Nuclear Decommissioning Authority

Issue 1.2

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The Role and Capabilities of Key R&D Organisations Involved in Supporting UK Decommissioning and Waste Management

Issue: 1.2

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Executive Summary

The purpose of this report is to inform the Nuclear Decommissioning Authority (NDA) Research Board as to the roles and capabilities of selected key UK national labs and the broader UK supply chain involved in delivering Research & Development (R&D) for nuclear decommissioning and waste management. It will also enable the NDA Research Board members to provide further advice on the adequacy of current or proposed R&D arrangements and the possible threats, risks/opportunities to the current strategy.

The report provides an up to date summary of the role and capabilities of key R&D organisations involved in supporting nuclear decommissioning and waste management programmes. The report summarises this firstly for the selected key UK national labs and secondly for the wider supply chain. The method employed to gather relevant information included some primary research through telephone and face to face interviews with the National Laboratories, dialogue with Tier 1 commercial managers and a desk-based review of publicly available secondary sources. The review of secondary sources focused on The UK Civil Nuclear R&D Landscape Survey 2017 report (Ref. 9) from Nuclear Innovation and Research Office (NIRO) and publicly available information (i.e. from organisation websites and publications).

The scope was limited to specified national laboratories and provision of an overview of the supply chain existing framework contracts. This report does not cover university led research and programmes or research initiated by UK Research & Innovation (UKRI). This report is intended to be a summary of key information, rather than a comprehensive account.

The core capabilities of the National Labs are summarised below:

British Geological Survey

i. Geochemistry and mineralogy of cements
ii. Geology and geological modelling
iii. Groundwater modelling engineering geology
iv. Fluid monitoring and modelling
v. National geological modelling and screening

Health and Safety Laboratory

i. Risk management and process safety (including hydrogen accumulation assessments)
ii. Large-scale testing and evaluation (i.e. fire and impact testing)
iii. Human factors and safety culture expertise
iv. Complete worker health solutions (i.e. conventional safety)
v. Performance benchmarking, accurate demographic data and integration of data sets

National Nuclear Laboratory

i. Fuel, Reactors and Reprocessing (including electron optics, nuclear physics, separation science, metallography, corrosion, chemistry)
ii. Nuclear Operations (including modelling, plant inspection, measurement and analysis, robotics, nuclear safety and security)
iii. Waste Management and Decommissioning (including waste/residues processing, waste behaviour/characterisation, waste packaging and disposal)

National Physical Laboratory

i. Radioactivity team: provides and disseminates primary standards for radioactivity metrology, national measurement infrastructure to monitor radioactivity & for nuclear decommissioning
ii. Expertise in: corrosion/environment induced cracking, engineered materials, environmental measurement, materials testing, metrology, modelling/simulation, quantum detection, thermometry, ultrasound/underwater acoustics, surface/nanoanalysis, photonics/optical radiation

Nuclear Advanced Manufacturing Research Centre

i. Intelligent machining & high integrity production of large/complex components, modularisation of new reactor designs, laser welding
ii. Automated techniques of industrial arc processes, large-volume metrology, metal powder manufacturing
iii. Risk management of component failure, virtual and augmented reality for design, simulation, planning and training

RACE

i. Fusion market (remote operations of JET, ITER robotics test facility, remote maintenance test facility for new fusion reactors)
ii. Fission decommissioning market (robotics / artificial intelligence development and testing for equipment to use in hazardous environments - including inspection, characterisation, sampling, size reduction & retrieval tools)
iii. Systems management (system controls, remote operations management and systems integration)
iv. Transport market (connected and autonomous vehicles / self-driving vehicles)

The selected National Laboratories are, to differing extents, already contributing to R&D for nuclear decommissioning and radioactive waste management. Some are involved in the Nuclear Waste Decommissioning Research Forum (NWDRF). Overall, it is estimated that they have 565 Full-Time Equivalents (FTEs) working on R&D related to spent fuel handling, waste management, decommissioning and cross-cutting technologies. NNL is the largest contributor (with 42% of the FTEs working across all four fields), followed by RACE (with 25% of the FTEs working on waste management and cross-cutting technologies). NPL and NAMRC contribute 14% of the FTEs each and mostly conduct cross-cutting research. BGS and HSL have the fewest FTEs (3% and 2% respectively) since their staff are not fully dedicated to nuclear R&D, but work across a variety of sectors. This shows the current numbers working on relevant R&D, but it is likely that there is scope for additional capacity within each of the national labs to support R&D in the future.

It was found that R&D work, specifically for nuclear decommissioning and radiological waste management in the NDA estate, is currently delivered by the supply chain and national labs mainly through a variety of competed frameworks (namely Specialist Nuclear Services (SNS), Direct Research Portfolio (DRP) and strategic partnerships (Technical Services Agreement)). NDA and Sellafield Ltd have also used grant-based funding either in collaboration with Innovate UK or NNL (i.e. GameChangers). These focus on supporting open innovation and generating a pipeline of ideas in early development (i.e. at both low and mid-range Technology Readiness Levels (TRLs)).

The Game Changers programme and Innovate UK issue grants for work programmes that enable innovations (technologies that tend to be immature and relatively low Technology Readiness Level, TRL) to develop which could be applied to the NDA estate in the future. These tend to be smaller packages of work and not as well funded because they may not be for a specific client or specific problem with a final deliverable.

Based on the evidence from the 'The UK Civil Nuclear R&D Landscape Survey FY15/16' report (Ref. 9), the three private sector supply chain organisations that have a large number of staff contributing to R&D supporting the NDA estate were NSG, Amec Foster Wheeler (now Wood Group) and Nuvia. Some companies in the supply chain have self-funded research programmes, but a significant proportion of the research conducted tends to be application specific and therefore only of commercial value to a limited number of clients. There is limited publicly available data from organisations about their contribution to the R&D, with the information being commercially sensitive.

There are many organisations in the nuclear supply chain contributing to R&D relevant for the NDA estate, but a more comprehensive review, with access to commercial information, would be required to understand how and where this can be utilised and developed further.

The main contracting routes for the supply chain are summarised below:

Sellafield has 5 direct contract routes through which it contracts R&D, with an annual spend of approximately £40m. 75% of this is spent on a technical services contract with NNL (who work with sub-contractors to complete the work). £5m goes through Direct awards from the Technical department to a range of R&D organisations. The remaining £5m is split between NPL (for metrology services) and to support Small-Medium Enterprises to innovate (i.e. Game Changers and EIF). There is likely additional R&D either self-performed by SL or embedded within projects which is not captured in this report.

The NDA's DRP framework has three Lots through which specific R&D projects can be initiated: Lot A - University interactions (with NNL & Frazer-Nash), Lot B - Integrated Waste Management and Site Decommissioning, and Lot C - Spent Fuel and Nuclear Materials. Across which the current annual spend is £5m per annum. Lot B has access to 56 organisations (including NAMRC, NNL & NPL) and 12 universities. Lot C has access to 24 organisations (including NNL & NPL) and 10 universities. The total budget for the whole of NDA's R&D portfolio is around £8M/annum.

The Specialist Nuclear Services (SNS) Framework was established for use by Magnox, NDA, RWM, RSRL, DSRL, INS and LLWR. Two of the lots within the framework are specifically for R&D (Lot 1 Laboratory based R&D and Lot 2 Desk based R&D). For FY17/18, RWM spent £5.5m and Magnox £1.3m across these frameworks. Lot 1 and Lot 2 has access to 31 organisations (albeit slightly different, but both including BGS & NNL) and 10 universities/institutes.

Contents

1. Introduction

1.1. Background

The Energy Act (2004) specifies that Research & Development (R&D) is a supplemental function of the Nuclear Decommissioning Authority (NDA). As such the NDA is required to promote and, where necessary, carry out research in relation to its primary function of decommissioning the UK's civil nuclear legacy. Technology and the underpinning R&D are fundamental to ensuring the safe, cost-effective delivery of our mission. Together with innovation and the sharing of good practice, both nationally and internationally, the intelligent application of R&D can reduce costs and timescales.

The aims of the NDA Research Board, as written in the Terms of Reference (Ref. 1), are to:

- Promote strategic coordination, a common understanding and collaboration between relevant bodies across the UK with respect to research & development needs, risks and opportunities in the fields of site decommissioning and remediation, spent fuels and nuclear materials management and radioactive waste disposal.
- Ensure that R&D strategies are being reviewed and that research & technology needs, risks and opportunities identified that impact the delivery of the decommissioning and site remediation, radioactive waste management, spent fuel and nuclear materials management and radioactive waste disposal agenda in the UK.
- Help to identify individual organisations that should be involved in such work and seek to facilitate their collaboration.
- Communicate with the relevant bodies to promote investment in and a broader appreciation of these activities.

The NDA commissioned this report, on behalf of the NDA Research Board, to be researched and produced by REACT Engineering, through the NDA's Multi Supplier Framework agreement for 'Specialist Independent Review of Technical and Strategic Work on Site Decommissioning and Remediation, Integrated Waste Management, Spent Fuels and Nuclear Materials'.

1.2. Purpose

The nuclear R&D landscape is becoming increasingly important in supporting the delivery of the NDA's mission. The development, deployment and commercialisation of innovative technologies, techniques and methods has the potential to unlock significant benefits to society if these can be successfully utilised to accelerate risk and hazard reduction, improve safety and/or security and reduce costs. This agenda also supports the recent UK Industrial Strategy and associated Nuclear Sector Deal by enabling innovative organisations, who are developing or commercialising new Intellectual Property, to access opportunities in the nuclear sector which can be used to generate regional and national economic benefit.

The purpose of this report is to inform the NDA Research Board on the roles and capabilities of the UK's national labs and the broader supply chain involved in delivering Research & Development (R&D) for nuclear decommissioning and waste management. This information will enhance the NDA Research Board's understanding of the capabilities within UK nuclear R&D landscape. It will also enable the NDA Research Board members to provide further advice on the adequacy of the current or proposed R&D arrangements and the possible threats, risks and opportunities to the current strategy.

1.3. Scope

The scope for this report includes compiling an up to date summary of the role and capabilities of key R&D organisations involved in supporting nuclear decommissioning and waste management programmes (e.g. UK national labs and supply chain delivering R&D for nuclear decommissioning).

For the national labs, it is important to understand their capability and capacity related to nuclear decommissioning and waste management therefore the following information (where possible) has been compiled for each of them:

- Available facilities, their location and associated experimental capabilities at each;
- Number of FTEs deployed on nuclear related R&D by area;
- Types of R&D work carried out by the organisation;
- Main funding mechanism;
- Main contract routes that the work is delivered under;
- Main organisations they collaborate with to deliver R&D.

INCLUDED FACILITIES / ORGANISATIONS:

- British Geological Survey (BGS)
- Culham Centre for Fusion Energy (CCFE), Remote Applications in Challenging Environments (RACE), United Kingdom Atomic Energy Authority(UKAEA)
- Health & Safety Laboratories (HSL)
- Nuclear Advanced Manufacturing Research Centre (NAMRC)
- National Nuclear Laboratory (NNL)
- National Physical Laboratory (NPL)

For the broader supply chain, the following information has been collected:

- Framework contracts in place with the NDA estate;
- Organisations available / accessible under each framework;
- High-level overview of the types of R&D work those organisations have delivered;
- The estimated value of the work (when not commercially sensitive);
- Any other major non-framework contracts in place to deliver nuclear decommissioning R&D.

1.4. Exclusions & Constraints

Collecting information on the broader supply chain requires dealing with commercial businesses and some have commercially-sensitive research projects, therefore these are not included.

University research facilities and UK Research & Innovation (UKRI) funded projects have been excluded (collaboration projects lead by the national labs and supply chain are the exception).

R&D projects in the following fields have been excluded, since they do not relate to the core challenges faced across the NDA estate: nuclear new build / advanced reactor technologies, fuel manufacturing, advanced reprocessing techniques. The focus has been on decommissioning and waste management projects. Cross-cutting and spent fuel management R&D projects have been included if they are thought to be relevant. There may be other R&D capabilities outside of the nuclear supply chain that could be applied in the NDA estate, but this information is not readily available.

