Radioactive Waste Management

NDA Report no. DSSC/201/01

Geological Disposal

Generic Transport Safety Case - Main Report

December 2016

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Preface

Radioactive Waste Management Limited (RWM) has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for the geological disposal of the higher activity radioactive wastes in the UK. As a pioneer of nuclear technology, the UK has accumulated a legacy of higher activity wastes and material from electricity generation, defence activities and other industrial, medical and research activities. Most of this radioactive waste has already arisen and is being stored on an interim basis at nuclear sites across the UK. More will arise in the future from the continued operation and decommissioning of existing facilities and the operation and subsequent decommissioning of future nuclear power stations.

Geological disposal is the UK Government's policy for higher activity radioactive wastes. The principle of geological disposal is to isolate these wastes deep underground inside a suitable rock formation, to ensure that no harmful quantities of radioactivity will reach the surface environment. To achieve this, the wastes will be placed in an engineered underground facility – a geological disposal facility (GDF). The facility design will be based on a multi-barrier concept where natural and man-made barriers work together to isolate and contain the radioactive wastes.

To identify potentially suitable sites where a GDF could be located, the Government has developed a consent-based approach based on working with interested communities that are willing to participate in the siting process. The siting process is on-going and no site has yet been identified for a GDF.

Prior to site identification, RWM is undertaking preparatory studies which consider a number of generic geological host environments and a range of illustrative disposal concepts. As part of this work, RWM maintains a generic Disposal System Safety Case (DSSC). The generic DSSC is an integrated suite of documents which together give confidence that geological disposal can be implemented safely in the UK.

Executive Summary

Background

RWM has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for the geological disposal of the UK's higher activity waste.

The generic Disposal System Safety Case (DSSC) plays a key role in the iterative development of a geological disposal system and is a demonstration that a geological disposal facility (GDF) can be implemented safely. The generic DSSC also forms a benchmark against which RWM provides advice to waste producers on the packaging of wastes for disposal.

One part of the generic DSSC is the generic Transport Safety Case (TSC). The generic TSC comprises three documents that together aim to provide confidence in the radiological safety of the transport of radioactive waste to a GDF, without being specific to any potential GDF location. This document, the generic Transport Safety Case Main Report (generic TSC Main Report), is the header report for the generic TSC. It draws together the safety arguments and main conclusions of its two underpinning reports: the Transport Package Safety (TPS) report and the generic Transport Safety Assessment (generic TSA). The generic TSC forms the basis for future optimisation studies, transport system design and disposability assessments.

Regulatory context and compliance

Legislation relating to the radiological safety of transport includes the Carriage of Dangerous Goods Regulations 2009, as amended by the Carriage of Dangerous Goods Regulations 2011, which together implement the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material 2012 (The IAEA Transport Regulations) in the UK, and the Ionising Radiations Regulations 1999.

The key principles enshrined in the IAEA Transport Regulations are to ensure safety by:

- containment of the radioactive contents
- control of external radiation levels
- prevention of criticality
- prevention of damage caused by heat

These requirements are satisfied firstly by applying a graded approach to contents limits for packages and conveyances and to performance standards applied to package designs, depending upon the hazard of the radioactive contents. Secondly, they are satisfied by imposing conditions on the design and operation of packages and on the maintenance of packaging, including consideration of the nature of the radioactive contents. Finally, they are satisfied by requiring administrative controls, including, where appropriate, approval by competent authorities.

Compliance of a transport package with the design requirements of the IAEA Transport Regulations is demonstrated by a Design Safety Report (DSR), which is produced by the Design Authority. For certain package or material designs, that is, those pertaining to higher hazard radioactive materials, the DSR is submitted to a competent authority for approval. For other designs, that is, those pertaining to lower hazard radioactive materials, self-approval by the Design Authority is sufficient, and is subject to audit by the competent authority.

In order to demonstrate approval, all material and package designs must have associated documentary evidence of the compliance of the design with applicable requirements. A competent authority will issue a certificate of approval when approval is granted, and bodies undertaking self-approval also issue evidence, usually in the form of a certificate of approval.

The TPS describes the procedures, assessments and approvals that are, or will be, in place to ensure compliance with the IAEA Transport Regulations.

Safety assessment

In addition to the assurance of appropriate waste package specification and design given in the TPS, the generic TSC includes an assessment of doses to workers from routine[1] operations. This assessment provides a basis for the prior radiological evaluation(s) that will be part of the radiation protection programme(s) required by the IAEA Transport Regulations. It also provides a baseline against which the safety benefits of potential additional risk control measures can be compared in future, as part of the optimisation process (to reduce risks so far as is reasonably practicable), that will be required to comply with the Ionising Radiations Regulations and the Health and Safety at Work etc Act. The results are compared to RWM's radiological protection criteria for individual doses, which are derived from health and safety regulation and guidance, as interpreted for a geological disposal system by RWM's Radiological Protection Criteria Manual (RPCM).

The dose assessment comprises a bounding dose assessment and a best estimate dose assessment. The bounding dose assessment considers operators who transport packages which are at regulatory dose rate limits, while the best estimate dose assessment considers the doses received from transporting RWM's best estimate of the inventory for disposal. The main results of the dose assessment were as follows:

1. Even under bounding conditions, there are no operator groups for which members could receive an annual individual dose in excess of the legal limit of 20 mSv/yr for employees working with radiation.
2. The best estimates of individual worker doses are all within the Basic Safety Objective of 1 mSv/yr for employees working with radiation. The most exposed group is train crew, for whom the maximum individual annual dose is estimated to be 79% of the RPCM Basic Safety Objective.

Conclusion

This generic TSC Main Report draws together and summarises the safety arguments made in the TPS report and the generic TSA, in order to provide confidence, at this stage of the system development process, that radioactive waste can be safely transported to the GDF.

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[1] For the purposes of the generic TSC, "routine operations" means incident-free transport, consistent with the "routine conditions of transport" as defined in the IAEA Transport Regulations. This corresponds to what would be called "normal operations" in a fixed facility.

List of Contents

Conditions of Publication ii

Preface iii

Executive Summary v

1 Introduction 1

1.1 Introduction to the generic Disposal System Safety Case 1
1.2 Introduction to the generic Transport Safety Case Main Report 3
1.3 Objectives 4
1.4 Scope 5
1.5 Document structure 6

2 Regulatory Context 7

2.1 Key requirements 7
2.2 Role of the TPS report in relation to regulatory and other requirements 8
2.3 Role of the generic TSA in relation to regulatory requirements 9

3 Safety Strategy, Principles and Approach to Producing the Generic TSC 11

3.1 Overview of safety strategy 11
3.2 Strategic transport safety principles 11
3.3 The safety integrated design process 12

4 Safety Arguments 13

4.1 Safety approach 13
4.2 Waste package safety 15
4.3 Transport dose assessment 16

5 Discussion 19

5.1 Main uncertainties 19
5.2 Forward programme 20

6 Summary 21

References 23

Glossary 25

1 Introduction

1.1 Introduction to the generic Disposal System Safety Case

RWM has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for geological disposal of the UK's higher activity radioactive waste. Information on the approach of the UK Government and devolved administrations of Wales and Northern Ireland[2] to implementing geological disposal, and RWM's role in the process, is included in an overview of the generic Disposal System Safety Case (the Overview) [1].

