and-radioactive-waste.

B15.2 Geological Disposal Facility (GDF) Utilities and Services

Task Number	410.002	**Status**	Ongoing
WBS Level 4	Sub-Surface Facilities Design and Operational Safety		
WBS Level 5			
Background			
At the current generic phase of work RWM has developed illustrative engineering designs for a geological disposal facility and its key elements and facilities based on mature, overseas disposal concepts. These designs enable planning and also demonstrate the feasibility to construct, operate and maintain a geological disposal facility within three typical UK geological environments, namely; higher strength rock, lower strength sedimentary rock and evaporite. At present, in our illustrative designs we consider the use of typical utilities and services that have been used in the overseas disposal concepts and other similar non-nuclear facilities.			
Research Driver			
Understand the utilities and services for a geological disposal facility in different host geological environments.			
Research Objective			
To provide continued confidence in the feasibility to construct, operate and maintain the utilities and services for a geological disposal facility.			
Scope			
The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon. The task comprises a series of work packages, including to: • evaluate the use of new/novel transfer systems, for the movement of goods that could be modified for use at a geological disposal facility to transport construction materials to a GDF and to export excavated spoil out of a GDF; • demonstrate the feasibility of the nuclear ventilation system required for the waste emplacement ventilation circuit, noting the requirements to manage gas and temperature, fire suppression systems, security and safe operations; • assess how the volumes of water that could arise from both the host rock and from construction and operation activities could be managed and treated. This objective is linked to Task 164; • produce an integrated waste strategy for the GDF and identify how secondary wastes (including both nuclear and non-nuclear) should be managed; and • consider the examination, inspection, maintenance and testing needed to demonstrate that the utilities and services fulfil their safety functions. These work packages will comprise desk based studies, often supported by calculation studies. The output of the work packages feeds into update of the generic disposal facility designs.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

An update to the generic disposal facility designs.					
SRL/TRL at Task Start	TRL 4	**SRL/TRL at Task End**	TRL 5	**Target SRL/TRL**	TRL 5
Further Information					
There are other publications relevant to this report [1]. 1 Radioactive Waste Management, *Geological Disposal: Generic Disposal Facility Designs*, RWM Report DSSC/412/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-disposal-facility-designs/.					

B15.3 Geological Disposal Facility (GDF) Disposal Vault and Tunnel Design

Task Number	410.003	**Status**	Ongoing
WBS Level 4	Sub-surface Facilities Design and Operational Safety		
WBS Level 5			

Background

At the current generic phase of work, RWM has developed illustrative engineering designs for a GDF and its key elements and facilities based on mature, overseas disposal concepts. These illustrative designs demonstrate that it is feasible and safe to handle and emplace waste packages within underground excavations using currently available technologies, and then backfill, seal and close the disposal vaults or tunnels. As RWM moves into a site-specific phase of work with feasibility studies and site-specific designs developed, RWM will need to further understand appropriate technologies and increase its technical readiness with respect to the disposal vault and disposal tunnel systems.

Research Driver

Demonstrate the feasibility and develop site-specific engineering designs of disposal vaults and tunnels suitable for disposal of various radioactive wastes and package types.

Research Objective

To provide continued confidence in the feasibility to construct, operate, maintain, backfill and close disposal vaults and tunnels as well as inform site-specific design decision making.

Scope

The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, identification of new and emerging technologies, changes to regulatory requirements and learning from external events. The task scope comprises the following:

- Feasibility of constructing underground spaces (e.g. disposal vaults and tunnels) in a particular site-specific context. Optioneering studies considering the requirements, constraints, construction hazards and available technologies for excavation and support;
- Feasibility of subsurface handling arrangements for waste packages in a particular site-specific context. Optioneering studies considering the requirements, constraints, interfaces with other systems, operational hazards, inspection and maintenance and handling technology development;
- Feasibility of backfilling, sealing and closure of disposal tunnels and vaults in a particular site-specific context. Optioneering studies considering the requirements, constraints, timing of backfilling, interfaces with other systems, hazards and backfill material technology development.
- System development for subsurface disposal spaces. Understanding of the system context for these elements e.g. requirements, interfaces with other systems, system hierarchy.

Geology Application

HSR, LSSR, Evaporite

Output of Task

- Feasibility studies for construction and operation of sub-surface disposal systems.

• Structured requirements sets and systems architecture for sub-surface disposal systems. • Site-specific design outputs for sub-surface disposal systems including models, process flow diagrams and calculations at a conceptual level of detail.					
SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 4	**Target SRL/TRL**	TRL 4
Further Information					
There are other publications relevant to this task [1]. 1 Nuclear Decommissioning Authority, *Geological disposal: Generic disposal facility designs*, NDA Report NDA/RWMD/048, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-disposal-facility-designs-december-2010/.					

B15.4 Geological Disposal Facility (GDF) Package Handling and Transfer

Task Number	410.004	**Status**	Ongoing
WBS Level 4	Sub-surface Facilities Design and Operational Safety		
WBS Level 5			
Background			
At the current generic phase of work RWM has developed illustrative engineering designs for a GDF based on mature, overseas disposal concepts. These designs enable planning and also demonstrate the feasibility to construct, operate and maintain a GDF within three typical UK geological environments, namely: HSR, LSSR and evaporite. The current illustrative designs and operational programme are underpinned by a number of assumptions regarding the throughput and emplacement rates for different waste types. For our illustrative designs, these rates are currently consistent with the assumptions used in the overseas disposal concepts, upon which the illustrative designs are based. These activities are on the critical path for the emplacement of waste packages. The drift capacity is assumed to be up to 3,900 journeys per year and this is assumed to be the same for the waste emplacement shaft in an evaporite rock. These rates have been underpinned in previous studies and are consistent across all three host geological environments, but it is necessary to explore the range of assumptions underpinning these rates to ensure that they remain appropriate.			
Research Driver			
To understand the package handling and throughput capacity, including any associated activities, for the GDF in different host geological environments and understand the impacts on the operational programme.			
Research Objective			
To provide continued confidence in the feasibility to operate and maintain the GDF and to meet throughput requirements.			
Scope			
The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon. The task comprises a series of work packages, including: • To review the throughput for the safe unloading and processing of packages in the vault reception area and identify any additional issues relating to different waste package types; and • To consider the examination, inspection, maintenance and testing needed to demonstrate that the package handling an transfer systems fulfill their safety functions. These work packages will comprise desk-based studies, often supported by computational studies. The output of the work packages feeds into update of the generic disposal facility designs.			
Geology Application			
HSR, LSSR, Evaporite			
Output of Task			

The output will be a report detailing an understanding of the package handling and throughput capacity restrictions for the illustrative designs and the impacts on the operational programme for key areas of the facility considered to constrain the programme. This includes arrival at the GDF, preparation for and transfer underground, unpacking (UILW, SILW, HHGW) and emplacement.					
SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 3	**Target SRL/TRL**	TRL 9
Further Information					
There are other publications relevant to this task [1].					

1 Nuclear Decommissioning Authority, *Geological disposal: Generic disposal facility designs*, NDA Report NDA/RWMD/048, 2010. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-disposal-facility-designs-december-2010/.

B15.5 Potential Role Of Digital Twins In Seeking Consensus For GDF Siting

Task Number	410.005	**Status**	Start date in future
WBS Level 4	Sub-surface Facilities Design and Operational Safety		
WBS Level 5			

Background

A new consent-based process for siting a GDF was launched by the UK Government in December 2018. Proposals for the implementation of this process are captured in a revised 'Working with Communities' framework published as part of the launch [1]. This document draws on recent experience in recognising that 'The availability of clear, evidence-based information on both technical issues, and the process of working with communities, will enable communities to engage in the process with more confidence.' Digital twins are being used increasingly by designers to develop what is called "optimised design" of significant infrastructure projects [2]. Digital twins are computational representations of individual physical systems that can be used to inform all phases of a typical plant lifecycle. Scientists and engineers recognise that the successful implementation of virtual reality will require new ways to gather, process and share increasingly large volumes of data.

Research Driver

The adoption of digital twins in the GDF siting process will facilitate improved communication and public/stakeholder/regulator confidence.

Research Objective

- To investigate the potential provided by the adoption of digital twins within the GDF siting process to facilitate improved communication and public/stakeholder confidence.
- To develop an optimal specification for a digital twin of both disposal packages and the GDF environment, outlining parameters to be modelled and how validation could be achieved.
- To explore how existing methods used in other industries might be adapted, or new methodologies developed, for employing the digital twin within the siting process for the GDF.
- To make recommendations on digital twin scope, usage, validation and governance that will improve the potential for a successful outcome from the siting process.

Scope

The research will build on the recent work by Patterson & Taylor [2] and their collaborators on integrated digital frameworks for powerplants. UK Government has launched its new consent-based process for siting a GDF, with RWM identified as the implementor for GDF development, which appears to present the opportunity to develop the current approach and to assess the potential provided by the adoption of an integrated nuclear digital environment in the context of geological disposal. The PhD project will develop a specification for a digital twin of both disposal packages and the GDF design, outlining parameters that could be modelled and how validation could be achieved. Methods for employing the digital twin within the consent-based process as a means to promote stakeholder confidence will also be examined, including options for model ownership/governance, use of virtual/augmented reality to enhance communication and the potential for public accessibility of digital twin information.

Geology Application

HSR, LSSR, Evaporite

Output of Task

A PhD thesis detailing the application of the digital twin concept to RWM's programme.					
SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 4	**Target SRL/TRL**	TRL 9
Further Information					

This PhD will be part of the GREEN Centre for Doctoral Training run out of University of Manchester.

1 BEIS, *Implementing geological disposal - working with communities*, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766643/Implementing_Geological_Disposal_-_Working_with_Communities.pdf.

2 E. Patterson, R. Taylor, and M. Bankhead, *A framework for an integrated nuclear digital environment*. Progress in Nuclear Energy, vol. 87, pp. 997–103, 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0149197015301104#:~:text=%20A%20framework%20for%20an%20integrated%20nuclear%20digital,section%20in%20generic...%204%20Conclusions.%20%20More%20.

B15.6 Improve Understanding of Evaporite Concepts in a UK Context

Task Number	410.006	**Status**	Ongoing
WBS Level 4	Sub-surface Facilities Design and Operational Safety		
WBS Level 5			
Background			
At the current generic phase of work, RWM has defined a limited number of generic geological environments, encompassing typical, potentially suitable UK geologies. RWM has developed illustrative designs for different geological environments (HSR, LSSR and evaporite rock). For the current evaporite host-rock illustrative design for LHGW, the concept for the disposal of transuranic wastes (TRU) (long-lived ILW) in a bedded salt host rock at the WIPP facility in New Mexico was selected because of the wealth of information available from this facility. The concept for disposal of HHGW in a salt dome host rock developed by DBE Technology (Germany) was selected due to the extent of concept information available. Since publication of the 2016 gDSSC, RWM has undertaken work to improve our understanding of evaporite rocks within a UK context. The regulators review of the 2016 gDSSC also recommended that RWM should enhance its knowledge base on evaporites at this generic stage of the GDF programme if it is to be considered further as a potential host rock.			
Research Driver			
Develop LHGW and HHGW disposal concept options applicable to a UK evaporite context and provide support to site evaluation			
Research Objective			
To improve our understanding of what a geological disposal facility could look like in a UK evaporite geology and how it could be constructed, operated and closed.			
Scope			
The scope of work has been split into a series of work packages, including to the following: • Develop a generic dataset describing the key geological properties of a UK halite which can be used for this task and other generic research programmes. The data should be broad and not be applicable to a single location or site. • Identify disposal concept options for LHGW and HHGW in a UK evaporite rock • Undertake a feasibility assessment of the potential for anhydrite as a host rock for a UK GDF. • Develop and deliver a fully justified and integrated roadmap to ensure that RWM enhances its knowledge base on evaporites at this generic stage of the GDF programme. The roadmap will include learning from experience from analogous UK and international projects and will work cross-functionally within RWM to co-ordinate and integrate interfaces between other work packages related to evaporites. Delivery of the roadmap would be undertaken in future years which would include aspects of work related to elements specific to a GDF within an evaporite host rock. This would include requirements identification and capture and feasibility and option studies on construction and excavation, waste handling and emplacement, backfilling, sealing and closure, engineering design, programme and cost, and operational and post-closure safety. These work packages will comprise desk based studies. The output of the work packages will prepare for the end of Tranche 2 – moving toward Tranche 3 and therefore will need to ensure the provision of the required information and evidence to support comparative assessment of potential GDF sites.			

<table>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Improved understanding of what a geological disposal facility could look like in a UK evaporite geology and a knowledge base to support site evaluation.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>TRL 2</td><td>SRL/TRL at Task End</td><td>TRL 3</td><td>Target SRL/TRL</td><td>TBA</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1], [2].
1 Wilmot, R. and White, M. and Crawford, M. and Gilbert, A. and Evans, D. and Hough, E. Field, L. and Reay, D. and Milodowski, A. and McHenry, J. and Wolf,J., UK Halite Deposits – Structure, Stratigraphy, Properties and Post-closure Performance, Galson Science, Contractor Report 1735-1, 2018.
2 Office for Nuclear Regulation and Environment Agency, Pre-application advice and scrutiny of Radioactive Waste Management Limited: Joint regulators' assessment of the 2016 generic Disposal System Safety Case, 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/756205/Joint_regulators__assessment_of_the_2016_generic_Disposal_System_Safety_Case.pdf.</td></tr>
</table>

B15.7 Capability Development - HHGW Concepts

Task Number	410.007	**Status**	Start date in future
WBS Level 4	Sub-surface Facilities Design and Operational Safety		
WBS Level 5			
Background			
RWM maintains illustrative designs, which form the basis for the 2016 gDSSC, informing estimates for cost of a GDF and demonstrating feasibility of constructing, operating and closing a GDF. As the siting process develops, RWM will need to manage the development of site-specific conceptual designs, with integration of nuclear and environmental safety, requirements and programme and many of the key disciplines at RWM.			
Research Driver			
As RWM has had limited opportunity to develop conceptual designs to date, and in order to prepare for managing and undertaking this work for specific sites, RWM plans to initiate multi-disciplinary capability development projects. These will ensure RWM's capability for the design and development of an engineered barrier system and its associated performance assessments is sufficient to undertake site-specific designs, and that the capability is ready when required to ensure that the geological disposal technical programme timescales can be satisfied. Three capability development projects are planned and this task sheet addresses one, the development of HHGW concept(s).			
Research Objective			

Develop RWM's capability to deliver safety-integrated conceptual designs and test out RWM's procedures to give confidence that site-specific conceptual designs can be undertaken efficiently once site(s) for a GDF are identified. This will:
• De-risk future work by rehearsing RWM's ability to produce conceptual designs to the quality and timescales required by testing the processes and procedures;
• Develop RWM's knowledge base, generating information that could have a wider value to the GDF Programme, for example:
  ◦ Providing design and safety information that could inform the conceptual designs for particular sites.
  ◦ Providing design and safety information that could support waste management decisions.
• Test how the initial Site Descriptive Model could be used to inform conceptual designs and how the conceptual designs could inform the specification of site characterisation information needs.			

Scope			
Undertake an engineering feasibility study for a disposal concept for the UK's HHGW, working from first principles rather than adapting one of the concepts identified in the Concept Status Report [1] . The work will focus on the underground HHGW disposal area, with consideration of the interfaces with other GDF systems and with other aspects of the HHGW management lifecycle. The scope will be dynamic in order to achieve maximum learning from the work, and it is planned to deliver the work in two phases: • Phase 1: Detailed assessment of scope options and development of a design delivery plan. The aim of this phase is to maximise the potential learning from the task, both in terms of design capability and enhancing RWM's knowledge base in relation to HHGW disposal considerations.			

• Phase 2: Implementation of the design delivery plan to develop conceptual-level designs for a HHGW disposal concept, with continual lessons learned in relation to design processes, tools and systems in order to recommend optimisation actions.					
Geology Application					
To be confirmed following detailed development of the scope.					
Output of Task					
The outputs of Phase 1 will be a detailed roadmap for the task and a design delivery plan for implementation in Phase 2. The outputs of Phase 2 will be conceptual designs for a HHGW disposal concept and an action plan to address lessons learned about the efficacy of design processes, tools and systems.					
SRL/TRL at Task Start	N/A	**SRL/TRL at Task End**	N/A	**Target SRL/TRL**	N/A
Further Information					
1 Radioactive Waste Management, *Geological disposal: Concept status report*, RWM Report NDA/RWM/155 Issue 1, 2017. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-concept-status-report/.					

B15.8 Capability Development - Accessways

<table>
<tr><td colspan="2">Task Number</td><td>410.008</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Sub-surface Facilities Design and Operational Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM maintains illustrative designs which form the basis for the 2016 gDSSC, informing estimates for cost of a GDF and demonstrating feasibility of constructing, operating and closing a GDF. As the siting progress develops, RWM will need to manage the development of site-specific conceptual designs with integration of nuclear and environmental safety, requirements and many of the key underpinning disciplines.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">As RWM has had limited opportunity to develop conceptual designs to date, and in order to prepare for managing and undertaking this work for specific sites, RWM plans to initiate multi-disciplinary capability development projects. Three separate capability development projects are to be undertaken. This task sheet covers GDF accessways, that is, the shaft(s) or drift(s) (inclined tunnel or ramp) which would be used to access the underground environment at the GDF, transfer waste packages underground and provide utilities and services (water, air, electricity, etc).</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop RWM’s capability to deliver safety-integrated conceptual designs and test our processes and procedures to give confidence that site-specific conceptual designs can be undertaken efficiently once sites for a GDF are identified. This will:
De-risk future work by rehearsing RWM’s ability to produce conceptual designs to the quality and timescales required by testing the processes and procedures;
Provide design and safety information that informs the conceptual designs for particular sites; and
Contribute to addressing Regulatory Issues, Observations and Recommendations.
Develop construction methodology for accessway
Demonstrate safety integrated design process applied to a sub-system
Demonstrate collaborative working in a digital environment</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Develop RWM’s capability to realise conceptual design by developing conceptual designs for accessways (drift and shaft), although the scope will likely be agile to best achieve the learning from the work.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Conceptual designs for accessways. Identification of gaps either in processes, skills/capability or technical understanding.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>N/A</td><td>SRL/TRL at Task End</td><td>N/A</td><td>Target SRL/TRL</td><td>N/A</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B15.9 GDF Construction Materials

Task Number	410.009	Status	Start date in future
WBS Level 4	Sub-surface Facilities Design and Operational Safety		
WBS Level 5			

Background

RWM has undertaken generic studies regarding the use of different construction materials including concretes, grouts, rock bolts and mesh [1]. These are materials that are likely to be required in the GDF to ensure the safety and stability of underground spaces, enabling the construction and operational activities of the GDF to take place. These materials cannot be systematically removed when closing the GDF so will remain a permanent feature after closure. Previous work undertaken included high level scoping studies to assess the potential post-closure safety impacts that these materials may have for the GDF, considering the various processes that could take place over extended timescales. This work highlighted certain categories of construction materials which may have an impact on post-closure safety which cannot be screened out. These materials include concretes, grouts, steel mesh, rock bolts and steel/polymer fibre reinforcement.

Research Driver

To develop understanding of the potential post-closure safety impacts of construction materials to inform site-specific design decisions.

Research Objective

To provide confidence that potential adverse post-closure safety impacts are either low enough such as to be screened out or, where relevant, to articulate fully justified constraints to be placed on the site-specific designs for the GDF.

Scope

Where appropriate, this should take into account site-specific geological conditions as well as understanding of the sealing methodology. The task scope comprises the following:

- Consideration of the impact of concrete materials on the safety functions of the host rock and sealing materials (e.g. bentonite), including development of non-functional requirements (e.g. constraints) to be placed on GDF design development with regards to the use and composition of concrete materials.
- Consideration of the impact of metallic reinforcing materials (e.g. steel mesh, rock bolts and steel fibres) with regards to gas generation caused by their corrosion. This includes:
    - Development of an enhanced understanding of the corrosion implications of these materials within the disposal system.
    - Development of non-functional requirements (e.g. constraints) to be placed on GDF design development with regards to the use and composition of metallic reinforcing materials.
- Consideration of the impact of polymeric construction materials (e.g. Glass Fiber Reinforced Plastic, polymer fibres, membranes and resins) with regards to the transport of radionuclides. This includes:
    - Development of an enhanced understanding of the degradation mechanisms of these materials within the disposal system.
    - Development of non-functional requirements (e.g. constraints) to be placed on GDF design development with regards to the use and composition of polymeric materials.

Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Underpinning reports assessing the impacts of construction materials on the post-closure safety of a GDF, taking into account relevant site-specific context. Structured non-functional requirements will be incorporated into the relevant requirements sets for the GDF design.					
SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 4	**Target SRL/TRL**	TRL 4
Further Information					
Relevant publications include: https://rwm.nda.gov.uk/publication/construction-materials-phase-2-post-closure-impacts-of-construction-materials/ 1 Galson Sciences, WSP, Parsons Brinckerhoff, *Construction materials phase 2: Post-closure impacts of construction materials*, Contractor Report 1615-1 Issue 1.1, 2019. [Online]. Available: http://rwm.nda.gov.uk/publication/construction-materials-phase-2-post-closure-impacts-of-construction-materials/.					

B16 WBS 420 - Surface Facilities Design and Operational Safety

Early tasks focus on further developing confidence and capability following previous proof of feasibility work that enabled the generic DSSC. Tasks relate to the following objectives:

- To maintain and develop an understanding of the technology and techniques for the application of nuclear security (Task 420.002) to the transport system and the GDF.
- To fill knowledge gaps and develop a thorough understanding of the factors which may affect the siting of a coastal or inshore GDF (Task 420.003), including the production of high-quality visualisations which will be used to assist siting activities.

B16.1 Develop and Maintain the Disposal Container Designs

<table>
<tr><td>Task Number</td><td>420.001</td><td>Status</td><td>Start date in future</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Surface Facilities Design and Operational Safety</td></tr>
<tr><td>WBS Level 5</td><td colspan="3"></td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">RWM develops and maintains a range of illustrative disposal container designs to demonstrate the feasibility of disposal of spent fuel, high level waste, high enriched uranium and separated plutonium in a range of geological environments. Two variants of illustrative disposal containers have been developed:
The variant one disposal container is a copper disposal container with a cast iron structural insert based on the SKB/Posiva spent fuel disposal concept. The contents of a variant one disposal container are located in lodgements cast into the insert.
The variant two disposal container is a steel disposal container based on the Nagra spent fuel disposal concept. The contents of a variant two disposal container are located in a carbon steel tube, rod and plate basket assembly.
The disposal container designs have a common diameter and lifting features, but have varying lengths depending on their contents. In addition, RWM considers the development of other concept designs for the disposal of spent fuel. For instance, the development of multi-purpose containers.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">Develop and maintain disposal container designs to demonstrate that spent fuel, high level waste, highly enriched uranium and separated plutonium can safely be disposed of in a GDF.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To provide continued confidence in container designs for the disposal of spent fuel, high level waste, high enriched uranium and separated plutonium in a GDF.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">The task scope is kept under review and evolves in response to needs identified from; the iterative design process and safety integrated design, peer review, regulatory scrutiny, decisions regarding the type of new nuclear build reactor types to be used in the UK, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon. The task comprises a series of work packages, including to:
demonstrate that the disposal container designs can accommodate additional materials identified in the 2013 and more recent Derived Inventory (that is spent fuel from possible new nuclear build reactors, mixed oxide spent fuel, Magnox spent fuel and Prototype Fast Reactor spent fuel); and
these work packages will comprise desk based studies, often supported by computational studies. In limited circumstances prototype manufacture and testing may be required to underpin the technical readiness level. The output of the work packages feeds into update of the generic disposal facility designs.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
<tr><td colspan="4">Conceptual designs for disposal containers for the HHGW in the inventory of disposal.</td></tr>
</table>

SRL/TRL at Task Start	TRL 3	SRL/TRL at Task End	TRL 6	Target SRL/TRL	TRL 6
Further Information					
There are other publications relevant to this task [1]–[3].					

1 Radioactive Waste Management, *Geological Disposal: Generic Transport System Design*, RWM Report DSSC/411/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-transport-system-designs/.
2 Radioactive Waste Management, *Geological Disposal: Generic Disposal Facility Designs*, RWM Report DSSC/412/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-disposal-facility-designs/.
3 ARUP, *Disposal container for HLW and Spent Fuel; Conceptual Design*, Contractor Report Report 218762-01-03 v4, 2014.

B16.2 Technology and Techniques for Nuclear Security

<table>
<tr><td>Task Number</td><td>420.002</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Surface Facilities Design and Operational Safety</td></tr>
<tr><td>WBS Level 5</td><td colspan="3"></td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">The Conceptual Security Arrangements have been developed and address the relevant security objectives, national Objectives, requirements and model Standards, that are applicable to all three generic illustrative designs for a geological disposal facility. It follows that the designs will be further affected by site-specific considerations. The Conceptual Security Arrangements inform the development and production of the site layouts that will form part of the CSSP and later the NSSP for a geological disposal facility that will require regulatory approval. These plans should detail all aspects of the integrated security system throughout the site that provides security measures to counter threats. The different waste types to be transported and disposed of in a geological disposal facility could range from Category I to Category IV materials for physical protection purposes to prevent theft. There will also be a requirement to carry out a process known as Vital Area Identification to determine if an act of sabotage against specific equipment, systems or devices comprising part of the site's infrastructure could potentially create a radiological hazard to the public and/or the environment. Work will continue to apply nuclear security considerations to the geological disposal facility. As in other areas of geological disposal facility development, the technology and techniques used to verify the contents of waste packages, the as-built condition of facilities, the transport systems and potential security threats will be used to maintain the Conceptual Security Arrangements. In 2017 national objectives, requirements and model standards were replaced by the Security Assessment Principles for the Civil Nuclear Industry. Work is now ongoing to review the Conceptual Security Arrangement and the processes & procedures that lie behind it, in order to ensure that all planned security activities and outputs are compliant with the new principles. This will include a roadmap for the delivery of a Generic Security Report, an updated Vital Area Identification study and a report on the security organisation RWM will need going forward.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">Maintain and develop an understanding of the technology and techniques for the application of nuclear security to the transport system and the GDF.</td></tr>
<tr><td colspan="4">Research Objective</td></tr>
<tr><td colspan="4">To ensure that techniques and technology are available for the efficient application of nuclear security to the design, operation and closure of a GDF with input of this knowledge and understanding into the following:

The development of RWM's approach to nuclear security and discussions with key stakeholders.
Application of knowledge to inform the design, operation and closure of a GDF, including the:

Transport system.
Surface facilities and above-ground areas.
Tunnels or shafts leading to the underground operational areas and disposal vaults and tunnels (both during construction and during operational use).
Underground operational areas and disposal vaults and tunnels.

</td></tr>
</table>

<table>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To maintain an understanding of available data acquisition techniques through liaison with waste packaging and storage organisations for nuclear material that is packaged for transport and disposal in a GDF.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">A Generic Security Report Roadmap, Vital Area Identification Study and security organisation development plan.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>TRL 4</td><td>SRL/TRL at Task End</td><td>TRL 7</td><td>Target SRL/TRL</td><td>TRL 7</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">During 2002 to 2005, Nirex updated the 1993 security plan for the PGRC for ILW/LLW disposal to align with the Nuclear Industry Security Regulations (2003) Technical Requirements Document, which set out prescriptively what duty-holders should do to ensure security standards are met and maintained. To supplement this, Nirex produced a ‘Reference repository concept for UK HLW/spent fuel security plan’ in 2007 for a standalone HLW/spent fuel repository and also to (a) consider the impact of including plutonium and (b) co-locating HLW/spent fuel with the PGRC. The 2005 PGRC security plan assumed the GDF would be a Category III facility. The 2007 plan assumed that a GDF would be upgraded to become a Category II facility before receipt of HLW/spent fuel and would be further upgraded to become a Category I before receipt of Pu/HEU. In 2010 the illustrative designs were produced for all UK higher activity wastes which assumed the same nuclear material categorisations; i.e. a GDF would be a Category III facility until upgrading to Category II before receipt of HLW/spent fuel in 2075 and Category I facility before receipt of Pu/HEU. In 2012, ONR issued new security guidance [1]. The generic security plan, which is titled ‘Conceptual Security Arrangements for a Geological Disposal Facility’ is an update of the 2005 generic security plan to include all UK higher activity wastes and compliance with the National Objectives, Requirements and Model Standards guidance. There are other publications relevant to this task [2], [3].
1 Office for Nuclear Regulation, National objectives, requirements and model standards (NORMS) for the protective security of civil licensed nuclear sites, other nuclear premises and nuclear material in transit, 2012.
2 CPNI, Guide to producing operational requirements for security measures, 2013.
3 Office for Nuclear Regulation, Guidance on how to assess the adequacy of a vital area identification submission, CNS-TAST-GD-005, 2013.</td></tr>
</table>

B16.3 Coastal Solutions

Task Number	420.003	**Status**	Start date in future
WBS Level 4	Surface Facilities Designs and Operational Safety		
WBS Level 5			

Background

In order to progress the programme for geological disposal in the absence of a specific site RWM has developed generic, illustrative disposal system designs for three host rock types: HSR; LSSR and Evaporite Rock. These designs have been developed based on the assumption that the host geology would be an inland location. In a review of alternative concepts is has been suggested that an inshore or coastal facility may be both desirable and feasible.

Research Driver

Work has previously been undertaken by Nirex and RWMD (both predecessors to RWM) which has looked at various aspects of both coastal and inshore GDF options. The purpose of this task is to bring together all of the work undertaken previously, identify any gaps and fill those gaps.

Research Objective

To address knowledge gaps and develop a thorough understanding of the factors which may affect the siting of a coastal or inshore GDF. This will be supported by the production of high quality visualisations which may be used to assist siting activities.

Scope

The Coastal Solutions report will include the following scope activities:

- Undertake a literature review of the work undertaken previously and provide a summary.
- Identify any knowledge gaps.
- Coastal GDF feasibility study:
  - Marine transport.
  - GDF surface facilities.
  - GDF underground facilities.
- Feasibility of coastal hazard mitigation measures.
- Implications on GDF cost, programme and human resources.
- Production of visualisations:
  - High-quality rendered images.
  - Fly-through visualisations.

Geology Application

HSR, LSSR, Evaporite

Output of Task

The output will be an overarching report which draws together the coastal work undertaken previously with new work to fill any identified knowledge gaps. This will be complemented with the production of high-quality rendered images and fly-throughs depicting different aspects of a coastal GDF.

SRL/TRL at Task Start	TRL 2	**SRL/TRL at Task End**	TRL 2	**Target SRL/TRL**	TBA

Further Information
There are other publications relevant to this task [1]–[5].

1 Nirex, *Options for Radioactive Waste Management that have been Considered by Nirex – Printable version*. N/049, 2002.
2 *Sea transport of radioactive waste. feasibility and logistics study*, 2005.
3 *Feasibility Study for Nirex. Off-Shore Sub-Seabed Disposal of Radioactive Waste. Phase 1 Report*. Sir Robert McAlpine and Sons Ltd, 1986.
4 H. Beale, A. Kay, and S. Taylor, *Deep Repository Design: Offshore and On-shore Concepts*. 1989.
5 J. Bristow, T. Stephen, S. Blackburn, A. Brown, and A. (Thomas, *Feasibility Study for Transporting Low Level Radioactive Waste by Sea. Issue 2*. 037, Nuclear Transport Limited, British Nuclear Fuels plc, James Fisher & Sons plc, 1987.

B17 WBS 430 - Transport System and Containers Design and Safety

Our transport system development will focus on increasing the design maturity and underpinning documentation for the suite of proposed transport containers:

- To produce a family of SWTC conceptual designs to a TRL of 3 (Task 430.001), demonstrating the SWTC sealing system and unloading cycle times to a TRL of 5.
- To develop and maintain a range of transport container designs to demonstrate that higher activity wastes can safely be transported to a GDF (Task 430.002).
- To maintain an understanding of the constraints of the UK transport infrastructure (Task 430.003) on the geological disposal system, providing continued confidence that higher activity waste, construction materials and spoil can be transported to and from a GDF.
- To develop and maintain a suite of contents specification documentation (Task 430.004).
- To provide toolkits (Task 430.005) and manuals (Task 430.006) to check waste producer waste packaging proposals against the transport package contents limits to ensure transport safety (watching brief).
- To ensure that the DCTC has clear contents limits (Task 430.007) to enable waste producers to produce suitable waste packaging proposals for the disposability process and to ensure that the User Requirements and System Requirements of the DCTC have been successfully captured and recorded.