EXAMPLES OF EXCLUDED FACILITIES / ORGANISATIONS:

- Dalton Cumbrian Facility (DCF), University of Manchester;
- Interface Analysis Centre, University of Bristol;
- Materials for Innovative Dispositions from Advanced Separations (MIDAS), Sheffield University;
- National Nuclear User Facility (NNUF) Laboratories;
- U/Th/Beta Gamma Active process chemistry R&D (UTGARD), Lancaster University;
- Sir Henry Royce Institute for Advanced Materials.

2. National Laboratories

2.1. Overview

The approach utilised for this work has been to review websites of national labs (Ref. 2, Ref. 3, Ref. 4, Ref. 5, Ref. 6, Ref. 7) and conduct search of publicly available information, in addition to discussing information with R&D managers and/or other relevant contacts at the facilities (see Appendix 1). This information was used to determine the number of Full-Time Equivalent (FTE) technical staff working in the National Labs across the relevant R&D areas (i.e. spent fuel management, waste management, decommissioning and relevant cross-cutting fields). The data is presented in Figure 1 and Figure 2.

Figure 1 shows the split of resource across each organisation. The data shows that NNL have the most resources (42% of the total) which cover a diverse range of disciplines. NNL have dedicated resources which align with NDA's research themes. On the other hand, HSL and BGS have the fewest resources since their staff are not fully dedicated to nuclear R&D. HSL has multidisciplinary teams delivering evidence-based solutions to assess and control risk, with much of their experience and knowledge being gained by investigating serious incidents on behalf of HSE. Therefore, this does not align with the specific R&D fields and has been classed as cross-cutting. BGS resource is specialist in the waste management field, since specific disciplines include: geochemistry, earth hazards, geoscientists, engineering geologists, geoanalytics and modellers, groundwater scientists. NPL, NAMRC, and RACE have resources that are conducting nuclear-related R&D that are mostly applicable to a variety of applications (i.e. cross-cutting).

Figure 2 combines the total number of FTEs (565 in total) working in spent fuel management, waste management, decommissioning and cross cutting fields across all the National Labs. The data shows that two-thirds of the resources are working on R&D for cross-cutting technologies, with the rest relatively equally split across the other areas.

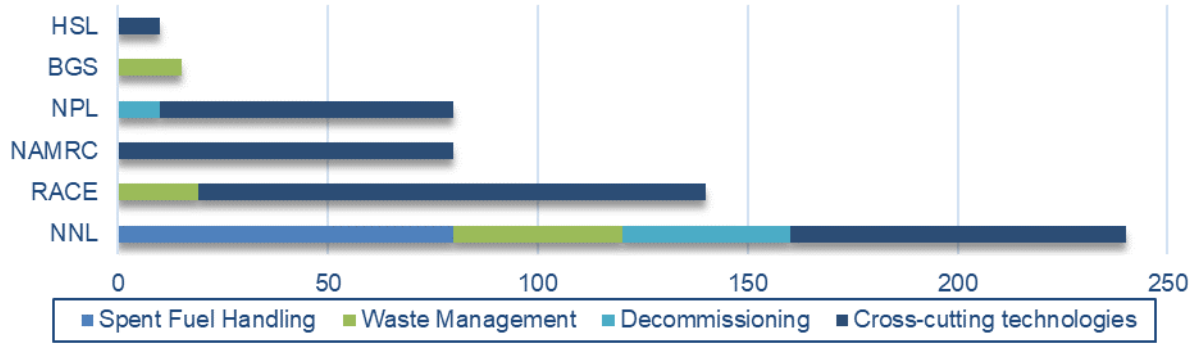


Figure 1 - Number of FTE conducting R&D in National Labs (estimate from Appendix 1 sources)

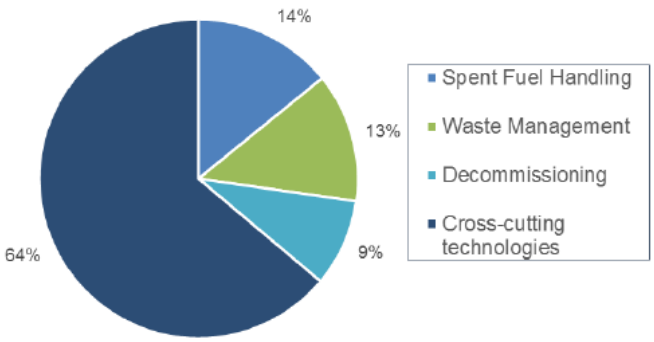


Figure 2 – National Labs FTE split across R&D Fields (estimate from Appendix 1 sources)

2.2. British Geological Survey (BGS)

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

The British Geological Survey is a world-leading geological survey organisation.

It focuses on public-good science for government, and research to understand earth and environmental processes.

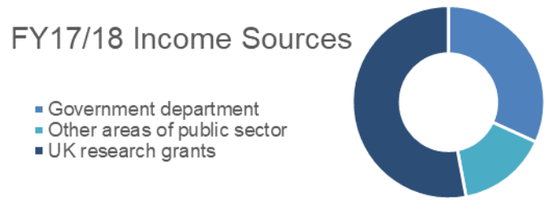
It is the UK's premier provider of objective and authoritative geoscientific data, information and knowledge to help society to: use its natural resources responsibly, manage environmental change, be resilient to environmental hazards.

The BGS provides expert services and impartial advice in all areas of geoscience. Their client base is drawn from the public and private sectors both in the UK and internationally.

Contract Routes & Funding Mechanisms

The main contract route for BGS supporting R&D in the nuclear industry is through direct contracts with NDA/RWM (i.e. **SNS Lot 1&2 through Wood Group**).

- Other radiological waste R&D funding comes from:
  - BGS national capability research funds
  - UK bodies: UKAEA, Environment Agency, DEFRA
  - European research projects
  - International radioactive waste management organisations
  - UK research grants



Collaborations

Fate Of Repository Gases (FORGE)

- The FORGE project ran from February 2009 to September 2013 and studied key gas migration issues in repository performance assessment.
- Contributors included radioactive waste management organisations, regulators and academia from across Europe.

BGS regularly work with international radioactive waste management organisations such as NAGRA, SKB, Andra, ENRESA, JAEA.

Capabilities

BGS are experts in a wide range of geoscientific areas:

- Geochemistry and mineralogy of cements, and fluid-rock processes and interactions with geological materials, and cement carbonation studies
- Geology and geological modelling: a strong 3D conceptual modelling capability of the subsurface, expertise across the UK formations bedrock and superficial deposits and structural geology expertise.
- Groundwater Modelling: Expertise in numerical and probabilistic modelling of groundwater flow and transport Hydrogeology and hydrochemistry: In-depth knowledge of the hydrogeology and hydrochemistry of the UK from regional to site level.
- Engineering geology: Geotechnical and geophysical properties and processes, geophysical tomography (non-invasive geoelectrical imaging of the shallow subsurface) and shallow geohazards and risks
- Geophysical expertise and advanced seismic techniques for fluid monitoring and modelling.

BGS provides a comprehensive suite of geological and hydrogeological field services:

- Expertise in groundwater survey/sampling.
- Coastal processes and coastal evolution.
- Seismic Surveys - sedimentary basins and basement terrains.
- Geophysical expertise.
- Geoscience data management - The BGS has a long track record in providing government departments, industry and academia with environmental data management and web delivery services. BGS has extensive data holdings which it delivers through its National Geoscience Data Centre.
- Rock mechanics and geotechnics.
- Thermal Modelling.
- Information and advice - consulting services for interpreting our data.

Examples of Relevant R&D Projects

National geological screening for appropriate sites for a Geological Disposal Facility - **RWM**

- BGS have developed a 3D national geological model of the geology of Great Britain and Northern Ireland which is being used to determine the appropriate siting and safety of an underground GDF.

Automated time-Lapse Electrical Resistivity (ALERT) - **Sellafield Ltd.**

- 4D electrical imaging system to monitor temporal and spatial changes in subsurface electrical properties. Such changes may be related to changes in fluid flow, hydrochemistry, or saturation levels. This technology is applicable for the remote time-lapse monitoring on contaminated land remediation and effluent management.

Laboratory Facilities

BGS facilities (including the National Geological Repository and the National Geological Data Centre) are in Keyworth (Nottingham), Edinburgh, Wallingford (Oxfordshire), Cardiff and Belfast.

Mineralogy, petrology, microanalysis and imaging	• Researching and characterising the mineralogical, textural and biostratigraphical composition of geological and engineered materials, processes, interactions and alterations.
Centre for Environmental Geochemistry (with University of Nottingham)	• Encompassing: • inorganic geochemistry facility • organic chemistry facility (soil, sediment & water -bulk/molecular level) • stable isotope facility
Geochronology and Tracers facility (part of the NERC Isotope Geosciences Laboratories)	• Focussed on the following for a range of environmental processes: • (1) uranium-daughter geochronology • (2) isotope tracers (eg. Sr, Pb, U etc.)
Geotechnical and Geophysical Properties Laboratories	• For comprehensive, integrated rock and soil testing facility capable of both standard and specialised tests.
Fluid Processes Laboratories	• State-of-the-art experimental facilities for understanding complex fluid processes (biological, chemical and physical) in the geo- and biosphere, where appropriate, under representative in situ conditions. • This includes: • geomicrobiology • hydrothermal (simulating chemical reactions between minerals and fluids under high pressures and temperatures) • hydrates and ices laboratory (permafrost) • transport properties research laboratory (processes and mechanisms governing the movement of fluids in low permeability materials) • gas monitoring facility (for the field measurement of a range of gas concentrations and fluxes in the near surface environment)

2.3. Nuclear AMRC

The Nuclear Advanced Manufacturing Research Centre (NAMRC) is owned by the University of Sheffield .

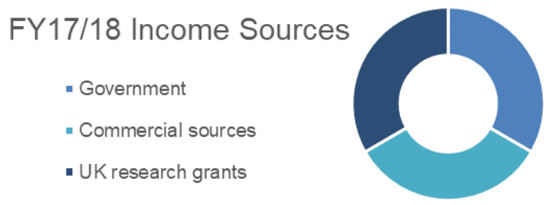
The Nuclear AMRC mission is to help UK companies win work in nuclear (e.g. new build, operations, decommissioning, and defense) and adjacent sectors (renewable energy, oil & gas, marine, aerospace, chemicals etc.).

Work at the Nuclear AMRC focuses on metals engineering and does not involve nuclear critical aspects such as fuels or other radioactive materials.

Contract Routes & Funding Mechanisms

NAMRC are currently supporting R&D in the nuclear industry being a member of a consortia with NSG Environmental on **DRP Lot B.**

- Other nuclear R&D contracting/funding routes include:
  - Through the High Value Manufacturing Catapults Government programme
  - From Industry Members (including Sellafield Ltd. and DSRL) - establishing projects to help supply chain companies improve their capabilities
  - Collaborative R&D projects (i.e. through Innovate UK and UKRI)



Capabilities

Nuclear AMRC operate in:

- Manufacturing innovation:
  - Working with companies to overcome their manufacturing problems, and help them develop the technical capability to be competitive globally, increasing high-value jobs, export orders and GDP for the benefit of all.
  - Aims to help suppliers reduce cost, improve quality, reduce lead time and cycle time, and reduce risk in manufacturing.
  - Industry can access the capabilities through company-led commercial R&D projects, or by joining collaborative R&D programmes supported by third-party funding.
  - Developing advanced manufacturing processes for nuclear applications and embedding them in the supply chain, increasing UK manufacturing productivity and reducing risk in the nuclear programme. The research aims to help UK manufacturers compete.
- Supply chain development:
  - Work across UK's nuclear supply chain to help companies compete by raising quality, reducing costs, and developing new capabilities.
  - Offer a wealth of targeted support services to manufacturers, from free advice and expertise (through the 'Ask Nuclear' service); to demand modelling (to map future contract opportunities and help match manufacturers with relevant work packages).

Examples of Relevant R&D Projects

Virtual glovebox offers a helping hand for Sellafield

- Visualisation engineers at the Nuclear AMRC have demonstrated an interactive model which can simulate any kind of glovebox used to handle hazardous material for the nuclear decommissioning programme.
- The collaboration with Sellafield Ltd and the National Nuclear Laboratory (NNL) will support the design of new kinds of glovebox, the planning of experiments and waste handling programmes, and training of operatives.

Laboratory Facilities

Main site is at the Advanced Manufacturing Park in South Yorkshire.

Modularisation R&D is at the site of Cammell Laird in Birkenhead.