A geological disposal facility (GDF) will be a highly-engineered facility, located deep underground, where the waste will be isolated within a multi-barrier system of engineered and natural barriers designed to prevent the release of harmful quantities of radioactivity and non-radioactive contaminants to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a consent-based approach based on working with interested communities that are willing to participate in the siting process [2]. Development of the siting process is ongoing and no site has yet been identified for a GDF.

In order to progress the programme for geological disposal while potential disposal sites are being sought, RWM has developed illustrative disposal concepts for three types of host rock. These host rocks are typical of those being considered in other countries, and have been chosen because they represent the range that may need to be addressed when developing a GDF in the UK. The host rocks considered are:

- higher strength rock, for example, granite
- lower strength sedimentary rock, for example, clay
- evaporite rock, for example, halite

The inventory for disposal in the GDF is defined in the Government White Paper on implementing geological disposal [2]. The inventory includes the higher activity radioactive wastes and nuclear materials that could, potentially, be declared as wastes in the future. For the purposes of developing disposal concepts, these wastes have been grouped as follows:

- High heat generating wastes (HHGW): that is, spent fuel from existing and future power stations and High Level Waste (HLW) from spent fuel reprocessing. High fissile activity wastes, that is, plutonium (Pu) and highly enriched uranium (HEU), are also included in this group. These have similar disposal requirements, even though they don't generate significant amounts of heat.
- Low heat generating wastes (LHGW): that is, Intermediate Level Waste (ILW) arising from the operation and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste (LLW) unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium (DNLEU).

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[2] Hereafter, references to Government mean the UK Government including the devolved administrations of Wales and Northern Ireland. Scottish Government policy is that the long term management of higher activity radioactive waste should be in near-surface facilities and that these should be located as near as possible to the site where the waste is produced.

RWM has developed six illustrative disposal concepts, comprising separate concepts for HHGW and LHGW for each of the three host rock types. Designs and safety assessments for the GDF are based on these illustrative disposal concepts.

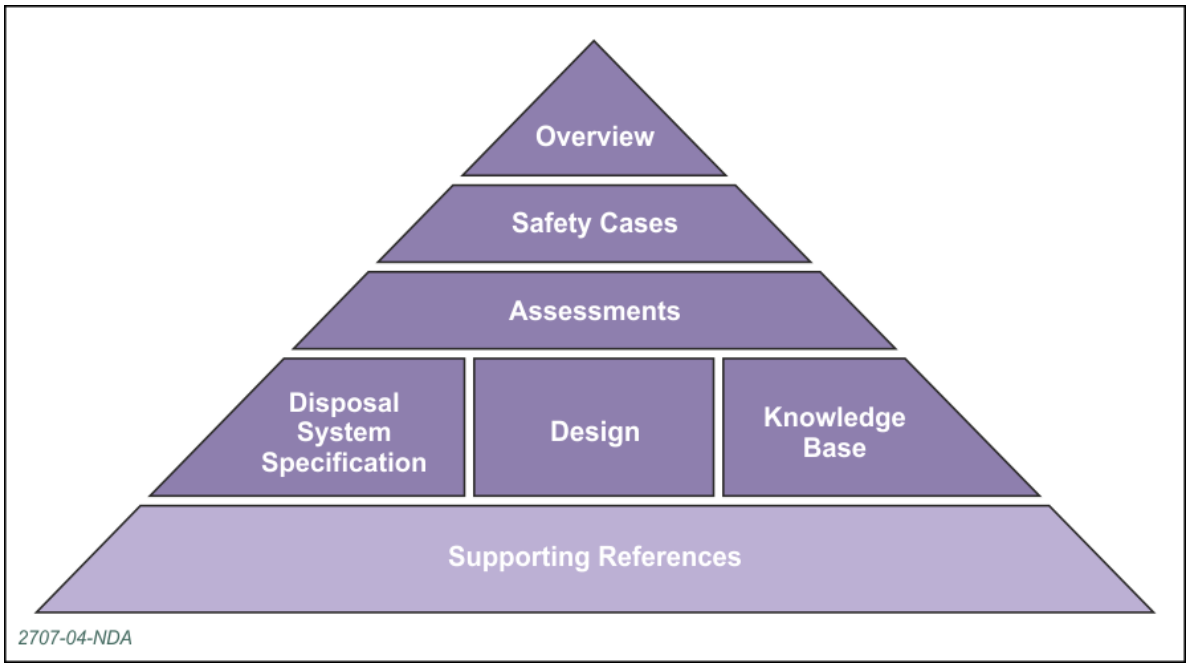
High level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

The generic Disposal System Safety Case (DSSC) plays a key role in the iterative development of a geological disposal system. This iterative development process starts with the identification of the requirements for the disposal system, from which a disposal system specification is developed. Designs, based on the illustrative disposal concepts, are developed to meet these requirements, which are then assessed for safety and environmental impacts. An ongoing programme of research and development informs these activities. Conclusions from the safety and environmental assessments identify where further research is needed, and these advances in understanding feed back into the disposal system specification and facility designs.

The generic DSSC provides a demonstration that geological disposal can be implemented safely. The generic DSSC also forms a benchmark against which RWM provides advice to waste producers on the packaging of wastes for disposal.

Document types that make up the generic DSSC are shown in Figure 1. The Overview provides a point of entry to the suite of DSSC documents and presents an overview of the safety arguments that support geological disposal. The safety cases present the safety arguments for the transportation of radioactive wastes to the GDF, for the operation of the facility, and for long-term safety following facility closure. The assessments support the safety cases and also address non-radiological, health and socio-economic considerations. The disposal system specification, design and knowledge base provide the basis for these assessments. Underpinning these documents is an extensive set of supporting references. A full list of the documents that make up the generic DSSC, together with details of the flow of information between them, is given in the Overview.