B17.1 Development of the Standard Waste Transport Container- Conceptual Design and supporting works

<table>
<tr><td>Task Number</td><td>430.001</td><td>Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="3">Transport System and Container Design and Safety</td></tr>
<tr><td>WBS Level 5</td><td colspan="3"></td></tr>
<tr><td colspan="4">Background</td></tr>
<tr><td colspan="4">RWM is the developer for the designs of radioactive waste transport containers that are compliant with the gDSSC, underpin RWM’s advice to waste producers on the disposability of wastes and support the RWM’s stakeholder and community engagement teams. The SWTC designs will enable transport of most LHGW.</td></tr>
<tr><td colspan="4">Research Driver</td></tr>
<tr><td colspan="4">There are presently three SWTC design variants identified by the steel shielding thickness in millimetres:
The SWTC-285 would be the most utilised of the SWTC family, it is the most shielded and can accommodate waste packages with an envelope of 1245x1720x1720mm. It has a TRL of 3.
The SWTC-150 has a larger cavity at the expense of reduced shielding. It can accommodate waste packages with an envelope of 1372x1853x1853mm. It would be used to transport larger waste packages, including the 500 litre robust shielded drums and MBGWS boxes. It has a TRL of 1.
The SWTC-70 has the same cavity size as the SWTC-285 but has less shielding and therefore a lower mass. The need for the SWTC-70 is limited. It has a TRL of 2.
The key near-term driver is to obtain conceptual designs of transport containers to a minimum TRL of 3 to support the disposability assessment process. The SWTC-285 meets this benchmark but the SWTC-150 does not. The SWTC-150 has a TRL of 1, noting that, at the current level of maturity, it has not been demonstrated to withstand the test requirements for accident conditions of transport. An improved or replacement design is required now to ensure RWM’s waste management advice is provided against a robust technical baseline.</td></tr>
<tr><td colspan="4">Research Objective
To produce a family of SWTC conceptual designs to a TRL of 3.
To demonstrate the SWTC sealing system to a TRL of 5.
To demonstrate the SWTC unloading cycle times to a TRL of 5.</td></tr>
<tr><td colspan="4">Scope</td></tr>
<tr><td colspan="4">The SWTC designs were developed circa 2003-2008 and will enable the transport of most low-heat generating waste. A review of transport container development needs or opportunities in 2016 identified work needed to maintain the SWTC designs. To scope the work needed, a new SWTC requirement set was produced and a design review was undertaken resulting in the current work programme. That current work programme is to produce a single replacement design that meets all the needs of the SWTC family. In addition the work includes physical testing of the sealing and lidding operations’ Critical Technology Elements to a TRL of 5.</td></tr>
<tr><td colspan="4">Geology Application</td></tr>
<tr><td colspan="4">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="4">Output of Task</td></tr>
</table>

The output is a design, appropriately substantiated to TRL 3. As a result of this design update safety documentation, shielding calculations held in the DIQuest Inventory tool and Waste Package Specifications will need to be revised.					
SRL/TRL at Task Start	TRL 1	**SRL/TRL at Task End**	TRL 3	**Target SRL/TRL**	TRL 3
Further Information					
There are other publications relevant to this task [1]–[3].					

1 P. Dixon, *SWTC-285: Contract Design Report*. TR/21238/001, RWE NUKEM Ltd, 2004.
2 RWE Nukem Ltd, *SWTC-70 contract design report*, TR/82015/01, 2004.
3 P. Dixon, *SWTC-150 Design: First Phase Final Design Report*. AEAT/NE/0024, AEAT, 2001.

B17.2 Develop and Maintain Transport Container Designs

Task Number	430.002	Status	Start date in future
WBS Level 4	Transport System and Container Design and Safety		
WBS Level 5			

Background

RWM develops and maintains a range of transport container designs to demonstrate that higher activity radioactive wastes can be safely packaged, transported and disposed of in a GDF. Included in that range are the DCTC and Transport Overpack designs as described below. The DCTC designs were developed to demonstrate the feasibility of transporting a disposal container containing spent fuel, HLW, HEU or separated plutonium. The DCTC designs are composed of a steel flask body, a bayonet content retention system, a bolted steel lid, neutron shielding and wood impact limiters. A transport overpack design based upon a 6 metre ISO freight container is proposed to transport a range of ILW packages, including the concrete drums and the robust shielded waste packages introduced in the 2013 Derived Inventory. These waste packages types may be transported as an Industrial Package Type 2 transport package in their own right, but require an overpack to facilitate handling. In addition, RWM considers the development of other transport container designs to support other concept options for the transport and disposal of higher activity radioactive wastes.

Research Driver

To develop and maintain a range of transport container designs to demonstrate that higher activity wastes can safely be transported to a GDF.

Research Objective

To provide continued confidence that higher activity waste can be safely transported to a GDF.

Scope

The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements or learning from external events. The task comprises a series of work packages, including the following:

- Develop the DCTC design to demonstrate that it can be safely used to transport additional materials identified in the 2013 Derived Inventory (that is, spent fuel from possible new-build nuclear reactors, mixed oxide spent fuel, Magnox spent fuel and Prototype Fast Reactor spent fuel). Current TRL 1
- Develop the conceptual designs for a transport overpack for concrete drums and robust shielded waste packages. Current TRL 1
- Develop a new transport and disposal overpack design as a potential concept option for the disposal of DNLEU. Current TRL 1

These work packages will comprise desk-based studies, often supported by computational studies. In limited circumstances prototype manufacture and testing may be required to underpin the technical readiness level. The outputs of the work packages feed into updates of the generic transport system designs.

Geology Application

HSR, LSSR, Evaporite

Output of Task

Conceptual designs for transport containers for the inventory for disposal.

SRL/TRL at Task Start	TRL 1	SRL/TRL at Task End	TRL 6	Target SRL/TRL	TRL 6

Further Information

There are other reports relevant to this task [1].

1 Nuclear Decommissioning Authority, *Geological Disposal: Generic Transport System Designs*. NDA/RWMD/046, Areva RMC, 2011.

B17.3 Transport Infrastructure Constraints on the Geological Disposal System

Task Number		430.003	**Status**	Start date in future	
WBS Level 4		Transport System and Container Design and Safety			
WBS Level 5					
Background					
The disposal of higher activity waste in the GDF will require transport of radioactive waste from sites of interim storage to the GDF. In addition, construction of the GDF will require transport of construction materials to the site of the GDF and transport of spoil away from the GDF. At this generic stage in development of the site it is assumed that transport could be by road, rail or sea. The existing UK transport infrastructure, particularly the road and rail infrastructure, will impose constraints on the vehicles used to transport materials to and from the GDF, for example, limits on the maximum mass or the maximum dimensions of road or rail vehicles. In turn, these infrastructure constraints indirectly impose limits on the radioactive waste transport packages used to transport waste to the GDF, for instance, on the maximum mass or maximum dimensions. RWM develops and maintains designs of road vehicles and rail wagons for the transport of higher activity waste to the GDF in order to determine any constraints imposed on radioactive waste transport packages.					
Research Driver					
To maintain an understanding of the constraints of the UK transport infrastructure on the geological disposal system.					
Research Objective					
To provide continued confidence that higher activity waste, construction materials and spoil can be transported to and from a GDF.					
Scope					
The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements or learning from external events. The task comprises a series of work packages, including the following: • Develop an updated design for a rail wagon for the transport of radioactive waste transport packages on the UK rail network and maintain road vehicle designs to current regulatory requirements and technologies. • Maintain a watching brief on sea transportation systems. These work packages will comprise desk-based studies, often supported by computational studies.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
Understanding of the constraints and opportunities of UK transport infrastructure for the construction and operation of the GDF.					
SRL/TRL at Task Start	TRL 5	**SRL/TRL at Task End**	TRL 5	**Target SRL/TRL**	TRL 9

Further Information
There are other publications relevant to this task [1]. 1 Nuclear Decommissioning Authority, *Geological Disposal: Generic Transport System Designs*. NDA/RWMD/046, Areva RMC, 2011.

B17.4 Development of a Suite of Contents Specification Documentation for all Package Types

Task Number	430.004	Status	Ongoing
WBS Level 4	Transport System and Container Design and Safety		
WBS Level 5			
Background			
RWM develops and maintains a range of transport container designs and an associated suite of contents specification documentation. This is to demonstrate that radioactive wastes can be transported safely to a geological disposal facility and to inform the disposability assessment of the transport safety or waste producer waste packaging proposals. The contents specification documentation sets out the contents requirements in order to ensure the following: • Containment of the radioactive contents during handling and transport (containment system). • Control of external radiation levels (e.g. by shielding). • Prevention of nuclear criticality in the case of fissile material. • Prevention of the damage caused by heat (e.g. by heat dissipation). Prior to commencing radioactive waste transport to a geological disposal facility a range of transport container designs will require approval. It is envisaged that the contents specification documentation will be used as a basis for producing the package design safety reports for the transport container designs for which RWM is the design authority. RWM's contents specification documentation is currently structured into two subsets of documents: contents specification documents, which set out the limits to ensure containment, control external radiation levels and prevent damage caused by heat; and criticality safety assessments, which set out limits to ensure sub-criticality for package designs anticipated to be qualified to contain fissile material.			
Research Driver			
To demonstrate that radioactive wastes can be transported safely to a GDF and to inform disposability assessments of the transport safety or waste producer waste packaging proposals.			
Research Objective			
To develop and maintain a suite of contents specification documentation.			
Scope			
The scope of this task includes: development of the contents specification documentation (i.e. the suite of contents specification documents and criticality safety assessments), their underpinning methodologies and some supporting data or information. Thus the task scope for mature designs is a watching brief. Other scope includes the following: • Accounting for improvements in the knowledge base, e.g. changes in good practice in the wider radioactive material transport community. • Addressing new or innovative waste packaging proposals or changes to generic transport system design. • Responding to changes in regulatory requirements for the transport of radioactive material. • Production of methodology and contents specification for the SWTC.			

• Development of criticality safety assessments for the SWTC family of transport package designs. • Consideration of the effect of packaging materials that contain other classes of dangerous goods, as well as class 7 (radioactive materials). • Completion of methodology and assessment of the SWTC's compliance with the IAEA SSR-6 20% increase in allowable dose rates on the surface of a package.					
Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A suite of reports.					
SRL/TRL at Task Start	SRL 3	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					
There are other publications relevant to this task [1]. 1 Radioactive Waste Management, *Geological disposal: Transport package safety*, RWM Report NDA/RWMD/023, 2010.					

B17.5 Maintenance of Transport Safety Assessment Toolkits

Task Number	430.005	**Status**	Ongoing
WBS Level 4	Transport System and Container Design and Safety		
WBS Level 5			

Background

To inform the disposability assessment of transport safety or waste producer waste packaging proposals, RWM develops and maintains a range of transport container designs and an associated suite of contents' specification documentation. The contents specification documentation sets out the contents requirements in order to ensure the following:

- Containment of the radioactive contents during handling and transport (containment system).
- Control of external radiation levels (e.g. by shielding).
- Prevention of nuclear criticality in the case of fissile material.
- Prevention of the damage caused by heat (e.g. by heat dissipation).

To provide a robust means of checking a waste packaging proposal against the constraints set out in the contents specification documentation, RWM produces toolkits that automate the comparison of a waste package inventory against the numerical contents limits. RWM currently maintains three transport safety assessment toolkits:

- Transport Contents Assessment Toolkit, which considers limits to ensure containment safety, control external radiation levels and prevent damage caused by heat.
- Criticality Contents Assessment Toolkit, which considers limits to ensure subcriticality.
- Transport and Operations Dose Assessment toolkit, providing dose uptake information.

Research Driver

To provide a means to check waste-producer waste packaging proposals against the transport package contents limits to ensure transport safety.

Research Objective

The scope of this task is maintenance of existing transport safety assessment toolkits. Thus the task scope is responsive to changes in the underlying contents limits and other needs. Specific development needs are as follows:

- Update of the toolkits to take account of revisions in the transport regulations.
- Update of the toolkits to the contents limits for a new package design.
- Update of the toolkits to provide compatibility with a new software operating environment.
- Update of the toolkits facilitate the new fissile exception.
- Update of the Transport and Dose Assessment Toolkit to include optimisation and integration with operations and the operational Environmental Safety Assessment.

Scope

This task is a watching brief to maintain the transport safety assessment toolkits in response to changes in the underlying contents limits.

Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
An updated version of the toolkit manual and the toolkit.					
SRL/TRL at Task Start	SRL 6	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					
There are several publications relevant to this task [1].					

1 Radioactive Waste Management, *Geological disposal: Transport package safety*, RWM Report NDA/RWMD/023, 2010.

B17.6 Review and Update the Transport Safety Manual (TSM) to Take Account of Peer Review by INS and Lessons Learned in TSM 2016

<table>
<tr><td colspan="2">Task Number</td><td>430.006</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Transport System and Container Design and Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The transport safety manual, taken to include the associated procedures and work instructions, was adopted as part of the RWM management system in 2015. This will be used to support and control production of the 2016 transport safety case.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To review and update the transport safety manual based on learning from using the manual in the 2016 transport safety case update and to address feedback provided as a result of INS peer review.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To provide confidence that the transport safety manual remains fit for purpose.</td></tr>
<tr><td colspan="6">Scope
• Commission peer review of transport safety manual from INS, agree peer review comments and consequential required changes.
• Update, undertake review of the transport safety manual and supporting procedures and work instructions, identify lessons learned and identify appropriate changes. Note: This should be the first of an on-going review cycle.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Maintain a watching brief on the update of the transport safety manual.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>N/A</td><td>SRL/TRL at Task End</td><td>N/A</td><td>Target SRL/TRL</td><td>N/A</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">See the DSSC for more information.</td></tr>
</table>

B17.7 DCTC Contents Specification & Definition of System and User Requirements

<table>
<tr><td colspan="2">Task Number</td><td>430.007</td><td>Status</td><td colspan="2">Start date in future</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Transport System and Container Design and Safety</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">Reference concepts have been developed to demonstrate the viability of a disposal container for vitrified HLW, spent fuel and other materials. A study has been undertaken to consider design options for the DCTC. This study was directed towards developing an appropriate payload configuration for the Disposal Container Transport Container (DCTC) over a range of contents whilst demonstrating compliance with the criticality safety requirements of the IAEA transport regulations.

The study demonstrated that for transport in the public domain, enrichment limits for AGR and Sizewell B PWR spent fuel were constrained to approximately 2.5%. Furthermore, this study also demonstrated that in order to permit transport of enrichments up to 5%, multiple water barrier features are the preferred option for the DCTC, prompting a number of design changes. The current design of the DCTC has been summarised in a summary report. To date, the DCTC design iterations have been bound, in part by the transportation of contents outlined in the Derived Baseline Inventory. However, it is standard practice at RWM to develop a contents specification that defines the bounding contents limits against which the anticipated contents of planned waste packages can be assessed.

In order to further develop the design options of the DCTC, RWM will develop a set of User Requirements and System Requirements that can be used to underpin the design of the DCTC and provide a set of targets to substantiate the design against.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To further develop RWM's safety case claims and arguments underpinning the disposability of vitrified HLW, spent fuel and other materials using a DCTC.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To ensure that the DCTC has clear contents limits to enable waste producers to produce suitable waste packaging proposals for the disposability process and to ensure that the User Requirements and System Requirements of the DCTC have been successfully captured and recorded.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">The scope comprises the following activities:
• Produce a Contents Specification for the DCTC.
• Develop a set of User Requirements for the DCTC.
• Develop a set of Systems Requirements for the DCTC.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Define research requirements, Contents Specification, User Requirements and System Requirements for the DCTC.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>TRL 1</td><td>SRL/TRL at Task End</td><td>TRL 3</td><td>Target SRL/TRL</td><td>TRL 6</td></tr>
</table>

Further Information
There are other publications relevant to this task [1]–[4].

1 Radioactive Waste Management, *Geological Disposal: Transport Safety Case, Main Report*, RWM Report DSSC/201/01, 2016. [Online]. Available: http://rwm.nda.gov.uk/publication/geological-disposal-generic-transport-safety-case-main-report/.

2 International Nuclear Services, *Summary report on the design of the disposal container transport container (DCTC)*, INS ENG R 15 146, 2015.

3 ARUP, *Disposal container for HLW and Spent Fuel; Conceptual Design*, Contractor Report Report 218762-01-03 v4, 2014.

4 *Criticality solution for the transport of spent fuel, plutonium and highly enriched uranium*, INS, INS Report TD/ETS/R/12/271 Rev 0, 2012.

B18 WBS 510 - Site Characterisation

These tasks will better position RWM in readiness for site characterisation, with the following desired outputs:

- To ensure that the data acquisition techniques needed to acquire the necessary information are available or can be made available in a timely manner to support site investigation activities (Task 510.001).
- To ensure that the techniques needed to interpret and model site characterisation information are available or can be made available in a timely manner to support site investigation activities (Task 510.002).
- Identify mathematical methodologies that RWM may use during the design of boreholes and the site characterisation programme, in order to increase efficiency and cost-effectiveness (Task 510.003).
- To build and demonstrate capability for the site characterisation phase of the programme and ensure that all the relevant teams within RWM are aligned with the processes involved in characterising a site (Task 510.004).

B18.1 Watching Brief on Geosphere Data Acquisition Techniques

<table>
<tr><td colspan="2">Task Number</td><td>510.001</td><td>Status</td><td colspan="2">Ongoing</td></tr>
<tr><td colspan="2">WBS Level 4</td><td colspan="4">Site Characterisation</td></tr>
<tr><td colspan="2">WBS Level 5</td><td colspan="4"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">In order to inform a decision on the suitability of a site or sites to host a GDF, detailed surface-based investigations will need to be undertaken to acquire and interpret information on the geological, hydrogeological and environmental conditions. The information acquired will be used as an input to the development of the safety case, for engineering design of the disposal facility and to demonstrate confidence to stakeholders that the geosphere of the potential disposal facility site is adequately understood.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To maintain and develop understanding of approaches to the design and implementation of information-led investigations (surface-based and underground investigations), input this knowledge and understanding into discussions with key stakeholders, as necessary, and apply it to the design and implementation of site-specific investigations in due course.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To ensure that the data acquisition techniques needed to acquire the necessary information are available or can be made available in a timely manner to support site investigation activities.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">To maintain an understanding of available data acquisition techniques through work with the supply chain and our sister organisations overseas. This includes periodically reviewing the state-of-the-art in data acquisition techniques and carrying out research into emerging techniques. As the siting process progresses we are beginning to focus work on building the capability to specify, procure and manage investigations using seismic geophysics. We continue to maintain an understanding of approaches to underground investigations in underground research facilities worldwide through partnerships with our sister organisations overseas and attendance at technical meetings of the IAEA’s Underground Research Facility Network.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">This work is required for all geological environments at the generic stage. As the siting process progresses work will focus on site-specific geological environments.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Technical notes and reports which act as inputs to knowledge base, business cases and specifications for site characterisation.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 6</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">Further information can be found on the IAEA website at: [1]

1 IAEA - Modelling and Data for Radiological Impact Assessments web-site. [Online]. Available: https://nucleus.iaea.org/sites/connect/URFpublic/Pages/default.aspx.</td></tr>
</table>

B18.2 Watching Brief on Interpretation and Modelling Techniques for Generation of a Site Descriptive Model

Task Number		510.002	**Status**	Ongoing	
WBS Level 4		Site Characterisation			
WBS Level 5					
Background					
In order to inform a decision on the suitability of a site or sites to host a GDF, detailed surface-based investigations will need to be undertaken to acquire and interpret information on the geological, hydrogeological and environmental conditions. The information acquired will be used as an input to the development of the safety case, for engineering design of the disposal facility and to demonstrate confidence to stakeholders that the geosphere of the potential disposal facility site is adequately understood.					
Research Driver					
To maintain and develop understanding of approaches to the design and implementation of information-led investigations (surface-based and underground investigations), input this knowledge and understanding into discussions with stakeholders, as necessary, and apply it to the design and implementation of site-specific investigations in due course.					
Research Objective					
To ensure that the techniques needed to interpret and model site-characterisation information are available or can be made available in a timely manner to support site-investigation activities.					
Scope					
To maintain an understanding of available data interpretation and modelling techniques through liaison with sister organisations, working with the supply chain and sharing knowledge with the site investigation, mining, oil and gas, geothermal and carbon capture and sequestration sectors. In order to maintain an understanding of approaches to underground investigations in underground research facilities worldwide we will continue our partnership with our sister organisations' experiments in active URLs and participation in the IAEA's Underground Research Facilities Network.					
Geology Application					
This work is required for all geological environments at the generic stage. As the siting process progresses work will focus on site-specific geological environments.					
Output of Task					
Technical notes and reports which act as inputs to knowledge base, business cases and specifications for site characterisation.					
SRL/TRL at Task Start	SRL 6	**SRL/TRL at Task End**	SRL 6	**Target SRL/TRL**	SRL 6
Further Information					
Further information on the underground research facilities network can be found on the IAEA website at: at: [1] 1 *IAEA - Modelling and Data for Radiological Impact Assessments web-site*. [Online]. Available: https://nucleus.iaea.org/sites/connect/URFpublic/Pages/default.aspx.					

B18.3 Analytical Advice, Including Mathematical Approaches, to Site Characterisation

Task Number	510.003	**Status**	Ongoing
WBS Level 4	Site Characterisation		
WBS Level 5			
Background			
As part of a programme of work to identify areas where cutting edge mathematics may have a role to play in solving problems of relevance to various aspects of RWM's work programme, this task is looking at mathematical approaches used during sub-surface investigation across different industries to reduce uncertainty of the sub-surface most efficiently. This work will help identify mathematical methods for aiding the siting and design of boreholes and other geoscientific investigations during the site characterisation for a GDF, and methods relating to the 'inverse problem' which is the process of calculating from a set of observations the causal factors that produced them.			
Research Driver			
As the siting process progresses, RWM is proceeding with preparation for site characterisation. Site characterisation represents a step-change in cost. This work will help identify mathematical methodologies which may reduce the cost of site-characterisation, and potentially more efficiently reduce subsurface uncertainty. The work will draw on experience in other sectors such as oil, gas and mining.			
Research Objective			
Identify mathematical methodologies that RWM may use during the design of boreholes and the site-characterisation programme, in order to increase efficiency and cost-effectiveness.			
Scope			

The scope of this task is to look at how other industries (such as oil and gas and mining) use mathematical methods when designing ground investigations to reduce uncertainty of the subsurface. These methodologies will then be explored to understand their applicability to GDF site characterisation. The envisaged tasks can be summarised as follows:
• Agree a description of the challenges faced by RWM in GDF site characterisation.
• Define a principled approach to addressing such challenges and corresponding sub-problems.
• Discuss candidate analogous applications that require the same challenges to be addressed.
• Identify published reports and people that describe principles and claims of successful methods to address analogous challenges or a subset of the corresponding analogous sub-problems.
• Review the identified methods to identify what was critical to the assessment of success and, by comparing with the principled approach above, aim to understand:
  ◦ In cases where these principles are applied, how have they addressed the highlighted subproblems, and
  ◦ In other cases, what principles are used instead.
• Report a gap analysis of the comparison with the challenges of GDF site characterisation.			

Geology Application					
HSR, LSSR, Evaporite					
Output of Task					
A technical report on mathematical methods employed in ground investigations.					
SRL/TRL at Task Start	SRL 2	**SRL/TRL at Task End**	SRL 4	**Target SRL/TRL**	SRL 6
Further Information					

B18.4 Site Characterisation Capability Building

<table>
<tr><td>Task Number</td><td colspan="2">510.004</td><td colspan="2">Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Site Characterisation</td></tr>
<tr><td>WBS Level 5</td><td colspan="5"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM has recognised a need to further develop its capability to characterise sites, and summarise the understanding gained during characterisation in the production of Site Descriptive Models. This work builds upon an earlier task which built capability in the early stages of the siting process.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">Site characterisation represents a step-change in the expenditure and risk for RWM. This work will ensure that RWM can build and demonstrate capability for the site characterisation phase of the programme and ensure that all the relevant teams within RWM are aligned with the processes involved in characterising a site.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">The task aims to develop and test processes for the following:
Managing site characterisation data.
Synthesising data to provide a site understanding for use in concept selection and site evaluation.
Transfer of the site understanding to allow GDF design and safety assessment.
Production of Initial Site Evaluation for Environmental Permits. These are the specific applications which the Environment Agency in England will require from RWM to award an Environmental Permit for site investigations in support of the GDF.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">This scope of this task covers the site characterisation activities that would need to be undertaken by RWM from initial understanding based upon desk-based studies through initial seismic reflection surveys to the design, specification, permitting and planning for the initial boreholes for characterising an LSSR host rock in a sedimentary sequence. A second task is planned covering the site characterisation activities from the understanding following initial deep boreholes through subsequent borehole cycles for characterising an HSR host rock.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">LSSRHSR</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Procedures, work instructions, guidance documents, work-process maps, manuals etc.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>N/A</td><td>SRL/TRL at Task End</td><td>N/A</td><td>Target SRL/TRL</td><td>N/A</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6"></td></tr>
</table>

B19 WBS 610 - Strategic Waste Programmes

RWM's strategic waste programme supports improvements in the clean-up of NDA sites, enabling faster, cheaper and safer decommissioning. Two further tasks have been identified at this time with the following outcomes:

- To develop a conceptual design for a larger waste container along with other supporting documentation (Task 610.001).
- To update the 2006 'filters' guidance to capture new research and techniques used for the conditioning of filters (Task 610.002).

B19.1 Development of a Larger Waste Transport Container

<table>
<tr><td>Task Number</td><td colspan="2">610.001</td><td colspan="2">Status</td><td>Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Strategic Waste Programmes</td></tr>
<tr><td>WBS Level 5</td><td colspan="5"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">The limits placed on the size and mass of waste packages (plus transport container, if required) are expected to be constrained by the required configuration for rail transport to the GDF. However there is significant scope to increase the size of waste containers within the current constraints. Previous work undertaken within the Strategic Waste Programmes identified a range of possible benefits from the use of larger waste transport containers, including a reduced requirement for waste size reduction, reduced risk to operators and the production of less secondary waste.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To develop a conceptual design for a larger waste transport container.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">To develop a conceptual design for a larger waste container, along with other supporting documentation including and not limited to user requirements document, systems requirements document, manufacturability assessments and handling & operational reviews.</td></tr>
<tr><td colspan="6">Scope
Liaise with Site Licence Companies to determine the demand for a larger waste transport container and functional requirements.
Develop the concept design and other supporting documentation for a larger waste transport container design.
Ensure confidence in disposability of the proposed container to allow SLCs to plan for the use of a larger waste container with RWM.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR and Evaporite.</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">LWTC Summary Report.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>TRL 2</td><td>SRL/TRL at Task End</td><td>TRL 3</td><td>Target SRL/TRL</td><td>TRL 3</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">A target TRL of 3 has been identified for this feasibility study, pending a decision to fully develop this container.</td></tr>
</table>

B19.2 Guidance on the Disposability of Filters

<table>
<tr><td>Task Number</td><td>610.002</td><td>Status</td><td colspan="3">Ongoing</td></tr>
<tr><td>WBS Level 4</td><td colspan="5">Strategic Waste Programmes</td></tr>
<tr><td>WBS Level 5</td><td colspan="5"></td></tr>
<tr><td colspan="6">Background</td></tr>
<tr><td colspan="6">RWM produces guidance to waste producers as part of the suite of documents in the Waste Package Specification and guidance documentation. One such guidance document focuses on the disposability of filters, which are widely used in nuclear ventilation and containment systems to remove particulate matter from air and other gas streams. The conditioning of used filters for long-term management presents a challenge for waste packagers because they may:
• Constitute a potentially significant source-term of radioactivity in loose particulate form;
• Incorporate significant voidage in their design that can be difficult to infiltrate using standard techniques and encapsulants; and
• Incorporate materials and features that may evolve in a way that potentially weakens the performance of the final waste package (e.g. aluminium spacers). As the initial version of the guidance was produced in 2006, it was recognised that an update was required to capture new research and techniques used for the conditioning of filters.</td></tr>
<tr><td colspan="6">Research Driver</td></tr>
<tr><td colspan="6">To ensure an up-to-date and useful guidance document on the conditioning of filters is available to Site Licence Companies.</td></tr>
<tr><td colspan="6">Research Objective</td></tr>
<tr><td colspan="6">Update the 2006 ‘filters’ guidance to capture new research and techniques used for the conditioning of filters. This work will incorporate input from Site Licence Companies who have undertaken practical work on the conditioning of filters.</td></tr>
<tr><td colspan="6">Scope</td></tr>
<tr><td colspan="6">Undertake a review and update the guidance to capture new research and techniques developed by Site Licence Companies for the conditioning of filters.</td></tr>
<tr><td colspan="6">Geology Application</td></tr>
<tr><td colspan="6">HSR, LSSR, Evaporite</td></tr>
<tr><td colspan="6">Output of Task</td></tr>
<tr><td colspan="6">Updated guidance published on the packaging of filters.</td></tr>
<tr><td>SRL/TRL at Task Start</td><td>SRL 6</td><td>SRL/TRL at Task End</td><td>SRL 6</td><td>Target SRL/TRL</td><td>SRL 6</td></tr>
<tr><td colspan="6">Further Information</td></tr>
<tr><td colspan="6">There are other publications relevant to this task [1].
1 Nirex, Guidance Note on the Packaging of Filters. WPS/905, 2006.</td></tr>
</table>

Appendix C Change Log: Breakdown by Work Area

Table C1: 010 - Biosphere

2016 Information	Title	Status	Comments
[1, Task 1] in Biosphere\Biosphere Assessment Approach	BIOPROTA: Geosphere/Biosphere Interface Modelling	Start date in FY21/22 (deferred start)	The 1st phase of BIOPROTA is complete, awaiting future international collaboration for the 2nd phase to proceed. [1, Task 1] has now been superseded by Task 10.8.001.
[1, Task 2] in Biosphere\Biosphere Assessment Approach	Updated Marine Model for Climate States Posing a Potential Challenge to the Risk Guidance Level	Start date in FY23/24 (deferred start)	Task deferred as a site-specific approach is more beneficial to progress this work. This Task is included in the 2020 S&T Plan as Task 10.6.001.
[1, Task 3] in Biosphere\Biosphere Assessment Approach	BIOPROTA: Update of BIOMASS (BIOsphere Modelling and ASSessment) methodology	Completed, undergoing review	Task 10.1.001 now supersedes [1, Task 3]. Final report is undergoing review, see interim report [2].
[1, Task 4] in Biosphere\Biosphere Assessment Approach	Interface of Biosphere Programme with Environmental Impact Assessment (EIA)	Start date in FY22/23 (deferred start)	Proposed project on biosphere site characterisation, review and potential BIOPROTA joint project will assess the Task in the future as a more beneficial approach to the work, hence the Task has not yet proceeded. [1, Task 4] has now been superseded by Task 10.2.001.

[1, Task 11] in Biosphere\Uptake of Radionuclides	MODARIA: Review and Update of Radioecological Data	Start date in FY21/22 (deferred start)	Task 10.3.001 now supersedes [1, Task 11]. Task deferred due to awaiting international collaboration for MODARIA III on the completion of MODARIA II (2016-2019) [3].
[1, Task 12] in Biosphere\Uptake of Radionuclides	MODARIA: Biota Modelling and Parameter Update	Start date in FY21/22 (deferred start)	Task 10.4.001 now supersedes [1, Task 12]. Task deferred due to awaiting international collaboration for MODARIA III on the completion of MODARIA II (2016-2019) [3].
[1, Task 13] in Biosphere\Uptake of Radionuclides	MODARIA: Effects of Acute and Chronic Exposure on Wildlife	Start date in FY21/22 (deferred start)	Task 10.4.002 now supersedes [1, Task 13]. Task deferred due to awaiting international collaboration for MODARIA III on the completion of MODARIA II (2016-2019) [3].
[1, Task 14] in Biosphere\Uptake of Radionuclides	NERC TREE: Development of a Mechanistic Undertaking of Acute and Chronic Low Dose Uptake and Transgenerational Effects in Non-human Biota	Completed	NERC TREE concluded, see relevant publications and websites [4], [5].
[1, Task 15] in Biosphere\Uptake of Radionuclides	NERC TREE: Spatial Behaviour of Non-human Biota Reference Species	Completed	NERC TREE concluded, see relevant publications and websites [4], [5].
[1, Task 16] in Biosphere\Uptake of Radionuclides	NERC TREE: Biogeochemical Behaviour of Key Radionuclides (I-129, Se-79, Tc-99 and U-235) in Soil-Plant Systems	Completed	NERC TREE concluded, see relevant publications and websites [4], [5].