Manufacturing Technology Research Laboratory is within the University of Manchester's Dalton Nuclear Institute facilities in Manchester.

Intelligent machining	New and optimised processes for the machining of large and complex components.
Modularisation	Innovative techniques for modular production and assembly of new reactor designs.
Laser welding & cladding	High-speed cladding, welding and additive manufacturing.
Mechanised arc welding & cladding	Automated techniques for the range of industrial arc processes, in conventional and narrow-groove welding.
Metal powder manufacturing	Near-net shape manufacturing from metallic powder using hot isostatic pressing.
Bulk additive manufacturing	High-integrity production and customisation of large metal components.
Surface integrity	Understanding and minimising the surface quality effects of manufacturing to reduce the risk of component failure.
Visualisation	Virtual and augmented reality for design, simulation, planning and training.
Large-volume metrology	Innovative techniques for contact and non-contact measurement of large parts.
Thick section joining	Power beam and arc welding techniques for very thick sections.

Collaborations

The NAMRC is a collaboration of academic and industrial partners from across the nuclear supply chain.

MANCHESTER 1824
The University of Manchester
Dalton Nuclear Institute

The applied manufacturing research is underpinned by the nuclear and materials technology expertise of The University of Manchester Dalton Nuclear Institute.

The NAMRC has worked with hundreds of businesses, including many Small-Medium Enterprises, to help them to become more competitive in the nuclear sector (including Abbey Forged Products, Barrnon, Hargreaves, Larkshill Engineering, Lestercast, Lloyd Morris, Paul Fabrications, Stainless Metalcraft).

As well as company-led commercial research, the Nuclear AMRC leads or partners in externally-funded collaborative research projects including those supported by Innovate UK, EPSRC and European Horizon 2020 programme.

CATAPULT
High Value Manufacturing

The NAMRC is part of the High Value Manufacturing Catapult, an alliance of seven leading manufacturing research centres backed by Innovate UK; allowing access to a national network of manufacturing research excellence.

2.4. Health & Safety Laboratories

The Health and Safety Laboratory (HSL) is one of the world's leading providers of workplace health and safety research, training and consultancy. They employ over 350 scientific, medical and technical specialists. The HSL are part of Health and Safety Executive (HSE). Carrying out investigations for HSE gives them unique insight into the causes of workplace accidents and ill-health.

HSL know that health and safety can't be considered in isolation. Central to any business are people and their interaction with plant (the site, equipment, tools), process (how you use the plant), product (what you produce) and place (the working environment you are in). HSL have been developing health and safety solutions for over 100 years, so they know what goes wrong in the workplace and why.

Contract Routes & Funding Mechanisms

- HSL are not part of any framework contracts in the nuclear industry.
- HSL conduct work for Sellafield and the NDA through direct contracts.
- HSL is part of HSE and receives some funding through the government.

UNKNOWN SPLIT

Collaborations

HSL currently have formal collaborative agreements with 20 scientific and technical organisations in the UK and overseas, plus extensive informal networks throughout the world. This includes:

- Thomas Ashton Institute (a collaborative partnership between the HSE and the University of Manchester set up as an interdisciplinary research institute concerned with the understanding of failures that occur in the world of work leading to injury or ill-health). Programmes:
  - Working with the UK Government
  - Lloyd's Register Foundation with the Discovering safety programme enabling Safety Performance Improvement using Data Enabled Research.
- International Association of Hydrogen Safety (founded by EC, it facilitates the networking for the further development and dissemination of knowledge and for the coordination of research activities in the field of hydrogen safety.)
- Centre for Workplace Health (a national centre of excellence, with HSL, University of Sheffield and Sheffield Teaching Hospitals NHS Foundation Trust).

Capabilities

HSL's strength is in bringing together different disciplines and teams to create practical, innovative and useful solutions. These include expert advice and consultancy, targeted research, testing and modelling, tools for your organisation and specialised training.

HSL take an evidence-based approach when evaluating workplace problems, drawing on their wealth of scientific research and knowledge.

HSL have an international reputation for high-quality research and we collaborate worldwide through a network of partnerships.

The HSL works with the nuclear industry specifically to:

- Reduce hazards at legacy radioactive waste facilities, particularly on the Sellafield site.
- Help assess the effects of ageing plant, such as the risk of cracks in graphite bricks.
- Measure, benchmark and improving safety culture across the Nuclear Decommissioning Authority estate using our Safety Climate Tool and human factors expertise.
- Develop High Reliability Organisations with health and safety leadership from the top down.

Photograph of Magnox Silo Test Facility.

Photograph Courtesy of HSL.

Examples of Relevant R&D Projects

- Hydrogen accumulation assessments for long term repository and silo storage of spent fuel and radioactive waste.
- Assessment of the cause of cracking in reactors.
- Human factors support to Sellafield.
- Fire & impact testing of nuclear transportation packages

Laboratory Facilities

HSL's main location is a 550-acre site near Buxton (Derbyshire), with a state-of-the-art, purpose-built laboratory.

HSL also have several field stations across Great Britain.

HSL provide expert advice and consultancy, targeted research, testing and modelling, tools and specialised training in the following aspects of Health & Safety:

Human Factors	•ergonomics, manual handling, behavior change for an excellent health & safety culture, site & transport safety, slips & trips prevention, workplace stress, workplace fatigue
Complete worker health solutions	•exposure to hazardous substances, occupational hygiene, PPE, noise & vibration control
Large-scale testing and evaluation services	•for fire & explosion, impact & crashworthiness, explosives testing, batteries & energy storage, process safety, hydrogen & alternative fuels, general engineering and bespoke integrated solutions
Risk management and process safety	•strategic consultancy, risk assessment & analysis, hazard identification and consequence modelling—including DSEAR
Data analytics	•the provision of performance benchmarking, accurate demographic data and integration of data sets

2.5. UKAEA RACE

Remote Applications in Challenging Environments (RACE)

As part of the UKAEA, RACE is conducting R&D and commercial activities in the field of robotics and Autonomous systems.

The UKAEA's primary mission is fusion and this creates an imperative to develop remotely operated solutions to operate and maintain a fusion reactor.

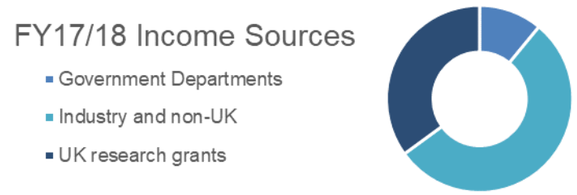
The RACE research centre was completed in 2015 and operates from a dedicated new building at the Culham Science Centre which opened in 2016. As such it has not been long in operation.

RACE is involved in exploring many areas of remote operations including inspection, maintenance and decommissioning. The vision is to create end to end remote handling systems that are applicable across multiple challenging environments including; nuclear, petrochemical, space, construction, mining and other nuclear research facilities, such as Joint European Torus (JET) and European Spallation Source (ESS).

Contract Routes & Funding Mechanisms

RACE is not on any framework contracts in the nuclear industry.

- RACE is a not for profit organisation and receives funding from research grants, UK government and other organisations/industry.
- RACE is a partner in UKRI grants worth £34 million (RACE component £6 million) with over 100 industrial collaborators and 10 university partners.



Collaborations

Launched in 2017, the Robotics and Artificial Intelligence in Nuclear (RAIN) Hub is a programme to make deployment of nuclear robotics the norm. RAIN is comprised of seven universities plus RACE; the purpose of the Hub is to solve real end-user nuclear challenges, undertake world-leading research, foster international collaboration and grow membership of the Hub. The Hub focuses on three main user challenges; Remote Handling, Remote Inspection and Safety Case and brings industry and academia to work together on these through challenge events.

RACE collaborates extensively with UK SMEs and industry to support grant funded projects and to win commercial contracts for UKplc.

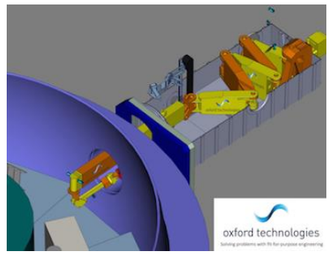
RACE works with Oxbotica, Millbrook, Oxford Robotics Institute, Zeta, Bosch, Siemens, Amey and many others on multiple driverless vehicles projects and host part of the UK's Connected and Autonomous Vehicle Test Bed.

RACE has contributed to the Nuclear Waste Decommissioning Research Forum (NWDRF) (an industry group that aims to enhance coordination of R&D across UK Site Restoration and Integrated Waste Management activities) but is not a member.

Capabilities

Overview

- RACE's unique skills relate to the routine two-shift operation of the JET remote handling system. RACE has conducted more than 30,000 hours of in-vessel remote operations, working mostly on the reactor shutdown critical path, and over 60,000 hours of ex-vessel training and process development.
- RACE has learnt how to make a fully remotely operated system productive. RACE is applying this knowledge in a growing range of commercial situations.
- RACE is being formed specifically to enable industry. Success measures include jobs and growth in the private sector and forming international collaborations to deliver global impact.
- RACE's core competencies include electro-mechanical design, control systems / systems integration, cybernetics and remote operations management.



(a) Drawing of VNS arm being deployed through portal. (b) RACE Demonstration Facility. (c) RACE Culham Science Centre. *Images Courtesy of RACE.*

Examples of Relevant R&D Projects

RACE is currently conducting 22 R&D projects, with a total value of £14M per annum, fourteen of these are collaborative R&D projects working with partners in industry.

The RACE Culham Science Centre is in Oxfordshire.

Supporting decommissioning of Fukushima reactors

- RACE is working with VNS (UK) Ltd (was Oxford Technologies) to support decommissioning of the Fukushima reactors.
- RACE will host the functional tests of VNS's 19m long arm that will reach into the reactors to inspect and retrieve samples.
- RACE is also working directly for NDF and TEPCO to develop risk based strategies for long term use of remotely operated tools.

SBRI - Integrated System Demonstrator Phase 2 'Elephant to Ants: Innovation in Integration'

- Working with Createc, RED Engineering, REACT engineering, OC Robotics and Structure Vision.
- The agility of robotics developments systems is perfectly suited to nuclear decommissioning, where flexibility and the adaptability in the presence of both known and unknown technical risks is the key to success.
- The project aims to demonstrate that this flexibility not only enables improved performance in and of itself, but that it also has a fundamental impact on the form of both the solution and the way it is deployed and operated.
- These new solutions will: maximise re-use (saving cost), reduce initial acquisition cost, reduce overall technical risk, reduce waste arising and accelerated decommissioning.
- RACE's role is systems integration using CorteX and demonstration.

SBRI - Integrated System Demonstrator Phase 2 'Nu-Decom'

- Working with Nuvia (Project Lead), Clicks & Links, Hu-Tech, MOOG, PaR Systems, Tacit-Connections, Imitec and academic partners University of Manchester and the University of Bristol.
- The aim of the project is to demonstrate a range of new decommissioning technologies that will deliver the safer, cheaper and quicker decommissioning of the UK's nuclear legacy.
- RACE's role is systems integration using CorteX and demonstration.

REACH

- Working in collaboration with OCRobotics (GE Aviation Company), Createc and Viridian.
- RACE is hosting full scale tests of a 12m long snake-arm robot concept for inspection, characterisation and sampling in areas that cannot normally be reached in confined and hazardous environments.

LaserPiglet

- RACE-only 'Gamechanger' project with Sellafield.
- Developing a remotely delivered in-bore, laser pipe-surface oblation tool to minimise waste fractions.

2.6. National Nuclear Laboratory (NNL)

NNL is a UK government owned and operated nuclear services technology provider covering the whole of the nuclear fuel cycle. NNL provides advice to the UK Government and works with other National Laboratories around the world to deliver a full range of research, technology and skills to support the nuclear fuel cycle.

NNL play a key role in the UK and global nuclear industry by contributing to reductions in the cost of clean-up and decommissioning, maintaining critical skills and attracting talented new people to the industry. NNL are the only UK organisation with the skills, facilities and expertise to provide technical support to all aspects of the nuclear industry.

Contract Routes & Funding Mechanisms

NNL is on **DRP Lot A** (lead), **DRP Lot B** (with Galson Sciences), **DRP Lot C** (lead), **SNS Lot 1** (lead), **SNS Lot 2** (with Galson Sciences) and has a **Technical Services Agreement** with Sellafield to work for them directly.