Figure 1 Structure of the generic DSSC



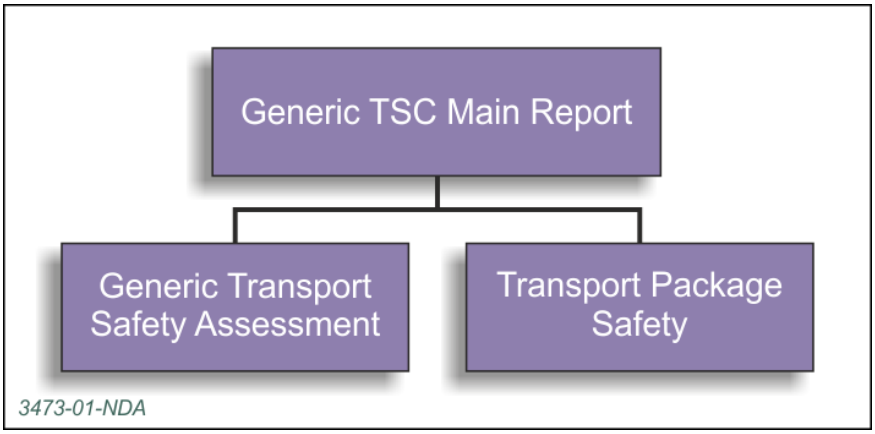
1.2 Introduction to the generic Transport Safety Case Main Report

This document is the generic Transport Safety Case (generic TSC) Main Report. It is the top level document in the suite of three documents that make up the generic Transport Safety Case (generic TSC). The structure of the generic TSC is shown in Figure 2.

The Transport Package Safety (TPS) report [4] describes the means by which the safety of transport packages is ensured. It describes the procedures, assessments and approvals that are, or will be, in place. The generic Transport Safety Assessment (generic TSA) [5], presents an assessment of the doses to workers incurred in routine[3] operations for the transport of wastes from producing sites to the GDF. It complements the TPS report, which considers the safety of each package, by considering the system as a whole. Both have an important role in providing a baseline to assess waste packaging proposals from producers under RWM's Disposability Assessment process [6], to determine whether they are likely to be transportable in the future.

This generic TSC Main Report draws together and summarises the safety arguments made in the TPS report and the generic TSA, in order to provide confidence, at this stage of the system development process, that the transport of radioactive waste to the GDF will be safe.

Figure 2 Structure of the generic Transport Safety Case



The generic DSSC was previously published in 2010. There are now a number of drivers for updating the safety case as an entire suite of documents, most notably the availability of an updated inventory for disposal.

This document updates and replaces the 2010 generic Transport Safety Case Main Report [7], which was published as part of the 2010 generic DSSC suite. This issue includes the following improvements:

- Changes in the assessment basis:
  - **Changes to the inventory**: The assessment reported here is based on the 2013 Derived Inventory [8]. The main changes to the inventory since publication of the 2010 generic DSSC are discussed in [9]. The most significant changes are: the inclusion of wastes and spent fuel associated with a 16 GW(e) nuclear new build programme; reuse of 95% of existing plutonium stocks as

[3] For the purposes of the generic TSC, "routine operations" means incident-free transport, consistent with the "routine conditions of transport" as defined in the IAEA Transport Regulations. This corresponds to what would be called "normal operations" in a fixed facility

mixed oxide spent fuel; the exclusion of waste managed under the Scottish Government's policy for higher activity wastes and the inclusion of material associated with UK defence activities. These changes have led to an increased GDF footprint and extended operating time.

- **New waste containers:** namely standardised disposal containers for HHGW; transport and disposal containers for DNLEU; and 500 litre robust shielded drums, 3 cubic metre robust shielded boxes and 500 litre and 1 cubic metre concrete drums, for ILW.
- **Changes in other data:** in particular an updated transport schedule aligned with the extended operating time and 2013 Derived Inventory.

- Improvements in the assessment method:
  - **Treatment of uncertainty in the inventory:** Understanding of uncertainty in the inventory for disposal has been improved through consideration of a wide range of inventory scenarios [10]. These inventory scenarios have been developed to allow consideration of potential changes to the UK nuclear programme, for example, a decrease in Magnox fuel reprocessing or an increase in the anticipated operational lifetime of legacy reactors. This differs from the approach in the 2010 generic TSC where inventory uncertainty was explored through the use of a single 'Upper Inventory' that made allowance for all the major uncertainties, including use of upper estimates, new build arisings and defence materials.

- Other improvements/changes include:
  - **Updated assumptions and methodologies in the generic TSA,** for example the generic TSA performs a bounding case assessment to gives confidence that doses received by operators will be within limits set out in the Radiological Protection Criteria Manual (RPCM) [11] even under bounding conditions of transport, and a best estimate assessment to provide a basis for future optimisation of the transport system.
  - Updates to take account of **revisions to the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material** [12] (hereafter referred to as the IAEA Transport Regulations), for example, in relation to new provisions for classifying material as fissile excepted.
  - Updates to reflect progress in the development of **package contents specifications and criticality safety assessments** where RWM is the Design Authority, and how RWM provides assurance that transport packages, for which it is not the Design Authority, will be safe to transport to the GDF in the future.
  - **Removal of duplicate information:** Detailed technical background information that had been duplicated across the 2010 generic DSSC documents has been removed and placed in the Technical Background document [3].

1.3 Objectives

This generic TSC Main Report draws together and summarises the safety arguments made in the TPS report and the generic TSA in order to meet the objectives of the generic TSC.

The generic TSC forms a part of RWM's demonstration to regulators and stakeholders that safe geological disposal is feasible. Primarily, it provides confidence (without being specific to any potential GDF location) that the necessary transport operations will meet the regulatory requirements for radiological safety and can be achieved with radiation exposures below statutory limits and RWM's own criteria.

The generic TSC also has an important role in providing a basis for assessing whether waste packaging proposals are likely to be transportable in the future, following RWM's Disposability Assessment process.

The generic TSC provides a vehicle for engaging with stakeholders, such as waste producers and communities interested in hosting a GDF, on topics related to transport safety.

Lastly, it informs RWM's generic Science and Technology Plan [13] as part of the iterative approach to implementing geological disposal.

The audience for this report is expected to be primarily:

- the radioactive material transport regulator: Office for Nuclear Regulation (ONR)
- RWM's internal functions, notably those involved in future optimisation studies, transport system design and disposability assessments
- waste producers

The public and other stakeholders, especially communities interested in hosting the GDF or those along a potential transport route, may also take an interest.

1.4 Scope

1.4.1 Aspects of safety considered

The generic TSC considers the radiological safety of the transport of the radioactive waste inventory for disposal to a GDF.

As no location has yet been identified for a GDF, there are uncertainties in aspects of transport system design, such as routes, transport modes and infrastructure. The document is therefore 'generic' in the sense that it provides a preliminary safety case, for an illustrative transport system design, rather than assessing a specific transport system.

Radiological risks from accidents are not explicitly assessed. Such risks will be kept as low as reasonably practicable (ALARP) through compliance with the IAEA Transport Regulations, as described in the TPS report, and by optimisation of the system design and its operation, for example through modifications to the design of handling equipment.