[1, Task 17] in Biosphere\Uptake of Radionuclides	NERC TREE: New Robust Approach to Predicting Radionuclide Activity Concentrations in Ecosystem-Food Transfer	Completed	NERC TREE concluded, see relevant publications and websites [4], [5].
[1, Task 18] in Biosphere\Uptake of Radionuclides	NERC Lo-RISE: Studies of Speciation, Environmental Transport and Transfer of Key Radionuclides (C-14, U & Ra) in Naturally Contaminated Environments and Laboratory Studies	Completed	NERC Lo-RISE concluded [6]. Further information can be found on the LO-Rise website [7].
[1, Task 19] in Biosphere\Uptake of Radionuclides	Further International Collaboration on Effects of Radiation on Non-human Biota	Start date in FY21/22 (deferred start)	Task deferred due to awaiting international collaboration for MODARIA III on the completion of MODARIA II (2016-2019). This Task can be found in the 2020 S&T Plan as Task 10.4.003.
[1, Task 20] in Biosphere\Uptake of Radionuclides	Synthesis of NERC TREE and Lo-RISE Outputs	Completed	NERC TREE outputs are concluded and published [5].
[1, Task 31] in Biosphere\Landscape and its Evolution	MODARIA: Climate Change Review, Incl. UK Specific Application	Completed	MOARIA II concluded. Report can be found on the MODARIA website [3].
[1, Task 32] in Biosphere\Landscape and its Evolution	Impact of Climate State Transitions	Start date in FY25/26 (deferred start)	Task 10.7.001 now supersedes [1, Task 32]. Task deferred to site-specific stage, as a site-specific approach is more beneficial to progress this Task.

[1, Task 33] in Biosphere\Landscape and its Evolution	Periodic Review of Climate Change Understanding	Start date in FY28/29 (deferred start)	[1, Task 33] has now been superseded by Task 10.7.002. There is sufficient current understanding to hold a watching brief on the Task until a review is required, hence the Task has not started yet.
[1, Task 46] in Biosphere\Understanding the Behaviour of C-14	BIOPROTA: Behaviour of C-14 in Terrestrial and Aquatic Systems – Follow-up International Model Comparison and Validation Study	Completed	Information relevant to the completion of this Task can be found in the following report: [8].

Table C2: 2020 New Biosphere Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 10.1.002	Biosphere	General Biosphere Methodology	Consistency of Biosphere with Other Technical Areas within RWM
Task 10.1.003	Biosphere	General Biosphere Methodology	Develop a roadmap for Site-specific Modelling and Assessment of Biosphere
Task 10.1.004	Biosphere	General Biosphere Methodology	Site-specific Research Needs Identification: Biosphere
Task 10.4.004	Biosphere	Non-human biota	Consideration of Non-human Biota in Deep Groundwater
Task 10.4.005	Biosphere	Non-human biota	A Review of the Knowledge Base of the Effect of Non-radiological Pollutants on Non-human Biota
Task 10.5.001	Biosphere	Non-radiological Pollutants	Effect of Multi-stressors in Addition to Radioactive Exposure

Task 10.5.002	Biosphere	Non-radiological Pollutants	Development of Safety Case Claims, Arguments and Evidence in Consideration of Non-radiological Pollutants
Task 10.7.003	Biosphere	Historical, Current and Future Climate	Downscaling Global Climate Data

Table C3: 020 Criticality Safety

2016 Information	Title	Status	Comments
[1, Task 66] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	MPC - Criticality Control Options Study	Completed	A report has been published as the output of this Task [9].
[1, Task 68] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Spent Fuel - Criticality Control Options	Completed	A report has been published as the output of this Task [10].
[1, Task 69] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Disposal Container - Criticality Control Options Study	Completed	A report has been published as the output of this Task [10].
[1, Task 70] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Concepts (IPT): Feasibility of Disposal Concepts for Exotics	Completed	A report was published as the output to this Task [11].
[1, Task 71] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Concepts IPT: Feasibility of Disposal Concepts for Metallic Fuel	Superseded	A preferred option was not identified, therefore did not advance criticality (103 to identify).Superseded by a new Task 20.3.005. Further information can be found [12].
[1, Task 73] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Spent Fuel - Initial Burn-up Credit Work	Completed	A report was published as the output of this Task [13].

[1, Task 74] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Disposal Container – CSA for Legacy Fuels	Superseded	[1, Task 74] is a follow on from [1, Task 69]. The full assessment was deferred until a site-specific concept becomes available. This is now superseded by new Task 20.4.005.
[1, Task 75] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Criticality Safety Assessment for Exotics	Superseded	[1, Task 70] and [1, Task 71] did not provide sufficient information for [1, Task 75] to proceed as the preferred disposal option focuses on AGRs. New Task 20.4.001 and Task 20.4.005 replace this Task.
[1, Task 76] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Criticality Safety Assessment for Metallic Fuel	Superseded	The initial work for this Task has been completed and the remaining scope has been replaced by new Task 20.3.005.
[1, Task 77] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Spent Fuel - Implementation / Validation of Burn-up Credit Arguments	Superseded	The ongoing work, which is due to be published shortly, largely completes this Task. There is a follow on Task planned in the 2020 S&T Plan (Task 20.4.001) that builds on this.
[1, Task 78] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Disposal Container – Criticality Safety Assessment for Future Higher Enriched New Build Fuels	Superseded	Task 67 was originally planned to follow on from [1, Task 66]. This Task is no longer planned as MPC concept is no longer the preferred option for spent fuel following the outcome of [1, Task 66]. The new Task 20.4.004 and Task 20.4.005 will address this research need.

[1, Task 79] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Spent Fuel - Extending Burn-up Credit Arguments to Future Higher Enriched New Build Nuclear Fuels and Low Burn-up Fuels	Superseded	Task 67 was originally planned to follow on from [1, Task 66]. This Task is no longer planned as MPC concept is no longer the preferred option for spent fuel following the outcome of [1, Task 66]. The new Task 20.4.004 and Task 20.4.005 will address this research need.
[1, Task 80] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Develop the Transport Criticality Safety Assessment for the Disposal Container Transport Container	Superseded	[1, Task 80] has been partly covered by the output reference published for [1, Task 77]. Further work has been deferred until site-specific work can be carried out with advanced designs. This further work is detailed in new Task 20.1.005 and Task 20.1.006.
[1, Task 81] in Criticality Safety\Criticality Safety Assessment for Spent Fuel	Develop the Disposal Container Transport Container Criticality Safety Assessment for New Fuels in the 2013 Derived Inventory	Ongoing	[1, Task 80] has been partly covered by the output reference published for [1, Task 77]. Further work has been deferred until site-specific work can be carried out with advanced designs. This further work is detailed in new Task 20.1.005 and Task 20.1.006.

[1, Task 92] in Safety\Criticality Safety for ILW Disposal	Fissile Limits for ILW Transported in an SWTC	Completed	The 500L drum experimental work has been completed; however, there is some further work to be carried out to complete the Task. There are also several publications relevant to this Task [14], [15].
[1, Task 93] in Criticality Safety\Criticality Safety for ILW Disposal	Transport Fissile Exception Test Case	Completed	The experimental work has been completed and is awaiting ONR approval.
[1, Task 102] in Criticality Safety\Criticality Safety Assessment for Plutonium and Uranium Disposal	Criticality Safety Considerations for Hot Isostatic Pressed (HIPed) Pu Wasteforms	Superseded	The work planned by this Task will be covered in the Plutonium IPT. Therefore, this Task is superseded by new Task 20.5.002 and Task 20.5.003.
[1, Task 103] in Criticality Safety\Criticality Safety Assessment for Plutonium and Uranium Disposal	Concepts IPT: Feasibility of Separated Highly-enriched Uranium (HEU) Disposal	Superseded	A report was published for this Task [16]. However, the Concepts IPT did not identify a preferred option for disposal; because of this, this work is superseded by new Task 20.5.006.
[1, Task 104] in Criticality Safety\Criticality Safety Assessment for ILW Disposal	Criticality Safety Assessment for HIPed HEU Wasteforms	Superseded	A preferred option was not identified, therefore criticality was not advanced ([1, Task 103] to identify).
[1, Task 116] in Criticality Safety\Likelihood of Criticality Post-closure	Applying the Likelihood of Criticality Models to Future Concepts, Facility Designs and Inventories	Deleted	Based on the output of [1, Task 901], this Task has become business as usual.
[1, Task 131] in Criticality Safety\Criticality Safety-Models of Consequences of Hypothetical Criticality	Types of Critical Systems and the Credibility of Rapid Transient Criticality During Post-closure	Completed	A report was published as the output of this Task [17].

[1, Task 132] in Criticality Safety\Criticality Safety-Models of Consequences of Hypothetical Criticality	Further Understanding of Types of Critical Systems and the Credibility of Rapid Transient Criticality During Post-closure.	Completed	A report was published as the output of this Task [18].
[1, Task 136] in Criticality Safety\Criticality Safety-Models of Consequences of Hypothetical Criticality	Update To The Post-Closure Criticality Consequence Assessment (PCCCA)	Completed	A report was published as the output of this Task [19].

Table C4: 2020 New Criticality Safety Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 20.1.001	Criticality Safety	Transport Criticality Safety	Scoping Criticality Safety Assessment for Robust Shielded Box Transport Container
Task 20.1.002	Criticality Safety	Transport Criticality Safety	Detailed Criticality Safety Assessment for Robust Shielded Box Transport Container
Task 20.1.003	Criticality Safety	Transport Criticality Safety	Criticality Safety for the Disposal of Spent Fuel - Water carry-over Compliance Validation
Task 20.1.004	Criticality Safety	Transport Criticality Safety	Scoping Transport Phase Criticality Safety Assessment - Plutonium IPT
Task 20.1.005	Criticality Safety	Transport Criticality Safety	Detailed Transport Criticality Safety Assessment for the Disposal Container Transport Container (DCTC)

Task 20.1.006	Criticality Safety	Transport Criticality Safety	Optimised Transport Criticality Safety Assessment for the Disposal Container Transport Container (DCTC)
Task 20.1.007	Criticality Safety	Transport Criticality Safety	Detailed Transport Criticality Safety Assessment for the Standard Waste Transport Container (SWTC)
Task 20.1.008	Criticality Safety	Transport Criticality Safety	Optimised Transport Criticality Safety Assessment for the Standard Waste Transport Container (SWTC)
Task 20.1.009	Criticality Safety	Transport Criticality Safety	Scoping Transport Criticality Safety Assessment for the Preferred Plutonium Disposal Concept
Task 20.2.001	Criticality Safety	Operational Criticality Safety	Review Inventory to Identify any Challenges to Criticality Accident Alarm System (CAAS) Omission Case
Task 20.2.002	Criticality Safety	Operational Criticality Safety	Develop Draft Criticality Emergency Plan Based on Site-specific Data
Task 20.2.003	Criticality Safety	Operational Criticality Safety	Scoping Transient Analysis of Hypothetically Criticality
Task 20.2.004	Criticality Safety	Operational Criticality Safety	Scoping Operational Phase Criticality Safety Assessment - Plutonium IPT
Task 20.2.005	Criticality Safety	Operational Criticality Safety	Review and Update Draft Criticality Emergency Plan for Two Sites

Task 20.2.006	Criticality Safety	Operational Criticality Safety	Develop and Document Appropriate Criticality Safety-related Acceptance Criteria
Task 20.2.007	Criticality Safety	Operational Criticality Safety	Detailed Transient Analysis of Hypothetical Criticality Based on Site-specific Data
Task 20.3.001	Criticality Safety	Post-closure Criticality Safety for LHGW	Extension of Low-likelihood Package Envelope
Task 20.3.002	Criticality Safety	Post-closure Criticality Safety for LHGW	Applying the Likelihood of and Consequences of Criticality Models to Future Concepts, Facility Designs and Inventories
Task 20.3.003	Criticality Safety	Post-closure Criticality Safety for LHGW	Review of Existing generic Criticality Safety Assessments (gCSAs) and Revision, if necessary
Task 20.3.004	Criticality Safety	Post-closure Criticality Safety for LHGW	Review of Likelihood and Consequences Assumptions Based on Revised Concepts, Facility Designs and Inventories
Task 20.3.005	Criticality Safety	Post-closure Criticality Safety for LHGW	Criticality Safety Assessment for Metallic Uranic Fuel in Self-shielded Boxes
Task 20.3.006	Criticality Safety	Post-closure Criticality Safety for LHGW	Collation of Records and Inputs against Assumptions for generic Criticality Safety Assessments (gCSAs)
Task 20.3.007	Criticality Safety	Post-closure Criticality Safety for LHGW	Collation of Assumptions from Extant Criticality Safety Assessment

Task 20.3.008	Criticality Safety	Post-closure Criticality Safety for LHGW	Review and Refinement of Criticality Safety Models and Assumptions to Maintain Capability
Task 20.3.009	Criticality Safety	Post-closure Criticality Safety for LHGW	Review of Extant Criticality Safety Assessment Assumptions against Site-specific Data
Task 20.3.010	Criticality Safety	Post-closure Criticality Safety for LHGW	Revision, if Required, of any Extant Criticality Safety Assessments Based on Site-specific Data
Task 20.4.001	Criticality Safety	Post-closure Criticality Safety for HHGW - Spent Fuel	Criticality Safety for the Disposal of Spent Fuel - Criticality Safety Assessment for Exotics
Task 20.4.002	Criticality Safety	Post-closure Criticality Safety for HHGW - Spent Fuel	Criticality Safety for the Disposal of Spent Fuel - Burn-up Credit Validation
Task 20.4.003	Criticality Safety	Post-closure Criticality Safety for HHGW - Spent Fuel	Underpinning Persistence of Iron-corrosion Products
Task 20.4.004	Criticality Safety	Post-closure Criticality Safety for HHGW - Spent Fuel	Criticality Safety for the Disposal of Spent Fuel - Extending Burn-up Credit to Future/Different Fuels
Task 20.4.005	Criticality Safety	Post-closure Criticality Safety for HHGW - Spent Fuel	Criticality Safety for the Disposal of Spent Fuel - Assessment for Future Fuels (if required)
Task 20.4.006	Criticality Safety	Post-closure Criticality Safety for HHGW - Spent Fuel	Criticality Safety for the Disposal of Spent Fuel - Refined Assessments Based on Available Records

Task 20.4.007	Criticality Safety	Post-closure Criticality Safety for HHGW - Spent Fuel	Criticality Safety for the Disposal of Spent Fuel - Detailed Assessments Based on Site-specific Data
Task 20.5.001	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Scoping Post-closure in-package Criticality Safety Assessment
Task 20.5.002	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Scoping Post-closure Out-of-package Criticality Safety Assessment
Task 20.5.003	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Scoping Plutonium Criticality Safety Assessment Based on Concept Developments and Experimental Outputs
Task 20.5.004	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Detailed Criticality Safety Assessment for Plutonium Disposal Concept
Task 20.5.005	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Optimised Criticality Safety Assessment for Plutonium Disposal Concept Based on Transport Considerations and Site-specific Data
Task 20.5.006	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Scoping HEU Criticality Safety Assessment Based on Concept Development
Task 20.5.007	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Detailed Criticality Safety Assessment for HEU Disposal Concept
Task 20.5.008	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Optimised Criticality Safety Assessment for HEU Disposal Concept Based on Transport Considerations and Site-specific Data

Task 20.5.009	Criticality Safety	Post-closure Criticality Safety for HHGW - Plutonium and HEU	Plutonium IPT - Wasteform Review
Task 20.6.001	Criticality Safety	Criticality Safety Assessments	Undertake Sensitivity Study on PCCCA Using Existing Desk-based Site-specific Data (Five Sites)
Task 20.6.002	Criticality Safety	Criticality Safety Assessments	Scoping Assessment of Alternative Disposal Concepts - Evaporite
Task 20.6.003	Criticality Safety	Criticality Safety Assessments	Undertake PCCCA using Existing Desk-based Site-specific Data (Two Sites)
Task 20.6.004	Criticality Safety	Criticality Safety Assessments	Undertake Sensitivity Study on PCCCA Using Existing Desk-based Site-specific Data (Two Sites Refined Data)

Table C5: 030 Engineered Barrier Evolution

2016 Information	Title	Status	Comments
[1, Task 416] in Near-field Evolution \ Evolution of Cement-based EBS	Hydrothermal Ageing of NRVB	Completed	Geochemical modelling study has been completed and published [20]. Hydrothermal ageing work complete with 10 year progress report produced to document the approach to the study. This will input to a new PhD to characterise the samples (Task 30.4.003)

[1, Task 417] in Near-field Evolution \ Evolution of Cement-based EBS	Experimental Design: High Temperature Backfill Functional Requirements	Start date in FY20/21 (deferred start)	Task deferred as a site-specific approach is more beneficial to progress the work area. Task 30.2.001 now supersedes [1, Task 417].
[1, Task 418] in Near-field Evolution \ Evolution of Cement-based EBS	Impact of Ductile Cast Iron Containers (DCICs) and Vitrified ILW on Cement Backfill Performance	Completed	Initial modelling study completed and published, experimental follow on study ongoing (see Task 30.4.001) [21].
[1, Task 419] in Near-field Evolution \ Evolution of Cement-based EBS	Effect of Groundwater Solutes on Physical Properties of Cementitious Backfill	Completed, undergoing review	Experimental work has been completed, including a successfully defended PhD thesis. The final report is undergoing peer review. 30.4.011 now supersedes [1, Task 419].
Task 420 in Near-field Evolution \ Evolution of Cement-based EBS	Experimental Demonstration of NRVB Carbonation	Completed	This Task was part of the 2014 S&T Plan. A final report has been published as the output of this Task [22].
[1, Task 421] in Near-field Evolution \ Evolution of Cement-based EBS	Effect of High Temperatures (>100°C) on Cement Backfill for Spent Fuel (SF) / Multi-Purpose Containers (MPC)	Start date in FY20/21 (deferred start)	[1, Task 421] is now superseded by Task 30.2.002. Work has been addressed by a subsequent report [23].
Task 422 in Near-field Evolution \ Evolution of Cement-based EBS	Characterisation and Leaching of Aged Waste Encapsulation Cements	Completed	This Task was part of the 2014 S&T Plan. Student has completed and been awarded PhD. Awaiting draft paper(s) for submission to journal.
[1, Task 423] in Near-field Evolution \ Evolution of Cement-based EBS	Ageing of Nirex Reference Vault Backfill (NRVB) and Impact on Safety Functions	Completed	A PhD has been completed and successfully defended [24].

[1, Task 424] in Near-field Evolution \ Evolution of Cement-based EBS	Pilot Backfill Leaching and Migration Experiment in Overseas Underground Research Laboratories (URL)	Deleted	The scope of [1, Task 424] [1, Task 425] has been included in the Backfill integrated project (Task 30.1.001) to deliver appropriate backfill, and technologies underpinning research.
[1, Task 425] in Near-field Evolution \ Evolution of Cement-based EBS	Demonstration Backfill and Leaching Experiment in Overseas URL	Deleted	The scope of [1, Task 424]/ [1, Task 425] has been included in the Backfill integrated project (Task 30.1.001) to deliver appropriate backfill, and technologies underpinning research.
[1, Task 426] in Near-field Evolution \ Evolution of Cement-based EBS	Further Experimental / Modelling Study	Start date in FY22/23 (deferred start)	[1, Task 426] (now superseded by Task 30.4.004) is deferred pending the outcome of [1, Task 441] and [1, Task 444]: if work arises that is necessary, it will proceed based on the outcome of [1, Task 441] and [1, Task 444].
[1, Task 427] in Near-field Evolution \ Evolution of Cement-based EBS	Effect of Crack Armouring on Groundwater Conditioning for Backfill Under Advective Flow Conditions	Deferred	[1, Task 417] will proceed based on the outcome and requirement of modelling work ([1, Task 441] and [1, Task 445]). The relevant report for [1, Task 441] is currently undergoing peer review.
[1, Task 428] in Near-field Evolution \ Evolution of Cement-based EBS	Novel experimental approaches to understanding long-term evolution of water-saturated cement	Completed	Short term pilot study/University of Leeds/ Geological Survey, methodology explored further PhD (pilot study available on request).

[1, Task 429] in Near-field Evolution \ Evolution of Cement-based EBS	Application of Novel Experimental Approaches to Understanding Long-term Evolution of Water-saturated Cements	Superseded	Following completion of the [1, Task 428], the scope of the follow on PhD could be defined more specifically. [1, Task 429] is replaced by new Task 30.4.003 ('Hydrothermal Ageing PhD').
[1, Task 430] in Near-field Evolution \ Evolution of Cement-based EBS	Participation in EC project CEBAMA	Completed	University of Sheffield PhD is complete and examined; we are awaiting receipt of the final version of the thesis. For the University of Surrey PhD, funding is complete and we are awaiting thesis submission. 30.4.010 now supersedes [1, Task 430].
[1, Task 431] in Near-field Evolution \ Evolution of Cement-based EBS	Rate and Extent of Reactions between NRVB and Robust Shielded Containers or Vitrified ILW.	Ongoing	[1, Task 431] is now superseded by Task 30.4.001. This Task is an experimental follow on study from [1, Task 418].
[1, Task 432] in Near-field Evolution \ Evolution of Cement-based EBS	Support to the Development and Implementation of Strategy for Management of NDA-owned Materials and Samples	Deleted	Since this work is related to the NDA archiving project, no technical development is involved, therefore the Task has been removed from the S&T Plan.
[1, Task 441] in Near-field Evolution \ Cement-based EBS Model and System Interactions	Acceptance Test and Further Development of the Near Field - Component Model	Completed, undergoing review	[1, Task 441] has been superseded by Task 30.4.006 in the 2020 S&T Plan and is currently undergoing peer review.
[1, Task 442] in Near-field Evolution \ Cement-based EBS Model and System Interactions	Effect of Ionising Radiation on Engineered Barrier System (EBS) Performance	Completed	A report has been published as an output of this Task [25].

Task 443 in Near-field Evolution \ Cement-based EBS Model and System Interactions	Study on Hydrogen Utilisation by Microbes in Cement-based Engineered Barrier Systems (EBS)	Deleted	This Task was part of the 2014 S&T Plan. This Task is no longer being undertaken as the PhD student has resigned.
[1, Task 444] in Near-field Evolution \ Cement-based EBS Model and System Interactions	Further Development of Near-field Component Model	Start date in FY22/23 (deferred start)	[1, Task 444] has been superseded by 30.4.007 in the 2020 S&T Plan. This Task has been deferred pending the outcome and publishing of [1, Task 441] (Task 30.4.006); further work will be considered based on this.
[1, Task 445] in Near-field Evolution \ Cement-based EBS Model and System Interactions	Further Investigation of the Effects of Ionising Radiation on Engineered Barrier System (EBS) Performance in Cement and Clay Systems (e.g. Effects on Redox, Organic Degradation Products, Microbial Processes, etc.)	Start date in FY22/23 (deferred start)	30.4.008 now supersedes [1, Task 445]. Scope of this Task is to be determined based on the outcome of [1, Task 442].
[1, Task 446] in Near-field Evolution \ Cement-based EBS Model and System Interactions	Application of Near-field Component Model Using Updated Understanding of Backfill Evolution	Start date in FY22/23 (deferred start)	Deferred pending the outcome of Task 30.4.006 (future Tasks in pipeline). 30.4.009 now supersedes [1, Task 446].
[1, Task 456] in Near-field Evolution \ Thermal Modelling of Heat-generating Processes	High Heat IPT: Data Collation for the Thermal Analysis of UK Design Concepts	Completed	A report has been published as the outcome of this Task [26].
[1, Task 457] in Near-field Evolution \ Thermal Modelling of Heat-generating Processes	High Heat IPT: 3D-Thermal Analysis Verification of Analytical Model	Completed	A report has been published as the outcome of this Task [26].
[1, Task 459] in Near-field Evolution \ Thermal Modelling of Heat-generating Processes	Thermal Modelling of Low-heat-generating Waste (LHGW) Disposal Areas	Completed	A report has been published as the output of this Task [27].

[1, Task 460] in Near-field Evolution \ Thermal Modelling of Heat-generating Processes	Thermal Modelling of High-heat-generating Waste - Scoping Analysis for Various Scenarios	Completed	A report has been published as the outcome of this Task [26].
[1, Task 461] in Near-field Evolution \ Evolution of Clay-based EBS	Modelling of Bentonite Resaturation using Data Provided from Aspo Underground Research Laboratory Under SKB Engineered Barrier System (EBS) Task Force and the FEBEX Dismantling Project	Completed	Report published [28].Work extended via new Task 30.3.005.
[1, Task 462] in Near-field Evolution \ Evolution of Clay-based EBS	Study on Diffusion Processes in Saturated Bentonite (e.g. Chloride, Sulphide) with Relevance to Corrosion	Completed	Report published [29]. Further work on the outcome of peer review is captured in new Task 30.3.005.
[1, Task 463] in Near-field Evolution \ Evolution of Clay-based EBS	EC BELBaR Study on Bentonite Erosion	Completed	A report was published as the output of this Task [30]. Work extended via new Task 30.3.005.
[1, Task 464] in Near-field Evolution \ Evolution of Clay-based EBS	Study of Bentonite Thermal Alteration, Including Participation in SKB ABM (Alternative Buffer Materials) Project	Completed	Task concluded via a PhD at University of Bristol [31]. Task 30.3.006 develops and extends the topic further.
[1, Task 465] in Near-field Evolution \ Evolution of Clay-based EBS	EPSRC GEOWASTE SAFE PROJECT WP 1: Development of a Mechanistic Understanding of the Steel-Clay Interface	Completed	A report was published as the output of this Task [32].
[1, Task 466] in Near-field Evolution \ Evolution of Clay-based EBS	Modelling and Laboratory Studies on Bentonite Homogenisation Upon Resaturation	Completed	Concluded. PhD Thesis by Imperial completed [33]. Topic extended via Work continued through Task 30.3.005.

[1, Task 467] in Near-field Evolution \ Evolution of Clay-based EBS	Study on Microbial Processes in Bentonite Systems, Including the Effect of Ionising Radiation and Swelling Pressure	Completed	PhD has been completed and papers prepared [34]. Work extended via Task 30.3.001.
[1, Task 468] in Near-field Evolution \ Evolution of Clay-based EBS	Review of International Work on Bentonite Erosion to Identify Future Research Needs	Start date in FY20/21 (deferred start)	Work continued via new Task 30.3.007.
[1, Task 469] in Near-field Evolution \ Evolution of Clay-based EBS	Further Validation of Bentonite Resaturation	Ongoing	Task superseded by new Task 30.3.005 , continuation work from [1, Task 461].
[1, Task 470] in Near-field Evolution \ Evolution of Clay-based EBS	Development of Mechanistic Understanding of Diffusion in Saturated Bentonite	Ongoing	The scope of this Task has been covered by new Task 30.3.006.
[1, Task 471] in Near-field Evolution \ Evolution of Clay-based EBS	Experimental and Modelling Studies on Bentonite Piping and Erosion	Ongoing	The scope of this Task has been subsumed by new Task 30.3.006.
[1, Task 472] in Near-field Evolution \ Evolution of Clay-based EBS	Experimental and Modelling Study on Alteration of Bentonite at Temperatures >100°C, Including the Possibility of Novel Formulations	Ongoing	Task superseded by Task 30.3.006.
[1, Task 473] in Near-field Evolution \ Evolution of Clay-based EBS	Validation of Bentonite Homogenisation Upon Resaturation in Realistic Conditions	Ongoing	The Task has been superseded by Task 30.3.005.
[1, Task 474] in Near-field Evolution \ Evolution of Clay-based EBS	Further Studies on Novel Clay Formulations (if Required)	Ongoing	Work ongoing through Task 30.3.006.
[1, Task 475] in Near-field Evolution \ Thermal Modelling of Heat-generating Processes	Maintenance and Development of the Thermal Dimensioning Tool (TDT)	Ongoing	[1, Task 475] is now superseded by Task 30.6.001.

Table C6: 2020 New Engineered Barrier Evolution Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 30.1.001	Engineered Barrier Evolution	EBS for LHGW	Integrated Project to Develop Backfill Materials for the Range of Geological Environments and Waste Types
Task 30.1.002	Engineered Barrier Evolution	EBS for LHGW	Identifying Options for Backfill
Task 30.1.003	Engineered Barrier Evolution	EBS for LHGW	Requirements and Backfill Formulation Guidance
Task 30.1.004	Engineered Barrier Evolution	EBS for LHGW	Consideration of Security of Supply and Sustainability of Backfill Materials
Task 30.1.005	Engineered Barrier Evolution	EBS for LHGW	Implications of gas Generation on Backfill Selection
Task 30.1.006	Engineered Barrier Evolution	EBS for LHGW	QA Aspects of Backfill Emplacement
Task 30.1.007	Engineered Barrier Evolution	EBS for LHGW	Practical Aspects of Backfill Emplacement
Task 30.1.008	Engineered Barrier Evolution	EBS for LHGW	Model Development to Support Backfill Selection
Task 30.1.009	Engineered Barrier Evolution	EBS for LHGW	Small-scale Testing of Backfills for HSR, LSSR and Evaporite
Task 30.1.010	Engineered Barrier Evolution	EBS for LHGW	Larger-scale Testing of Backfills for HSR, LSSR and Evaporite
Task 30.3.001	Engineered Barrier Evolution	Clay-based EBS	Microbiology in the Near-field
Task 30.3.002	Engineered Barrier Evolution	Clay-based EBS	Bentonite Sourcing for Clay-based EBS
Task 30.3.003	Engineered Barrier Evolution	Clay-based EBS	Bentonite Sourcing for Clay-based EBS follow on

Task 30.3.004	Engineered Barrier Evolution	Clay-based EBS	Development of a Clay EBS Material Characterisation
Task 30.3.005	Engineered Barrier Evolution	Clay-based EBS	EBS THM-C Coupled Process Model Development
Task 30.3.006	Engineered Barrier Evolution	Clay-based EBS	Impacts of High Temperatures on Clay-based EBS
Task 30.3.007	Engineered Barrier Evolution	Clay-based EBS	Piping and Erosion of Clay-based EBS - review
Task 30.3.008	Engineered Barrier Evolution	Clay-based EBS	Piping and Erosion of Clay-based EBS - follow on Task, laboratory and modelling programme
Task 30.4.002	Engineered Barrier Evolution	Cement-based EBS	Understanding the Impact of Alternative Wasteforms on Cement Backfill Performance
Task 30.4.003	Engineered Barrier Evolution	Cement-based EBS	Hydrothermal Treatment of Cement Backfill as a Method for Accelerated Cement Ageing
Task 30.4.012	Engineered Barrier Evolution	Cement-based EBS	Characterisation of Hydrothermally Aged Grout
Task 30.5.001	Engineered Barrier Evolution	Plugs and Seals	Integrated Project to Develop Plugs and Seals for the Range of Geological Environments and Waste Types

Table C7: 040 Gas Pathway

2016 Information	Title	Status	Comments

[1, Task 201] in Gas Pathway\C-14 Release from Irradiated Metals	EC CAST: WP2 Measurement of the C-14 Release Rate and Speciation from Irradiated Steels (Stainless, Mild and Inconel) in a Range of Aqueous Conditions	Completed	A report was published as the output of this Task [35].
[1, Task 202] in Gas Pathway\C-14 Release from Irradiated Metals	Manufacture and Commission Experimental Rig for CAST Stainless Steel Experiments	Completed	A report has been published as the output of this Task [35].
[1, Task 203] in Gas Pathway\C-14 Release from Irradiated Metals	C-14 IPT: Update model of C-14 Release from Irradiated Stainless Steel	Completed	A report was published as the output of this Task [35].
[1, Task 204] in Gas Pathway\C-14 Release from Irradiated Metals	C-14 IPT: Measurement of C-14 Release from Irradiated Reactive Metals (Magnox and Aluminium) to the Gas Phase	Completed	A report was published as the output of this Task [35].
[1, Task 205] in Gas Pathway\C-14 Release from Irradiated Metals	C-14 IPT: Capture Understanding of C-14 Release from Reactive Metals and Modelling of Package Re-saturation and Apply to Disposal Systems Concept Optioneering	Completed	A report was published as the output of this Task [36].
[1, Task 206] in Gas Pathway\C-14 Release from Irradiated Metals	EC CAST: WP3 Measurement of the C-14 Release Rate and Speciation from Irradiated Zircaloy in a Range of Aqueous Conditions	Completed	Relevant publication: [37], [38].
[1, Task 207] in Gas Pathway\C-14 Release from Irradiated Metals	EC CAST WP2 (UK Component): C-14 Release and Speciation from 316N (High Nitrogen) Stainless Steel Under pH12 Conditions	Completed	Relevant publication: [37].