- Most of the funding to NNL in connection with decommissioning programmes comes from Sellafield through the Technical Services Agreement. The majority of the specialist technical work is done in partnership (the work allocation partnership process is in place to decide which work goes into the supply chain and which work is done by NNL).
- NNL operates on a fully commercial basis and is charged by government to reinvest surplus funds, or Earnings to Reinvest, for the benefit of the nuclear industry. Government department funding is won in competitions (e.g. BEIS National Programmes and the Nuclear Safeguards Programme).

Collaborations

NNL coordinates nuclear industry collaboration and supervises PhD's through the following programmes:

- DISTINCTIVE (Decommissioning, Immobilisation and Storage soluTIons for NuClear wasTe InVEntories) with Sellafield and NDA, 10 universities and an EPSRC grant.
- TRANSCEND (Transformative Science and Engineering for Nuclear Decommissioning) with AWE, Cavendish Nuclear, LLWR, RWM, Sellafield and TUV SUD Nuclear Technologies, 11 universities and an EPSRC grant.
- Centres for Doctoral Training, with other industry partners, for universities, through EPSRC.

NNL supports Sellafield on the delivery of the Game Changers programme (including provision of resources and facilities to support companies with Proof Of Concept grants).

NNL is involved in projects funded by Innovate UK

NNL is represented on each of the NWDRF Working Groups.

Capabilities

The three technical capability areas that NNL Delivery Operations deliver technical services and R&D through are listed below, with examples of current R&D projects:

- **Fuel, Reactors and Reprocessing:** Capability teams in this area that support NDA include electron optics, nuclear physics, separation science, metallography, corrosion and plant chemistry.
- **Nuclear Operations:** Capability teams in this area that support NDA include modelling, plant inspection, measurement and analysis, robotics, nuclear safety and security.
- **Waste Management and Decommissioning:** All staff in this area carry out work relevant to NDA, including waste and residues processing, waste behaviour and characterisation and waste packaging and disposal.

Complementing the NNL's Central Laboratory facilities, additional capability is located at:

- **NNL Risley** leads on modelling and simulation and environmental management. This is also where the project management and corporate functions are based.
- **NNL Stonehouse** carries out UK reactor services (including station chemistry & corrosion and graphite technology).
- **NNL Culham** features materials science and chemistry (including Post Irradiation Examination analysis, analysis of fuel and graphite, materials evaluation and assessment and radiation chemistry).

Photographs of the Laser Cutting Rig for Size Reduction of Glove Boxes at NNL Workington. *Images Courtesy of NNL.*

Examples of Relevant R&D Projects

The electron optics team is playing a key role in a current programme to support safe storage of nuclear material, while the metallography team has carried out post storage examination of high burnup fuel pins following pond storage for periods of up to 25 years.

The Robotics capability is currently supporting the development of a laser cutting system for size reduction of redundant glove boxes.

As part of Waste Processing and Residues Services, NNL is participating in an NDA sponsored Integrated Project Team to develop thermal treatment of ILW using Geomelt and to install a Hot Isostatic Press in a glove box facility for the immobilization of PuO_2.

Laboratory Facilities

Central Laboratory (Sellafield Site)
- Active fume cupboard and glove box facilities that can handle a wide range of radioactive materials, including irradiated material and separated Nuclear Material. This facility includes a rig hall capable of handling bulk quantities of radioactive material, including for example, a pilot scale ILW vitrification rig. A shielded cell facility within Central Laboratory is currently awaiting commissioning .
- Capability to carry out physics, chemistry and materials science based activities.

Windscale Laboratory (Sellafield Site)
- The Windscale Laboratory is used for non-destructive and destructive examination of reactor fuel and irradiated materials. The Laboratory also has facilities dedicated to the processing and management of radioactive waste and sealed sources.
- Modules consisting of a fume hood and workbench, 13 shielded cells ("caves"), Active Corridor linking all cells allowing movement of materials, Concrete shielding (beta/gamma levels), Service Cranes able to transport flasks.

Preston Laboratory (Springfields site)
- Facilities that can handle Radioactive Elements, Uranium Active material, in addition to non-radioactive R&D Laboratories and Handling & Inspection facilities.
- A chemistry laboratory, a chemical engineering rig hall, a fluorine chemistry facility and a microscopy laboratory (incorporating an environmental scanning electron microscope, an energy dispersal x-ray microscope, a secondary ion mass spectrometer, a laser confocal microscope and an atomic force microscope).
- Uranium Active Oxide Power Facilities (capable of novel fuel fabrication process development, powder processing laboratories and total enclosures for bulk uranic work, Pellet pressing facilities, Sintering furnaces, Powder and pellet QA testing laboratory, Engineering development of uranium active rigs, Large rig hall).

Workington Laboratory
- This is a non-radioactive engineering and rig testing facility. Services Include:
  - Technical assessment & solution proposition
  - Design, manufacture and build of test rigs
  - Rig testing
  - Operator training

2.7. National Physical Laboratory (NPL)

NPL provides proficiency tests, reference materials and guidance to ensure that measurements of the radioactivity content of waste materials are accurate, consistent and demonstrably independent of the nuclear industry. NPL, as an integral part of its measurement research capability, develops highly accurate metrology instrumentation, sensors and artefacts. NPL's scientific R&D generates intellectual property in a wide range of technical fields, including new materials, sensors, optics, software and much more.

Contract Routes & Funding Mechanisms

NPL's main contract route for conducting R&D work in the nuclear industry is through NSG on **DRP Lot B,** Wood on **DRP Lot C**, and through the **Metrology and Technical Investigations Contract** with Sellafield.

- The main sources of funding for NPL are:
  - Government sources (i.e. BEIS)
  - European research grants (i.e. EMRP, Horizon 2020)
  - UK research grants (i.e. Innovate UK, NIHR)
  - Measurement services and technical services contracts with companies
  - Revenue generated through collaboration activities and IP exploitation

Collaborations

NPL conduct joint workshops with IOP and NNL to discuss the progress and challenges of nuclear data.

NPL collaborates with national & international organisations, including, but not limited to:

- The National Measurement System, funded by BEIS, which is a network of laboratories and processes that provide measurement standards and calibration testing facilities. It maintains measurement infrastructure, represents the position of UK measurement internationally and influences the development of standards.
- In 71 EMRP projects across Energy, Industry, Environment, Health, New Technologies and the SI units.
- The National Centre of Excellence in Mass Spectrometry Imaging, which focuses on the fundamentals and metrology of key imaging techniques, to boost applications and impact.

NPL is an active a member of the IRMF (facilitating the exchange of information about UK calibration and testing facilities), the MCNEG (for the dissemination of knowledge and technical information on Monte Carlo modelling) and the ARMUG (a forum for discussion of all aspects of air monitoring for radioactivity).

Capabilities

The NPL Radioactivity team specifically:

- Provides and disseminates primary standards for radioactivity metrology using conventional techniques, as well as newer developments.
- Participates in international comparisons of radioactivity standards to ensure international equivalence of primary standards.
- Standardises radionuclides routinely used for diagnostics and therapy in nuclear medicine.
- Provides a national measurement infrastructure for environmental monitoring of radioactivity and for nuclear waste decommissioning.
- Carries out evaluations, measurements and modelling of nuclear data.
- Provides measurement services to the UK user community.
- Provides advice on a range of radioactivity measurement problems.

NPL also have expertise in testing, measurement and consultancy services in the following areas:

- Corrosion and environment induced cracking
- Composites, polymeric materials and adhesives (from materials characterisation and design/modelling, to performance testing and failure analysis)
- Materials testing
- Chemical metrology, biological metrology and synthetic biology
- Dimensional metrology (providng measurement services using coordinate measuring machines, surface profilometers, interferometers, scanning probe microscopes)
- Environmental measurement
- Electronics interconnection
- Engineered materials
- Measurements of mass, force, pressure, and density
- Mathematics, modelling and simulation
- Neutron metrology
- Optical radiation and photonics
- Quantum detection
- Radiation dosimetry
- Surface and nanoanalysis
- Thermometry and humidity services
- Ultrasound and underwater acoustics

Examples of Relevant R&D Projects

NPL have completed several projects through DRP, including:

- Development of an Optimised Protocol for the Analysis of Strontium-90 in Decommissioning Wastes employing a Novel Technology for Inductively-Coupled Plasma Mass Spectrometry (completed in March 2017, project led by NSG)
- Development of an Improved Rapid Methodology for the Analysis of Carbon-14 in Solid Decommissioning Wastes (completed June 2018, project led by NSG with GAU)
- Reviewed the potential of graphene for water decontamination, sensors for radiation detectors and as part of new composite materials to build safer and more resilient facilities (with the University of Manchester and NSG Environmental)

NPL have completed several projects with Sellafield, including:

- Development of a prototype inspection system which could automatically process inspection data, identify and quantify areas of change between subsequent inspections (with ABS consulting). The project demonstrated the prototype within a storage cell on site and laboratory testing of the image analysis techniques was completed in a laboratory environment on target samples representative of those within the cell.
- Development of an integrity evaluation method based on low-frequency eddy-current induction for wall thickness measurements of a composite steel structure including an insulating layer (through the Metrology Services contract). A prototype coil was designed and built and its impedance behaviour in the presence of different material thicknesses was evaluated. A computational model of the system was generated, allowing comparison between experimental results and results from simulations.
- Thermal imaging technical demonstration module for inactive deployment demonstration (through the Metrology Services contract).

Laboratory Facilities

NPL is based in Teddington, Middlesex.

Radiochemistry Suite

- A suite of state-of-the-art radionuclide source handling and radiochemistry laboratories:
  - Various standardisation counting techniques (including absolute, liquid scintillation, Large-Area source and gas counting)
  - Ionisation chambers and spectrometry facilities (including alpha, gamma)
  - Monte Carlo modelling with a wide variety of radiation transport codes.

Corrosion and Environment Induced Cracking Testing Facilities

- NPL undertake leading-edge research combining advanced measurement and modelling to characterise the evolution of corrosion damage from its earliest stages, to develop testing standards and establish predictive tools for lifetime evaluation. Capabilities include:
  - Materials selection for resistance to environment assisted cracking (assessing slow strain rate, corrosion fatigue, Hydrogen Induced Cracking)
  - Eighteen autoclaves for high pressure/high temperature and for testing with / without H_2S
  - Corrosion inhibition measurement and pitting/crevice/intergranular corrosion evaluation

Material Characterisation

- Scanning probe microscopies (including analysis of topography, microscopy, nanoscale current response)
- Surface analysis (including analysis of surface chemical composition, material workfunction, chemical depth profiling, hydrophobicity, film thickness/optical properties)
- Morphological characterisation (including analysis of surface topography, surface roughness, high-resolution images of nanoscale topographic features)
- Mechanical characterisation (including analysis of mechanical properties such as yield strength, modulus and stress/strain, in addition to nano-indentation)
- Rheology (including analysis of shear viscosity, dynamic viscosity, stress relaxation, shear viscosity, creep, viscoelasticity, melt flow rate testing of polymers)
- Non-destructive testing (including radiography, ultrasonics, scanning acoustic microscopy, acoustic emission, scanning electron microscopy, thermography, optical micropscopy)

Environmental Measurements

- Acid gas analysis and metals analysis for airborne emissions monitoring and aerosol measurements
- Occupational air quality
- Remote emissions surveys (self-contained mobile lab that rapidly detects and accurately measures airborne atmospheric pollutants and creates 3D emission maps).
- Sampling and analysis of complex VOCs (including using contaminated land soil probes)
- Stack proficiency testing scheme and stack simulator

3. R&D Supply Chain

3.1. NDA R&D Contracts

The main contracting route currently available for the supply chain to contribute to research and development requirements for the decommissioning and waste management field directly with the NDA is the Direct Research Portfolio (DRP) framework. The framework contract lasts for 2 years with the option to extend for two further one-year terms. The latest framework was initiated in May 2016 and is currently in its third year. There are three Lots on the framework, across which the current annual spend is £5m, as listed below along with the organisations on each. See Appendix 2, Table 8 and Table 9 for overviews of the scope and the key R&D topic areas for DRP Lot B and DRP Lot C. See Appendix 6 for examples of some of the latest DRP projects.