The following aspects of safety are excluded from consideration at this stage of GDF implementation:

- Doses to the public: these will be considered at a site-specific stage, when there is sufficient information on the transport system to enable areas of significant potential public exposure to be identified; for example, in the vicinity of transhipment points.
- Conventional health and safety risks from vehicle movement accidents or package lifting and loading operations at transhipment points. These too will be considered at a site-specific stage, most probably within a Transport assessment forming part of, or accompanying the Environmental Assessment and/ or the Health Impact Assessment, or as part of employers' duties to manage health and safety at work [30, 31].
- Risks associated with non-radioactive hazardous materials within the waste: RWM is currently developing its approach to the assessment of such materials in all areas of safety.
- Security and safeguarding risks: these will be considered separately, taking account of the requirements of the Nuclear Industries Security Regulations [14] and associated regulations for security, and of the EURATOM treaty [15,16] for

safeguards. RWM's work on security and safeguards is described in the generic Transport System Design (GTSD) [18, Section 8] and in [17].

1.4.2 Transport operations considered

All aspects of the transport system including routes, conveyances, transport packages, operational procedures and logistics, as described in the generic Transport System Design and Disposal Facilities Design [18, 19] have been considered.

It is assumed, for the purpose of the dose assessment in the generic TSA, that the transport operation:

- starts at the point where a transport package is loaded and secured to a transport conveyance
- covers the journey through the public domain, including any en-route transhipment facilities at which packages are transferred from one conveyance to another
- Continues into the GDF up to the point where the responsibility for the transport packages is handed over to the GDF operator. This will be before the point when the package is untied from the vehicle.

Doses to handlers and health physicists working within waste producing sites are excluded, as it is assumed that their safety (including that related to any transport-related tasks) will be assured by the safety case process for that nuclear licensed site. The dose assessment therefore considers drivers and crew of transport vehicles and handlers at transhipment points. The TPS element of the safety case, however, considers more widely relevant aspects of safety, such as package design.

1.5 Document structure

The remainder of this document is structured as follows:

- Section 2 outlines the regulatory context
- Section 3 sets out RWM's overall safety strategy, principles and the approach taken to developing the generic TSC
- Section 4 summarises the arguments and evidence to date relating to waste package safety (from the TPS) and the results of the dose assessment (from the generic TSA)
- Section 5 outlines the main remaining uncertainties and the forward programme
- Section 6 gives a summary of this report

2 Regulatory Context

The regulatory regime that applies to transport of radioactive material is described in some detail in the TPS report. Here, the requirements are summarised (Section 2.1), together with an explanation of how the TPS report and the generic TSA contribute to satisfying those requirements (Sections 2.2 and 2.3 respectively).

2.1 Key requirements

The key legislation relating to the radiological safety of transport, and broader duties (where relevant to the scope of the current safety case) under general health and safety legislation is as follows:

- The Carriage of Dangerous Goods Regulations 2009 [20], as amended by the Carriage of Dangerous Goods Regulations 2011 [21], which implement the IAEA Transport Regulations in the UK. These regulations also implement provisions of European legislation on the carriage of dangerous goods and, in particular, the requirements contained in:
    - the European Agreement concerning the International Carriage of Dangerous Goods by Road (generally referred to as 'ADR') [22]
    - the Regulations concerning the International Carriage of Dangerous Goods by Rail (generally referred to as 'RID') [23]

  The International Maritime Dangerous Goods (IMDG) Code [24] provides the basis of UK maritime legislation for the safe transport of dangerous goods or hazardous materials, including radioactive materials. The current version of the IMDG code is invoked as regulation by the Merchant Shipping Notices (MSNs): the current relevant MSN number is 1854 [25]. The transportation of radioactive wastes and materials by sea also has to meet the requirements of the Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulations [26] and the Dangerous Substances in Harbour Areas Regulations [27].

  The international agreements, ADR, RID, and the IMDG Code, as well as the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways ('ADN'), are based upon the Recommendations on the Transport of Dangerous Goods Model Regulations published by the United Nations [28], of which the requirements for the transport of radioactive material are based upon the IAEA Transport Regulations.
- The Ionising Radiations Regulations 1999 [29] (the IRRs) place limits and other requirements on radiation exposures, requiring, amongst other things, that the radiation exposures of all persons are restricted 'so far as is reasonably practicable' (SFAIRP).
- Under the Health and Safety at Work (etc) Act 1974 [30] (the HSWA), there are general duties on employers to ensure, so far as is reasonably practicable[4], the health, safety and welfare of their employees, and that persons not in their

[4] Note on terminology: The IAEA Transport Regulations require individual doses, the number of persons exposed, and the likelihood of incurring exposure to be kept as low as reasonably achievable (ALARA). The HSWA and IRRs require risks, or radiation exposures respectively, to be reduced "so far as is reasonably practicable" (SFAIRP). More generally, UK regulatory guidance and practice commonly refer to the principle of keeping risks as low as reasonably practicable (ALARP). For most practical purposes satisfaction of the principles of ALARA, SFAIRP and ALARP call for the same tests to be applied. For convenience, therefore, we refer only to ALARP is referred to in the remainder of this report, except where quoting specifically from documents that use one of the other terms.

employment are not exposed to risks to their health or safety. These duties apply to both radiological and non-radiological risks.

- The Management of Health and Safety at Work Regulations 1999 [31] place a general requirement on employers to carry out 'suitable and sufficient risk assessment'. This applies to both radiological and non-radiological risks.

The key principles enshrined in the IAEA Transport Regulations are to ensure safety by:

- containment of the radioactive contents
- control of external radiation levels
- prevention of criticality
- prevention of damage caused by heat

These requirements are satisfied firstly by applying a graded approach to contents limits for packages and conveyances and to performance standards applied to package designs, depending upon the hazard of the radioactive contents. Secondly, they are satisfied by imposing conditions on the design and operation of packages and on the maintenance of packaging, including consideration of the nature of the radioactive contents. Finally, they are satisfied by requiring administrative controls, including, where appropriate, approval by competent authorities. This graded approach removes the need for dependency on operational and procedural controls, such as restrictions on transport modes or routes.

The IAEA Transport Regulations also:

- Specify criteria to be met by each transport package, for example, on external dose rates and surface temperatures.
- Require demonstration of the ability of transport packages to withstand certain physical challenges, and to satisfy other tests that simulate their performance under normal conditions of transport and in accidents.
- Assign responsibilities to those concerned with the operation, including the consignor, carrier and consignee, including requirements for administrative and operational controls, quality assurance, training and expertise, security, emergency provisions and accident reporting.
- Require a structured and systematic approach to ensuring safety of the transport operation, in order to keep the magnitude of individual doses, the number of persons exposed, and the likelihood of incurring exposures as low as reasonably achievable (ALARA), economic and social factors being taken into account. (Packaging and performance requirements are proportionate to the nature and quantity of the contents: that is, to the magnitude of the hazard.)
- Require the implementation of Radiation Protection Programmes (RPPs) documenting the controls in place by the consignor, transport operator and consignees to limit doses to workers and the public.