[1, Task 208] Gas Pathway\C-14 Release from Irradiated Metals	Update Task with New Understanding of C-14 Release from Reactive Metals (Magnox, Al)	Completed	Relevant publication: [39].
[1, Task 209] in Gas Pathway\C-14 Release from Irradiated Metals	Experimental Study on Rate and Speciation of C-14 Release to the Gas Phase from Irradiated Uranium	Start date in FY22/23 (deferred start)	[1, Task 209] is now superseded by Task 40.2.001, Task deferred until necessary given the minor contribution to the C-14 source term from irradiated uranium we concluded at the time it would not be ALARP to initiate further experimental work at this time.
[1, Task 210] in Gas Pathway\C-14 Release from Irradiated Metals	Synthesis of Recent EPSRC and EC CAST Outputs in UK Context	Completed	Relevant publications: [32], [40].
[1, Task 211] in Gas Pathway\C-14 Release from Irradiated Metals	Update Task with New Understanding of C-14 Release from Irradiated Uranium	Superseded	[1, Task 211] subsumed into Task 40.2.001.
[1, Task 212] in Gas Pathway\C-14 Release from Irradiated Metals	Mechanistic Study on C-14 Release and Speciation from Zircaloy	Start date in FY24/25 (deferred start)	[1, Task 212] is now superseded by Task 40.2.002 and will be progressed on a site-specific basis if required, hence task deferral.
[1, Task 213]in Gas Pathway\C-14 Release from Irradiated Metals	Further Update Model of C-14 Release from Irradiated Stainless Steel	Completed, undergoing review	[1, Task 213] is now superseded by Task 40.2.003.
[1, Task 214] in Gas Pathway\C-14 Release from Irradiated Metals	Carbon-14 release from AGR steels	Start date in future (deferred start)	[1, Task 214] is now superseded by Task 40.2.004 will be progressed on a site-specific basis if required, hence task deferral.
[1, Task 226] in Gas Pathway\C-14 Release from Irradiated Graphite	EPSRC Geowaste: C14-BIG – Micro-distribution, Release and Fate of C-14 in Irradiated Graphite	Completed	Relevant publication: [32].

[1, Task 227] in Gas Pathway\C-14 Release from Irradiated Graphite	EC CAST: WP5 (Excl 5.4) Measurement of the C-14 Release Rate and Speciation from Irradiated Graphite in a Range of Aqueous Conditions (See Waste-form Evolution: Graphite for WP 5.4)	Completed	Relevant publication: [41].
[1, Task 228] in Gas Pathway\C-14 Release from Irradiated Graphite	C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite	Completed	Relevant publication: [42].
[1, Task 229] in Gas Pathway\C-14 Release from Irradiated Graphite	C-14 IPT: Further Measurements on Release of C-14 from i-Graphite	Completed	Relevant publication: [42].
[1, Task 230] Gas Pathway\C-14 Release from Irradiated Graphite	C-14 IPT: Benefits of Graphite Segregation	Completed	Relevant publication: [42].
[1, Task 231] in Gas Pathway\C-14 Release from Irradiated Graphite	Update to Data and Model of C-14 Release from Irradiated Graphite	Completed	Relevant publication: [42].
[1, Task 232] in Gas Pathway\C-14 Release from Irradiated Graphite	Studies of C-14 Release from Irradiated Graphite from Reactors Other Than Oldbury	Ongoing	[1, Task 232] is now superseded by Task 40.2.006.
[1, Task 241] in C-14 Release from Other Sources	EC CAST: WP4 Measurement of the C-14 Release Rate and Speciation from Spent Ion-Exchange Resins from Light Water Reactor Systems in a Range of Aqueous Conditions	Completed	Relevant publication: [43].
[1, Task 242] in C-14 Release from Other Sources0	Mechanistic Study on C-14 Release and Speciation from Ion-Exchange Resins	Completed, undergoing review	[1, Task 242] is now superseded by Task 40.2.007.

[1, Task 251] in System Modelling for C-14	EC CAST: WP6 International Evaluation of Safety Case Approaches to C-14 Release	Completed	Relevant publication: [44].
[1, Task 252] in System Modelling for C-14	C-14 IPT: Integrate Revised Data & Understanding & Determine Impact on Operational & Post-Closure Safety Cases	Completed	Relevant publication: [45].
[1, Task 253] in System Modelling for C-14	C-14 IPT: Synthesis of Knowledge Gained from C-14 IPT	Completed	Relevant publication: [35].
[1, Task 261] in Gas Pathway\Other Radioactive Gases	Radon Emanation from Polymer Encapsulated Wastes	Start date in FY21/22 (deferred start)	[1, Task 261] is now superseded by Task 40.2.008, Task considered to be of low priority, re prioritisation of internal resources.
[1, Task 266] in Gas Pathway\Bulk Gas Generation	Gas Generation from Microbial Degradation of Organic Wastes Including Cellulose	Start date in FY21/22 (deferred start)	[1, Task 266] is now superseded by Task 40.2.009. Task considered to be of low priority, re prioritisation of internal resources
[1, Task 267] in Gas Pathway\Bulk Gas Generation	Review of Bulk Gas Generation from Corrosion, Radiolysis and Microbial Action	Start date in FY24/25 (deferred start)	[1, Task 267] is now superseded by 40.2.010This Task will proceed on the outcome of Task 40.2.009.
[1, Task 268] in Gas Pathway\Bulk Gas Generation	Progress Understanding of G-values in Relation to Gas Generation from Radiolysis.	Completed	Relevant publication: [46].
[1, Task 276] in Gas Pathway\Gas Migration Through Cement-based EBS Materials	C-14 IPT: C-14 Migration Through the Cementitious EBS	Completed	Relevant publication: [47].
[1, Task 277] in Gas Pathway\Gas Migration Through Cement-based EBS Materials	Experimental Study on Gas Interactions with the Package Vent and Curing Backfill	Completed	Relevant publication: [48].

Task 278 in Gas Pathway\Gas Migration Through Cement-based EBS Materials	Review of Benefits of ECFORGE Project to Gas Migration in Cementitious EBS Knowledge Base	Deleted	Task considered not to be necessary at this time, therefore Task deleted due to programme re-prioritisation.
[1, Task 280] in Gas Pathway\Gas Migration Through Cement-based EBS Materials	Review of Approaches to the Management of Gas During the Operational and Post-Closure Phases	Start date in FY23/24 (deferred start)	[1, Task 280] is now superseded by Task 40.1.001. Task is deferred to site-specific stage as approach is more beneficial in order to progress the work area.
[1, Task 282] in Gas Pathway\Gas Migration Through Cement-based EBS Materials	Implications of Understanding from Task 277 for Conceptual Model of Gas Interactions with the Package Vent and Curing Backfill	Completed	Relevant publication: [48].
Task 286 in Gas Pathway\Gas Migration Through Cement-based EBS Materials	Review of Benefits of EC FORGE Project to Gas Migration in Clay EBS Knowledge Base	Deleted	Task considered not to be necessary at this time, therefore Task deleted due to the prioritisation of internal resources.
[1, Task 287] in Gas Pathway\Gas Migration Through Cement-based EBS Materials	EPSRC GEOWASTE: Gas Flow in Saturated Bentonite at Elevated Temperature	Completed	Relevant publication: [32].
[1, Task 288] in Gas Pathway\Gas Migration Through Cement-based EBS Materials	Experimental Study of Gas Migration Through Clay to Investigate the Gas Migration Mechanism in Bentonite	Completed	Relevant publication: [49].
[1, Task 289] in Gas Pathway\Gas Migration Through Cement-based EBS Materials	LASGIT (Large-scale Gas Injection Test) International Collaborative Project at Aspo URL	Ongoing	[1, Task 289] is now superseded by Task 40.3.001.
[1, Task 297] in Gas Pathway\Gas Migration Through the Geosphere	C-14 IPT: Understanding of the Envelope of Geological Environments in which C-14 Bearing Wastes can be Managed Safely	Completed	Relevant publications: [35].

[1, Task 298] in Gas Pathway\Gas Migration Through the Geosphere	Holistic Review of Gas Consumption / Sinks in the Geosphere	Completed	Task concluded and published. Topic ongoing via Mont Terri (HT Task).Relevant publication: [50].

Table C8: 2020 New Gas Pathway Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 40.001	Geosphere	Preparatory Geosphere Studies to Facilitate Site-specific Characterisation and Investigation (to include thermal, mechanical and chemical, etc processes)	Development of Strategy for Generic to Site-specific Geosphere and Gas Research Transitioning
Task 40.3.002	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Mechanistic Understanding of Gas Transport in Clay Materials (GAS) EC EURAD
Task 40.3.003	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	GDF-derived Gas Migration through Salt Host Rock and Interactions with Salt-bearing Geological Environments
Task 40.3.004	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Bentonite Permeability under Relevant Material Conditions
Task 40.3.005	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Assessment of GDF-induced Effects in a Evaporite: Excavation Damaged Zone (EDZ) Formation, Evolution and Effect on Gas Migration

Task 40.3.006	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Assessment of GDF-induced Effects in a Lower Strength Sedimentary Rock (LSSR): Excavation Damaged Zone (EDZ) Formation, Evolution and Effect on Gas Migration
Task 40.3.007	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Assessment of GDF-induced Effects in High Strength Rock (HSR): Excavation Damaged Zone (EDZ) Formation, Evolution and Effect on Gas Migration
Task 40.3.008	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Gas Migration in a Tight Fractured Rock and Gas Hold-up by Cap Rocks (HSR)
Task 40.3.009	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Gas Migration in Cementitious Backfills (HSR and LSSR)
Task 40.3.010	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Gas Migration in Clay (LSSR)
Task 40.3.011	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Gas Migration in a Bedded Salt
Task 40.3.012	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Gas Migration through Plugs and Seals
Task 40.3.013	Gas Pathway	Develop Generic Knowledge Base on Gas Migration and Reaction	Gas Migration Processes in Clay Materials (e.g. Bentonite Buffers) (HSR and LSSR)
Task 40.4.001	Gas Pathway	Development of gas related conceptual models and numerical solutions (modelling)	Ongoing Development of SMOGG Toolkit

Table C9: 050 Geosphere

2016 Information	Title	Status	Comments
[1, Task 331] in Geosphere \ Tectonics and Seismicity	NERC RATE (HydroFrame) WP2: Integrated Seismic and Thermal-Hydraulic-Mechanical (THM) Simulation for Time Lapse Monitoring of Repository Sites	Completed	Relevant publication: [51].
[1, Task 332] in Geosphere \ Tectonics and Seismicity	NERC RATE (HydroFrame) WP3: Seismic Modelling of Fracture Response to Inform Survey Designs for Repositories	Completed	Relevant publication: [51].
[1, Task 333] in Geosphere \ Tectonics and Seismicity	Periodic Review of the Potential Impact of Natural Processes on a GDF – Tectonics & Seismicity	Start date in FY21/22 (deferred start)fu	[1, Task 333] is now superseded by Task 50.1.001, Task deferred as a site-specific approach is more beneficial to the work area.
[1, Task 336] in Geosphere \ Uplift, Errosion and Subsidence	Periodic Review of the Potential Impact of Natural Processes on a GDF – Uplift, Erosion & Subsidence	Start date in future (deferred start)	[1, Task 336] is now superseded by Task 50.1.002, Task deferred as a site-specific.
[1, Task 341] in Geosphere \ Impacts of Future Climate Change	Application of Permafrost Modelling Methodology: Consideration of Implications	Start date in FY20/21 (deferred start)	[1, Task 341] is now superseded by Task 50.1.003. Site-specifc stage.
[1, Task 342] in Geosphere \ Impacts of Future Climate Change	Periodic Review of the Potential Impact of Natural Processes on a GDF - Climate Change	Start date in future (deferred start)	[1, Task 342] is now superseded by Task 50.1.004, Task deferred as a site-specific approach is more beneficial to the work area.
[1, Task 343] in Geosphere \ Impacts of Future Climate Change	PhD to Investigate Signatures of Past Permafrost in Rocks	Ongoing	[1, Task 343] is now superseded by Task 50.1.005.

[1, Task 351] in Geosphere \ Thermal Processes	Impacts of Thermal Uplift Associated with an Evolving GDF	Completed	Relevant publications: [52], [53].
[1, Task 356] in Geosphere \ Hydrogeological Processes	Demonstration of Long-term Borehole Sealing	Completed	Relevant publication: [54].Phase 4 continued through new Task 50.4.005.
[1, Task 358] in Geosphere \ Hydrogeological Processes	Development of Generic Geological Environments	Completed	Final report: [55].
[1, Task 359] in Geosphere \ Hydrogeological Processes	Using Isotopes for Groundwater Ageing and Development of a Site Descriptive Model	Superseded	Task partially concluded by completion of LASMO project, University of Strathclyde PhD thesis/papers completed Dec 2019. Subsumed into new 50.5.008.
[1, Task 360] in Geosphere \ Hydrogeological Processes	Specification of Parameter Values Relevant to Generic Geological Environments	Completed	Final report: [55].
[1, Task 361] in Geosphere \ Hydrogeological Processes	Field-scale Borehole Sealing Experiment: Demonstration of Practicability of Approaches	Completed	Phase 4 continued through new Task 50.4.005.
[1, Task 363] in Geosphere \ Hydrogeological Processes	Status of Knowledge Review of Groundwater and Groundwater Chemistry Research	Completed	Report published: [56].
[1, Task 366] in Geosphere \ Mechanical Processes	Stress-induced anisotropy in crustal rocks and its influence on underground excavations	Start date in FY21/22 (deferred start)	[1, Task 366] is now superseded by 50.2.001, to be progressed based on the outcome of [1, Task 351], with a site-specific approach, hence the Task delay.
Task 371 in Geosphere \ Chemical Processes	UK Hydrogeochemistry at Depth: Collation of Knowledge Base and Generation of a ’Map’	Deleted	This Task has been deleted because it is superseded by work that is being undertaken as part of the National Geological Screening exercise.

[1, Task 372] in Geosphere \ Chemical Processes	Review of Understanding and Approach to Modelling Rock Matrix Diffusion (RMD)	Ongoing	[1, Task 372] is now superseded by Task 50.4.001.
[1, Task 373] in Geosphere \ Chemical Processes	Knowledge Capture - Summary Paper Collating Learning and Experience from EC PADAMOT Project (Palaeohydrogeology-basis)	Completed	Final report: [57].
[1, Task 381] in Geosphere \ Coupled Processes	Long-term Cement Study (LCS) at Grimsel Test Site, Including Consideration of the Cyprus Natural Analogue Project Dataset	Completed	Final report: [58].
Task 382 in Geosphere \ Coupled Processes	Impacts of Microbes on Hydrogeological Properties	Completed	PhD (The impact of hyperalkaline fluids from a geological radioactive waste repository on the biological and physical characteristics of the host rock environment) concluded at the University of Manchester [59].
[1, Task 384] in Geosphere \ Coupled Processes	DECOVALEX: Laboratory Study of the Interaction of a Groundwater with a Fresh Fracture	Completed	Final report: [60].
[1, Task 385] in Geosphere \ Coupled Processes	DECOVALEX: SEALEX Experiment at Tournemire URL Investigating Resaturation of Bentonite Plugs (Hydro-mechanical)	Completed	Final report: [60].
[1, Task 386] in Geosphere \ Coupled Processes	EPSRC GEOWASTE WP2: Behaviour of the Clay-Grout-Rock Interfaces	Completed	Final report: [32].

[1, Task 387] in Geosphere \ Coupled Processes	EPSRC GEOWASTE WP3: Thermal-Hydraulic-Mechanical-Chemical (THMC) Processes in Bentonite at Temperatures in Excess of 100°C (up to 150°C)	Completed	Final report: [32].
[1, Task 388] in Geosphere \ Coupled Processes	EPSRC GEOWASTE WP5: THMC Behaviour of Bentonite Along Block Interfaces	Completed	Final report: [32].
[1, Task 389] in Geosphere \ Coupled Processes	EPSRC GEOWASTE WP8: Modelling of Bentonite Behaviour	Completed	Final report: [32].
[1, Task 390] in Geosphere \ Coupled Processes	NERC RATE (HydroFrame) WP1: Hydraulic Transmissivity of Geologically Realistic Fracture Networks	Completed	Relevant publications: [61]–[63].
[1, Task 391] in Geosphere \ Coupled Processes	NERC RATE (HydroFrame) WP4: Hydro-thermo-mechanical and Fracturing Processes in Fractured Rocks Around a Repository	Completed	Clement Joulin
[1, Task 392] in Geosphere \ Coupled Processes	NERC RATE Hydroframe Project WP6: Do Microbes and Natural Organic Matter Lead to Increased Actinide Mobility in Fractured Rocks?	Completed	Matthew Kirby- ICLRelevant publication: [61].
[1, Task 393] in Geosphere \ Coupled Processes	Review of Implications of Extended GDF Operations on Geosphere Properties	Completed	Final report: [64], [65].
[1, Task 394] in Geosphere \ Coupled Processes	Co-locating Disposal Modules of a GDF – Derivation of Approach to Determine Separation Distances	Completed	Final report: [66].

[1, Task 395] in Geosphere \ Coupled Processes	LASMO: Hydrogeochemical Modelling in Response to Rock-mass Perturbations (Loading / Unloading) at the Grimsel Test Site	Completed	PhD (Exploring subsurface groundwater and geochemical rock interactions during drainage of a surface water reservoir in Switzerland) concluded. Awaiting publication of thesis on University of Strathclyde website.
[1, Task 396] in Geosphere \ Coupled Processes	Natural Analogue and Modelling Study of the Implications of GDF Operations on Geosphere Host Rock Properties	Ongoing	[1, Task 396] is now superseded by Task 50.2.002.
[1, Task 397] in Geosphere \ Coupled Processes	Consolidation of Knowledge Gained from Natural Analogue Studies, based on our Natural Analogue Catalogue	Start date in FY20/21 (deferred start)	[1, Task 397] is now superseded by Task 50.4.002. Task to be progressed on the outcome of Task 50.2.002.
[1, Task 399] in Geosphere \ Coupled Processes	Further Modelling and Benchmarking of Hydrochemical Processes in the Real Fractured Rock Environment (DECOVALEX D-2019)	Completed	Final report: [67], [68]. DECOVALEX 2023 is continued through Tasks: Task 50.3.002, Task 50.3.003, Task 50.3.004.
[1, Task 400] in Geosphere \ Coupled Processes	Further Modelling and Benchmarking of Clay THMC Processes in a Clay-based Environment (DECOVALEX D-2019)	Completed	Relevant publication: [67], [68]. DECOVALEX 2023 is continued through Tasks: Task 50.3.002, Task 50.3.003, Task 50.3.004.
[1, Task 401] in Geosphere \ Coupled Processes	Modelling the Evolution of the Alkali-disturbed Zone in Fractured Rock	Start date in FY20/21 (deferred start)	[1, Task 401] is now superseded by Task 50.3.001. Task deferred until a site-specific GDF basis stage in order to progress work area.
[1, Task 402] in Geosphere \ Coupled Processes	Impact of Ductile Cast Iron Containers and Polymer Encapsulants on Geosphere Performance	Deleted	Task 402 is no longer considered to be necessary.

[1, Task 404] in Geosphere \ Coupled Processes	EC Modern 2020 Project: Approaches to Monitoring Relevant to GDF Operational Period	Ongoing	[1, Task 404] is now superseded by Task 50.4.003.
[1, Task 405] in Geosphere \ Coupled Processes	EPSRC GEOWASTE: Application and Development of MEMS Wireless Technologies for Experimental Monitoring in Bentonite	Completed	Final report: [32].
[1, Task 406] in Geosphere \ Coupled Processes	EPSRC GEOWASTE: Development of Magnetic Sensors for Monitoring Bentonite Resaturation	Completed	Final report: [32].

Table C10: 2020 New Geosphere Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 50.1.006	Geosphere	Develop Generic Understanding of Potential Implications of Present and Future Large-scale Natural Processes for a UK GDF	CatchNet (Catchment transport and Cryo-hydrology Network
Task 50.1.007	Geosphere	Develop Generic Understanding of Potential Implications of Present and Future Large-scale Natural Processes for a UK GDF	Strategy for Considering Long-term Transients in the Environmental Safety Case and Supporting Assessment Studies
Task 50.2.003	Geosphere	Develop Generic Understanding of GDF-induced Impacts on the Geosphere	Copper Stability Natural Analogues Study (Keweenaw Peninsula, Michigan, USA – “Michigan International Copper Analogue Project”)

Task 50.2.004	Geosphere	Develop Generic Understanding of GDF-induced Impacts on the Geosphere	Host Rock Thickness, GDF Vault/Tunnel/Cavern Height and Choice of EBS Materials - Determination of Inter-relationships to Ensure Delivery of Isolation and Containment Safety Functions
Task 50.3.002	Geosphere	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)	DECOVALEX D2023: Task A ”Heat and Gas Fracturing Initiation in Claystone”
Task 50.3.003	Geosphere	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)	DECOVALEX D2023: Heated Brine Availability Test in Salt (BATS)
Task 50.3.004	Geosphere	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)	DECOVALEX 2023: Safety Implications of Fluid Flow, Shear, Thermal and Reaction Processes within Crystalline Rock
Task 50.3.005	Geosphere	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)	PhD: ”Modelling the Behaviour of Compacted Bentonite at High Temperatures”
Task 50.3.006	Geosphere	Development of Geosphere Conceptual Models and Numerical Solutions (Modelling)	DECOVALEX: Future Phases
Task 50.4.004	Geosphere	Preparatory Geosphere Studies to Facilitate Site-specific Characterisation and Investigation (to include thermal, mechanical and chemical, etc processes)	Kiruna Natural Analogue Project (KiNa)
Task 50.4.005	Geosphere	Preparatory Geosphere Studies to Facilitate Site-specific Characterisation and Investigation (to include thermal, mechanical and chemical, etc processes)	Sealing Deep Site Investigation Boreholes

Task 50.5.001	Geosphere	Groundwater Tools, Techniques and Methods	Assessment of Repository-induced Effects in a Clay Host Rock: EDZ Formation and Impact on Flow (LSSR)
Task 50.5.002	Geosphere	Groundwater Tools, Techniques and Methods	Tools, Equipment and Techniques for Collecting and Using Groundwater Information to Support GDF Programmes
Task 50.5.003	Geosphere	Groundwater Tools, Techniques and Methods	Conceptualisation and Numerical Representation of Groundwater Migration in HSR
Task 50.5.004	Geosphere	Groundwater Tools, Techniques and Methods	Conceptualisation and Numerical Representation of Groundwater Migration in LSSR
Task 50.5.005	Geosphere	Groundwater Tools, Techniques and Methods	Site Suitability Considerations
Task 50.5.006	Geosphere	Groundwater Tools, Techniques and Methods	Ground Support Methodologies in LSSR
Task 50.5.007	Geosphere	Groundwater Tools, Techniques and Methods	Use of Groundwater Chemistry in GDF Programmes

Table C11: 2020 New Modelling and Treatment of Uncertainty Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 70.1.001	Modelling and Treatment of Uncertainty	Analytical Advice Provision	Watching Brief on Methodologies for Modelling and Uncertainty
Task 70.2.001	Modelling and Treatment of Uncertainty	Modelling and Treatment of Uncertainty	Modelling Strategy Roadmap

Table C12: 080 Groundwater Pathway for Radionuclides and Non-radiological Species

2016 Information	Title	Status	Comments
[1, Task 51] in Non-radiological Species\Non-radiological Species	Development of Supporting Information for Post-closure Non-radiological Assessment	Deleted	This Task has been superseded by the non-rad integrated programme (IPT) (Task 10.5.002).
[1, Task 52] in Non-radiological Species\Non-radiological Species	Consideration of Chemotoxic Non-radiological Species in Post-Closure Safety	Deleted	This Task has been superseded by the non-rad integrated programme (IPT) (Task 10.5.002).
[1, Task 53] in Non-radiological Species\Non-radiological Species	Further Development of Approach to Chemotoxic Non-radiological Species in Post-Closure Safety	Deleted	This Task has been superseded by the non-rad integrated programme (IPT) (Task 10.5.002).
[1, Task 54] in Non-radiological Species\Non-radiological Species	Potential Synergistic Effects Resulting from Exposures to Mixtures of Radiotoxic and Chemically-toxic Substances	Deleted	This Task has been superseded by Task 10.5.001.
[1, Task 736] in Radionuclide Behaviour \ Radionuclide Behaviour in the EBS	Laboratory Demonstration of Chemical Containment	Completed, undergoing review	Work extended via Task 80.3.001.
[1, Task 737] in Radionuclide Behaviour \ Radionuclide Behaviour in the EBS	Mechanisms of Chemical Containment - Scoping Study (U, Ni + TBC)	Completed, undergoing review	Work extended via Task 80.3.001.
[1, Task 738] in Radionuclide Behaviour \ Radionuclide Behaviour in the EBS	EPSRC GEOWASTE (AMASS): Mechanistic Studies of Engineered Barrier System (EBS) Surface Interactions - Mineral Surface Evolution	Completed	Relevant publications: [32], [69]–[71].
[1, Task 739] in Radionuclide Behaviour \ Radionuclide Behaviour in the EBS	Review and Testing of Sorption Processes in Clay Backfills	Start date in FY25/26 (deferred start)	[1, Task 739] is now superseded by Task 80.2.007.

[1, Task 740] in Radionuclide Behaviour \ Radionuclide Behaviour in the EBS	Mechanism of Chemical Containment in Aged Cements for a Range of Key Radionuclides	Start date in FY24/25 (deferred start)	[1, Task 740] is now superseded by Task 80.3.002.
[1, Task 741] in Radionuclide Behaviour \ Radionuclide Behaviour in the EBS	Mechanistic Study of Sorption Processes in UK Engineered Barrier System Components	Start date in FY21/22 (deferred start)	Work is planned for FY21/22 and [1, Task 741] is now superseded by Task 80.2.005 and Task 80.2.006.
[1, Task 751] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Study Cellulose Degradation Product (CDP) Metabolism by Micro-organisms and Consequent Impact on Radionuclide Mobility	Completed	Manchester PhD project completed. [72]–[74]
[1, Task 752] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Assessment of the Impact of PVC Degradation Products on Radionuclide Mobility (using U, Ni & Pu)	Completed	Final report published July 2017 [75].
[1, Task 753] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Colloids: The Effect of Non-Clay Colloids on Radionuclide Mobility	Completed	PhD completed and published [76].
[1, Task 754] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Colloids: EC BELBaR - Laboratory Study of the Effect of Bentonite Colloids on Radionuclide Mobility	Completed	BELBaR Project now finished (Feb 2016), final report published [77].
[1, Task 755] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Colloids: Colloid Formation and Migration (CFM) Experiment – Underground Rock Laboratory (URL) Hot Migration Study on the Effect of Bentonite Colloids on Radionuclide Mobility	Ongoing	[1, Task 755] has now been superseded by Task 80.7.005.

[1, Task 756] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	NERC RATE (Imperial): Development of Coupled Process Models of Tracer and Colloidal Transport at the Grimsel URL	Completed, undergoing review	PhD concluded.
[1, Task 757] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Testing and Selection of Candidate Super-plasticisers	Completed	Final report: [78].
[1, Task 758] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Development of Process Model for Cellulose Degradation Product (CDP) Behaviour in the Near Field	Start date in FY23/24 (deferred start)	[1, Task 758] superseded by Task 80.5.012.
[1, Task 759] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Review of Potential Superplasticiser Inventory in Decommissioned Building Materials	Deleted	Task deleted due to programme re-prioritisation.
[1, Task 760] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Application of Knowledge Gained through BIGRAD (Biogeochemical Gradients and Radionuclide Transport)	Completed	Report published. Summary of the BIGRAD project and its implications for a geological disposal facility [79].
[1, Task 761] Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Detailed Evaluation of the Performance of a Candidate Superplasticiser for Waste Encapsulation	Completed	Final report [80], [81].
[1, Task 762] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Synthesis Report on Colloidal Understanding	Start date in FY21/22 (deferred start)	Programme optimisation/ re-prioritisation of internal resourcesTask deferred due to prioritisation of internal resources and [1, Task 762] replaced by new Task 80.5.004.
[1, Task 763] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Review of Organic Additives to Cement Powders (e.g. Grinding Agents)	Start date in FY22/23 (deferred start)	Programme optimisation/re-prioritisation of internal resources. [1, Task 763] replaced by new Task 80.5.010.

[1, Task 764] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Update Process Model - Understanding of Cellulose Degradation Product (CDP) Metabolism	Start date in FY24/25 (deferred start)	Programme optimisation/re-prioritisation of internal resources. [1, Task 764] superseded by new Task 80.5.013.
[1, Task 765] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Review of Superplasticisers for GDF Construction	Start date in FY22/23 (deferred start)	[1, Task 765] superseded by new Task 80.5.009.
[1, Task 766] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Investigation of Whether the Effect of Organics, Colloids and Microbes on Radionuclide Solubility are Additive	Superseded	Work SDIF. [1, Task 766] superseded by new Task 80.3.001.
[1, Task 767] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Experimental Screening Study of Radionuclide Behaviour in the Presence of Potential Complexants	Start date in FY24/25 (deferred start)	[1, Task 767] superseded by new Task 80.5.011.
[1, Task 768] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Synthesis Report on Microbial Understanding	Start date in superseded	[1, Task 768] now superseded by new Task 80.5.004.
[1, Task 769] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Update Synthesis Report on Colloidal Understanding	Ongoing/start date in future	[1, Task 769] superseded by new Task 80.5.006.
[1, Task 770] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Underground Research Laboratory (URL)-based Hot Migration Test to Validate Superplasticiser Performance	Completed	Negated due to prior work.
[1, Task 771] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Environmental Limits of Methanogenesis and Sulphate Reduction	Completed	PhD project concluded. Thesis available at: [82].
[1, Task 772] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Long-term Fate of Radionuclides During Sulfidation.	Completed	PhD project concluded [83].

[1, Task 773] in Radionuclide Behaviour \ Other Influences Radionuclide Behaviour	Microbial niches in the ILW near field	Completed	PhD project concluded.
[1, Task 786] in Radionuclide Behaviour \ Radionuclide behaviour in the Geosphere	NERC RATE Lo-RISE - Physicochemical Speciation and Transport	Completed	NERC RATE Lo-Rise concluded, see summary report: [6].
[1, Task 787] in Radionuclide Behaviour \ Radionuclide behaviour in the Geosphere	NERC RATE Lo-RISE - Ecological Transfers and Transformations	Completed	NERC RATE Lo-Rise concluded, see summary report: [6].
[1, Task 788] in Radionuclide Behaviour \ Radionuclide behaviour in the Geosphere	NERC RATE Lo-RISE: Cross Cutting Multi-scale Modelling	Completed	NERC RATE Lo-Rise concluded, see summary report: [6].
[1, Task 789] in Radionuclide Behaviour \ Radionuclide behaviour in the Geosphere	Application of Lo-RISE Outputs in the GDF Context	Start date in FY21/22 (deferred start)	[1, Task 789] now superseded by new Task 80.5.014 and Task 80.5.015.
[1, Task 790] in Radionuclide Behaviour \ Radionuclide behaviour in the Geosphere	Laboratory / In Situ Studies to Address any Key Radionuclide Behaviour Uncertainties Arising from Lo-RISE	Start date in FY24/25 (deferred start)	[1, Task 790] superseded by Task 80.5.015.
[1, Task 796] in Radionuclide Behaviour \ Representation of Radionuclide Behaviour in Assessment Models	Uranium Integrated Project Team (IPT): Improved Data Set for Depleted Natural and Low Enriched Uranium (DNLEU) and Daughter Elements in the Nearfield	Completed	Report: [84].
[1, Task 797] in Radionuclide Behaviour \ Representation of Radionuclide Behaviour in Assessment Models	Uranium Integrated Project Team (IPT): Improved Data Set for Depleted Natural Low-Enriched Uranium (U) and Daughter Elements in the Far-Field	Completed	Report: [84].