Lot A	Lot B	Lot C
UNIVERSITY INTERACTIONS • Lead by NNL. (details excluded from this report)	• **INTEGRATED WASTE MANAGEMENT AND SITE DECOMMISSIONING AND REMEDIATION** • Various organisations with the following lead contractors (see Appendix 2 Table 4 for full list of contractors): ○ Wood group ○ Arcadis Consulting (UK) Ltd ○ Arup ○ Eden NE Ltd ○ Galson Science Ltd ○ NSG Environmental Ltd	**SPENT FUEL AND NUCLEAR MATERIALS** • Various organisations with the following lead contractors (see Appendix 2 Table 5 for full list of contractors): ○ Wood group ○ Orano ○ NNL

Since 2010, the NDA has been collaborating with Innovate UK, the UK government's innovation agency, to engage the supply chain and develop innovative technologies and services to support the NDA's mission and the growing international nuclear decommissioning market. See Ref. 20 for an overview of the approach, associated benefits and technologies that have been developed through the process. See Appendix 3 for a list of examples of decommissioning and waste management related projects that have been initiated through Innovate UK and the organisations involved in delivering those.

3.2. Wider R&D Contracts

Specialist Nuclear Services Framework

The Specialist Nuclear Services (SNS) Framework was established for use by the following organisations within the NDA Estate.

- Magnox Limited
- Nuclear Decommissioning Authority (NDA)
- Radioactive Waste Management Limited (RWM)
- Research Sites Restoration Limited (RSRL)
- Dounreay Site Restoration Limited (DSRL)
- International Nuclear Services Ltd (INS)
- LLW Repository Limited (LLWR)

The current framework contract started in April 2015 and is due to expire in March 2019. SNS Framework 3 will commence from April 2019 to March 2023 and will be released for tender shortly. There are seven Lots within the framework, two of which are specifically for R&D projects, with the scope described below (see Ref. 12 for additional details).

Lot 1 Lab R&D:

- The aim of this service is to support the development of the knowledge base underpinning the safety case for geological disposal of the UK's highly active waste inventory. The support is via experimental research, so as to support the end-users in disposal system safety case, concept development, design studies and waste package disposability assessment.
- Technical subject areas include: wasteform evolution, container materials evolution, near field evolution, geosphere, groundwater, biosphere, radionuclide behaviour, criticality and waste package accident performance.

Lot 2 Desk R&D:

- The aim of this service is to provide desk-based research and analysis to support the development of the knowledge base for the Geological Disposal Facility (GDF) safety case. The support is also for post-closure performance assessment, model development, post-closure safety arguments and associated analysis relevant to environmental safety case development.
- Technical subjects as with Lot 1, in addition to safety case development, site evaluation development, knowledge transfer, GDF concept selection process, disposal system specifications and model development.

Table 1 – Specialist Nuclear Services Framework R&D Overview for FY17/18 (Ref. 13 & 18)

Contract Route	*Supply Chain Involved*	*Annual Spend*		
		RWM	*Magnox*	*Others*[3]
Specialist Nuclear Services Framework – **Lot 1 Lab R&D**	Various organisations with the following lead contractors (see Appendix 2 for list of all members): • NNL (orchid consortium) • Wood Group • NSG (nucleus consortium)	£2.23m	-	-
Specialist Nuclear Services Framework – **Lot 2 Desk R&D**	Various organisations with the following lead contractors (see Appendix 2 for list of all members): • Quintessa (Nucleus consortium) • Wood Group • Glason Sciences (Orchid Consortium)	£3.27m	£1.32m	-

[3] Others = NDA, RSRL, DSRL, INS and LLWR, who did not spend on this framework in FY17/18.

3.3. RWM R&D Contracts

Overview

Radioactive Waste Management Limited (RWM) utilise the SNS framework for most of its R&D work, as shown in the R&D spend split in Figure 3.

Sole source justifications (Ref. 18) for R&D work relate to the following:

- International collaborations with other waste management organisations;
- European projects (part funded by the European Commission);
- Underground research laboratories;
- Direct contracting with Universities for PhD's/Postdoctoral Research Associate's:

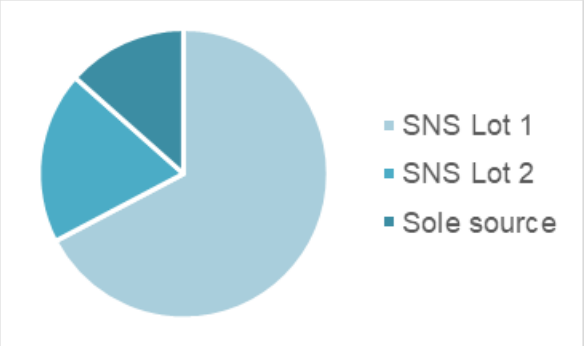


Figure 3 – RWM R&D Annual Spend Split

Specific R&D Sole Source Examples (from Ref. 18 and Ref. 19)

- For an experiment for Mont Terri, contracted through Swisstopo, it is a collaborative effort between RWM, the Swiss National Cooperative for the Disposal of Radioactive Waste (NAGRA - the lead contractor), the Canadian Nuclear Waste Management Organization (NWMO) and the French National Radioactive Waste Management Agency (Andra).
- RWM have a collaboration agreement SKB (the Swedish waste management organisation) with access to work carried out at the Aspo Hard Rock Laboratory (where much of the research about the final repository for spent nuclear fuel is taking place and where different technological solutions are tested in full scale in a realistic setting).
- RWM have 'buy-in's for the Grimsel Test Site (an international centre for underground R&D located in the Swiss Alps) and for the Mont Terri Project (an international research project for the hydrogeological, geochemical and geotechnical characterisation of a clay formation within the Jura Mountain range in Switzerland).
- RWM has paid for a PhD to explore mechanical, hydraulic and geochemical rock interactions during drainage of a surface water reservoir above the underground rock laboratory at Grimsel, Switzerland (July 2014 – March 2018).

RWM Working with National Labs

RWM routinely work with BGS, mostly through SNS Lot 1 and SNS Lot 2. Historically, in 2014, BGS had a direct contract with RWM for the preparation of nearshore geological information to inform the Managing Radioactive Waste Safely (MRWS) process in England and Wales (Ref. 19). BGS also have the responsibility to manage and preserve the NDA Data Archive, which is contracted through RWM (September 2014 – March 2020) (Ref. 19).

RWM work with NNL through SNS Lot 1 and SNS Lot 2. RWM work with NPL as sub-contractors for members of SNS Lot 1 and/or SNS Lot 2.

3.4. Sellafield R&D Contracts

Sellafield Ltd. have a range of contracting routes for engaging with National Labs and the Supply Chain to enable them to contribute to R&D requirements for decommissioning, spent fuel handling and waste management, in addition to cross-cutting technologies. An overview is presented in Table 2.

Table 2 – Sellafield Contract Routes for R&D Work

Contract Name	*Scope*	*National Lab / Supply Chain involved*	*Contract Period*	*Current Annual Spend*
Technical Services Agreement	R&D, plant support, technical demonstrations, technical services and technical skills maintenance.	NNL	2016 – 2033 (17 years)	~£30m
Metrology and Technical investigations	Skills and expertise to apply the most accurate and up-to-date measurement standards, science and technology available.	National Physical Laboratory	4-year framework (renewal due end of 2019)	~£0.1m
Direct awards with Technical department	Specific Research and Development support for project specific demands via Sellafield's Technical Department.	A range of UK and European suppliers covering equipment trials, additional research projects (often co-funded with other public bodies / contractors). See Appendix 4 Table 11 for a list of projects and supply chain companies involved in FY17/18.	Ongoing	~£5m
Game Changers	Game Changers is encouraging innovation from businesses, academia & individuals to address complex nuclear decommissioning challenges. Innovation that can make a substantial impact on the cost of decommissioning.	Up to September 2018 the programme has received over 160 applications, 70 have received initial grants for developing business cases, with 9 such projects progressing to proof of concept stage (Ref. 10) – listed in Appendix 5 Table 12.	Ongoing	Project has leveraged over £1m external funding
Enabling Innovation Framework (EIF)	EIF supports Sellafield Ltd in maintaining and strengthening its ability to act as an intelligent client and enables innovative projects to be undertaken. Note: not exclusively R&D projects.	Wood Group (previously Amec Foster Wheeler Ltd), Atkins, Capita, Cavendish Nuclear Ltd, EPI Consulting, North West Projects, Nichols Group, NSG Environmental, Quintessa, React Engineering, Tenet Consulting, Nuclear Technologies and Westlakes Engineering Ltd.	4-year framework (renewal due early 2019).	~£4m (includes non-R&D projects)

3.5. Others

There are other major framework contracts in place within the NDA estate, which include, but are not limited to, the following.

- Sellafield Design Services Alliance Framework
- Sellafield Link Framework
- Sellafield Decommissioning Demolition Partnership Framework
- DSRL Link Framework
- DSRL Design and Engineering services
- LLWR Business Services Marketplace
- LLWR Waste characterisation and assurance services Framework

These frameworks are not dedicated to R&D work and information is not readily available on whether the frameworks include delivery of R&D aspects. Therefore, details on which supply chain organisations are involved have been excluded from this report. These frameworks and other direct contracts that are in place are primarily to enable delivery of business objectives / ongoing operations. There could be elements of R&D work related to delivery of decommissioning and waste management, for example through concept design phase work. Details of current procurement plans (correct as of September 2018) can be found in Ref. 14, Ref. 15, Ref. 16, Ref. 17 and Ref. 18.

3.6. Supply Chain Landscape

Utilising data from the NIRO Landscape survey conducted in FY15/16 (Ref. 8), based on responses from various organisations across the supply chain, it is possible to gain an insight in to how many FTEs are working across the supply chain to deliver relevant R&D activities (related to spent fuel management, waste management, decommissioning and relevant cross-cutting fields). NIRO will continue to review the supply chain R&D landscape and conduct another survey for FY18/19.

Figure 4 shows the number of FTEs working in each area for each organisation. Data is also included on R&D FTEs for NDA, LLWR, DSRL, Magnox and Sellafield Ltd. Three of the supply chain organisations that have the largest number of staff contributing to R&D supporting the NDA estate were NSG, Amec Foster Wheeler (now Wood Group) and Nuvia.

Figure 5 shows the breakdown of the total number of FTEs working in spent fuel management, waste management, decommissioning and cross cutting fields from across the wider supply chain and for NDA, LLWR, DSRL, Magnox and Sellafield Ltd R&D FTEs. The area with the most resource aligned to is Waste Management, which has 50% of the total number collected in the survey (Total = 377 FTEs). The area with the second most resources is Decommissioning with almost a quarter of the FTEs working in that field. An eighth of the FTEs work each in Spent fuel handling and Cross-cutting areas.