2.2 Role of the TPS report in relation to regulatory and other requirements

The TPS report describes the procedures, assessments and approvals that are, or will be, in place to ensure the safety of people and the environment through compliance with the IAEA Transport Regulations. Through compliance, requirements for containment, control of external radiation levels, prevention of criticality and prevention of damage caused by heat are met.

The TPS demonstrates how compliance and therefore safety is ensured with regard to:

- the design and approval of transport package designs

- RWM's Disposability Assessment process, which aims to give confidence to waste packagers that proposed packages will comply with the eventual needs for transport to, and disposal in, a GDF, and confidence to RWM that the disposal system considered within the generic DSSC will be appropriate to the inventory for disposal
- pre-despatch activities necessary to ensure that a package remains compliant with transport requirements and the waste acceptance criteria (WAC) for disposal

2.3 Role of the generic TSA in relation to regulatory requirements

As noted above, the IAEA Transport Regulations require consignors, the transport operator and consignees to produce an RPP prior to transport. A necessary step in developing an RPP will be to make a 'prior radiological evaluation'. The generic TSA forms a basis for such evaluation by providing preliminary estimates of doses to operators from routine operations.

The dose estimates in the generic TSA also provide a baseline against which the safety benefits of potential additional risk control measures can be compared, as part of the optimisation and future ALARP studies that will be required to demonstrate that the requirements of the IRRs and the HSWA can be met.

3 Safety Strategy, Principles and Approach to Producing the Generic TSC

This section gives an overview of RWM's strategy for ensuring and demonstrating safety (Section 3.1), lists the strategic principles (Section 3.2) and outlines the safety-integrated design process (Section 3.3).

3.1 Overview of safety strategy

RWM's overall strategy to ensure safety is set out in the Transport Safety Strategy [32].

There are several elements to RWM's work in transport, as well as transport safety, such as design of the transport infrastructure, logistical planning and costing. These safety and other elements interact with each other, and with site selection. Hence RWM's work on transport has several very different purposes. These are described below in more detail.

A key objective of the transport safety work is to provide assurance that all transport operations associated with the implementation and operation of the GDF can be achieved safely.

There is also a need to provide a benchmark against which RWM can carry out disposability assessments of waste producers' packaging proposals. The generic TSC serves that purpose. It is possible that there will be parallel development of site-specific TSCs; the generic TSC may still be used for disposability assessments of some waste types, even after a site has been selected for others (for example, if the site is not suitable for disposal of the whole inventory).

As part of the iterative approach to disposal system specification development, transport safety assessment work is also necessary in order to inform the specification, development and design of the disposal system. The disposal system design includes the design of the transport system which covers the required infrastructure, vehicle requirements, transport routing, scheduling and costing.

Ultimately, there are transport-related documents that are required by law by regulators prior to transport, and by local authorities and UK Government as part of applications for site investigation and GDF construction.

This diversity of purposes gives rise to the need for a diversity of activities and documents. The scope of RWM's planned work in support of transport is given in the Transport Safety Strategy.

3.2 Strategic transport safety principles

RWM has defined a number of strategic principles for each safety strategy (transport, operational and environmental), informing the purpose and scope of the required safety documents. The principles specific to transport are included in the Transport Safety Strategy, which has been implemented in the management system. These principles are summarised below:

Principle 1: Building confidence in the safety cases

The fundamental basis of RWM's Transport Safety Strategy is that radiological safety is ensured through compliance with the IAEA Transport Regulations.

RWM's Corporate Strategy [33] notes that radioactive waste has been transported within the UK, and to and from the UK, for the last 50 years without serious incident. Confidence in the TSC is therefore underpinned by confidence in the IAEA Transport Regulations.

Principle 2: Parallel generic and site-specific safety cases

Generic safety cases for a range of possible geological environments and illustrative designs will be maintained, whilst developing site-specific cases in parallel. This allows for the generic TSC to support disposability assessments until there is confidence in a given site being taken forward, whilst a site-specific TSC will inform the iterative development of the design of the transport system for that site. This parallel approach allows for the possibility of additional, alternative sites being put forward, and to continue undertaking disposability assessments that encompass a broad range of potential disposal facility designs.

Principle 3: Continued maintenance of the generic safety cases

The generic TSC will be maintained as a living suite of documents under change control arrangements.

Principle 4: Iterative development of the site-specific safety case

The site-specific work programme will be based on the iterative development of a geological disposal system. Once a preferred site is identified, disposal concepts will be developed for that site, on which preliminary and preferred designs will be developed. The site-specific TSC will iteratively assess the transport safety of those designs as they evolve.

Principle 5: Responsibility for demonstrating transport safety

Responsibility for demonstrating and providing a safe transport operation will be shared between a number of organisations, for example consignors, carriers and the consignee (the GDF operator). Until such time as these responsibilities are assigned, RWM will represent the role of waste consignor, carrier and the consignee and take responsibility for developing and implementing the safety strategy.

Principle 6: Assessment of all safety impacts of transport

RWM recognises the need to address both radiological and non-radiological safety. The current generic TSC addresses the former and the latter will be addressed at a site-specific stage as part of the transport assessment required as part of the planning process.

3.3 The safety integrated design process

As explained in the Overview, RWM adopts a safety-integrated process to the design of the disposal system, and this applies to both the design of transport packages and the transport system as a whole. The assessment and approval processes as described in the TPS report inform the safety-integrated design process for packages. For the wider transport system, safety-integrated design will be facilitated via optimisation studies, informed by, amongst other inputs, the generic TSA.

4 Safety Arguments

This section describes RWM's arguments and evidence in support of the claims made regarding radiological safety in this generic TSC. It describes the approach to safety in Section 4.1 and discusses the arguments for safety in relation to the waste package and doses to transport workers in Sections 4.2 and 4.3 respectively.

4.1 Safety approach

RWM's governance in the context of safety, its current experience and competence, and the way in which RWM plans to evolve into a site licence company suitable to manage the development and operation of the GDF, and the associated transport system, are described in the Safety and Environmental Management Prospectus [34].

The Transport Safety Manual (part of the RWM Management System [35]) details the procedures and work instructions for the production and management of transport safety documents.