[1, Task 798] in Radionuclide Behaviour \ Representation of Radionuclide Behaviour in Assessment Models	Uranium Integrated Project Team (IPT): Review UK Solubility and Sorption Parameters for Uranium (U) and its Daughter Elements	Completed, undergoing review	Report [85].
Task 799 in Radionuclide Behaviour \ Representation of Radionuclide Behaviour in Assessment Models	Strategy for data Elicitation during the Focussing Phase	Deleted	This Task was originally part of the 2014 S&T Plan. Task deleted as it duplicates [1, Task 898].
[1, Task 800] in Radionuclide Behaviour \ Representation of Radionuclide Behaviour in Assessment Models	Data Elicitation for High Priority Radionuclide Sorption Parameters (e.g. Tc, U other long-lived HLW radionuclides)	Start date in FY24/25 (deferred start)	[1, Task 800] superseded by new Task 80.2.008.
[1, Task 801] in Radionuclide Behaviour \ Representation of Radionuclide Behaviour in Assessment Models	Data Elicitation for Other Radionuclide Sorption Parameters	Start date in FY24/25 (deferred start)	[1, Task 801] superseded by new Task 80.2.009.
[1, Task 802] in Radionuclide Behaviour \ Representation of Radionuclide Behaviour in Assessment Models	Review of the Use of Beta Values	Ongoing	[1, Task 802] superseded by Task 80.7.005.
[1, Task 806] Radionuclide Behaviour \ Development of Thermodynamic Database	NEA Thermodynamic Database (TDB): Development of Internationally Recommended High Quality Thermodynamic Data Parameters (Actinide Update, Cement Phases, High Ionic Strength Media and High Temperature Corrections)	Completed	Phase 5 concluded, Phase 6 (Task 80.1.001)Website states phase 5 should end March 2018

[1, Task 807] in Radionuclide Behaviour \ Development of Thermodynamic Database	Database Maintenance Including Updates From Reviews and Experiments on Elements of Importance Within Near Field and Geosphere	Ongoing	[1, Task 807] is now superseded by Task 80.1.002.
[1, Task 808] in Radionuclide Behaviour \ Development of Thermodynamic Database	NEA Thermodynamic Database (TDB): Further Development of Internationally Recommended High Quality Thermodynamic Data Parameters (Actinide Update, Cement Phases, High Ionic Strength Media and High Temperature Corrections	Ongoing	[1, Task 808] is now superseded by Task 80.1.001.
[1, Task 809] in Radionuclide Behaviour \ Development of Thermodynamic Database	Further Database Maintenance Including Updates From Reviews and Experiments on Elements of Importance Within the Near Field and Geosphere	Ongoing	[1, Task 809] is now superseded by Task 80.1.002.
[1, Task 816] in Radionuclide Behaviour \ Development and Maintenance of Thermodynamic Models	Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour	Start date in FY25/26 (deferred start)	Task deferred as it will be progressed, following the outputs of Task 80.5.004 and Task 80.5.005. [1, Task 816] superseded by Task 80.5.007.
[1, Task 817] in Radionuclide Behaviour \ Development and Maintenance of Thermodynamic Models	Update to Process Model for Colloidal / Microbial Processes	Start date in FY28/29 (deferred start)	Task deferred as it will be progressed, following the outputs of Task 80.5.004, Task 80.5.005 and Task 80.5.007. [1, Task 817] superseded by Task 80.5.008.

Table C13: 2020 New Groundwater Pathway for Radionuclide and Non-radiological Species

2020 Task Number	WBS 4	WBS 5	Task Title
Task 80.2.001	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System	International Knowledge Capture and Review of Radionuclide Behaviour in an Evaporite Setting
Task 80.2.002	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System	Further Experimental/Modelling Study to Understand Radionuclide Behaviour in an Evaporite Setting
Task 80.2.003	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System	Development of Thermodynamic Database Capabilities to Represent Evaporitic Environments
Task 80.2.010	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Generic Understanding of the Behaviour of Radionuclide and Non-radionuclide Species in a GDF System	Development of an Advanced Mechanistic Understanding of Radionuclide Behaviour
Task 80.3.001	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Radionuclide behaviour in the EBS	Further Demonstration of Chemical Containment
Task 80.4.001	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Radionuclide behaviour in the Geosphere	High Solubility Radionuclide Sinks in the Geosphere
Task 80.4.002	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Radionuclide behaviour in the Geosphere	Towards a Mechanistic Understanding of the Long Term Mobility and Fate of Technetium-99
Task 80.4.003	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Radionuclide behaviour in the Geosphere	The Impact of Groundwater Chemistry Fluxes on Radionuclide Transport and Sorption

Task 80.5.001	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	The Role of Microbes in Different Disposal Concepts and its Impact of Performance Assessment Modelling
Task 80.5.002	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Further Experimental Studies to Understand the Role of Microbes in Different Disposal Concepts
Task 80.5.003	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Determine the pH Limit for the Methanogenesis of Calcite
Task 80.5.004	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Synthesis Report on Colloidal Understanding
Task 80.5.005	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Further Understanding of the Effect of Colloids on Radionuclide Mobility
Task 80.5.006	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Update Synthesis Report on Colloidal Understanding
Task 80.5.008	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Update to Process Model for Colloidal/Microbial Processes
Task 80.5.010	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Review of Organic Additives to Cement Powders (e.g. Grinding Agents)
Task 80.5.011	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Experimental Screening Study of Radionuclide Behaviour in the Presence of Potential Complexants

Task 80.5.012	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Development of a Process Model for Cellulose Degradation Product (CDP) Behaviour in the Near Field
Task 80.5.014	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	NERC RATE Lo-RISE: Review of Findings
Task 80.5.015	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of Other Influences on Radionuclide Behaviour	Follow on from NERC RATE Lo-RISE: Review of Findings
Task 80.6.001	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research	Understanding the Laboratory Capacity and Methodologies Required for Site Characterisation
Task 80.6.002	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research	Development of a Gated Workflow for Site-specific Radionuclide Behaviour Analysis
Task 80.6.003	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research	Procurement of Laboratory Equipment and Execution of a Site-specific Experimental Programme
Task 80.6.004	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Capability, Infrastructure and Skills Required for Radionuclide and Non-radionuclide Research	Develop Experimental Methodologies for the Measurement of Site-specific and Other Safety Relevant Radionuclide Behaviour Parameters
Task 80.6.005	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Capability, Infrastructure, and Skills Required for Radionuclide and Non-radionuclide Research	Further Development of Methodologies for Measurement of Site-specific and Other Safety Relevant Radionuclide Behaviour Parameters

Task 80.6.006	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Capability, Infrastructure and Skills Required for Radionuclide and Non-radionuclide Research	Develop Capability to Perform In-situ Experiments on Strongly Sorbing Elements
Task 80.7.001	Groundwater Pathway for Radionuclide and Non-radiological Species	Representation of Radionuclide Behaviour in Assessment Models	Holistic Review of Assumptions Pertinent to Radionuclide Behaviour in Post-closure Models
Task 80.7.002	Groundwater Pathway for Radionuclide and Non-radiological Species	Representation of Radionuclide Behaviour in Assessment Models	Site-specific Review of Assumptions Pertinent to Radionuclide Behaviour in Post-closure Models
Task 80.7.003	Groundwater Pathway for Radionuclide and Non-radiological Species	Representation of Radionuclide Behaviour in Assessment Models	Update to Model of C-14 Transport in Gas Pathways
Task 80.7.004	Groundwater Pathway for Radionuclide and Non-radiological Species	Representation of Radionuclide Behaviour in Assessment Models	Update to Model of C-14 Transport in Groundwater
Task 80.8.001	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of the Behaviour of Carbon-14	Review of Potential C-14 Release from Irradiated Graphite from Whole Inventory
Task 80.8.002	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of the Behaviour of Carbon-14	Study of C-14 Release from Irradiated, Advanced Gas-cooled Reactor Graphite
Task 80.8.003	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of the Behaviour of Carbon-14	Studies of C-14 Release from Irradiated Graphite from Other Sources (if required)
Task 80.8.004	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of the Behaviour of Carbon-14	C-14 Treatment and Representation in Models: A Review of Understanding of C-14 Behaviour in the Geosphere

Task 80.8.005	Groundwater Pathway for Radionuclide and Non-radiological Species	Develop Understanding of the Behaviour of Carbon-14	Further Understanding of C-14 Speciation and Mobility from Source to Release

Table C14: 090 Waste Container Evolution

2016 Information	Title	Status	Status Justification
[1, Task 646] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Container Durability Study with Coupled Chemical and Mechanical Analysis	Completed	Final report: [86].
[1, Task 647] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Prototype Repository Project (Copper)	Completed	Completed, report published. Final report: [87].
[1, Task 648] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Materials Corrosion Test (MaCoTe): In-situ Test	Ongoing	[1, Task 648] is now superseded by Task 90.1.007 . Phase 1 of MaCoTe is now complete (2013-2018) and Phase 2 is now ongoing (2019-2023) [88].
Task in [1, Task 649] Package Evolution \ HLW/SF Corrosion Allowance Container Materials	EPSRC GEOWASTE: Development of Experimental Techniques to Study the Metal-Clay Interface	Completed	Final report: [32]
[1, Task 651] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Participation in the FEBEX Experiment (Full Scale Engineering Barrier Demonstration Experiment (FEBEX) - Dismantling Project)	Completed	Final report [89], [90].
Task 650 in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Studies of Internal Corrosion/Pressurisation	Completed	Final report [91]. This Task was originally part of the 2014 S&T Plan.

[1, Task 652] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Development of Component Models for HLW / SF containers	Completed, undergoing review	Task 90.2.001 now supersedes [1, Task 652]. PackET: A software tool to estimate the lifetimes of ILW/LLW and HLW/SF containers during the GDF post-closure period
[1, Task 653] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Studies of Container Durability During Prolonged Exposure to High Temperature Atmospheric Conditions	Start date in FY21/22 (deferred start)	[1, Task 653] has now been superseded Task 90.1.001.
[1, Task 654] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Further Studies of Internal Corrosion / Pressurisation, Including Considerations of Accident Scenarios	Start date in FY20/21 (deferred start)	Task 90.1.002 now supersedes [1, Task 654].
[1, Task 660] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Collaboration on the Feasibility and Quality of Manufacture of Copper Electrodeposition on Steels	Completed	
[1, Task 661] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Considerations on the Feasibility and Quality of Manufacture of Containers for HLW and Spent Fuel	Start date in FY 21/22 (deferred start)	[1, Task 661] has now been superseded by Task 90.1.003.
Task 666 in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Scoping Studies on Durability of Grade-2 Ti Alloys	Completed	Final report [92]. This Task was originally part of the 2014 S&T Plan.
[1, Task 667] in Package Evolution \ HLW/SF Corrosion Allowance Container Materials	Further Experimental Studies on the Corrosion Behaviour of Corrosion Resistant Materials	Deleted	[1, Task 667] deleted due to programme re- prioritisation.
[1, Task 680] in Package Evolution \ ILW Corrosion Allowance Container Materials	Review of the Durability of Paint Systems in Atmospheric Conditions	Completed	Final report: [93].

[1, Task 681] in Package Evolution \ ILW Corrosion Allowance Container Materials	Studies of Internal Pressurisation and Hydrogen Embrittlement on Carbon Steel / Cast Iron Containers	Ongoing	[1, Task 681] is now superseded by the new 90.1.010.
[1, Task 682] Package Evolution \ ILW Corrosion Allowance Container Materials	Testing and Refinement of the ACSIS (Atmospheric Corrosion of Stainless Steel in Stores) Model, Including Extension to Carbon Steel and Cast Iron Components	Deleted	The work area is continued via Task 90.1.004 due to programme optimisation.
[1, Task 683] in Package Evolution \ ILW Corrosion Allowance Container Materials	Corrosion Studies of Carbon Steel / Cast Iron in Cyclic Conditions and Salt Mixtures	Ongoing	[1, Task 683] has now been superseded by Task 90.1.004.
[1, Task 684] in Package Evolution \ ILW Corrosion Allowance Container Materials	Development of Component Models for ILW Containers	Completed, undergoing review	[1, Task 684] is now superseded by Task 90.2.002. PackET: A software tool to estimate the lifetimes of ILW/LLW and HLW/SF containers during the GDF post-closure period
[1, Task 685] in Package Evolution \ ILW Corrosion Allowance Container Materials	Monitoring and Demonstration of Carbon Steel and Cast Iron Components in Atmospheric Conditions	Deleted	Task deleted due to work not considered to be necessary/of importance at this current stage.
[1, Task 696] in Package Evolution \ ILW Corrosion Allowance Container Materials	Experimental Studies on Stainless Steel in Cyclic Conditions and with Salt Mixtures	Start date in FY21/22 (deferred start)	Superseded by 'Studies of Stress Corrosion Cracking Initiation and Propagation' - Task 90.1.009
[1, Task 697] in Package Evolution \ ILW Corrosion Allowance Container Materials	EPSRC-GEOWASTE: Mechanistic Studies of Pitting and Stress Corrosion Cracking of Stainless Steel	Completed	Report published: [32].
[1, Task 698] in Package Evolution \ ILW Corrosion Allowance Container Materials	Development of Parametric Model: Atmospheric Corrosion of Stainless Steel in Stores (ACSIS)	Completed	Report published [94].

[1, Task 699] in Package Evolution \ ILW Corrosion Allowance Container Materials	Studies of Stress Corrosion Cracking Propagation in Stainless Steel	Superseded	Superseded by 'Studies of Stress Corrosion Cracking Initiation and Propagation' Task 90.1.009.
[1, Task 700] in Package Evolution \ ILW Corrosion Allowance Container Materials	Monitoring and Demonstration Studies of Stainless Steel Components in Atmospheric Conditions	Ongoing	Work ongoing, superseded by Task 90.2.003.
[1, Task 701] in Package Evolution \ ILW Corrosion Allowance Container Materials	Studies of Stainless Steel Corrosion in Cement in the Presence of Radiation and Thiosulphate	Start date in FY23/24	[1, Task 701] is now superseded by Task 90.1.005.
[1, Task 711] in Package Evolution \ ILW Concrete Containers	Review of the Durability of Concrete ILW containers	Completed	Final report: [95].

Table C15: 2020 New Waste Container Evolution Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 90.1.006	Waste Container Evolution	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)	The Effect of Gamma Radiation on the Corrosion Behaviour of Container Materials
Task 90.1.007	Waste Container Evolution	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)	Materials Corrosion Test (MaCoTe): In Situ Test (Phase II)
Task 90.1.008	Waste Container Evolution	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)	State of the Art Review of ILW Container Evolution under Atmospheric Conditions and Identification of Further Research Needs
Task 90.1.009	Waste Container Evolution	Material Science Studies in Support of Waste Container Development (SF, HLW, ILW, LLW)	Studies of Stress Corrosion Cracking Initiation and Propagation

Task 90.1.011	Waste Container Evolution	Develop Models for LHGW and HHGW Container Evolution using Data Derived from Generic Stage Work Scope	Studies of Stainless Steel Corrosion in Relevant Storage Conditions - Chloride Deposition Measurement Methods
Task 90.2.003	Waste Container Evolution	Develop Models for LHGW and HHGW Container Evolution using Data Derived from Generic Stage Work Scope	Studies of Stainless Steel Corrosion in Relevant Storage Conditions

Table C16: 100 Waste Package Accident Performance

2016 Task Number	Title	Status	Comments
[1, Task 911] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Performance of Aged Packages - Effect of Ageing	Ongoing	[1, Task 911] is now superseded by Task 100.1.001.
[1, Task 912] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Develop Methodologies for Scaling Release Fraction Data for Varying Drop Heights	Ongoing	[1, Task 912] is now superseded by 100.1.002.
[1, Task 913] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Develop, Refine and Document Holistic Impact Methodology	Ongoing	[1, Task 913] is now superseded by Task 100.1.003.
[1, Task 914] Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Develop Improved ILW Package Models (Finite Element Analysis, FEA)	Ongoing	[1, Task 914] is now superseded by Task 100.1.004.
[1, Task 915] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Impact Accident - Behaviour and Properties of Containers and Wasteforms	Ongoing	[1, Task 915] is now superseded by Task 100.1.005.

[1, Task 916] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Validation and update of the impact performance methodology for the 500 litre robust shielded drum and the 3 cubic metre robust shielded drum.	Ongoing	[1, Task 916] is now superseded by Task 100.1.006.
[1, Task 917] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Develop Improved ILW Package Models - Including Credit for Design Features (e.g. Capping Grout)	Ongoing	[1, Task 917] is now superseded by Task 100.1.007.
[1, Task 918] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Package Decontamination Factors - Part 1 – Selecting Appropriate Analogues	Start date in FY20/21 (deferred start)	Task 100.1.008 now supersedes [1, Task 918], Task start delayed due to programme optimisation.
[1, Task 919] Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Package Decontamination Factors - Part 2 – Accounting for Multiple Barriers	Start date in FY20/21 (deferred start)	Task 100.1.009 now supersedes [1, Task 919], Task start delayed due to programme optimisation.
[1, Task 920] in Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Effect of Cracked Wasteform on Impact Performance	Start date in FY20/21 (deferred start)	Task 100.1.010 now supersedes [1, Task 920], Task start delayed due to programme optimisation.
[1, Task 921] Waste Package Accident Performance \ Impact Accident Methodologies and Criteria	Update to the Holistic Impact Methodology Following Breakup Versus Flow Tests	Ongoing	[1, Task 921] is now superseded by Task 100.1.011.
[1, Task 926] in Waste Package Accident \ Impact Accident Release Fraction Data	Group Various Package Types	Ongoing	[1, Task 926] is now superseded by Task 100.1.012.
[1, Task 928] in Waste Package Accident \ Impact Accident Release Fraction Data	Impact Thresholds Below Which Releases Will Not Occur	Ongoing	[1, Task 928] is now superseded by Task 100.1.013.

[1, Task 929] in Waste Package Accident \ Impact Accident Release Fraction Data	Derivation of ab initio Release Fraction Values for the 6 cubic metre box; revised 3 cubic metre drum; MBGWS Box and Corner Lifting 3 cubic metre Box	Ongoing	[1, Task 929] is now superseded by Task 100.1.014.
[1, Task 930] in Waste Package Accident \ Impact Accident Release Fraction Data	Prepare Impact Performance Data Set	Ongoing	[1, Task 930] is now superseded by 100.1.015.
[1, Task 931] in Waste Package Accident \ Impact Accident Release Fraction Data Fire Accident	Data Requirements for Updated Operational Safety Case Approach	Start date in FY23/24 (deferred start)	Task deferred due to low priority at the current stage, hence prioritisation of internal resources. Task 100.1.016 supersedes [1, Task 931].
[1, Task 946] in Waste Package Accident Performance \ Fire Accident Methodologies and Criteria	Development of Fire Release Fractions	Ongoing	[1, Task 946] has now been superseded by Task 100.2.001.
[1, Task 947] in Waste Package Accident Performance \ Fire Accident Methodologies and Criteria	Methodology for Use of Analogy to Other Waste Package Types	Ongoing	[1, Task 947] has now been superseded by Task 100.2.002.
[1, Task 948] in Waste Package Accident Performance \ Fire Accident Methodologies and Criteria	Development of Improved ILW Package Models for Fire Analysis	Ongoing	[1, Task 948] has now been superseded by Task 100.2.003.
[1, Task 1006] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Derivations of Temperature Thresholds Below Which Release Will Not Occur	Ongoing	[1, Task 1006] has now been superseded by Task 100.2.004.
[1, Task 1007] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Revise Volatility Groups	Ongoing	[1, Task 1007] has now been superseded by Task 100.2.005.
[1, Task 1008] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Revision of Release Fractions for Volatility Group 1 Radionuclides	Ongoing	[1, Task 1007] has now been superseded by Task 100.2.006

[1, Task 1009] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Derivation of a Reference Data Set for Fire Accident Scenarios	Ongoing	[1, Task 1009] has now been superseded by Task 100.2.007.
[1, Task 1010] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Fire Performance of Aged Packages	Ongoing	[1, Task 1010] has now been superseded by Task 100.2.008.
[1, Task 1011] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Evaluation of RFs from Aged Samples	Start date in FY21/22 (deferred start)	Task deferred as the scope is to be refined based on the outcome of Task 100.1.008. Task 100.2.009 supersedes [1, Task 1011].
[1, Task 1012] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Scaling Release Fraction Data for Different Fire Scenarios	Ongoing	[1, Task 1012] has now been superseded by Task 100.2.010.
[1, Task 1013] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Effect of Re-Heating on Vitrified Waste	Ongoing	[1, Task 1013] has now been superseded by Task 100.2.011.
[1, Task 1014] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Derivation of Fire Release Fractions for Packages Within the Standard Waste Transport Container (SWTC)	Ongoing	[1, Task 1014] has now been superseded by Task 100.2.012.
[1, Task 1014] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Update to Standard Reference Report for Fire Release Fractions	Ongoing	[1, Task 1015] has now been superseded by Task 100.2.013.
[1, Task 1016] in Waste Package Accident Performance \ Fire Accident Release Fraction Data	Mixed Oxide Spent Fuel (MOX SF) - Thermal Properties for Use in Fire Fault Modelling	Start date in FY22/23 (deferred start)	Task deferred due to low priority at current stage, hence prioritisation of internal resources. [1, Task 1016] has now been superseded by Task 100.2.014.

[1, Task 1026] in Waste Package Accident Performance \ Combined Fault Accident Methodologies and Criteria	Methodology for Determining Release Fractions in Combined Fault Accidents and Identification of Modifying Mechanisms	Ongoing	[1, Task 1026] has now been superseded by Task 100.3.001.
[1, Task 1031] in Waste Package Accident Performance \ Combined Fault Accident Methodologies and Criteria	Review and Revision of Release Fraction (RF) Data in Combined Fault Accident Scenarios	Deleted	Task deleted as work no longer considered to be necessary.

Table C17: 2020 New Waste Package Accident Performance

2020 Task Number	WBS 4	WBS 5	Task Title
Task 100.1.017	Waste Package Accident Performance	Impact Accident Performance	Performance of Generic Waste Packages Types in Aggressive Feature Impacts
Task 100.1.018	Waste Package Accident Performance	Impact Accident Performance	Evidence to underpin SWTC Containment Argument in Transport Safety Case
Task 100.1.019	Waste Package Accident Performance	Impact Accident Performance	The Effect of Voidage on Waste Package Accident Performance
Task 100.3.002	Waste Package Accident Performance	Combined Fault Accident Performance	Review of the Waste Package Accident Performance Knowledge Base

Table C18: 110 Wasteform Evolution

2016 Information	Title	Status	Comments

[1, Task 536] in Package Evolution \ Vitrified HLW	Scoping Groundwater Dissolution Studies on Simulant Magnox / Blend Glasses	Completed	Final report undergoing review, for further information see interim progress report [96]
[1, Task 537] in Package Evolution \ Vitrified HLW	Understanding the Relationship Between the Durability of Simplified and Complex UK HLW Glasses	Start date in FY20/21 (deferred start)	[1, Task 537] has now been superseded by Task 110.2.001.
[1, Task 538] in Package Evolution \ Vitrified HLW	Further Groundwater Dissolution Studies on Simulant Magnox, Blend and Post-Operational Clean Out (POCO) Glasses	Start date in FY20/21 (deferred start)	[1, Task 538] has now been superseded by Task 110.2.002.
[1, Task 539] in Package Evolution \ Vitrified HLW	Effect of Iron-based Materials and Radiation Damage on the Dissolution Behaviour of Simulant HLW Glasses	Start date in FY23/24 (deferred start)	[1, Task 539] has now been superseded by Task 110.2.003.
[1, Task 540] in Package Evolution \ Vitrified HLW	Exposure of Inactive HLW Glass at MACOTE URL Experiment (Phase 2)	Deleted	Task deleted due to programme optimisation.
[1, Task 541] in Package Evolution \ Vitrified HLW	Review of Microstructural Evolution of Glassy and Ceramic Wasteforms and their Impact on Leaching Properties	Start date in FY23/24 (deferred start)	[1, Task 541] is now superseded by Task 110.2.004.
[1, Task 546] in Package Evolution \ Spent Fuel	Scoping Dissolution Studies on AGR Fuel in Oxic Conditions	Completed	Final report undergoing review, see interim report: [97].
[1, Task 547] in Package Evolution \ Spent Fuel	EPSRC GEOWASTE: Scoping studies on SimFuel to understand the dissolution behaviour of AGR fuel	Completed	PhD student at Cambridge University [32]
Task 548 in Package Evolution \ Spent Fuel	Understanding the Evolution of the Carbon Component of Dragon Reactor Fuel During the Post-closure Phase	Completed	Final report: [98].

[1, Task 549] in Package Evolution \ Spent Fuel	Scoping Dissolution Studies of Historical Fuels (Windscale AGR: WAGR)	Ongoing	[1, Task 549] is now superseded by Task 110.4.001.
[1, Task 550] in Package Evolution \ Spent Fuel	Review of Research Needs for Exotic and High Pu-bearing Spent Fuels	Completed	Completed, relevant publication: [99].
[1, Task 551] in Package Evolution \ Spent Fuel	Dissolution studies on Advanced Gas-cooled Reactor Fuels in Anoxic Conditions	Completed, undergoing review	Final report undergoing review, for further information, see interim report: [97].
[1, Task 552] in Package Evolution \ Spent Fuel	Further Work on SimFuel to Understand Dissolution Behaviour of Spent Fuel	Ongoing	[1, Task 552] is now superseded by Task 110.4.002.
[1, Task 553] in Package Evolution \ Spent Fuel	Scoping Studies on Dissolution Behaviour of Exotic and High Pu-bearing Spent Fuels	Ongoing	[1, Task 553] is now superseded by Task 110.4.003 and will be progressed based on the outcome of [1, Task 550].
[1, Task 554] in Package Evolution \ Spent Fuel	Review of Research Needs for Un-reprocessed Metallic Fuel	Completed	Partially covered by [1, Task 550], [99], [100].
[1, Task 555] in Package Evolution \ Spent Fuel	Further Dissolution Studies on Advanced Gas-cooled Reactor (AGR) Fuel	Start date in FY23/24 (deferred start)	[1, Task 555] is now superseded by Task 110.4.004 and will be progressed based on the outcome of completed [1, Task 546] and [1, Task 551].
[1, Task 556] in Package Evolution \ Spent Fuel	Further Dissolution Studies on Pressurised Water Reactor (PWR) Fuel	Start date in FY25/26 (deferred start)	[1, Task 556] is now superseded by Task 110.4.005.
[1, Task 557] in Package Evolution \ Spent Fuel	Further Studies on Dissolution Behaviour of Exotic and High Pu-bearing Fuels	Start date in FY20/21 (deferred start)	[1, Task 557] is now superseded by Task 110.4.006 and will be progressed based upon the outcome of Task 110.4.001.

[1, Task 558] in Package Evolution \ Spent Fuel	Scoping Studies on Dissolution Behaviour of Un-reprocessed Metallic Fuel	Ongoing	[1, Task 558] is now superseded by Task 110.4.007.
[1, Task 559] in Package Evolution \ Spent Fuel	Further Studies on Dissolution Behaviour of Un-Reprocessed Metallic Fuel	Start date in FY21/22 (deferred start)	[1, Task 559] is now superseded by Task 110.4.008.
[1, Task 571] in Package Evolution \ Cement-based Wasteforms for ILW	Corrosion Studies of Uranium Hydride in Cement	Completed	Relevant publication: [101].
[1, Task 572] in Package Evolution \ Cement-based Wasteforms for ILW	Studies on the Impact of Reactive Metal Corrosion in Cement	Start date in FY26/27 (deferred task)	[1, Task 572] is now superseded by 110.3.005.
[1, Task 573] in Package Evolution \ Cement-based Wasteforms for ILW	Further Research Needs For Expansive Processes	Deleted	Task has now been superseded by 110.3.002.
[1, Task 574] in Package Evolution \ Cement-based Wasteforms for ILW	Studies of the Impact of Uranium Hydride Formation in Cements	Completed	Relevant publication: [101].
[1, Task 586] in Package Evolution \ Polymer-based Wasteforms for ILW	Review Research Needs for Polymeric Wasteforms	Deferred	This Task is informed by the priorities and needs in terms of waste form research driven by the SLCs. RWM is currently involved in the NDA encapsulation coordination group and a Sellafield project on alternative encapsulants and will undertake work in alignment with those programmes to provide disposability advice. [1, Task 586] is now superseded by Task 110.1.001.

[1, Task 601] in Package Evolution \ Alternative Inorganic Wasteforms	Scoping Dissolution Studies of Non-optimised Vitrified ILW Simulants in Oxic, Alkaline Groundwaters	Completed	Report currently undergoing peer review, for further information see the published interim report:
[1, Task 602] in Package Evolution \ Alternative Inorganic Wasteforms	Scoping Dissolution Studies of Non-optimised Vitrified ILW Simulants in Oxic, Near-neutral Groundwaters	Completed	Report currently undergoing peer review, for further information see the published interim report:
[1, Task 603] in Package Evolution \ Alternative Inorganic Wasteforms	Dissolution Studies of Realistic Vitrified ILW Simulants in Oxic, Alkaline Groundwaters	Deleted	[1, Task 603] deleted due to programme re-prioritisation.
[1, Task 604] in Package Evolution \ Alternative Inorganic Wasteforms	Dissolution Studies of Realistic Vitrified ILW Simulants in Oxic, Near-Neutral Groundwaters	Deleted	[1, Task 604] deleted due to programme re-prioritisation.
[1, Task 605] in Package Evolution \ Alternative Inorganic Wasteforms	Studies of Effect of Iron and Radiation on the Leaching Behaviour of Realistic ILW Product Simulants	Deleted	[1, Task 605] deleted due to programme re-prioritisation.
[1, Task 616] in Package Evolution \ Plutonium Wasteforms	Definition of Research Needs for Hot Isostatic Pressed (HIPed) Product	Completed	Nuclear Technologies (NT) report delivered the objectives of Task 616, Technology Roadmap for GDF Disposal of Immobilised Plutonium
[1, Task 617] in Package Evolution \ Plutonium Wasteforms	Scoping Studies on the Dissolution Behaviour of Hot Isostatic Pressed (HIPed) Product	Superseded	[1, Task 617] is now incorporated under the Plutonium IPT (110.3.003 and Task 110.4.003).
[1, Task 618] in Package Evolution \ Plutonium Wasteforms	Scoping studies on the use of simulants to study the dissolution behaviour of Hot Isostatic Pressed (HIPed) Plutonium and unirradiated MOX Fuel	Ongoing	[1, Task 618] is now superseded by 110.3.001.

[1, Task 619] in Package Evolution \ Plutonium Wasteforms	Further Studies on the Dissolution Behaviour of Hot Isostatic Pressed (HIPed) Products	Superseded	[1, Task 619] is now incorporated under the Plutonium IPT (Task 110.3.003 and Task 110.3.003).
[1, Task 620] in Package Evolution \ Plutonium Wasteforms	Further Studies on Hot Isostatic Pressed (HIPed) Products and Unirradiated MOX Fuel to Address Outstanding Uncertainties	Superseded	[1, Task 620] will be addressed based on the outcome of the Plutonium IPT (Task 110.3.003 and Task 110.3.004).
[1, Task 631] in Package Evolution \ Uranium Wasteforms	Review of Uranium (U) Integrated Project Team (IPT) Output and Identification of Wasteform Research Needs	Completed	Relevant publication: [102].
[1, Task 636] in Package Evolution \ Graphite Wasteforms and Non-encapsulated Wasteforms	CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite	Completed	Final report [103].
[1, Task 637] in Package Evolution \ Graphite Wasteforms and Non-encapsulated Wasteforms	Review of CAST WP5 in UK context	Ongoing	[1, Task 637] is now superseded by Task 110.5.001 [104].