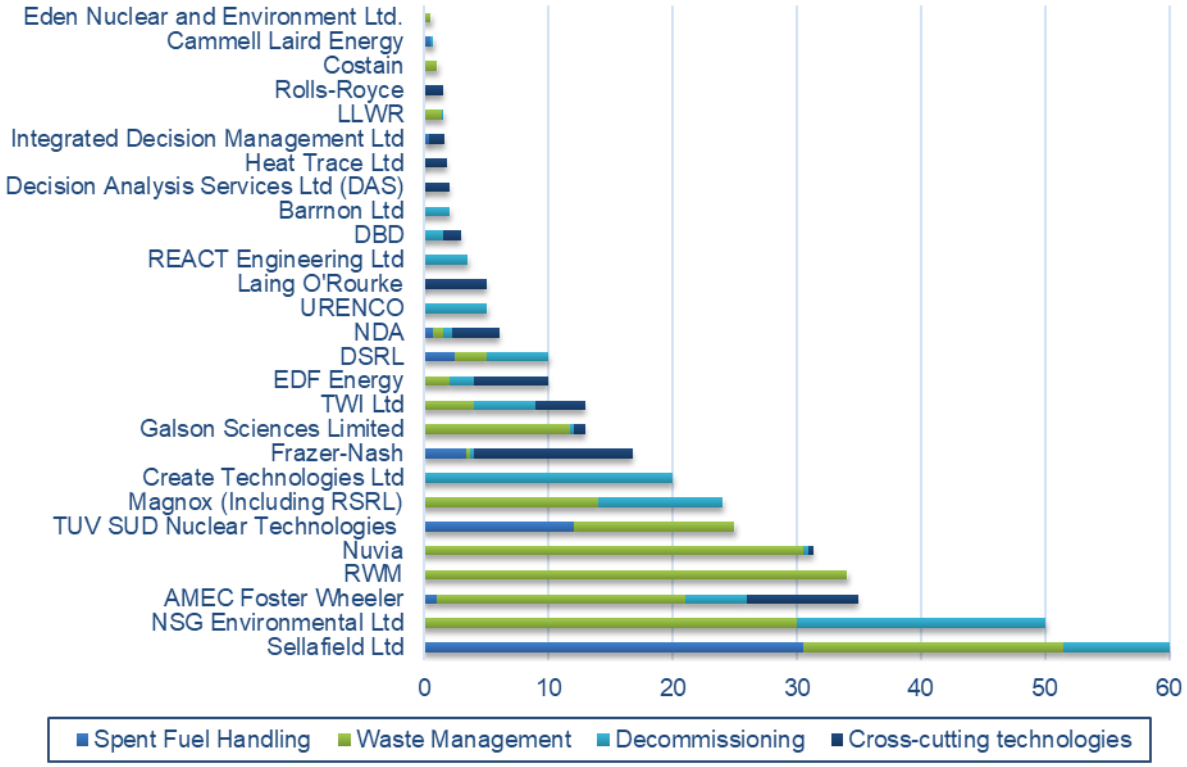


Figure 4 – FTEs conducting R&D across supply chain in FY15/16 (NIRO data - Ref. 8)

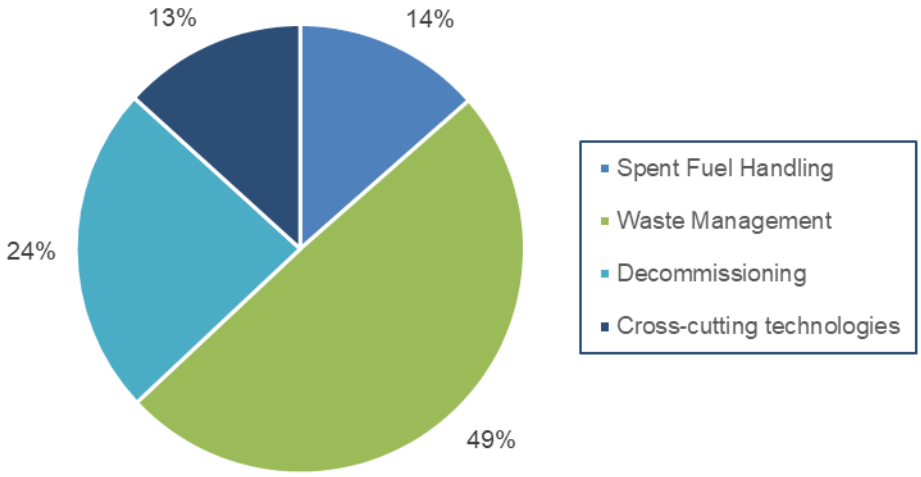


Figure 5 – Supply Chain FTE split across R&D Fields in FY15/16 (NIRO data - Ref. 8)

4. Summary

The purpose of this report is to inform the NDA Research Board as to the roles and capabilities of selected key UK national labs and the broader supply chain involved in delivering Research & Development (R&D) for nuclear decommissioning and waste management. It will also enable the NDA Research Board members to provide further advice on the adequacy of the current or proposed R&D arrangements and the possible threats, risks and opportunities to the current strategy.

The report provides a high-level overview of the capabilities of selected National Laboratories for contributing to R&D for radioactive waste management and nuclear decommissioning, as well as, the existing contracting routes for the supply chain to get involved.

The selected National Laboratories are to differing extents already contributing to R&D for nuclear decommissioning and radioactive waste management. Overall, it is estimated that they have 565 Full-Time Equivalents (FTEs) working on R&D related to spent fuel handling, waste management, decommissioning and cross-cutting technologies. NNL being the largest contributor (with 42% of the FTEs working across all four fields), followed by RACE (with 25% of the FTEs working on waste management and cross-cutting technologies). NPL and NAMRC contribute 14% of the FTEs each and mostly conduct cross-cutting research. BGS and HSL have the fewest FTEs (3% and 2% respectively) since their staff are not fully dedicated to nuclear R&D, but work across a variety of sectors. This shows the current numbers working on relevant R&D, but it is likely that there is scope for additional capacity within each of the national labs to support R&D in the future.

It was found that R&D work, specifically for nuclear decommissioning and radiological waste management in the NDA estate, is currently delivered by the supply chain and national labs mainly through a variety of competed frameworks (namely Specialist Nuclear Services (SNS), Direct Research Portfolio (DRP) and strategic partnerships such as the Technical Services Agreement).

The NDA's DRP framework has two relevant Lots through which specific R&D projects can be initiated, across which the current annual spend is £5m per annum. The total budget for the whole of NDA's R&D work is around £8m.

- Lot B - Integrated Waste Management and Site Decommissioning, with access to 56 organisations (including NNL, NPL and NAMRC) and 12 universities
- Lot C - Spent Fuel and Nuclear Materials, with access to 24 organisations (including NNL and NPL) and 10 universities.

The Specialist Nuclear Services (SNS) Framework was established for use Magnox, NDA, RWM, RSRL, DSRL, INS and LLWR. Two of the lots within the framework are specifically for R&D (Lot 1 Laboratory based R&D and Lot 2 Desk based R&D). For FY17/18, RWM spent £5.5m and Magnox £1.3m across these frameworks. Lot 1 and Lot 2 has access to 31 organisations (albeit slightly different, but both including BGS and NNL) and 10 universities/institutes.

Sellafield has 5 direct contract routes through which it contracts R&D, with an annual spend of approximately £40m. 75% of this is spent on a technical services contract with NNL (who work with sub-contractors to complete the work). £5m goes through Direct awards from the Technical department to a range of R&D organisations. The remaining £5m is split between NPL (for metrology services) and to support companies to innovate new technologies (i.e. Game Changers and EIF).

NDA and Sellafield Ltd have also used UK grant-based funding either in collaboration with Innovate UK or with NNL (through the Game Changers programme). These funding sources focus on supporting open innovation and generating a pipeline of ideas in early development (at both low and mid-range Technology Readiness Levels (TRLs)).

The supply chain companies also have direct contracts with AWE, NDA, RWM and the SLCs and deliver specific work packages, which can relate to R&D in these areas and can be delivered solely by individual organisations or through consortiums/joint ventures. There are many organisations in the nuclear supply chain contributing to R&D relevant for the NDA estate, but a more comprehensive review, with access to

commercial information, would be required to understand how and where this can be utilised and developed further.

Based on the evidence from the 'The UK Civil Nuclear R&D Landscape Survey FY15/16' report (Ref. 9), the three private sector supply chain organisations that have a large number of staff contributing to R&D supporting the NDA estate were NSG, Amec Foster Wheeler (now Wood Group) and Nuvia. Some companies in the supply chain have self-funded research programmes, but a significant proportion of the research conducted tends to be application specific and therefore only of commercial value to a limited number of clients. There is limited publicly available data from organisations about their contribution to the R&D, with the information being commercially sensitive.

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Acronyms

Acronym	*Description*
Andra	French National Radioactive Waste Management Agency
ARMUG	Airborne Radioactivity Monitoring Users' Group
AWE	Atomic Weapons Establishment
BEIS	Business, Energy & Industrial Strategy
BGS	British Geological Survey
CCFE	Culham Centre for Fusion Energy
DCF	Dalton Cumbrian Facility
DEFRA	Department of Environment, Food and Rural Affairs
DRP	Direct Research Portfolio
DSA	Design Services Alliance
DSEAR	Dangerous Substances and Explosive Atmosphere Regulations
DSRL	Dounreay Site Restoration Ltd
ENRESA	The Empresa Nacional de Residuos Radiactivos (Spanish Radio Active Waste Management Agency)
EPSRC	Engineering and Physical Sciences Research Council
ESS	European Spallation Source
FORGE	Fate of Repository Gases
FTE	Full Time Equivalent
GDF	Geological Disposal Facility
HSE	Health & Safety Executive
HSL	Health & Safety Laboratories
ILW	Intermediate Level Waste
INS	International Nuclear Services
IOP	Institute of Physics
IRMF	Ionising Radiation Metrology Forum
ITER	International Thermonuclear Experimental Reactor
JAEA	Japan Atomic Energy Agency
JET	Joint European Torus
LLWR	Low Level Waste Repository Limited
MCNEG	Monte Carlo Neutron, Hadron, Electron and Gamma radiation transport codes
NAGRA	National Cooperative for the Disposal of Radioactive Waste
NAMRC	Nuclear Advanced Manufacturing Research Centre
NDA	Nuclear Decommissioning Authority
NERC	Natural Environment Research Council
NIGL	NERC Isotope Geosciences Laboratories
NIRO	Nuclear Innovation and Research Office
NNL	National Nuclear Laboratory
NNUF	National Nuclear User Facility
NPL	National Physical Laboratory
NWDRF	Nuclear Waste Decommissioning Research Forum
ONR	Office for Nuclear Regulation
PPE	Personal Protective Equipment
R&D	Research & Development
RACE	Remote Applications in Challenging Environments
RAIN	Robotics and Artificial Intelligence in Nuclear
RSRL	Research Sites Restoration Limited
RWM	Radioactive Waste Management
SBRI	Small Business Research Initiative
SKB	Swedish Nuclear Fuel and Waste Management Company
SLC	Site Licensed Company
SNS	Specialist Nuclear Services (framework contract)
TRL	Technology Readiness Level
UKAEA	United Kingdom Atomic Energy Authority
UKRI	UK Research & Innovation

Appendix 1 – List of Interviewees

Table 3 lists the organisations that were contacted (in alphabetical order), who was interviewed (only the role is identified for personal data protection reasons) and what information was obtained that was used for this report.

Table 3 – Organisation Sources of Information

Organisation Interviewed	*Role of Interviewees*	*Information Provided*
BGS	Principal Geologists	Information on BGS for the one-page summary (Section 2.2) and FTE information for Figure 1 and Figure 2.
Create Technologies Ltd (Createc)	Operations Manager	Information on the types of R&D work involved in, framework membership and the number of FTEs working in R&D (data presented in Figure 4 and Figure 5).
Game Changers	Technical Manager	List of projects given 'Proof of Concept' grants by Game Changers, shown in Appendix 5.
HSL	Head of Centre for Energy	Information on HSL for the one-page summary (Section 2.4) and FTE information for Figure 1 and Figure 2.
Magnox	SNS Framework Manager	Information on SNS framework spends from FY17/18 and list of members - discussed in Section 3.2.
NAMRC	Business Manager	Information on NAMRC for the one-page summary (Section 2.3) and FTE information for Figure 1 and Figure 2.
NDA	Research Manager	List of NDA framework contracts and members. List of DRP projects from the last year, some of which are listed in Appendix 6. Contact details for National Labs.
NIRO	Senior Technical Advisor	The number of FTEs working in relevant R&D fields at national labs, and the surveyed organisations from the supply chain, for FY15/16. The data is presented in Figure 4 and Figure 5.
NNL	Chief Technologist	Information on NNL for the one-page summary (Section 2.6) and FTE information for Figure 1 and Figure 2.
NPL	Nuclear Strategy Lead	Information on NPL for the one-page summary (Section 2.7) and FTE information for Figure 1 and Figure 2.
NSG Environmental	Research Manager	Information on the types of R&D work involved in, framework membership and the number of FTEs working in R&D (data presented in Figure 4 and Figure 5).
REACT Engineering Ltd	Director	Information on the types of R&D work involved in, framework membership and the number of FTEs working in R&D (data presented in Figure 4 and Figure 5).
RWM	Senior Research Manager	Information on R&D contracts & collaborations in place for RWM and spends on SNS framework - discussed in Section 3.3.
Sellafield	Contract Manager	Confirmation of Sellafield frameworks/contracts facilitating R&D, their contract lengths and annual spends -in Section 3.4.
Sellafield	NWDRF Co-Chair	The role of NWDRF and how they pursue R&D work by putting projects out through the DRP.
TUV SUD Nuclear Technologies	Research Manager	Information on the types of R&D work involved in, framework membership and the number of FTEs working in R&D (data presented in Figure 4 and Figure 5).
UKAEA	Director of RACE	Information on RACE for the one-page summary (Section 2.5) and FTE information for Figure 1 and Figure 2.