4.1.1 Safety of the transport package

RWM aims to ensure the safety of the transport of radioactive materials principally by complying with the regulatory regime set out in the IAEA Transport Regulations and consequential national legislation. The IAEA regulations were first published in 1961 and are regularly reviewed to ensure they keep pace with scientific and technological developments. They are based on the fundamental principle that transported radioactive material should be packaged adequately to *"protect persons, property and the environment from all the effects of ionising radiation during the transport of radioactive material"*. This principle applies to routine (incident free), normal (including minor mishaps) and accident conditions of transport with minimal reliance on operational controls. Therefore, safety and protection is to be provided by the design of the package for all transport modes.

The required level of protection and safety is achieved by adopting sound package design and manufacturing principles that call upon built-in safety, rather than on human intervention. The package design and safety performance requirements are related to the potential hazard of the radioactive materials being transported: the more hazardous the material, the better the safety performance required of the package. The IAEA Transport Regulations set out safety criteria for nine different types of packages designated as: Excepted package; Industrial Packages Type IP-1, Type IP-2, and Type IP-3; and Type A, Type B(U), Type B(M), Type C packages, and packages containing uranium hexafluoride. Criteria are defined for the design of these packages according to both the activity and the physical form of the radioactive material they may contain. The IAEA Transport Regulations require demonstration of the ability of transport packages to withstand certain physical challenges which increase in severity as the hazard of the radioactive content of the package increases.

The IAEA Transport Regulations also address packing, labelling, loading, storage, in-transit storage, testing requirements and impose limits on external radiation and surface contamination. They impose additional requirements for packages containing fissile material. Quality assurance requirements are specified for all stages in the life of a package, from design and manufacture to operation and maintenance. The IAEA Transport Regulations are multi-modal in that they apply to the transport of radioactive materials by any mode.

The argument for radiological safety is therefore based principally on demonstrating compliance with the IAEA Transport Regulations. The TPS report provides confidence that procedures and processes are, or can be put, in place to ensure compliance.

The Disposability Assessment process for proposals for waste packaging confirms that the proposed transport package complies with the relevant regulatory requirements as currently defined, and also gives confidence to the waste producers, stakeholders and RWM itself that waste packaged now will be suitable for transport and disposal.

4.1.2 Safety of the transport system

As no location has yet been identified for the GDF, there are uncertainties in certain aspects of the transport system design, such as routes, transport modes and infrastructure. Hence, as reported in the generic TSA, a preliminary assessment of a generic transport system has been carried out, based on an illustrative transport system design [19]. Systematic optimisation studies will be undertaken in future to aid decision making on the system design, following the process described in RWM's Quality Management System [35]. The evolution of the generic TSA, as knowledge on possible location information develops, is described in the Transport Safety Strategy.

The generic TSA provides an indication of the levels of external radiation dose to which transport operators would be exposed in routine transport operations. Compliance with the regulatory design requirements for transport packages ensures that internal dose is trivial, but a quantitative assessment of external dose is required.

The aims of the dose assessment are to:

- determine whether routine doses to operators could potentially exceed the legal dose limit
- determine a best estimate routine dose, for comparison with the Basic Safety Objective defined in the RPCM

To achieve these aims, there are two parts to the assessment:

- a bounding assessment
- a best estimate assessment

The bounding assessment provides information on whether routine doses could, in bounding circumstances, exceed dose limits. Bounding circumstances include, for example, operations involving packages with the maximum allowable dose rate and maximum annual exposure times. It forms part of the iterative safety integrated design process, which is defined in the Engineering Design Manual in the RWM Management System. The doses predicted in the bounding assessment are compared with the legal dose limit (as opposed to the Basic Safety Objective set in the RPCM). The demonstration that bounding package dose rates and exposure parameters lead to operator doses within the legal dose limit is an important factor in disposability assessments carried out by RWM on waste producers' packaging proposals. It shows that any proposed packages which are consistent with the basis of assessment (that is, they do not require more close-handling) will not challenge the legal dose limit [5, Section 5.2].

The best estimate assessment provides an understanding of how predicted operator doses compare to the Basic Safety Objective (as opposed to the legal dose limit) set out in the RPCM [5, Section 5.1]. It informs the optimisation of the transport system by providing a basis to estimate the effectiveness of optimisation measures. As for the bounding assessment, the best estimate assessment also forms part of the iterative safety-integrated design process.

The Transport Safety Manual requires that in the event that bounding or best estimate doses remain above the legal dose limit or Basic Safety Objective respectively, once undue pessimisms are removed, this is fed back into the safety integrated design process so that any reasonably practicable measures to reduce dose can be identified.

The legal dose limits and Basic Safety Objectives for routine doses to operators are defined in the RPCM in units of dose per year to an individual operator [11, Table 1]. Thus individual annual dose to operators (mSv/yr) is a key output of this assessment. In addition, collective dose (man-mSv/yr) is calculated, taking account of the number of operators exposed as well as the dose to each individual operator. Collective dose estimates are an important complement to individual dose, especially for comparison of options. In particular, in future ALARP assessments, consideration of collective as well as individual dose will ensure that the risk control measures achieve overall safety benefits and do not simply result in dose sharing or dose redistribution.

4.2 Waste package safety

The arguments and evidence for the safety of each waste package are presented in the TPS report and summarised below.

4.2.1 Transport package approval

Waste package and material designs need to be checked and approved for compliance with the requirements of the IAEA Transport Regulations. The Design Authority is required to gain approval for such designs, and does so by producing a Design Safety Report (DSR). The DSR includes all the information required to demonstrate the safety of the package or material and establishes clear limits on key safety parameters such as dose rate, containment of contents, heat loading and limits on fissile contents.

For certain package or material designs, that is, those pertaining to higher hazard radioactive materials, the DSR is submitted to a competent authority for approval. The legal competent authority in the UK for transport of civil waste is currently the Office for Nuclear Regulation [36]. The legal competent authority for transport of defence waste is the Secretary of State for Defence [20] (with the Defence Nuclear Safety Regulator acting as the regulator). For designs pertaining to lower hazard radioactive materials, self-approval by the Design Authority is sufficient, and is subject to audit by the competent authority.

In order to demonstrate approval, all material and package designs must have associated documentary evidence of the compliance of the design with applicable requirements. A competent authority will issue a certificate of approval when approval is granted, and bodies undertaking self-approval also provide evidence, usually in the form of a certificate of approval.

RWM will be required to produce DSRs for the transport containers for which it is the Design Authority. The Standard Waste Transport Container SWTC-285 is the transport container whose design is most advanced, and elements of the DSR for its use with different types of waste container have already been produced to support RWM's design and assessment work. DSRs for the SWTC-70 and the SWTC-150 will also be produced when required. Ultimately, RWM will produce a DSR for each transport and waste package combination, for which it is the Design Authority, covering all wastestreams likely to be packaged within it.