Table C19: 2020 New Wasteform Evolution Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 110.1.002	Wasteform Evolution	Non-cementitious ILW, LLW Wasteforms	Knowledge Capture Exercise on Progress in Thermally Treated ILW
Task 110.2.006	Wasteform Evolution	HLW Glass	Further Groundwater Dissolution Studies on Simulant Magnox, Blend and Post-operational Clean Out (POCO) HLW Glasses using Site-specific Groundwaters

Task 110.3.003	Wasteform Evolution	Plutonium, Uranium and Other Wasteforms	Further Development of RWM's Immobilised Plutonium Disposal Concepts
Task 110.3.004	Wasteform Evolution	Plutonium, Uranium and Other Wasteforms	Further Development of RWM's Immobilised Plutonium Disposal Concepts (follow on)
Task 110.4.009	Wasteform Evolution	Spent Fuel	Scoping Studies to Assess Behaviour of Metallic Uranic Fuel in Self-shielded Boxes
Task 110.4.010	Wasteform Evolution	Spent Fuel	Processing,Characterisation and Corrosion/Leaching Behaviour of Simulated MOX Spent Fuel
Task 110.4.011	Wasteform Evolution	Spent Fuel	DISCO: Modern Spent Fuel Dissolution and Chemistry in failed Container Conditions
Task 110.4.012	Wasteform Evolution	Spent Fuel	Spent Fuel Strategy
Task 110.4.013	Wasteform Evolution	Spent Fuel	Review of Irradiated MOX for Disposal
Task 110.4.014	Wasteform Evolution	Spent Fuel	Confirm PWR Spent Fuel Behaviour
Task 110.4.015	Wasteform Evolution	Spent Fuel	Assess the Nature and Quantity of MoD Owned Wastes
Task 110.4.016	Wasteform Evolution	Spent Fuel	Review the Understanding of the Effect of Hydrogen on Spent Fuel Matrix Dissolution
Task 110.5.002	Wasteform Evolution	Graphite	Understanding the Potential Impact of Wigner Energy
Task 110.5.003	Wasteform Evolution	Graphite	Addressing Identified Gaps to Understand the Potential Impact of Wigner Energy

Table C20: 210 Environmental and Socioeconomic Assessment

2016 Information	Title	Status	Comments
[1, Task 897] in Safety Assessments \ Environmental Assessments	Developing the approach to Generic Environmental, Socio-economic and Health Impact Assessments	Completed	The 2016 generic Disposal System safety case included updates of RWM's generic Environmental, Socio-economic and Health Impact Assessments. The scope of / approach to this work was informed by stakeholder feedback on the 2010 DSSC and from the MRWS siting process, as well as feedback from other WMOs on current good practice [105]–[107].
[1, Task 881] in Safety Assessments \ Environmental Assessments	Environmental Baseline Monitoring	Completed	An internal note on RWM's monitoring strategy was produced in March 2019. This documents current practice and technical approaches, and includes a 'roadmap' for future monitoring requirements as the implementation programme develops. We are currently investigating community participation in impact assessment work (including baseline monitoring) and will report on this by the end of the financial year.

[1, Task 900] in Environment and Socio-economic \ Socio-economic assessment	Development and Implementation of Community Benefit Agreements	Completed	A review of community based agreements was commissioned in 2016 and a draft report produced. Responsibility for this subject area was then passed to the community engagement team for further development as part of their community investment work.
[1, Task 901] in Environment and Socio-economic \ Socio-economic assessment	Web-based and Social Media Tools for Community Engagement	Superseded	No further research work has been undertaken. Responsibility for development of this area of our work now lies with the Communication and Stakeholder Engagement Directorate.
[1, Task 896] in Socio-economic \ Socio-economic	Participation in the Forum for Stakeholder Confidence (FSC) of the Nuclear Energy Agency (NEA).	Superseded	Superseded by Communication and Stakeholder Engagement Directorate.
[1, Task 898] in Socio-economic \ Socio-economic	Development of a Consistent Methodology for Data Elicitation and Quantification of Uncertainty	Completed	Final report [108].
[1, Task 899] in Socio-economic \ Socio-economic	Effect of Individual Differences in Psychology on Approach to Mathematical Modelling	Superseded	Partially covered by the Smith Inst
[1, Task 902] in Socio-economic \ Socio-economic	EPSRC: Series of Seminars on the Societal Aspects of Geological Disposal	Completed	RWM joint funded (with ESRC) a series of 7 seminars, organised and run by the University of Sheffield and the University of Exeter. The aim of the seminars was to improve understanding of the societal aspects of radioactive waste disposal [109].

Table C21: 2020 New Social Science Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 210.001	Social Science		Assessing Community Well-being

Table C22: 220 ESC Production

2016 Information	Title	Status	Comments
[1, Task 866] in Safety Assessments \ Environmental Safety Case	Understanding the Implications of Voidage to the Post-closure Safety Case	Ongoing	Task 220.1.001 now supersedes [1, Task 866].
[1, Task 869] in Safety Assessments \ Environmental Safety Case	Uranium IPT: Preferred Options for DNLEU Disposal	Completed	Relevant publication: [110].
[1, Task 870] Safety Assessments \ Environmental Safety Case	Review and update the Environmental Safety Manual to Take Account of Peer Review by LLWR and Lessons Learned in Environmental Safety Case 2016	Completed	

Table C23: 2020 New Environmental Safety Case Production Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 220.001	Environmental Safety Case		Environmental Safety Case Development
Task 220.1.002	Environmental Safety Case	Post-closure Safety Production	ESC Production - Total System Model Development
Task 220.1.003	Environmental Safety Case	Post-closure Safety Production	Post Closure Safety Assessment Development

Task 220.2.001	Environmental Safety Case	Operational and Environmental Safety Assessment	OESA Roadmap

Table C24: 230 PCSA Production

2016 Task Number	Title	Status	Comments
[1, Task 867] in Safety Assessments \ Environmental Safety Case	Development of Total System Models to Assess the Post-closure Performance of Disposal Concepts for the 2016 Generic Disposal System Safety Case Update	Completed	
[1, Task 868] in Safety Assessments \ Environmental Safety Case	Preparation of Total System Models for Future Application in the Siting Process	Superseded	Task 220.1.002 now supersedes [1, Task 868].

Table C25: 310 Concept Options and Alternatives

2016 Information	Title	Status	Comments
[1, Task 56] in Review of Options\Review of Options	Review of Alternative Waste Management Options	Ongoing	[1, Task 56] is now superseded by Task 310.003.
Task in Concept Development\Concept Development	Concepts IPT: Development of a Range of Disposal Concepts	Ongoing	[1, Task 57] extended via Task 310.002 [111].
[1, Task 58] in Concept Development\Concept Development	Concepts IPT: Development of Disposal Concept Options for Radioactive Materials Potentially Requiring Geological Disposal	Completed	Final report [111].
[1, Task 59] in Concept Development\Concept Development	Concepts IPT: Development of the Concept Selection Process	Completed	Final Report [111].

Task 060 in Concept Development\Concept Development	Perform a validation of the 1D thermal model by developing both a 2D and 3D thermal model based on the same starting conditions	Deleted	Task deleted as duplicates other thermal modelling Tasks in the V1 S&T Plan.

Table C26: 2020 New Concept Options and Alternatives

2020 Task Number	WBS 4	WBS 5	Task Title
Task 310.001	Concept Options and Alternatives		Develop Disposal Options for MoD Irradiated Fuel
Task 310.002	Concept Options and Alternatives		Further Develop Understanding of Disposal Concept Options

Table C27: 320 Waste Inventory Characterisation

2016 Information	Title	Status	Comments
[1, Task 306] in Inventory Report Development \ Inventory Report Development	Further Development of the Derived Inventory	Ongoing	[1, Task 306] is now superseded by Task 320.001.

Table C28: 410 Sub-surface Facilities Design and Operational Safety

2016 Information	Title	Status	Comments
[1, Task 161] in Design \ Disposal System Facility Designs	GDF Construction Materials	Completed	Relevant publications include: [112], [113].

[1, Task 162] in Design \ Disposal System Facility Designs	Watching Brief on Technology and Techniques for Safeguards Verification	Ongoing	[1, Task 162] is now superseded by Task 410.001.
[1, Task 163] in Design \ Disposal System Facility Designs	Develop and Maintain the Disposal Container Designs	Ongoing	[1, Task 163] is now superseded by Task 420.001.
[1, Task 164] in Design \ Disposal System Facility Designs	Geological Disposal Facility (GDF) investigations and construction	Completed	Relevant publications include: [65].
[1, Task 165] in Design \ Disposal System Facility Designs	Geological Disposal Facility (GDF) Package Handling and Transfer	Ongoing	Task 410.004 now supersedes [1, Task 165].
[1, Task 166] in Design \ Disposal System Facility Designs	Geological Disposal Facility (GDF) Disposal Vault and Tunnel Design	Ongoing	Task 410.003 now supersedes [1, Task 166].
[1, Task 167] in Design \ Disposal System Facility Designs	Geological Disposal Facility (GDF) Utilities and Services	Ongoing	Task 410.002 now supersedes [1, Task 167].
[1, Task 168] in Design \ Disposal System Facility Designs	Geological Disposal Facility (GDF) Sealing and Closure	Superseded	Task 410.003 now subsumes [1, Task 168] .
[1, Task 169] in Design \ Disposal System Facility Designs	Technology and Techniques for Nuclear Security	Ongoing	Task 420.002 now supersedes [1, Task 169].
[1, Task 181] in Design \ Transport System Designs	Develop and Maintain Transport Container Designs	Ongoing	Task 430.002 now supersedes [1, Task 181].
[1, Task 182] in Design \ Transport System Designs	Transport Infrastructure Constraints on the Geological Disposal System	Ongoing	Task 430.003 now supersedes [1, Task 182].
[1, Task 850] in Safety Assessments \ Operational Safety Case	Extension of the Operational Safety Case to Cover Backfilling, Sealing and Closure	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.

[1, Task 853] in Safety Assessments \ Operational Safety Case	Undertake Evaluation of GDF Design and Safety Case Against the Western European Nuclear Regulators Association (WENRA) Safety Reference Levels for Radioactive Waste Disposal	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.
[1, Task 854] in Safety Assessments \ Operational Safety Case	Develop Licence Condition Arrangements Pertaining to Safety Case Development	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.
[1, Task 855] in Safety Assessments \ Operational Safety Case	Update of Disposability Assessment Work Instructions Based on 2016 Disposal System Safety Case	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.

Table C29: 2020 New Sub-surface Facilities Design and Operational Safety

2020 Task Number	WBS 4	WBS 5	Task Title
Task 410.005	Sub-surface Facilities Design and Operational Safety		Potential Role of Digital Twins in Seeking Consensus for GDF Siting
Task 410.006	Sub-surface Facilities Design and Operational Safety		Improve Understanding of Evaporite Concepts in a UK Context
Task 410.007	Sub-surface Facilities Design and Operational Safety		Capability Development -HHGW Concepts
Task 410.008	Sub-surface Facilities Design and Operational Safety		Capability Developments - Accessways
Task 410.009	Sub-surface Facilities Design and Operational Safety		GDF Construction Materials

Table C30: 420 Surface Facilities Design and Operational Safety

2016 Information	Title	Status	Comments
[1, Task 196] in Design \ Disposal System Facility Design	Maintain Up-to-date Cost Estimates for the Geological Disposal Facility Programme	Deleted	This Task has been deleted as this is now a business as usual (BAU) activity.
Task 846 in Safety Assessments \ Operational Safety Case	Develop Off-Site Risk Assessment Methodology	Completed	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.
[1, Task 847] in Safety Assessments \ Operational Safety Case	Develop and Maintain Operational Safety Assessments Toolkit(s)	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.
[1, Task 848] in Safety Assessments \ Operational Safety Case	Develop and Maintain Operational Safety Assessments Toolkit(s) to Assess Specific Sites	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.
[1, Task 849] in Safety Assessments \ Operational Safety Case	Development of Methodologies and Safety Assessment for 2016 Operational Safety Case	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.
[1, Task 851] in Safety Assessments \ Operational Safety Case	Review and Update the Nuclear Operational Safety Manual (NOSM) to Take Account of Lessons Learned in 2016 Operational Safety Case	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.
[1, Task 852] in Safety Assessments \ Operational Safety Case	Respond to Regulator Recommendation R21	Deleted	The Operational Safety Case is currently undertaking a rigorous review of past work to coordinate the future work area.

Table C31: 2020 New Surface Facilities Design and Operational Safety

2020 Task Number	WBS 4	WBS 5	Task Title
Task 420.003	Surface Facilities Design and Operational Safety		Coastal Solutions

Table C32: 430 Transport System and Containers Design and Safety

2016 Information	Title	Status	Comments
[1, Task 826] in Safety Assessments \ Transports Safety Case	Development of a Suite of Contents Specification Documentation for all Package Types	Ongoing	Task 430.004 now supersedes [1, Task 826].
Task 827 in Safety Assessments \ Transports Safety Case	Develop a Fissile Exception Application for Waste Materials Bearing a Low Concentration of Fissile Radionuclides	Deleted	This Task was originally part of the 2014 S&T Plan. Deleted because this Task duplicated [1, Task 93] in the Criticality Safety area.
[1, Task 828] in Safety Assessments \ Transports Safety Case	Maintenance of Transport Safety Assessment Toolkits	Ongoing	Task 430.005 now supersedes [1, Task 828].
Task 829 in Safety Assessments \ Transports Safety Case	Develop the Transport Criticality Safety Assessment for the Disposal Container Transport Container	Deleted	This Task was originally part of the 2014 S&T Plan. This Task has been re-numbered Task 080: Criticality Safety area.
[1, Task 830] in Safety Assessments \ Transports Safety Case	Review and Update the Transport Safety Manual (TSM) to Take Account of Peer Review by INS and Lessons Learned in TSM 2016	Ongoing	Task 430.006 now supersedes [1, Task 830].

Table C33: 2020 New Transport System and Containers Design Safety

2020 Task Number	WBS 4	WBS 5	Task Title
Task 430.007	Transport System and Containers Design and Safety		DCTC Contents and Requirements

Table C34: 510 Site Characterisation

2016 Information	Title	Status	Comments
Task 486 in Preparations for Site Investigations \ Preparations for Site Investigations	Development of an Approach to the Safe Sealing of Boreholes	Deleted	This Task was originally part of the 2014 S&T Plan. Duplicates with [1, Task 356] which is now completed and continued through new Task 50.4.005.
Task 487 Preparations for Site Investigations \ Preparations for Site Investigations	UK Hydrogeochemistry at Depth: Collation of Knowledge Base	Deleted	This Task was originally part of the 2014 S&T Plan. This Task has been deleted because it is superseded by work that is being undertaken as part of the National Geological Screening exercise
[1, Task 488] in Preparations for Site Investigations \ Preparations for Site Investigations	Watching Brief on Geosphere Data Acquisition Techniques	Ongoing	[1, Task 488] has now been superseded by Task 510.001.
Task 490 in Preparations for Site Investigations \ Preparations for Site Investigations	Development of an Approach for Monitoring and Underground Investigations During the Excavation Phase	Completed	Relevant publication: Identifying the information requirements and setting out approaches for underground investigations. Final Report. 13 June 2018

[1, Task 489] in Preparations for Site Investigations \ Preparations for Site Investigations	Watching Brief on Interpretation and Modelling Techniques for Generation of a Site Descriptive Model	Ongoing	[1, Task 489] has now been superseded by Task 510.002.
[1, Task 491] in Preparations for Site Investigations \ Preparations for Site Investigations	Review of the Impacts of Ongoing Excavation Work on Long-Term Underground Investigations	Completed	Relevant publication: Investigation and Construction- GDF Construction and Operations phase site investigation and characterisation, 15th October 2018
[1, Task 492] in Preparations for Site Investigations \ Preparations for Site Investigations	Mechanics of Rock Discontinuities Under Elevated Temperatures and Pressures	Completed	Final report: [52], [53].
Task 493 in Preparations for Site Investigations \ Preparations for Site Investigations	Evaluation of the Occurrence of Low Strength and Evaporite Rocks ar Depth in the Context of a UK Geological Setting (to support generic design)	Deleted	This Task was originally part of the 2014 S&T Plan. This Task has been deleted because it is superseded by work that is being undertaken as part of the National Geological Screening exercise. In addition to NGS, the following report was undertaken on UK halite [114].
[1, Task 494] in Preparations for Site Investigations \ Preparations for Site Investigations	Development of an understanding of information requirements for underground monitoring and investigations	Completed	Identifying the information requirements and setting out approaches for underground investigations, 13th June 2018

Table C35: 2020 New Site Characterisation Tasks

2020 Task Number	WBS 4	WBS 5	Task Title
Task 510.003	Site Characterisation		Analytical Advice, Including Mathematical Approaches, to Site Characterisation

Task 510.004	Site Characterisation		Site Characterisation Capability Building

Table C36: 610 Strategic Waste Programmes

2016 Information	Title	Status	Comments
[1, Task 511] in Higher Activity Waste Programme \ Higher Activity Waste Programme	Development of a Larger Waste Container	Ongoing	[1, Task 511] has now been superseded by Task 610.001.
[1, Task 512] in Higher Activity Waste Programme \ Higher Activity Waste Programme	Development of Disposability Manufacturing Specifications	Deleted	[1, Task 512] will be superseded by ongoing work at the NDA.
[1, Task 513] in Higher Activity Waste Programme \ Higher Activity Waste Programme	Guidance on the Disposability of Decontamination Agents	Completed	Report: [115].
[1, Task 514] in Higher Activity Waste Programme \ Higher Activity Waste Programme	Guidance on the Disposability of Filters	Ongoing	[1, Task 514] has now been superseded by Task 610.002.

Table C37: Design (2014)

2016 Information	Title	Status	Comments
Task 152 in Design (2014)	MPC Vault Design	Completed	This Task was originally part of the 2014 S&T Plan [116].
Task 153 in Design (2014)	Development of SWTC-150 for Increased Payload	Ongoing	This Task was originally part of the 2014 S&T Plan. Work is extended via Task 430.001.
Task 154 in Design (2014)	Development of a 500 litre drum disposal stillage	Completed	This Task was originally part of the 2014 S&T Plan. Relevant publications include: [117], [118].

Task 155 in Design (2014)	Development of MPC Designs	Completed	This Task was originally part of the 2014 S&T Plan. Relevant publications include: [119]–[121].
Task 156 in Design (2014)	Development of Inlet Cell	Deleted	This Task was originally part of the 2014 S&T Plan. Task removed and rationalised into a new combined ”Package Handling and Transfer” Task ([1, Task 165])
Task 157 in Design (2014)	Development of Monitoring Programme Requirements	Deleted	This Task was originally part of the 2014 S&T Plan. Task removed. No requirement for R&D under Design. R&D associated with sub-surface monitoring around a GDF is contained in Tasks under Geosphere ([1, Task 404]) and Site Characterisation ([1, Task 494]) areas.
Task 158 in Design (2014)	Development of Inlet Cell	Deleted	This Task was originally part of the 2014 S&T Plan. Task removed and rationalised into a new combined ”Package Handling and Transfer” Task ([1, Task 165]).
Task 159 in Design (2014)	Develop Inspection and Reworking Cell	Deleted	This Task was originally part of the 2014 S&T Plan. Task removed and rationalised into a new combined ”Package Handling and Transfer” Task ([1, Task 165]).

Task 160 in Design (2014)	Develop Inspection and Reworking Cell	Deleted	This Task was originally part of the 2014 S&T Plan. Task removed and rationalised into a new combined "Package Handling and Transfer" Task ([1, Task 165]).

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Appendix D Wiring Diagrams

Figure D1 Long Range Graphic

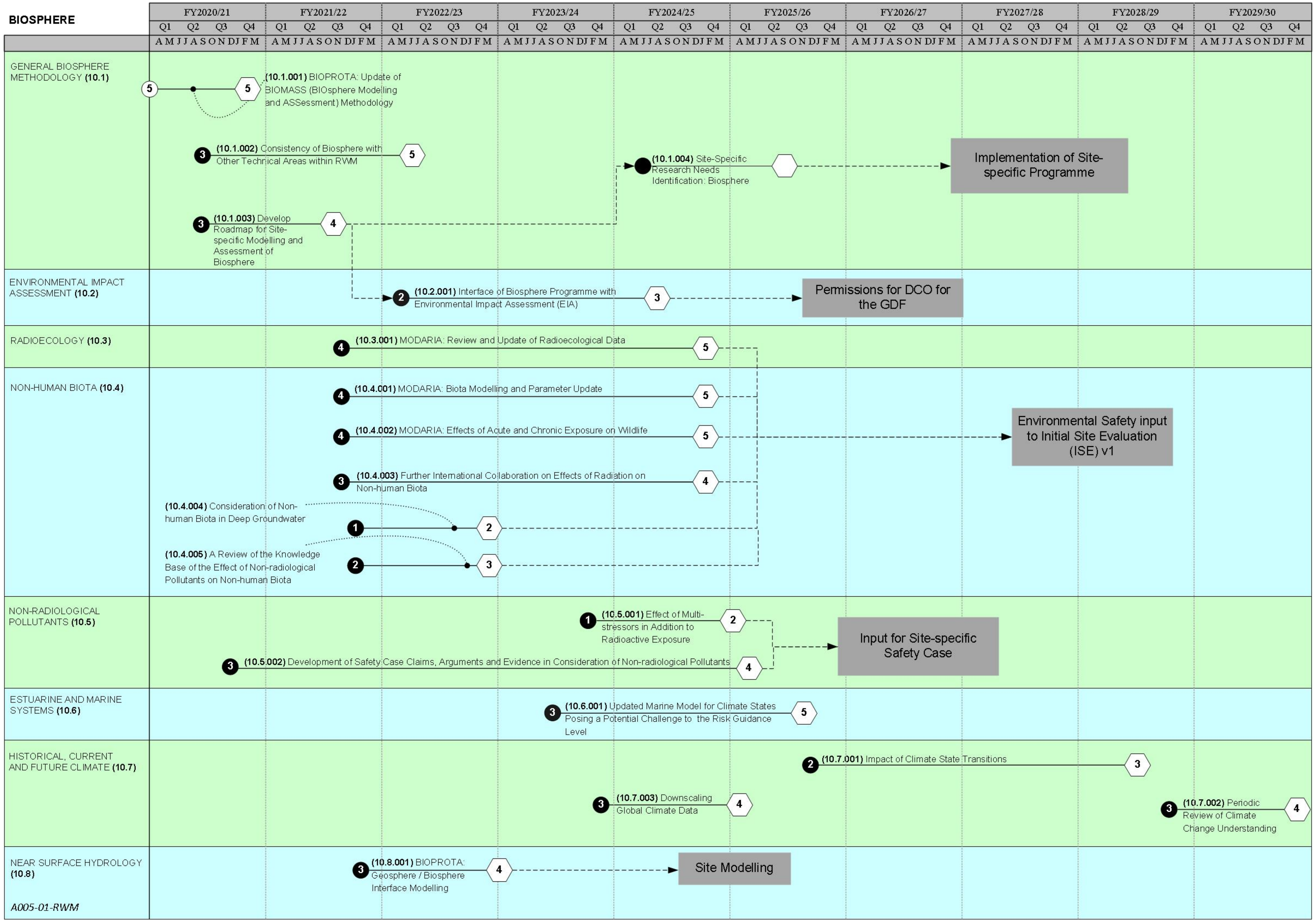


Figure D2 Long Range Graphic (Continued)

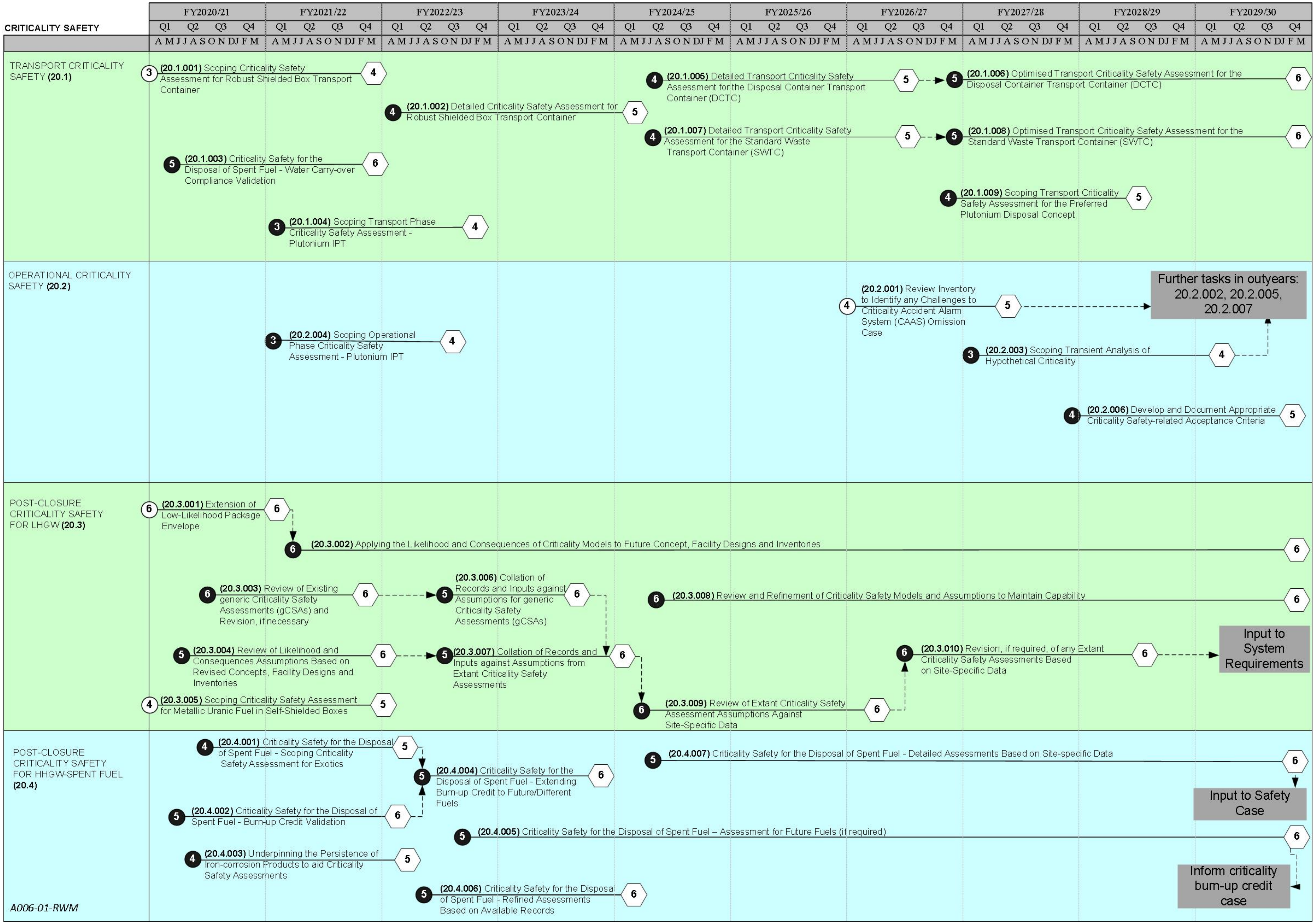


Figure D3 Long Range Graphic (Continued)

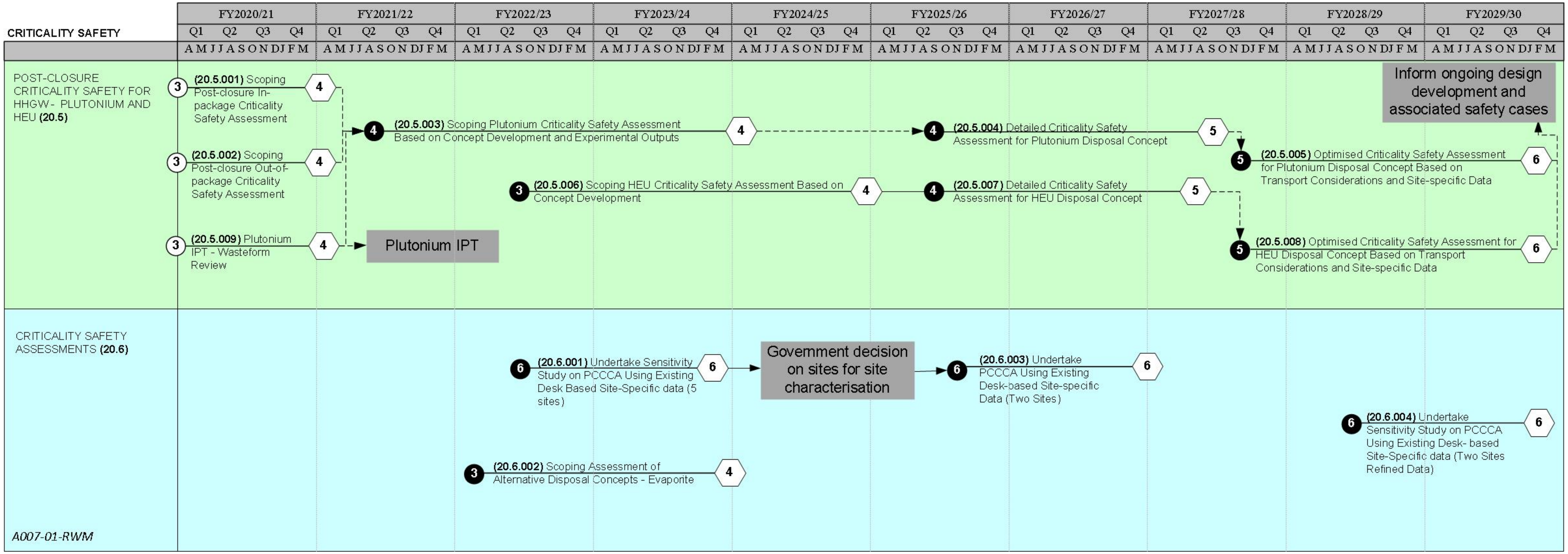


Figure D4 Long Range Graphic (Continued)

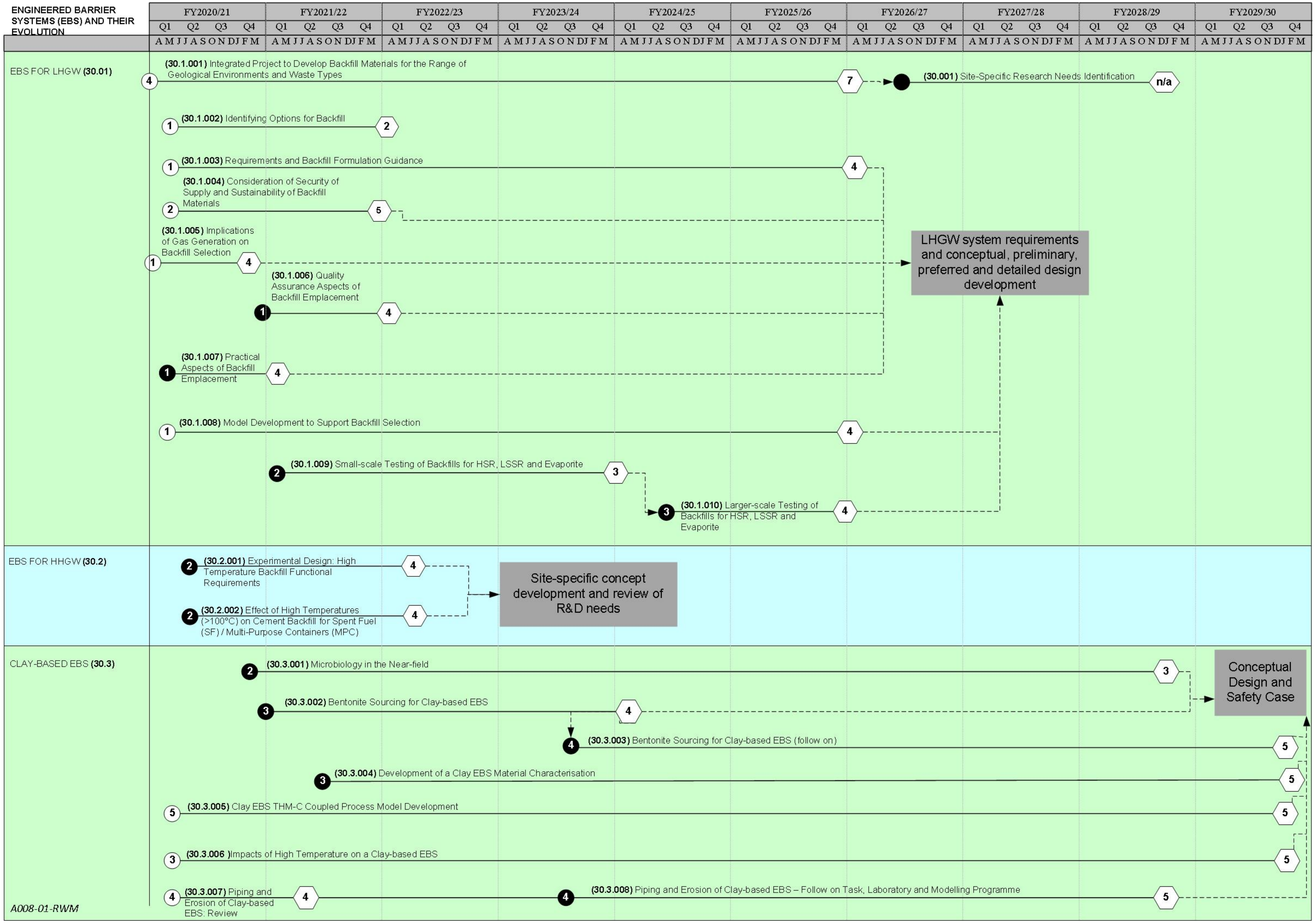


Figure D5 Long Range Graphic (Continued)