Appendix 2 – Additional Details on Frameworks

Table 4 - Direct Research Portfolio Lot B (Integrated Waste Management & Site Decommissioning and Remediation) Framework Members

Lead Contractor	*Consortium Members*
Wood Group (formerly Amec Foster Wheeler Ltd)	Andra, Brenk Systemplanung and Jülich Research Centre, Cogentus Consulting, DAS Ltd, Imperial College London, Longenecker & Associates, MMI Engineering, NuVision, OC Robotics, Fortum, University of Birmingham, University of Bristol, University of Cambridge, University of Manchester.
Arcadis Consulting Ltd	AdvanSci, Applied Photonics (APL), Orano (formerly Areva RMC), Aurora, ESI, MDecon, Pöyry, ProNu-Dec, Tradebe Inutec, TWI, University of Liverpool, Dalton Nuclear Institute, University of Surrey.
Arup	Costain, Pöyry, Studsvik, James Fisher Nuclear Ltd, SN3, AdvanSci, MCM, Bilfinger GVA, Pinsent Masons, CL:AIRE, r3 Environmental Technology, Dalton Nuclear Institute.
Eden NE Ltd	Cavendish Nuclear, DBE TECHNOLOGY GmbH, Golder Associates Limited, Tradebe Inutec, Project Time and Cost International Limited.
Galson Sciences Ltd	National Nuclear Laboratory, Frazer-Nash Consulting, Advansci, Amphos 21, Cogentus Consulting, Integrated Decision Management, Jacobs, Kurion, Rodgers Leask, VTT, University of Bristol, Lancaster University, University of Leeds, University of Manchester, University of Sheffield.
NSG Environmental Ltd	AECOM, ARC, Oxford Technologies, NPL, ESG, Quintessa, React Engineering, KDC, Tradebe Inutec, Synergy Health, Nuclear AMRC, Loughborough University, University of Manchester, University of Surrey.

Table 5 – Direct Research Portfolio Lot C (Spent Fuel & Nuclear Materials) Framework Members

Lead Contractor	*Consortium Members*
Wood Group (formerly Amec Foster Wheeler Ltd)	Andra, Brenk Systemplanung and Jülich Research Centre, DAS Ltd, Fortum, MMI Engineering, NPL, NRG, OC Robotics, Studsvik, University of Birmingham, University of Manchester, University of Bristol, University of Cambridge, Loughborough University, Imperial College.
Orano (formerly Areva NC)	NSG Consultancy, MDecon, Quintessa, University of Liverpool, University of Sheffield.
National Nuclear Laboratory	Frazer-Nash Consulting, Galson Sciences Ltd, ALD France, Aquila Nuclear Engineering, DBD, DAS, IDM, Jacobs, Kurion, Rodgers-Leask, University of Bristol, Lancaster University, University of Leeds, University of Manchester, University of Sheffield, Imperial College.

Table 6 – Specialist Nuclear Services Lot 1 (Lab R&D) Framework Members

Lead Contractor	*Consortium Members*
NNL (Orchid Consortium)	Gardiner & Theobald, Galson Sciences, Nuvia, Parsons Brinkerhoff, NNL, Frazer-Nash, Amphos 21, VTT, University of Sheffield, University of Manchester, Loughborough University, University of Leeds, University of Birmingham.
Wood Group (previously Amec Foster Wheeler)	Studsvik (Cyclife), NRG, CEA, University of Cambridge, Croft Associates, University of Manchester, University of Birmingham, Bedrock Geosciences, University of Leeds, Imperial College, MCM, Savage Earth, Paul Schroder Institute, Intellisci, BGS, University of Nottingham, NAGRA, Loughborough University, Arup, Frauhofther Institute.
NSG (Nucleus Consortium)	Abbott Risk Consulting, Nuclear Technologies, NSG, Quintessa, Eden Nuclear, Enviras, ESG, Golder Associates, MMI, RSSl, Synergy Health.

Table 7 – Specialist Nuclear Services Lot 2 (Desk-based R&D) Framework Members

Lead Contractor	*Consortium Members*
Quintessa (Nucleus Consortium)	Quintessa, NSG, Abbott Risk Consulting, Nuclear Technologies, MMI Engineering, Eden Nuclear, Golder Associates, Tessella, Nukem, Lloyds Register, Oxand.
Wood Group (previously Amec Foster Wheeler)	Studsvik (Cyclife), NRG, CEA, University of Cambridge, Croft Associates, University of Manchester, University of Birmingham, Bedrock Geosciences, University of Leeds, Imperial College, MCM, Savage Earth, Paul Schroder Institute, Intellisci, BGS, University of Nottingham, NAGRA, Loughborough University, Arup, Frauhofther Institute.
Galson Sciences (Orchid Consortium)	Gardiner & Theobald, Galson Sciences, Nuvia, Parsons Brinkerhoff, NNL, Frazer-Nash, Amphos 21, VTT, University of Sheffield, University of Manchester, Loughborough University, University of Leeds, University of Birmingham.

Table 8 – Overview of Scope and Key R&D Topic Areas for DRP Lot B (Information from Ref. 21)

Contract	DRP Lot B Integrated Waste Management					DRP Lot B Site Decommissioning and Remediation				
Topic Area	Radioactive Waste (both Higher Activity Wastes and Solid Low Level Wastes, HAW & LLW)			Liquid & Gaseous Discharges	Non-Radioactive Waste	Decommissioning	Land Quality Management		Site Interim and End States	Land Use
Key R&D Topics	Application of the Waste Hierarchy	Alternative waste treatment, with a particular focus on volume reduction	Underpinning of interim storage	Alternative liquid treatment technologies	Technology improvement requirements driven by multi-sector needs and commercial opportunities	Strategic approach to prioritisation of decommissioning and remediation activities	Addressing the barriers to on-site and in-situ disposal of waste and the management of residual land contamination as part of final Site End States	Improving management and remediation technologies for ground and groundwater contamination	Technically underpin approach to defining and optimising Interim and Site End States (for land, structures and infrastructure)	Technically underpin factors that influence land use
	Waste retrieval technologies	Alternative Encapsulants	Alternative disposal approaches	Alternative effluent treatment technologies	Use of industry groups to monitor the requirements.	Improved characterisation to support decommissioning	Improved decommissioning (e.g. decontamination, dismantling)	Improving characterisation of ground and groundwater	Assessing risk from land and groundwater contamination	Technically underpin approach to controls of in situ waste disposals and residual contamination	

Table 9 – Overview of Scope and Key R&D Topic Areas for DRP Lot C (Information from (Ref. 21)

Contract	DRP Lot C Spent Fuels			DRP Lot C Nuclear Materials		
Topic Area	Magnox Spent Fuels	Oxide Spent Fuels	Exotic Spent Fuels	Plutonium		Uranics
Key R&D Topics	Interim wet storage capability for Magnox	Options for improved wet storage	Potential fuel drying and dry storage	Improved technical options for long term storage of exotic fuel materials.	Understanding the suitability of the UK's plutonium inventory for re-use as MOX	Long-term storage of plutonium	Identification of ways to make re-use more attractive
	Options for long term management of spent Magnox fuel	Potential strategic option to extend wet fuel storage beyond 25 years	Fuel storage strategy alignment with disposal	Identify functional requirements and candidate treatments to facilitate storage and disposal exotics fuel materials.	Development of immobilisation techniques for plutonium	The disposability and disposal of relevant spent fuel and immobilised plutonium	Identification of alternative disposal methods and routes

Appendix 3 – Innovate UK Nuclear Related Projects

Table 10 – List of Nuclear Related Innovate UK Funded Projects (selected from Ref. 23)

Area	*Participants*	*Project Title*	*Project Description*	*Grant Offered (Status)*
Decommissioning	University of Sheffield NNL	To develop computer software to enable the prediction melt viscosity for nuclear waste glass. This will be deployed in support of nuclear waste decommissioning R&D delivering significant improvements against the current baseline.		~£20k (closed)
Decommissioning	Barrnon Limited	Feasibility - pre-industrial research of horizontal sludge dredge	Barrnon Ltd. are developing a novel new system to safely remove sludge from nuclear storage ponds and silos where nuclear waste is stored under water. The system will allow faster and more efficient collection of the sludge and will not unduly disperse it	~£140k (closed)
Decommissioning	University of Leeds Sellafield Ltd MMI Engineering Limited	Measurement and modelling of sludge transport and separation processes	Sellafield Limited is committed to the acceleration of the decommissioning of its highest hazard legacy plants. To do that it is necessary to retrieve and process radioactive waste sludges in a safe and efficient manner.	~£600k (closed)
Decommissioning	Costain Create Technologies Limited	D:EEP : Estimating Entrained Products	Dealing with nuclear legacy is expensive. A universal challenge found at many nuclear facilities is that associated with the management of entrained radioactivity within the walls of nuclear waste storage facilities found on many nuclear sites.	~£400k (final claim)
Decommissioning	University of Cambridge Fiberstone Products Ltd	Feasibility study to develop DEnsification processing of a Ceramic MAtrix composite material for Nuclear waste containment (DECMAN)	The aim of this collaborative feasibility study is to investigate the potential of whether a metal matrix ceramic reinforced composite can be used to store low level nuclear waste.	~£130k (closed)
Decommissioning	UKAEA Oliver Crispin Robotics Ltd Viridian Consultants Ltd Create Technologies Ltd	REACH: the enabler for long-reach asset integrity inspection & nuclear decommissioning	Throughout the UK and global nuclear markets, there are numerous and substantial long-reach challenges in asset integrity and decommissioning sectors which require new & disruptive technology. REACH is developing an innovative solution for long-reach remote technologies	~£1.25M (live)

Area	*Participants*	*Project Title*	*Project Description*	*Grant Offered (Status)*
Decommissioning	Airbus Defence & Space Ltd Oliver Crispin Robotics Ltd	ASRND: Autonomous Scout Rover for Nuclear Decommissioning	This project will develop an autonomous scout rover system, for scanning and mapping of a nuclear environment as a part of decommissioning effort. The scout rover is an intelligent autonomous machine capable of conducting operations without human interaction.	~£200k (closed)
Spent Fuel Handling	Lancaster University Hybrid Instruments Limited	TRIBECA2 (TRItium detection By ElectroChemically Assisted radiometrics 2)	Tritium (T) is a radioactive isotope of hydrogen made during routine operation of nuclear reactors. This can give rise to waterborne tritium (as tritiated water HTO) in, inter alia, spent fuel (SF) cooling ponds and SF processing & waste treatment facilities.	~£80k (complete)
Waste Management	Wood Group IS-Instruments Limited	Monitoring of Nuclear Waste Using Raman	The characterisation and monitoring of nuclear waste and the storage facilities (tanks, silos etc) in which they housed is critical both for the industry and wider society. Currently this process is conducted by visual inspections which is costly.	~£50k (complete)
Waste Management	Create Technologies Limited	Development of a Depth Measurement Technique for Entrained Radioactive Contamination by Createc	Dealing with nuclear waste is expensive. Decommissioning of obsolete storage area such as that currently underway at Sellafield or cleaning up after a nuclear incident such as Fukushima Dai-Ichi, generates a large quantity of concrete waste.	~£30k (closed)
Waste Management	Sellafield Limited Lucideon Limited	Development of high fluidity, high radiation tolerant, inorganic encapsulant for difficult to treat radioactive waste	Nuclear wastes are stored in several containers. It is proposed that such wastes may be stabilised simply by deploying a high fluidity inorganic suspension onto the wastes and allowing a low-temperature solidification to take place.	~£65k (closed)
Waste Management	TWI Ltd ImiTec Limited	Project INTEGRAL	Project INTEGRAL aims to combine two innovative technologies to make a prototype system that will make a step-change in the characterisation and size reduction of the UK's radioactive waste.	~£70k (closed)
Waste Management	GeoRoc Ltd	Large-scale hot-isostatic pressing of waste forms for the treatment of Magnox sludge and other wastes	The thermal treatment of radioactive wastes offers the opportunity to significantly reduce the waste volume and realise life-cycle cost savings. In this project GeoRoc Limited aims to demonstrate the use of Hot-isostatic pressing (HIPing) to treat Magnox	~£110k (closed)