RWM has embarked on some aspects of the DSR for the Disposal Container Transport Containers (DCTC). However, the DCTC is currently at an early stage of the design and this work is not planned to be completed for several years.

Certain elements of DSRs have been prepared by RWM for both the 4 metre and 2 metre box transport packages in order to support RWM's disposability advice to waste packagers. However, RWM is not the Design Authority for these transport containers; a number of variants have been developed by waste packagers, and it is those waste packagers or their suppliers that are the Design Authorities.

DSRs have been, or will be, produced by other Design Authorities for waste container and transport container designs. Examples of these containers include the 6 metre cube concrete box, the 1 cubic metre and 500 litre concrete drums, the 500 litre robust shielded drum and the 3 cubic metre robust shielded box. All of these are described in the Generic Transport System Design.

4.2.2 Disposability Assessment process

Packaging operations are already under way at waste producing sites, and some packages have already been placed in interim storage awaiting transport to the GDF. In addition, waste packagers need to make plans for manufacture and storage of packages for future waste arisings. Compliance of these packages with regulations and RWM's own requirements for transport and disposal is assessed as part of RWM's Disposability Assessment process. This process allows waste packaging to proceed with confidence that packages will be suitable for transport and disposal. RWM expects that any waste package made now will be periodically reviewed and will have a detailed history, including waste conditioning and storage records. It is expected that such packages will be compliant with a future certificate of approval and will therefore be acceptable for transport to the GDF. It will be necessary to confirm this acceptability prior to despatch.

4.2.3 Pre-despatch activities

Following confirmation of the suitability for transport, the waste package can be retrieved from interim storage, checked to confirm that there has been no degradation during storage and loaded into a transport container, where applicable. The transport package can then be loaded onto the transport conveyance and cleared for despatch. These activities will be specified in detailed procedures and local work instructions prepared by the consignor to meet the requirements set out in the certificate of approval.

4.3 Transport dose assessment

The dose assessment and its conclusions are presented in the generic TSA.

The dose assessment comprises a bounding dose assessment and a best estimate dose assessment. The bounding dose assessment considers operators who transport packages which are at regulatory dose rate limits, while the best estimate dose assessment considers the doses received from transporting RWM's best estimate of the inventory for disposal.

The assessment considers transport by road, rail, sea, or a combination of these, in order to cover bounding cases for operators involved in any of the possible modes. However, as the Transport Safety Strategy [32] is to use rail transport rather than road where practical, the best estimate assessment considers transport to the GDF by rail, with road transport from the waste storage site to a nearby railhead where necessary.

Transport by inland waterway is not assessed as there are currently very few significant movements by this mode and few, if any, possible GDF locations might use this mode. Air transport has also been discounted as a possibility at this stage due to the weight of the transport packages and the limited availability of suitably located and equipped airports.

The findings are summarised below.

4.3.1 Bounding case doses

Bounding annual individual doses to the various transport operator groups and a comparison against the legal limit, are given in Table 1. Note that these are the doses that would be experienced by an operator working with packages at the dose rate limit for a full year.

Table 1 Bounding individual doses to transport operators

Operator Group	Annual individual dose (mSv/yr)	Percentage of legal limit (20 mSv/yr)
STGO[5] 1 and STGO 3 drivers	9.0	45%
Train crew	7.9	40%
Ship crew	2.7	14%
Rail transhipment handlers	2.8	14%
Rail transhipment crane operators	2.8	14%
On-board ship banksmen	10.9	55%
On-board ship crane operators	7.5	38%

These results show that, even under bounding conditions, no group would receive an annual individual dose in excess of the legal limit of 20 mSv/yr for employees working with ionising radiation.

4.3.2 Best estimate case

Best estimate individual annual doses are shown in Table 2. Maximum, minimum and mean values refer to the range of doses calculated for each year of the transport operation and for each notional GDF location considered.

Table 2 Best estimate individual doses to transport operators

Operator Group	Individual Dose (mSv/yr) max/mean/ min across all years and zones			Percentage of Basic Safety Objective (1 mSv/yr)	
	Maximum	Mean	Minimum	Maximum	Mean
STGO1 drivers	2.2E-01	1.2E-02	1.2E-08	22%	1.2%
STGO3 drivers	4.1E-01	5.0E-02	0.0E+00	41%	5.0%
Train crew	7.9E-01	5.7E-02	9.0E-06	79%	5.7%
Rail transhipment handlers	5.0E-02	3.2E-03	1.6E-07	5.0%	0.3%
Rail transhipment crane operators	2.3E-01	1.3E-02	7.4E-07	23.0%	1.3%

It can be seen that these doses are within the Basic Safety Objective of 1 mSv/yr, for all years of transport and for all notional GDF locations considered. The most exposed group

[5] Transport by road is by vehicles with Special Type (General Order 2003) (STGO) authorisation; higher categories are for packages with higher per-axle mass [Road Traffic Act 1988, Part 2]

is train crew, for whom the maximum individual annual dose is estimated to be 79% of the Basic Safety Objective.

These results are based on the transport system defined in the generic TSA. There are some waste packages for which the dose rate at the time of transport is not yet known. In this best estimate assessment, no doses were calculated for tasks involving these packages. While this assumption affects less than 5% of transport units, it is optimistic. The generic TSA also discusses an alternative, pessimistic, approach whereby it is assumed that all such packages have the maximum dose rate, as in the bounding dose assessment. This would make the best estimate assessment for such years more similar to the bounding case, distorting the best estimate assessment as it would be dominated by the bounding assumptions rather than known information.

The assessment will need to be revisited when dose rate data for these packages become available.

This lack of information does not affect the bounding dose assessment as it includes an assumption that all transport packages are at the maximum dose rate allowed by the IAEA Transport Regulations.

5 Discussion

At this early stage in the development of a geological disposal system, the generic TSC presented here is of necessity an indication of how RWM plans to ensure safe transport. The main remaining uncertainties and the forward programme are outlined in this section.

5.1 Main uncertainties

At this stage in the implementation of a geological disposal system there are a number of uncertainties. The main uncertainties relevant to transport are:

- the location of the GDF
- the inventory for disposal
- the transport modes and routes
- the organisational structure and management arrangements
- details of job design, procedures and tasks for operators
- detailed design of tie-down and handling systems
- the scheduling of the transport

These uncertainties vary in their nature and in how and when they may be resolved. For example, there is currently a real uncertainty about the details of operator tasks, but this will be resolved in due course. Uncertainties about the scheduling of transport, on the other hand, are likely to persist into the operational period, since they will depend on unpredictable factors such as the rate at which wastes will arise from any new build power stations, how quickly stores can be emptied and wastes processed and packaged. RWM's strategy aims to take into account and manage these different types of uncertainty.