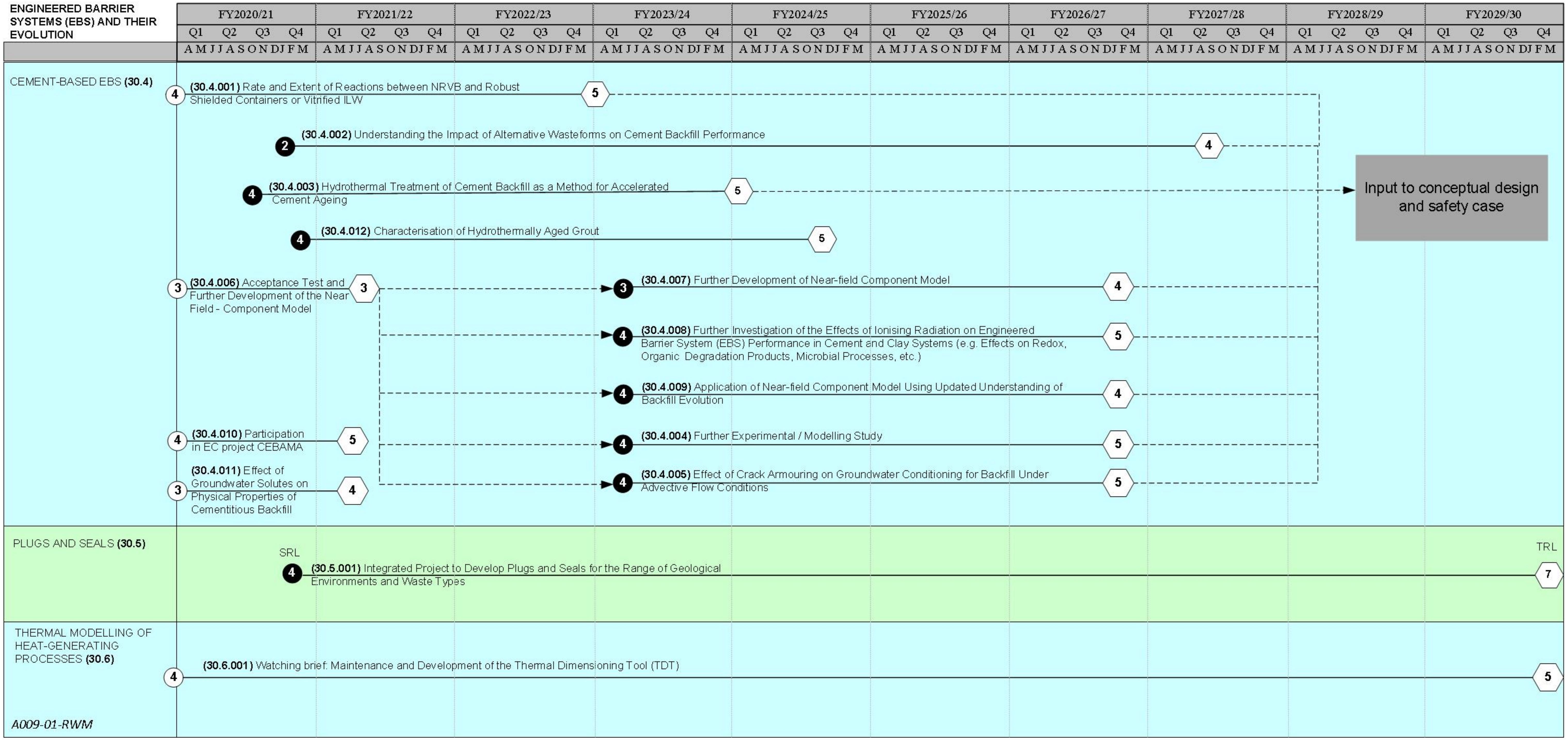


Figure D6 Long Range Graphic (Continued)

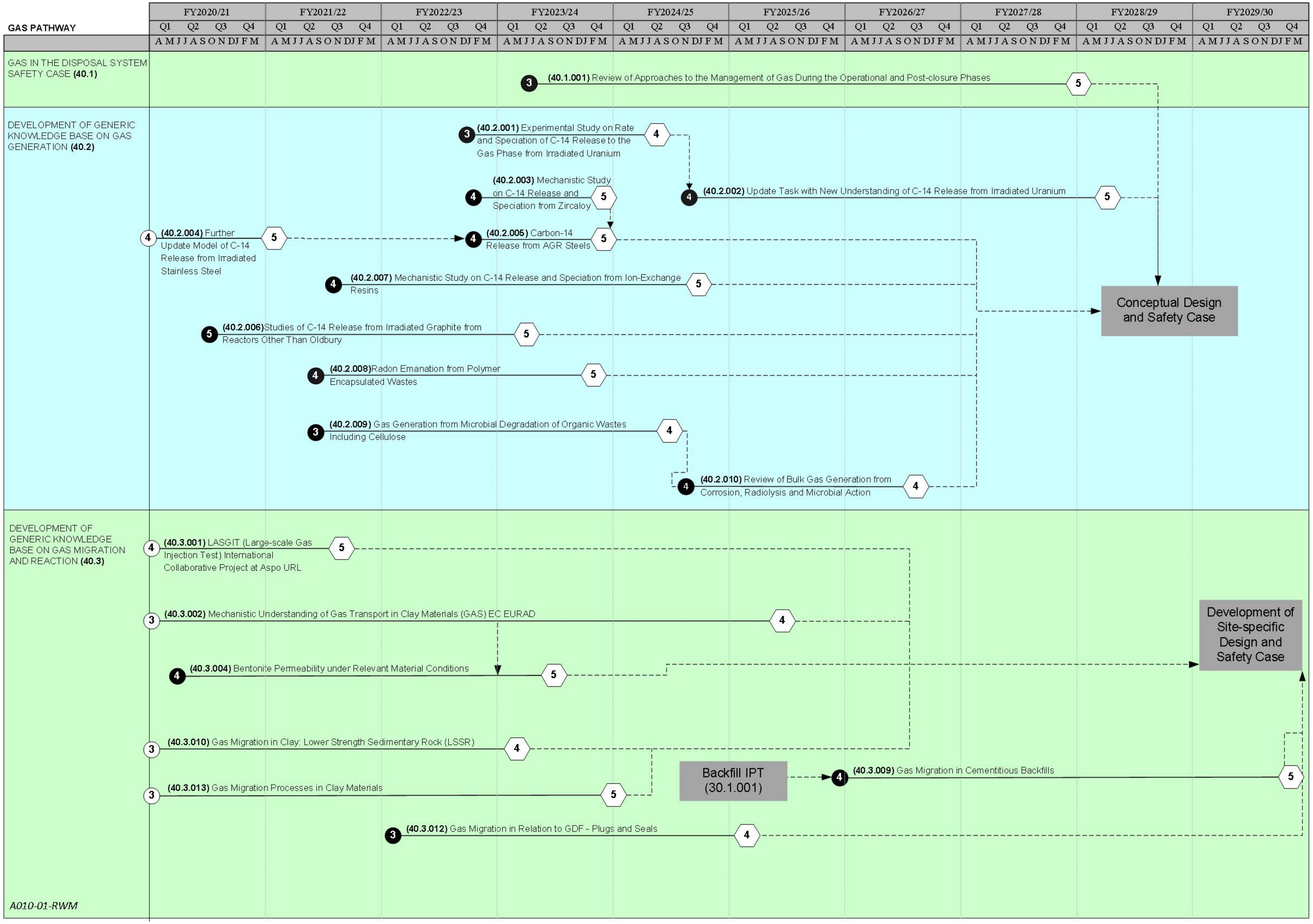


Figure D7 Long Range Graphic (Continued)

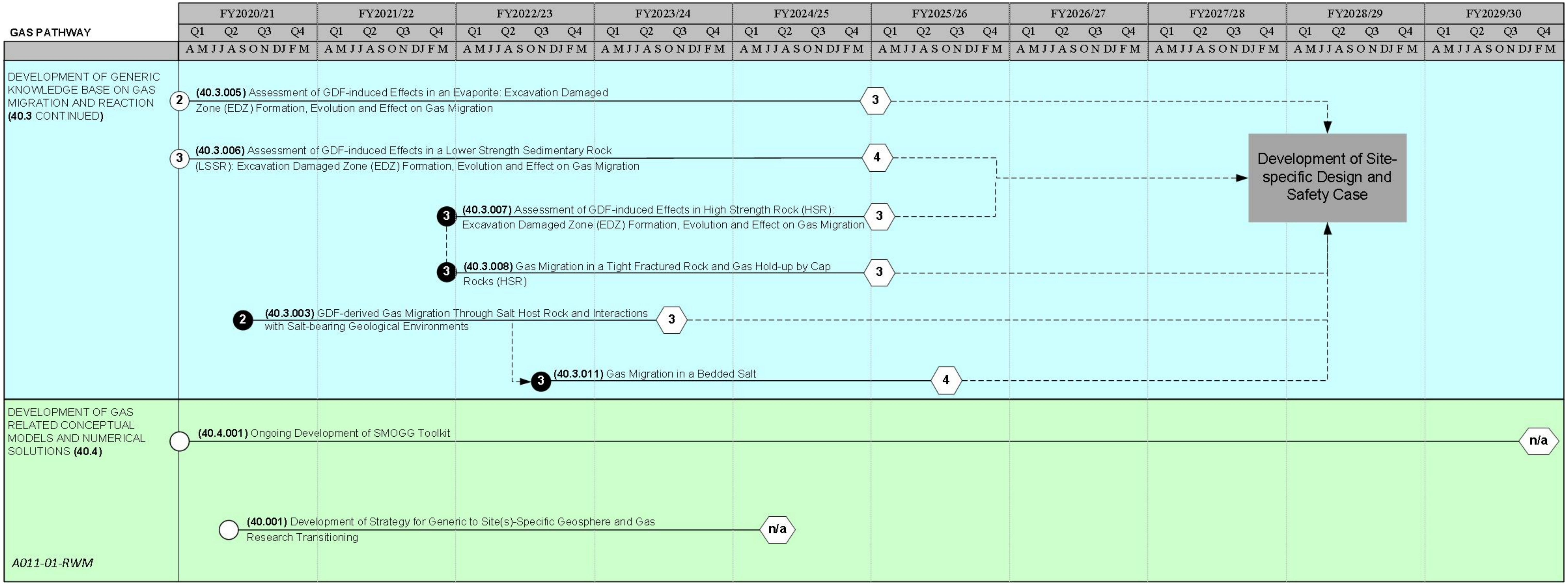


Figure D8 Long Range Graphic (Continued)

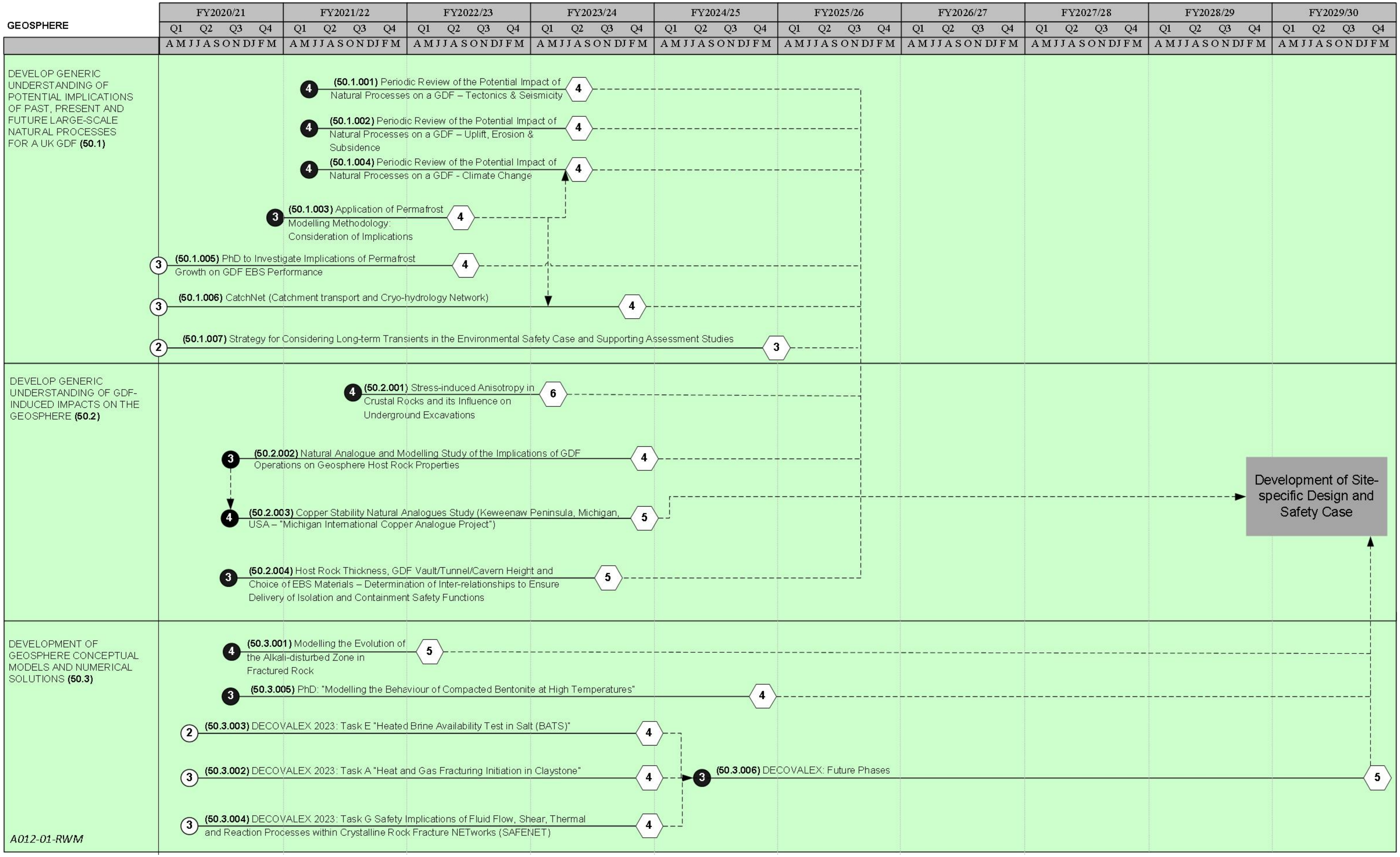


Figure D9 Long Range Graphic (Continued)

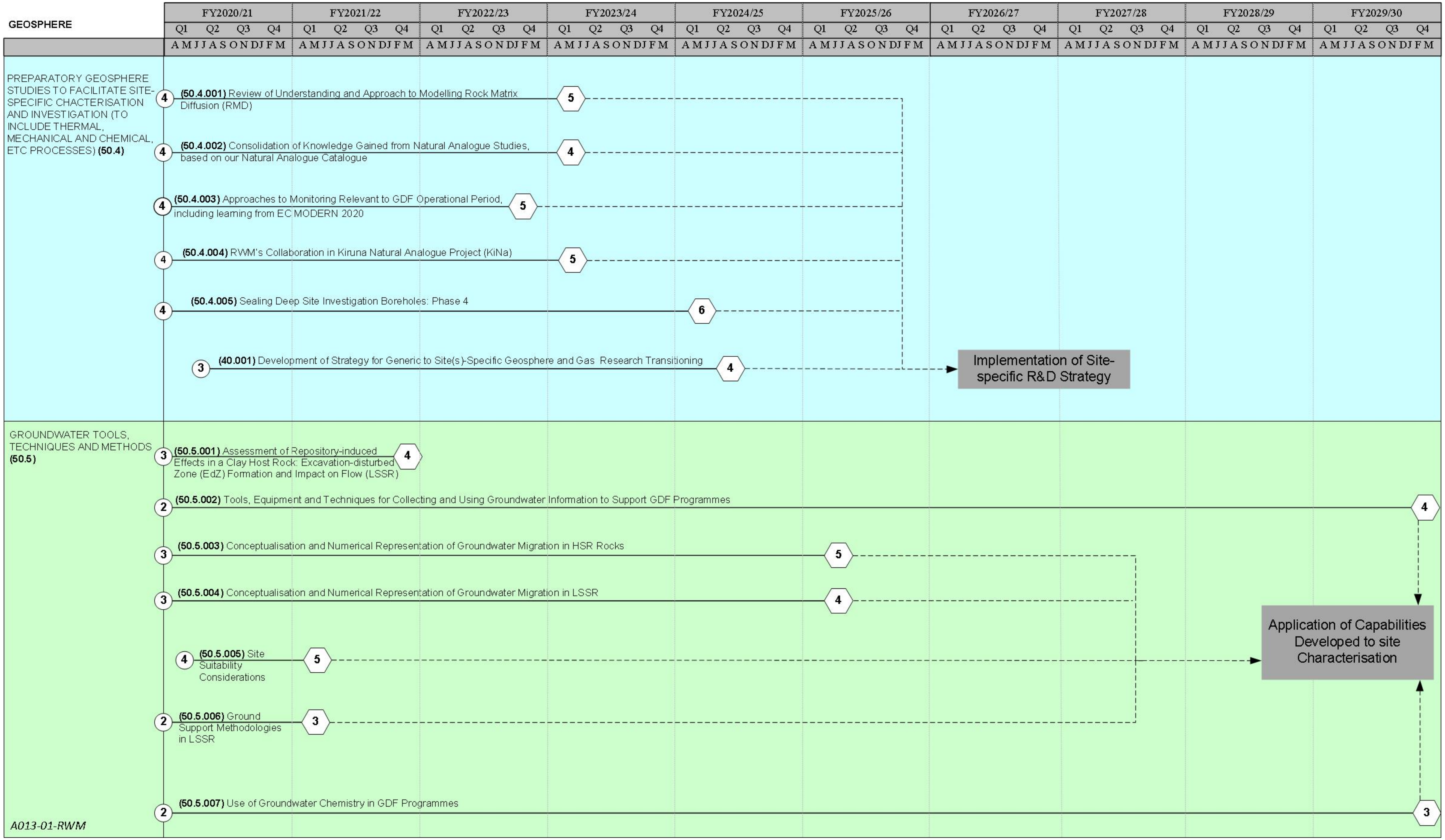


Figure D10 Long Range Graphic (Continued)

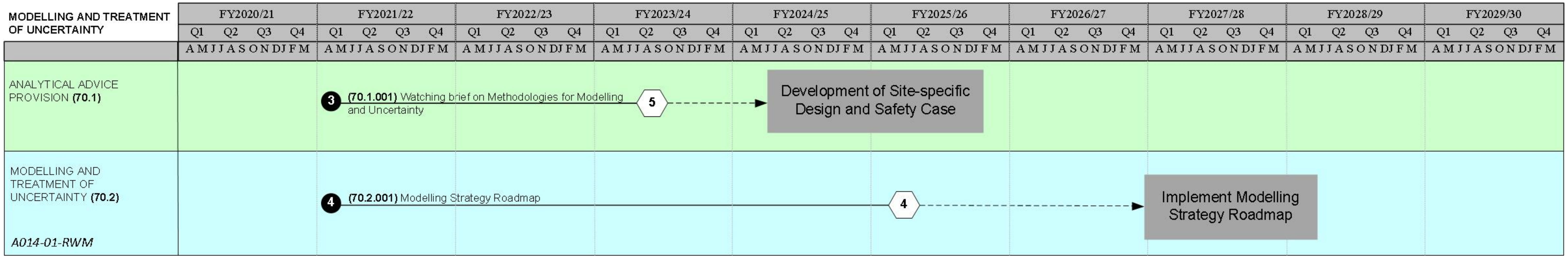


Figure D11 Long Range Graphic (Continued)

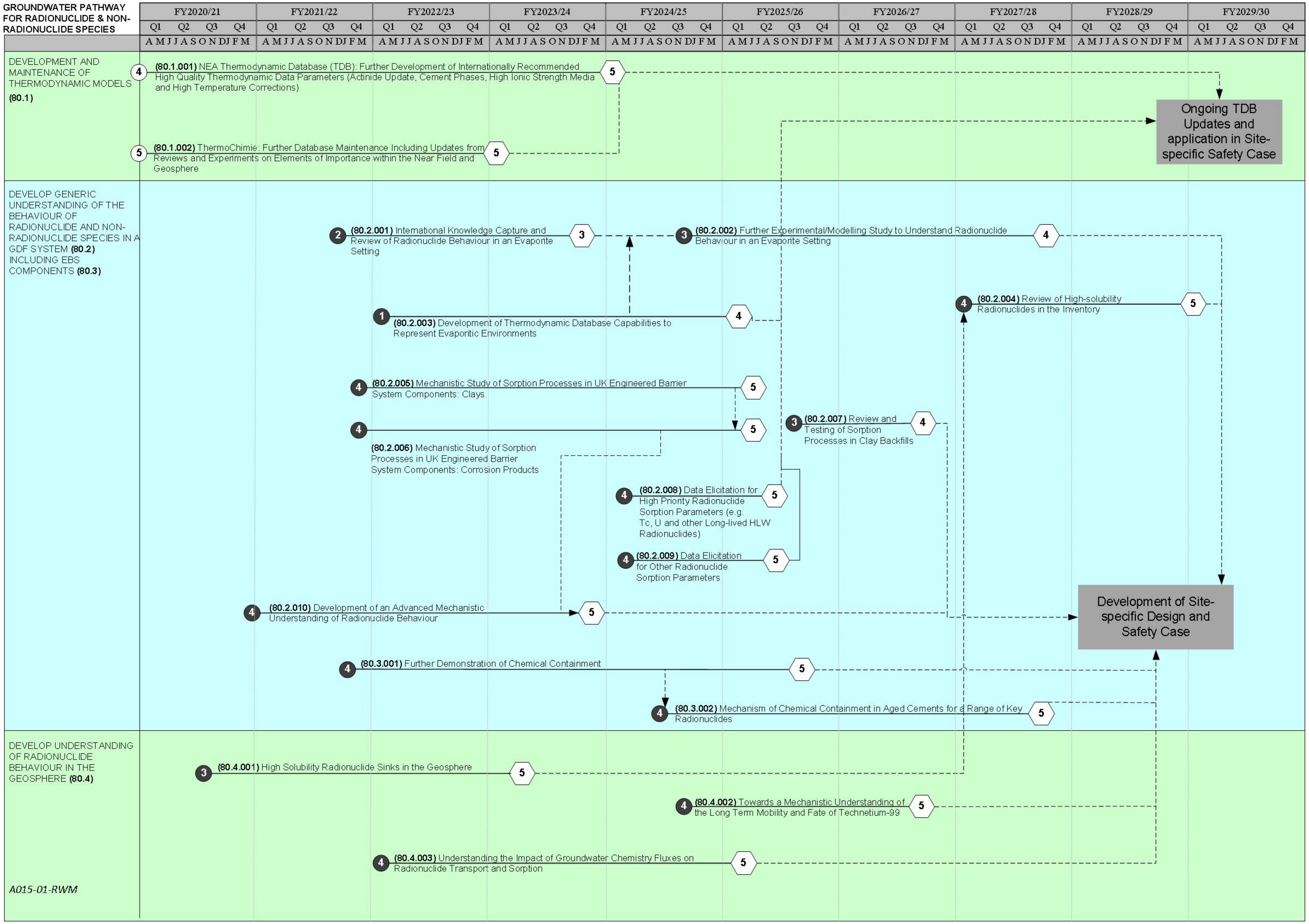


Figure D12 Long Range Graphic (Continued)

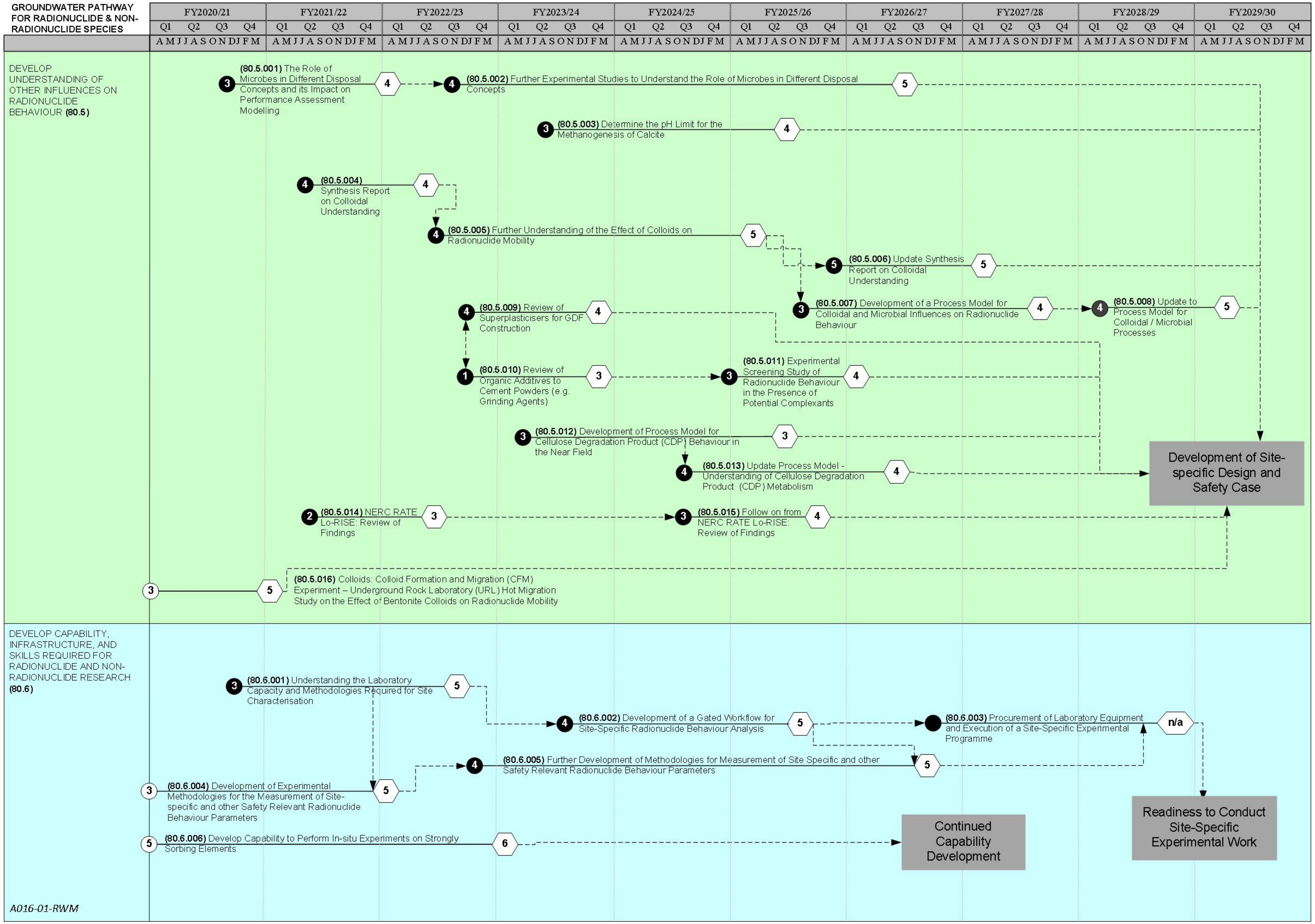


Figure D13 Long Range Graphic (Continued)

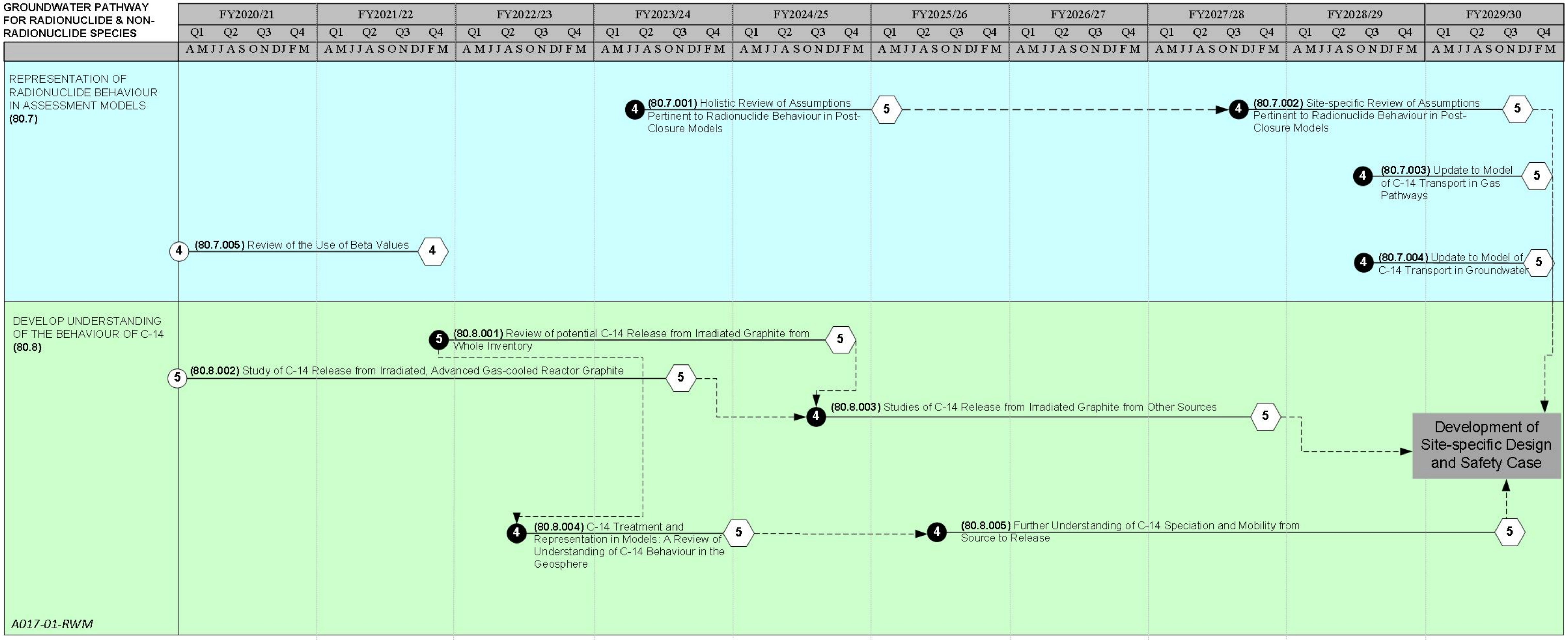


Figure D14 Long Range Graphic (Continued)