Appendix 4 - Sellafield Ltd R&D Projects

Table 11 – List of R&D Projects Completed for Sellafield in 2017/18 (Ref. 10)

Area	*Company*	*Project*
Cross-cutting	Jacobs	Environmental monitoring and assessments beach monitoring tool
Cross-cutting	Saker Solutions Ltd.	Developing an agent-based evacuation modelling architecture
Cross-cutting	Sellafield	Geographic information system to produce a web-based master planning tactical land request tracker
Cross-cutting	Sellafield	Innovative method using a geographic information system to present master planning concepts
Cross-cutting	Sellafield	Machine learning and artificial intelligence
Decommissioning	Cavendish Nuclear	Non-destructive depth profiling development
Decommissioning	Cavendish Nuclear	Plant status monitoring using neutron detectors
Decommissioning	Costain	Non-destructive depth profiling development
Decommissioning	Createc	Non-destructive depth profiling development
Decommissioning	C-Tech Innovation Ltd.	Post operational clean-out IRT
Decommissioning	DBD Ltd	Management of oversized items in the Magnox Swarf Storage Silo
Decommissioning	Equivital™	Black Ghost - biometric vest
Decommissioning	Forth Engineering Ltd.	AVEXIS: a small submersible robotic family for the underwater exploration of facilities with restricted access
Decommissioning	Mirion Technologies	Measurement of hydrogen emission rates from skips of Magnox swarf storage silo
Decommissioning	Nichols Group	Management of oversized items in the Magnox Swarf Storage Silo
Decommissioning	ProNu-Dec Ltd.,	Post operational clean-out IRT
Decommissioning	REACT Engineering Ltd.	Management of oversized items in the Magnox Swarf Storage Silo
Decommissioning	ROVtech Solutions Ltd.	Variable buoyancy heavy lift remotely operated vehicle
Decommissioning	Saker Solutions Ltd.	First Generation Magnox Storage Pond planning tool
Decommissioning	Saker Solutions Ltd.	Magnox Swarf Storage Silo maintenance planning tool
Decommissioning	Saker Solutions Ltd.	Magnox Swarf Storage Silo stream distributed simulation
Decommissioning	Saker Solutions Ltd.	Silo Emptying Plant machine relocation tool
Decommissioning	Sellafield	Characterisation of excavated materials from areas of Sellafield site with low risk of radiological/chemical contamination
Decommissioning	Sellafield	Land quality knowledge management tools
Decommissioning	Sellafield	Legacy ponds underwater visibility improvement strategy
Decommissioning	Sellafield	Management of hydrogen during export of uranium bit bins from the First-Generation Magnox Storage Pond

Area	*Company*	*Project*
Decommissioning	TWI Ltd.	Glovebox and crate breakdown by laser cutting
Decommissioning	TWI Ltd.	Laser decontamination
Decommissioning	viZaar Industrial Imaging	Thorp pneumercator access tank inspection
Decommissioning	WeSubsea UK Ltd	Magnox Swarf Storage Silos third extension swarf flattening project
Decommissioning	Wood	Measurement of hydrogen emission rates from skips of Magnox swarf storage silo
Spent Fuel Handling	ENVINET GmbH	Real-time in-situ monitoring of 137Cs in the AGR Storage Pond using a SARA 137Cs probe
Waste Management	ABS Consulting	Condition monitoring and inspection IRT
Waste Management	AWE	Waste treatment, conditioning and packages IRT
Waste Management	Banah UK Ltd.	Waste treatment, conditioning and packages IRT
Waste Management	DBD Ltd.	Magnox Swarf Storage Silo 3m3 box project
Waste Management	Fauske Associates	Magnox Swarf Storage Silo 3m3 box project
Waste Management	Galson Sciences Ltd	Waste treatment, conditioning and packages IRT
Waste Management	Interface Analysis Centre	Proof-of-concept trials for in-situ testing of filter performance on Sellafield Self-Shielded Boxes
Waste Management	James Fisher Nuclear Ltd.	Condition monitoring and inspection IRT
Waste Management	KUKA Systems (UK) Ltd	Box Encapsulation Plant waste handing robots
Waste Management	NDA	Waste treatment, conditioning and packages IRT
Waste Management	NSG Environmental Ltd	Condition monitoring and inspection IRT
Waste Management	NSG Environmental Ltd	Box Encapsulation Plant waste handing robots
Waste Management	RTL Materials Ltd	Condition monitoring and inspection IRT
Waste Management	RWM	Waste treatment, conditioning and packages IRT
Waste Management	Sellafield	Export Cell trials in support of the Self-Shielded Box project
Waste Management	Decommissioning Alliance*	First Generation Magnox Storage Pond skip disposal – active demonstrator
Waste Management	Decommissioning Alliance*	Handling and treating First Generation Magnox Storage Pond sludge
Waste Management	TÜV SÜD Nuclear Tech.	Box Encapsulation Plant waste handing robots
Waste Management	TÜV SÜD Nuclear Tech.	Waste treatment, conditioning and packages IRT

* The Decommissioning Alliance consists of Atkins Ltd., Jacobs UK Ltd., Westinghouse Electric Company UK Ltd.

Appendix 5 – Game Changers

Working in collaboration with Sellafield Ltd, the programme is inviting proposals for 'Game Changers' – new ideas and technologies which can reduce costs, reduce risk and make operations safer whilst accelerating the safe delivery of decommissioning. NNL and FIS360 Ltd are key delivery partners.

They are working with the Wood Group innovation fund, which has secured £1.5million of funding earlier this year and anticipate providing up to £250k for projects that have the potential to make nuclear decommissioning safer.

Game Changers support projects that are between Technology Readiness Levels (TRL) two to six, as shown in Figure 6. These stages cover projects from 'research to feasibility' and 'technology development' through to 'demonstration of the technology'. As of October 2018, there are around 80 funded projects currently in the 'research to feasibility' stage, having been funded with £5k grants. There are currently eleven projects that have obtained Proof Of Concept (POC) grants. The POC projects and information on who is involved in them is shown in Table 12.

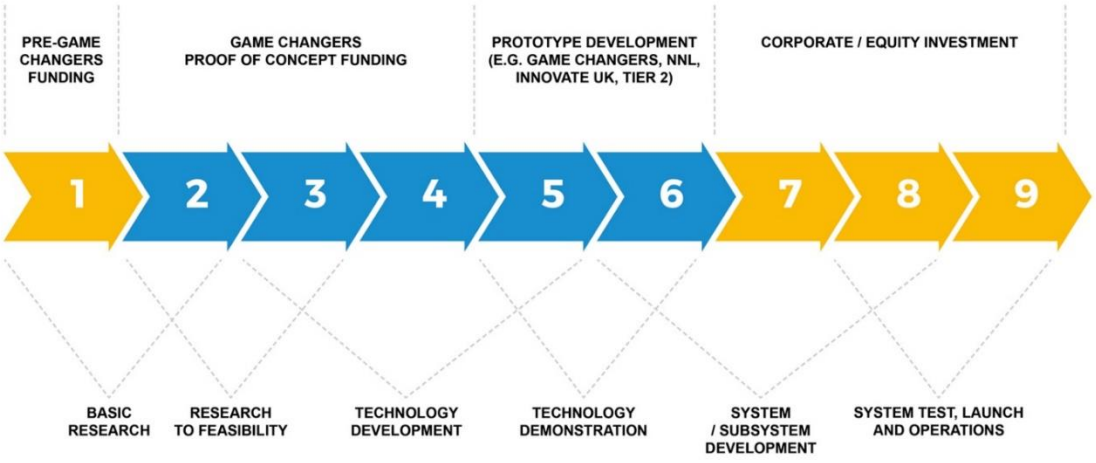

Figure 6 – Technology Readiness Levels for Game Changers
(https://www.gamechangers.technology/technology-readiness-levels/)

Table 12 - Game Changers Proof Of Concept Projects (Source: interview & online research)

Name of Project	*Organisation Involved*	*Fields for Potential Application*	*Additional Information*
Biomorphic sensors	Lancaster University's Engineering Department enablingMNT UK Ltd	Decommissioning	See Game Changers website for overview: https://www.gamechangers.technology/biomorphic-sensors-support-complex-nuclear-challenges/
Alpha Liquid in-situ Assay Systems	Parajito Scientific Corp.	Analytical Services / characterisation	[no additional information publicly available]
HyperSpectral Imaging (HSI)	University of Strathclyde	Condition Monitoring and Inspection	A type of real time, non-destructive chemical analysis which could be used for package inspection prior to storage to detect chemical contamination or corrosion.
Large Area Laser Gas Sensing	Fraunhofer	Condition Monitoring and Inspection	Stand-off detection, spectroscopy and identification.
Dexterous Remote Handling System	Oxford Technologies Limited	Analytical Services	See Game Changers website for overview: https://www.gamechangers.technology/oxford-technologies-drhcell-robotics/
Molten Metal Manipulation	Rawwater	Repair / remediation	Novel means of sealing cracks in pipework and civil structures http://www.moltenmetalmanipulation.com/
Immobilisation of wastes in ceramic materials	Cryoroc	Waste containers / encapsulation	Using freeze casting technology to immobilise Intermediate Level Waste (ILW) by reacting with ceramics to form a consolidated product. Benefits include significant volume reduction, higher waste incorporation rates, good resistance to solubility in water and it can be cast into any shape for convenient storage.
Active Fast Neutron Analysis for Fissile Materials	Hybrid Instrumentation	Analytical Services / characterisation	Real-time pulse-shape discrimination enables the measurement of both plutonium and uranium mass without the need for thermalisation, more rapidly and to competitive levels of accuracy. It removes the concern over 'accidental' events and removes the need for heavy / bulky quantities of moderator.
Fibre Reinforced Concrete (FRC) / MagnaDense	DaveyMarkham (inc. Amber Pre-cast) RWS (inc. Tarmac) LKAB	Waste containers	[no additional information publicly available]
3M3 Diffusion Bonded Solution	Heatric	Waste containers	[no additional information publicly available]
Stackable box configuration	Eadon Consulting Arc Energy GFSA	Waste containers	[no additional information publicly available]

Appendix 6 - DRP Project Examples

The NDA's Direct Research Portfolio (DRP) has facilitated the delivery of many R&D projects. See Ref. 22 for the latest status of ongoing DRP projects and DRP projects completed in 2018/19 Q1. Table 13 and Table 14 show examples of the DRP projects that are ongoing/complete for each of the active suppliers, the area that they relate to and the full contract value, for Lot B and Lot C respectively.

Table 13 – Examples of Lot B DRP Projects (from Ref. 22)

Area	*Lead Supplier*	*Project Title*	*Full Contract Value*
Decommissioning	Arup	Overview of International R&D Workstreams and Projects relevant to Integrated Waste Management and Site Decommissioning and Remediation and involve UK Collaboration.	~£100k
Decommissioning	CL:AIRE Ltd	Membership to CL:AIRE for NDA and its SLCs. CL:AIRE works with its Members to raise awareness and pursue shared objectives in land, water and environmental management by collecting strategic industry information and developing industry initiatives that improve efficiency and save money.	£3k/year
Decommissioning	Wood Group	Creation of guidance to SLCs to assist them in determining optimum end state associated with off-site structures.	~£100k
Waste Management	Eden Nuclear & Environment Limited	Informing the Development of a Strategic Approach for Alternative Encapsulation.	~£100k
Waste Management	Galson Sciences	Thermal Treatment of Low Level and Intermediate-Level Waste: Active Trials of Surrogate Waste Stream Vitrification.	~£3m
Waste Management	National Nuclear Laboratory	Active Demonstration of Geomelt In-container vitrification of contaminated soils.	~£150k
Waste Management	NSG Environmental	Identification and Implementation of Treatment Technologies for Ion Exchange Materials and others for Sludges, Oily sludges and Oily Wastes.	~£100k

Table 14 – Examples of Lot C DRP Projects (from Ref. 22)

Area	*Company*	*Project*	*Full Contract Value*
Spent Fuel Handling	National Nuclear Laboratory	Inactive Hot Isostatic Pressing Trials in support of Plutonium Disposition.	~£250k
Spent Fuel Handling	Wood Group	Radiation Induced Sensitisation (Modelling and Experimental).	~£400k