RWM's plans for compliance with the IAEA Transport Regulations, as set out in the TPS report, are in accordance with the underlying principle that radiological safety is primarily ensured by the package and contents limits, regardless of how the package is transported. Safety is inherent in the package, rather than being dependent on site and route-specific factors or operational and procedural controls, and thus independent of such uncertainties.

Nevertheless, RWM acknowledges that operational and procedural controls and site and route-specific factors could have a role in optimisation, helping to satisfy the legal (HSWA) requirement to reduce risks to an ALARP level. More generally, uncertainties must be taken into account in the iterative development of the system. The generic TSC has therefore aimed to consider a range of parameter values that would encompass these uncertainties. For example, the dose assessment in the generic TSA estimated doses for the GDF located in each of the seven notional zones and for a wide range of illustrative operator groups, and also considered the effects of alternative inventory scenarios. A bounding case, in which parameter values were set to define worst credible conditions, was also considered.

On these bases, RWM has confidence that none of the uncertainties noted above fundamentally jeopardise the claims made in this generic TSC.

To address these uncertainties, RWM has an active research and development programme as described in the RWM Science and Technology plan [13] and a developing site characterisation strategy. This is based on RWM's own work, as well as work carried out by overseas waste management organisations, collaborative international projects (such as EC framework projects), work by international bodies such as the Organisation for Economic Co-operation and Development (OECD), Nuclear Energy Agency (NEA) and IAEA, and experience gained in related industries.

5.2 Forward programme

As outlined in Section 3.1 (Strategy), the generic TSC will evolve as the development and implementation of a geological disposal system progresses. The transport system design and the associated safety case are expected to evolve significantly as site-specific information on potential GDF locations becomes available and site-specific disposal concepts and designs are developed.

5.2.1 Optimisation

An integral part of the site selection process for the GDF will be optimisation of the transport system. The generic TSC will provide a sound foundation for optimisation studies in the site-specific stage.

By considering the most significant contributors to dose, a number of areas where optimisation could be most effectively focused have been identified in the generic TSA [5, Section 6.2.1].

5.2.2 Stakeholder engagement

As potential GDF locations and transport choices become more clearly defined, RWM will continue to engage with stakeholders to provide the information necessary to aid discussions during the siting process. Stakeholders are those who may influence or make the decisions associated with the establishment of the GDF and its transport system, and those who may be impacted by or have an interest in RWM's work, such as:

- communities local to the GDF or to transport routes
- local authorities
- waste producers and their associated sites
- future GDF regulators
- transport system regulators
- UK Government

The policy framework set out in the 2014 White Paper comprises a number of initial actions for the UK Government and devolved administrations and RWM as the developer to carry out in order to deliver clear, evidence-based information at the national level, to inform any local discussions. The initial actions set out in the 2014 White Paper include a national geological screening exercise [37] to help answer questions about local geological prospects that are likely to be raised by any community thinking about engaging in the GDF development process. The national geological screening exercise is the responsibility of RWM. It began in 2014, in parallel and in conjunction with the development of this generic DSSC. The findings from the national geological screening exercise and the safety assessments presented in this generic DSSC for a range of geological environments will together provide information to communities in the next stage of the siting process.

5.2.3 Continuing the Disposability Assessment process

RWM remains committed to continue implementation and refinement of the Disposability Assessment process, such that waste producers can be assured of the suitability of their packaging proposals and that transport of waste can begin without undue delay once the GDF is operational. The generic TSC will continue to provide a basis for disposability assessments until there is certainty that all waste can be disposed of at a specific site or sites.

6 Summary

This generic TSC Main Report and its supporting documents provide confidence in the radiological safety of the transport of radioactive waste to the GDF, without being specific to any potential GDF location.

It summarises the procedures, assessments and approvals that need to be in place to meet regulatory requirements for radiological safety, and gives confidence that transport of radioactive waste from waste producer sites to the GDF can be achieved with radiation exposures below allowable limits.

The argument for radiological safety is based principally on demonstrating compliance with the IAEA Transport Regulations. The key principles enshrined in the IAEA Transport Regulations are to ensure:

- containment of the radioactive contents
- control of external radiation levels
- prevention of criticality
- prevention of damage caused by heat

These requirements are satisfied firstly by applying a graded approach to contents limits for packages and conveyances and to performance standards applied to package designs, depending upon the hazard of the radioactive contents. Secondly, they are satisfied by imposing conditions on the design and operation of packages and on the maintenance of packaging, including consideration of the nature of the radioactive contents. Finally, they are satisfied by requiring administrative controls, including, where appropriate, approval by competent authorities.

Compliance of a transport package with the design requirements of the IAEA Transport Regulations is demonstrated by a DSR which is produced by the Design Authority. For certain package or material designs, that is, those pertaining to higher hazard radioactive materials, the DSR is submitted to a competent authority for approval. For other designs, that is, those pertaining to lower hazard radioactive materials, self-approval by the Design Authority is sufficient, and is subject to audit by the competent authority.

In order to demonstrate approval, all material and package designs must have associated documentary evidence of the compliance of the design with applicable requirements. A competent authority will issue a certificate of approval when approval is granted and bodies undertaking self-approval also issue evidence, usually in the form of a certificate of approval.

The Disposability Assessment process for proposals for waste packaging confirms that the proposed transport package complies with the current regulatory requirements, and also gives confidence to the waste producers, stakeholders and RWM itself that waste packaged now will be suitable for transport and disposal.

In addition to these package safety measures, the generic TSC includes an assessment of the doses to operators from the overall transport operation under routine conditions. This assessment is documented in the generic TSA, which serves two purposes. Firstly, it forms a basis for the prior radiological evaluations that will be required as part of developing RPPs. Secondly, the dose estimates provide a baseline to compare the safety benefits of potential additional risk control measures. This will be required for the optimisation (ALARP) studies that will be needed in future to ensure compliance with the requirements of the IRRs and the HSWA.

The dose assessment has shown that for the illustrative transport system design,

1. Even under bounding conditions there are no operator groups for which members could receive an annual individual dose in excess of the legal limit of 20 mSv/yr for employees working with radiation.
2. The best estimates of individual worker doses are all within the Basic Safety Objective of 1 mSv/yr for employees working with radiation. The most exposed group is train crew, for whom the maximum individual annual dose is estimated to be 79% of the RPCM Basic Safety Objective.

By considering the most significant contributors to dose, as identified in the generic TSA, a number of areas where optimisation could be most effectively focused have been identified [5, Section 6.2.1].

In conclusion, RWM has confidence that waste can be safely transported to the GDF. However, this does not remove the requirement for optimisation of the transport system, nor for updating and refining the assessment as better information becomes available.

This safety case will provide the transport safety basis for future disposability assessments and iterative design development.

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Glossary

A glossary of terms specific to the generic DSSC can be found in the Technical Background.

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