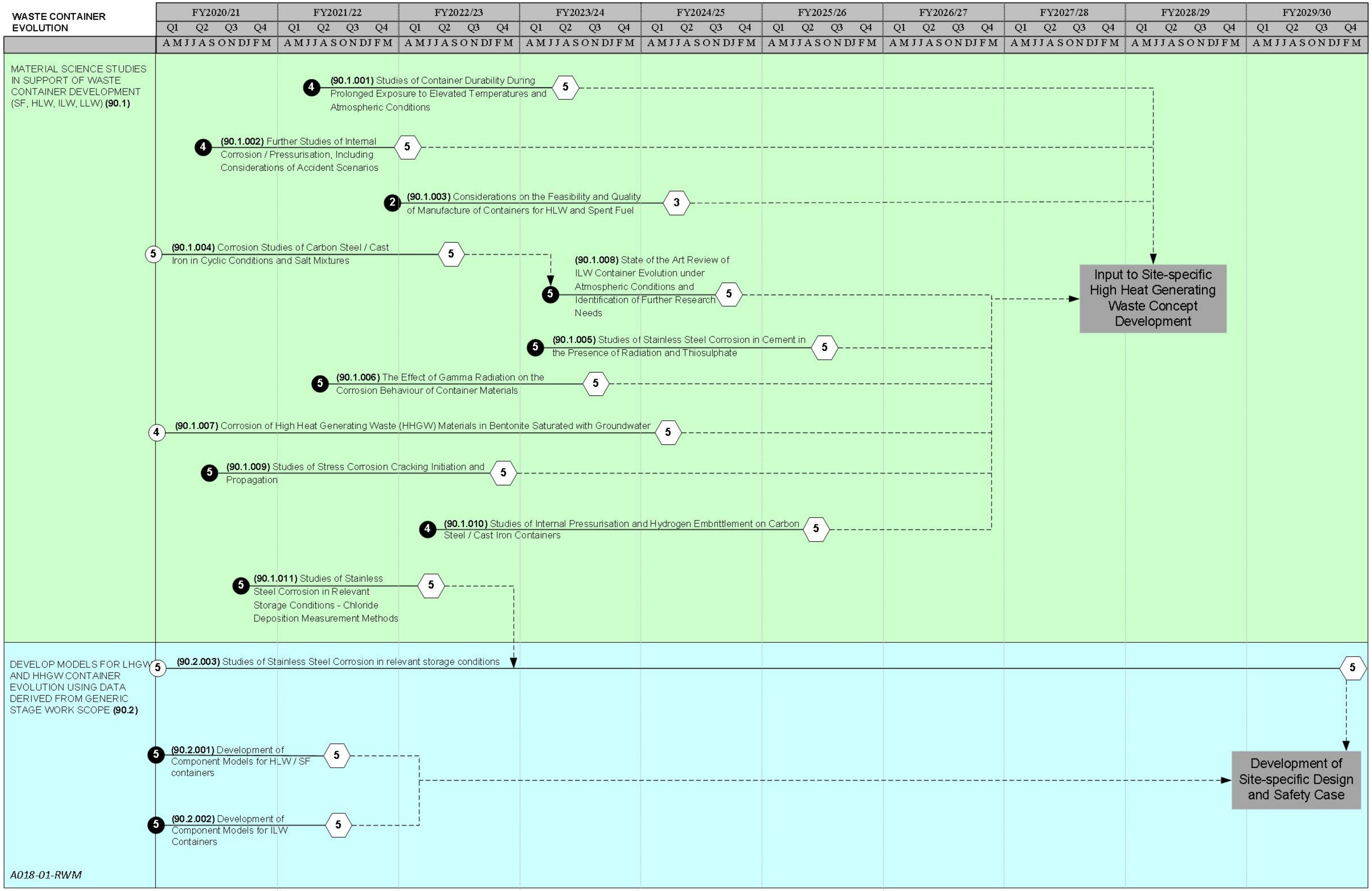


Figure D15 Long Range Graphic (Continued)

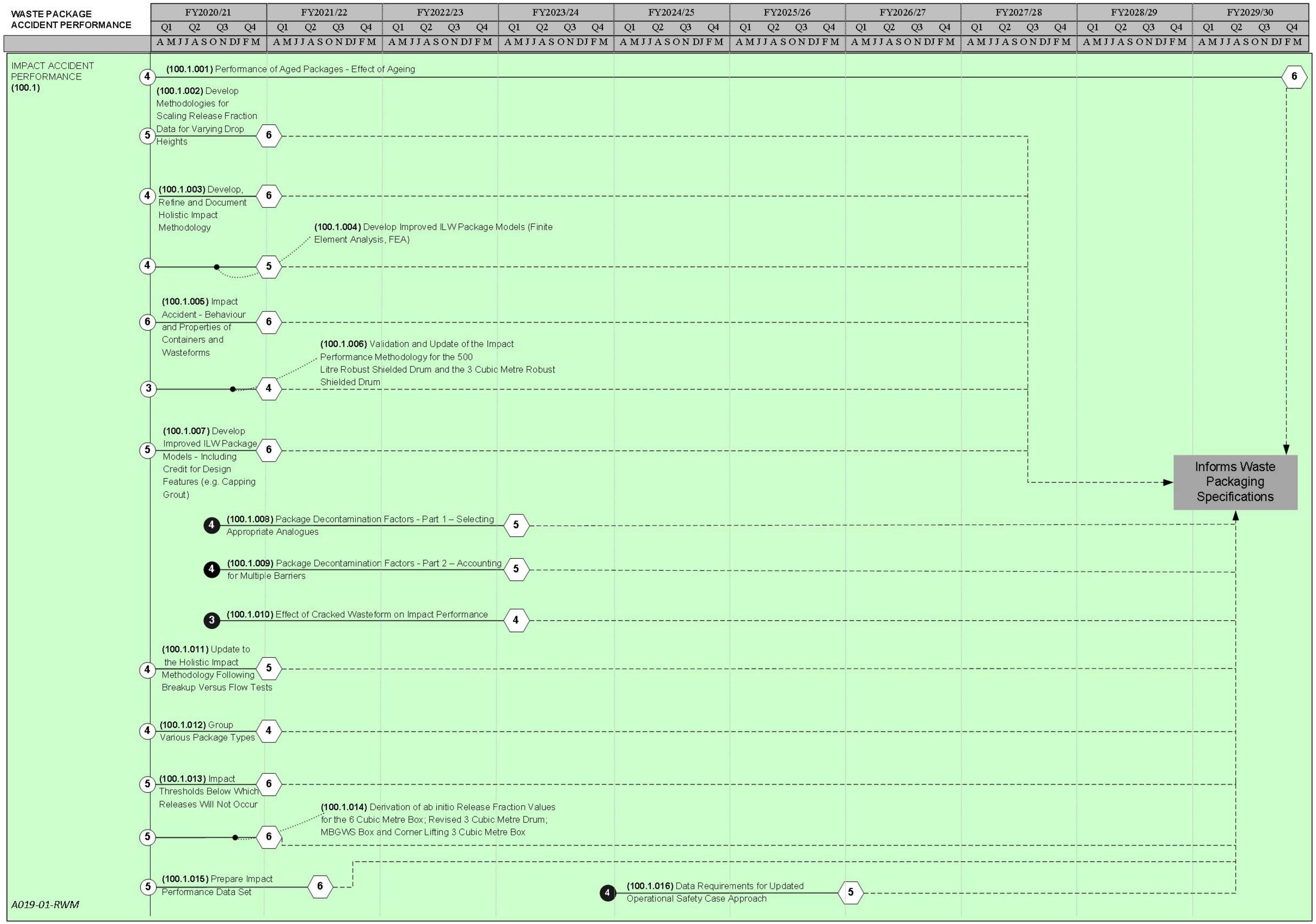


Figure D16 Long Range Graphic (Continued)

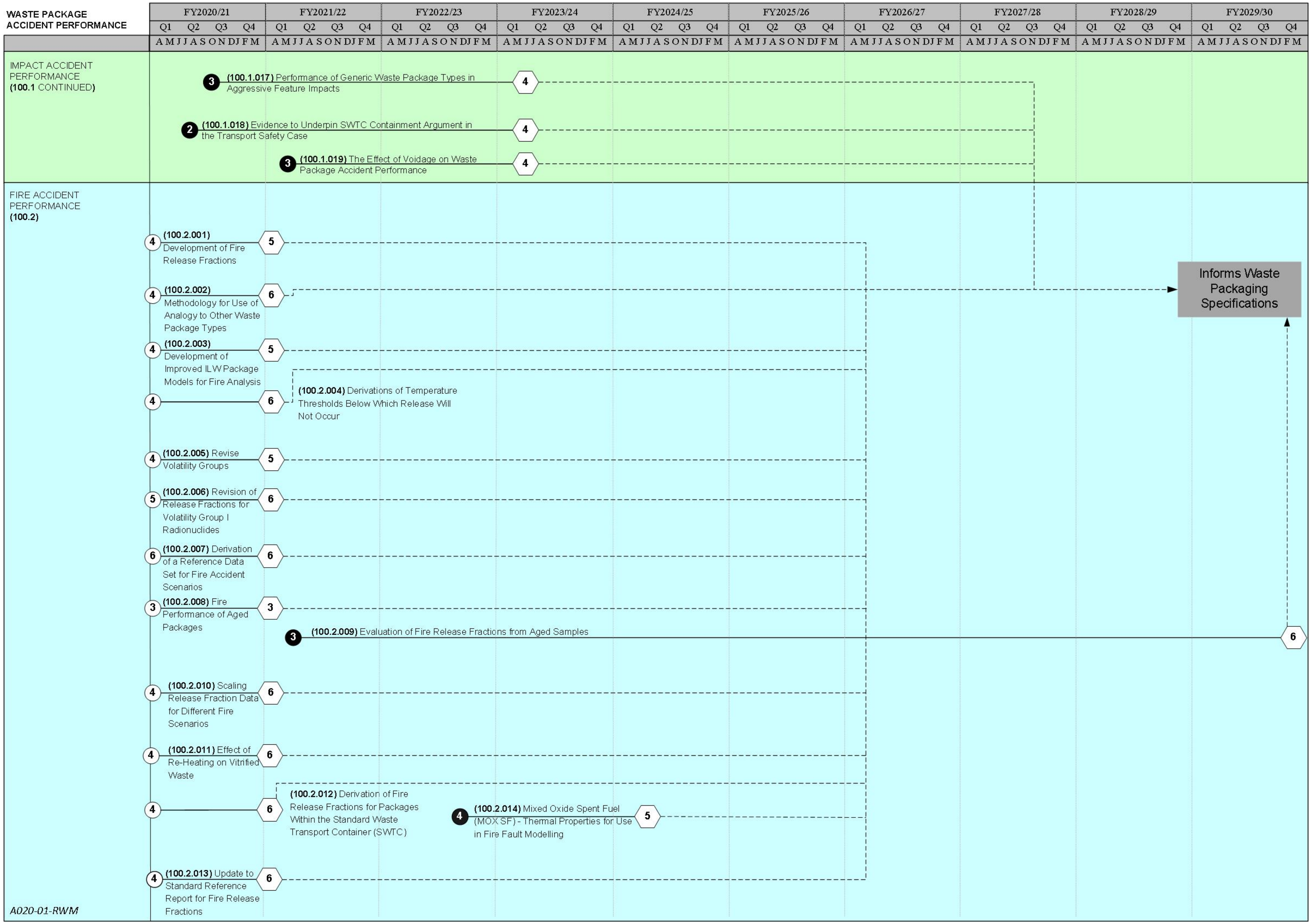


Figure D17 Long Range Graphic (Continued)

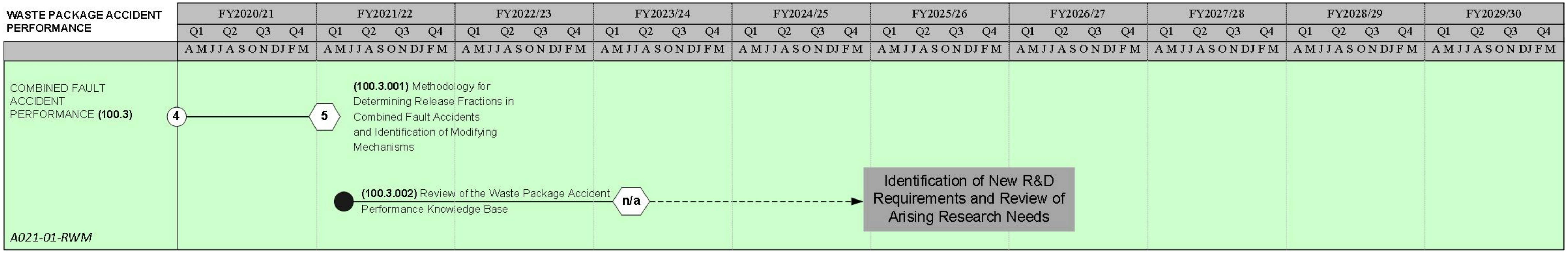


Figure D18 Long Range Graphic (Continued)

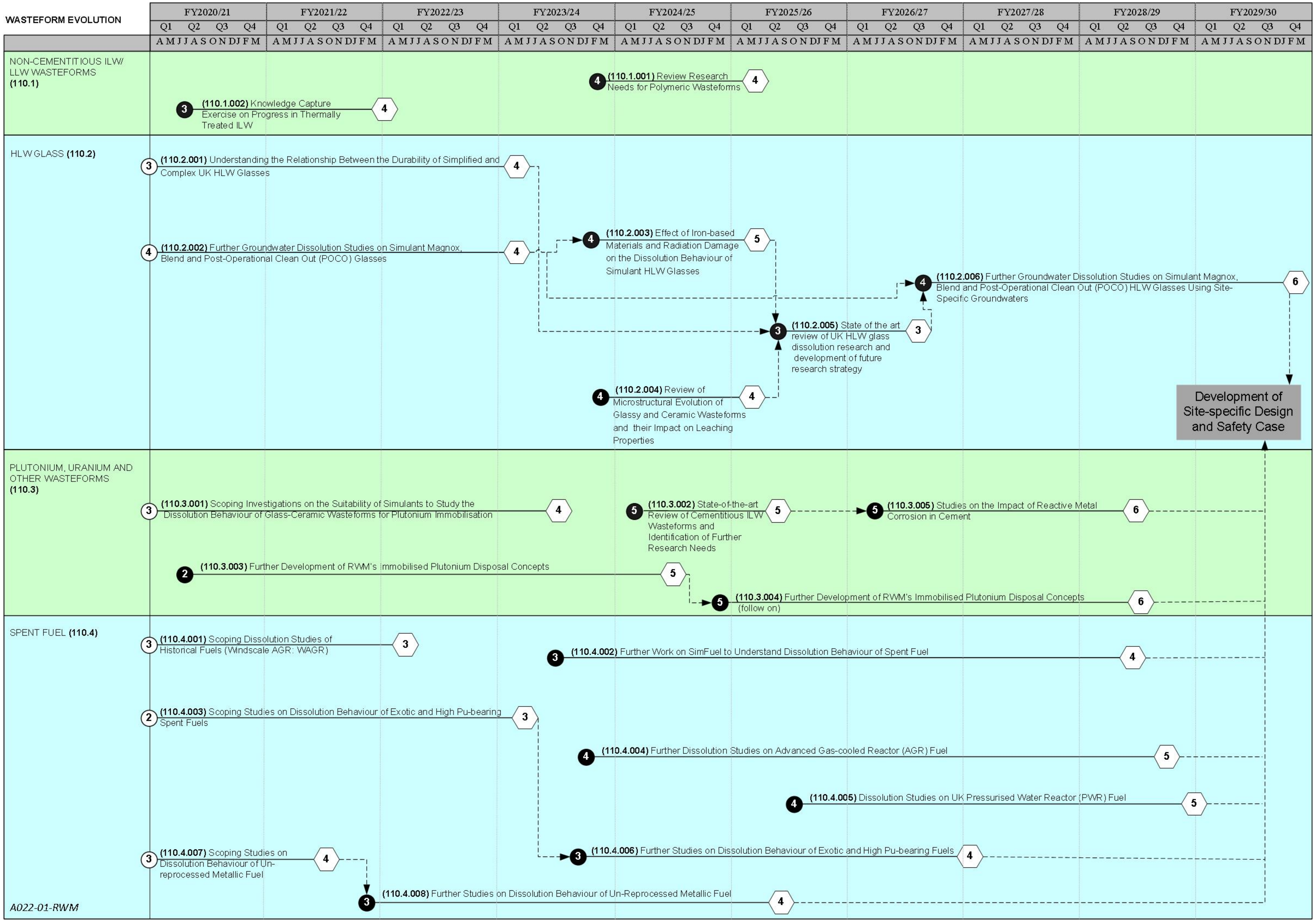


Figure D19 Long Range Graphic (Continued)

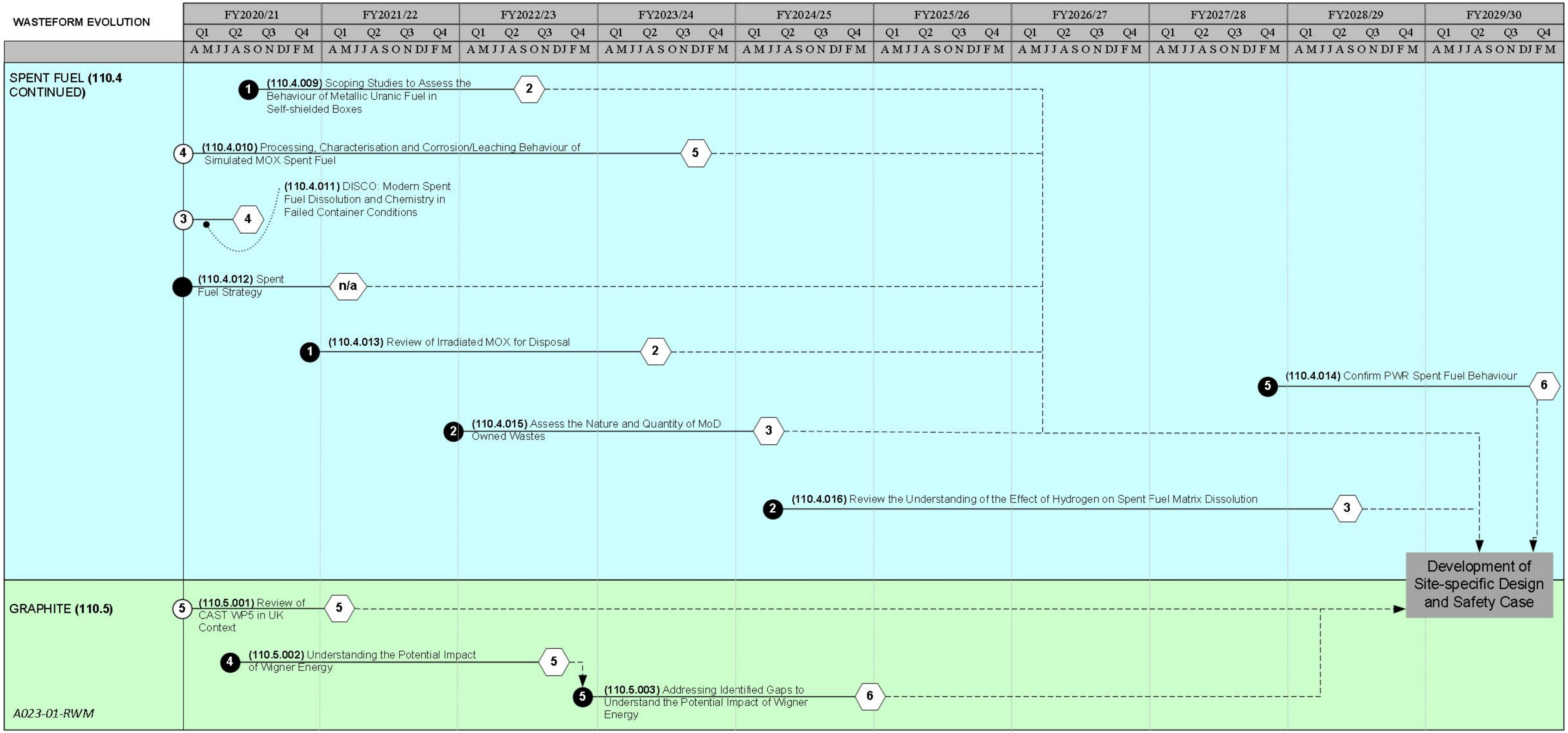


Figure D20 Long Range Graphic (Continued)

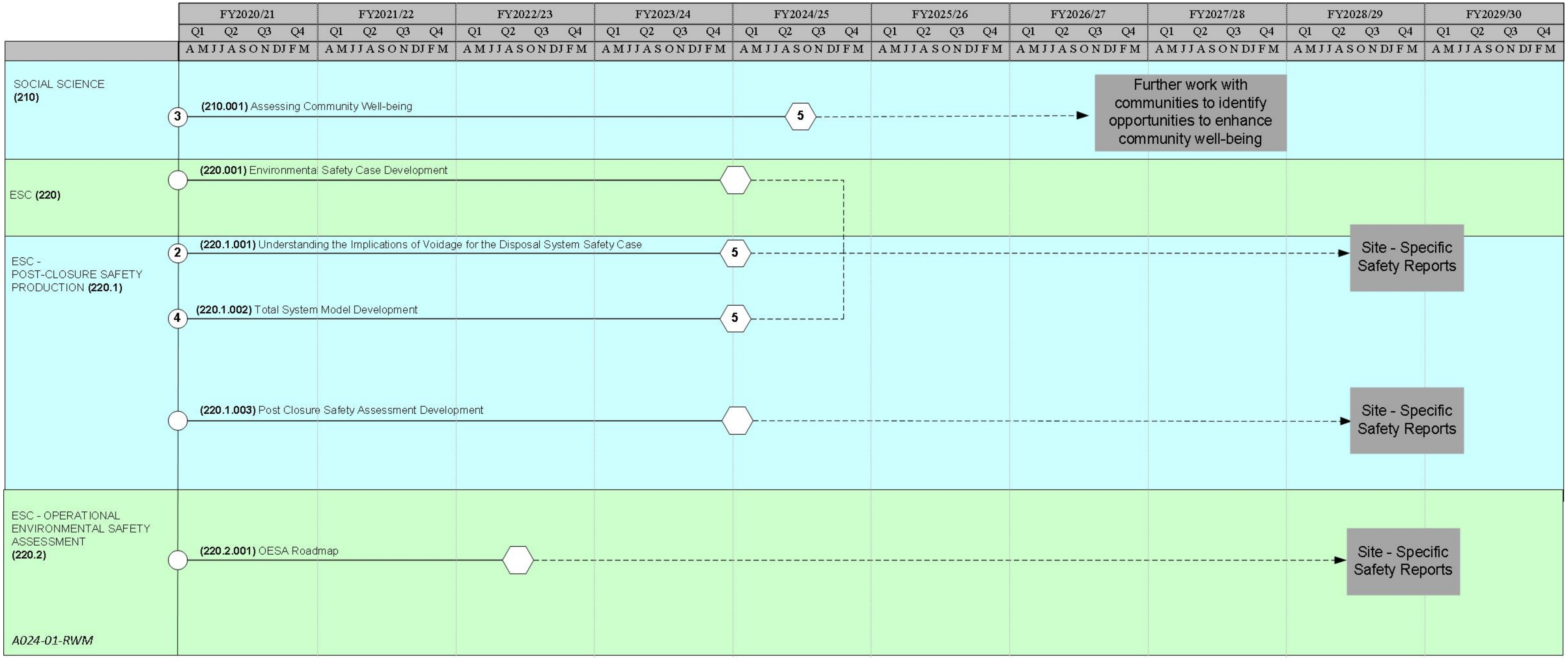
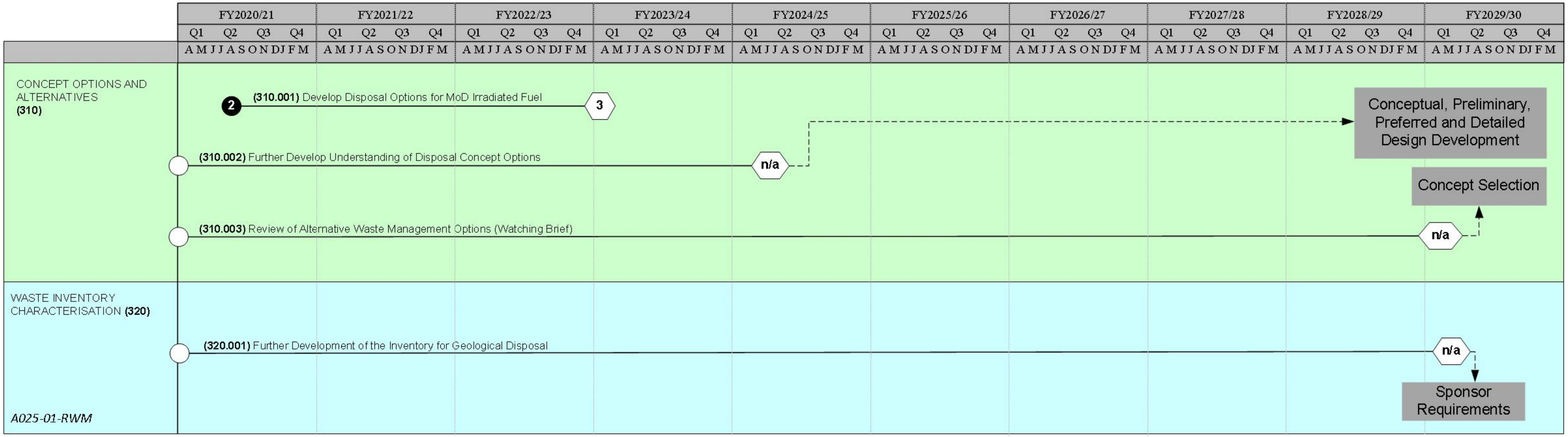


Figure D21 Long Range Graphic (Continued)



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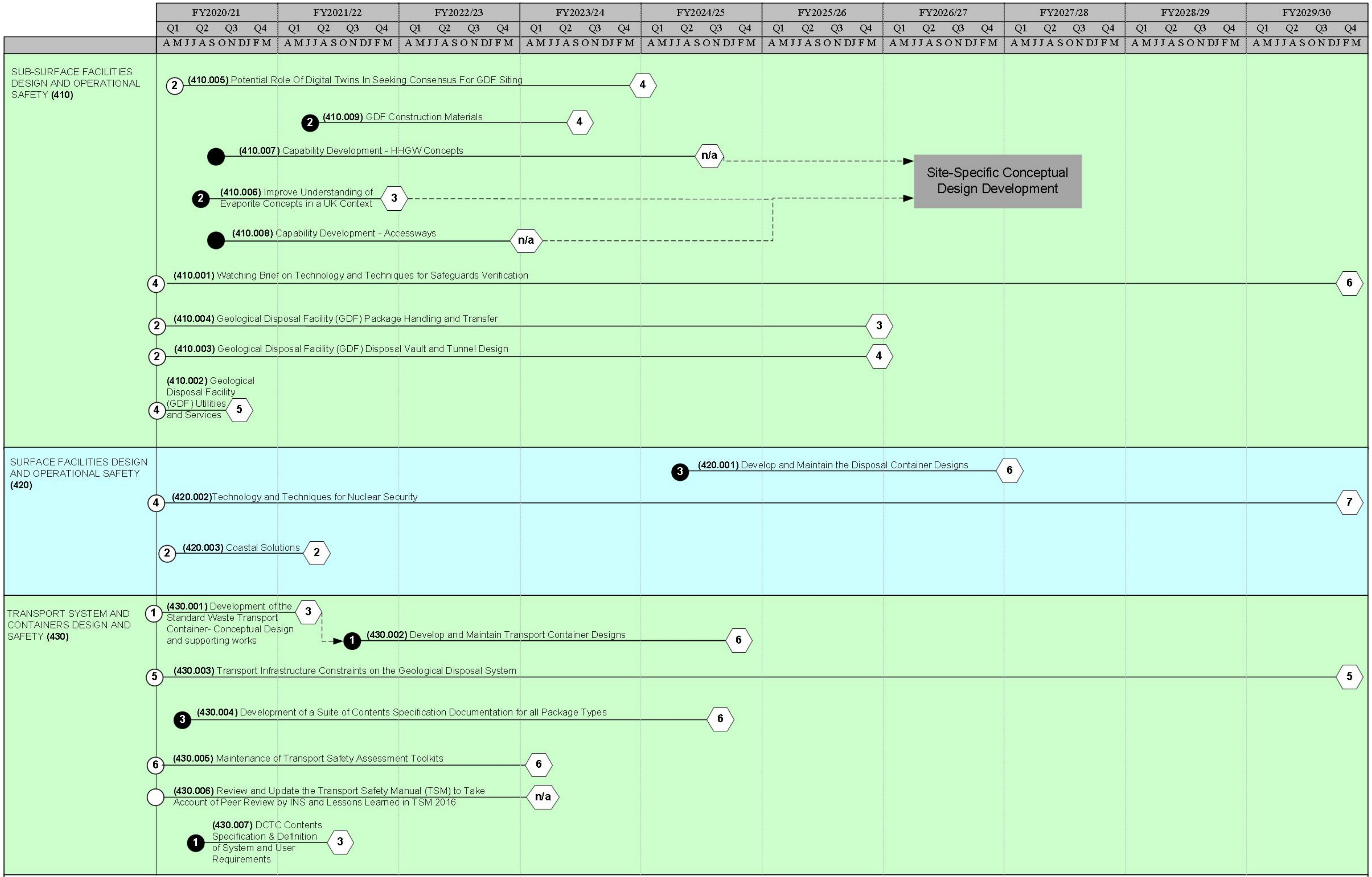

For engineering design tasks the concept of Technology Readiness Levels (TRLs) is more appropriate than Scientific Readiness Levels (SRLs) as this research and development concerns the planning and provision of engineering solutions rather than developing scientific underpinning. Hence, unless stated otherwise, TRLs are used on this sheet.

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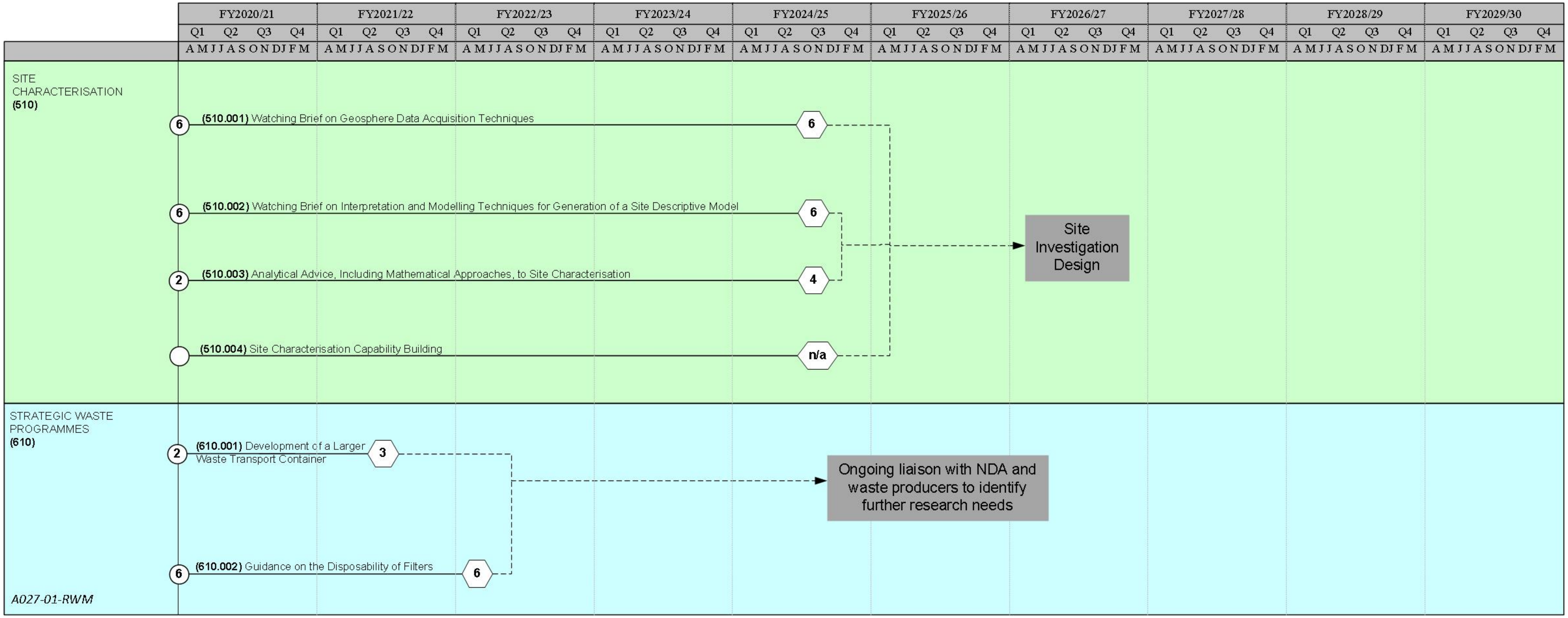
Figure D23 Long Range Graphic (Continued)



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