

Research and Development

5 Year Research and Development Plan 2014-2019

Issue 2

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1. Preface

The original 5 Year Research and Development plan was published in December 2013 and outlined our planned R&D activities for the period 2014 – 2019. Now that we're three years into that period, we have addressed some of the tasks that we originally planned, and revised some of our focus areas based on;

- Ongoing discussion with Site Licence Company (SLC) technical experts via the Nuclear Waste and Decommissioning Research Forum (NWDRF),
- Updates to SLC Technical Baselines and underpinning Research and Development (TBuRDs), and
- Current government policy.

So, to make sure this document continues to be useful and relevant over the period 2017-2019, we have updated the text to reflect the progress and revisions that have been made so far. Where we have made significant changes, we have added commentary to support those decisions.

2. Introduction

The UK's civil nuclear legacy represents the largest most important environmental restoration programme in Europe and is a major public liability. The Nuclear Decommissioning Authority (NDA) was set up to *'ensure that the UK's nuclear legacy sites are decommissioned and cleaned up safely, securely, cost-effectively and in ways that protect people and the environment'*, and its mission needs to be technically underpinned by sufficient and appropriate Research and Development (R&D) (Energy Act, 2004)¹.

The majority of this R&D is carried out across the NDA estate by SLCs, subsidiaries and their supply chains. The NDA also maintains two directly funded R&D programmes:

- a) A strategic R&D programme managed by the NDA's Strategy & Technology Directorate which includes the Direct Research Portfolio (DRP)
- b) An R&D programme managed by the NDA subsidiary Radioactive Waste Management Ltd (RWM) associated with implementing geological disposal

R&D is essential for successful delivery of the decommissioning mission. The NDA is a key funder of nuclear related R&D, primarily indirectly through NDA's SLCs. The total R&D spend varies each year depending upon the number and scale of R&D projects undertaken. In many cases the R&D is integrated within larger projects and R&D costs are estimated

¹ Energy Act 2004

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from total project costs. Requirements for SLCs to underpin their delivery programmes by R&D are outlined in EGG10².

This report provides an overview of the NDA's strategic R&D programme (a) out to 2019. The R&D programme can be broken down into five areas:

1. Direct Research Portfolio
2. Technical Innovation
3. International Collaboration
4. Radiation Epidemiology and Radiobiology Research
5. UK Inventory of Radioactive Waste and Materials

Details of the RWM R&D programme (b) can be found via the RWM section of the NDA website and are not included in this document.

² NDA (2014), Technical Baseline and Underpinning Research and Development Requirements, EGG10

3. NDA drivers to directly fund R&D

Under the Energy Act (2004) the NDA is required to promote and where necessary carry out research in relation to its primary function of decommissioning and clean-up of the UK nuclear legacy sites. Other related Energy Act requirements include sharing good practice, enabling innovation and developing skills. The R&D Strategy was reviewed in 2011³ and again in 2015-16, and the conclusion was that the majority of the R&D is technical underpinning work for site or fleet specific issues that needs to be carried out by the SLCs. R&D and technical underpinning are integral to the delivery of the SLC decommissioning plans and will be focussed on addressing their needs, risks and opportunities. In addition, it is believed that this approach is more likely to lead to successful implementation of the results gained through R&D.

The R&D Strategy states that where possible, R&D is undertaken by the SLCs, subsidiaries and their supply chain. Where necessary, the NDA will directly maintain a strategic R&D programme. From the Energy Act requirements and R&D Strategy, the NDA has identified the following drivers for its directly funded programme:

1. Inform Strategy

Under Energy Act (2004) obligations, the NDA must review and publish its Strategy at least every five years. It is essential that the strategy is technically underpinned. R&D is focused on two areas:

- i. *Develop Strategy* – This is research to underpin strategic options.
- ii. *Support Current Strategy* – This is research around risk mitigation, exploring the tolerance of an existing strategy to change or challenging existing assumptions that foreclose options.

2. Deliver Innovation

If a common R&D need, risk or opportunity is identified across multiple SLCs then it may be more effective and efficient for NDA to fund a project directly on behalf of its estate. This also minimises the potential for duplication of work. These projects fall under two areas:

- i. *Incremental Improvements to Multiple Sites' Lifetime Plans* – These projects are targeted at increasing efficiency and effectiveness within more than one SLC.
- ii. *Step Change to Multiple Sites' Lifetime Plans* – These projects seek to drive early innovation and look at the feasibility of a step change in the technology adopted by SLCs to deliver their lifetime plans.

³ NDA (2011), Research and Development – Approve Strategy (Gate C)

3. Maintain and Develop Skills

Where possible, R&D projects to maintain and develop skills are funded by the SLCs. Where there is an estate-wide need NDA may support R&D projects that maintain and develop skills. Wherever possible this will be delivered whilst informing strategy or delivering innovation. The R&D may fall within one of four categories:

- i. Estate-Wide Capability Gaps* – These are projects to maintain skills in a subject area that impacts on a number of SLCs.
- ii. Future Strategic Gaps* – These are projects to maintain skills in areas that will be required beyond an SLC's current contracted programme.
- iii. Knowledge Transfer and Resources* – These are projects that contribute to understanding and consistency of approach across the NDA estate.
- iv. Maintenance of the Intelligent Client Role within the NDA* – These are projects that enable NDA to act as a strategic body.

As part of day-to-day operations, the NDA monitors the wider UK nuclear landscape and considers changes in this arena with respect to its mission; as such, the R&D strategy remains flexible so that relevant changes can be accounted for.

4. Direct Research Portfolio (DRP)

The DRP is the main mechanism by which the NDA directly funds R&D. The DRP is delivered through framework contracts which are awarded, through a competitive process, to various consortia. The framework contracts span a period of 2 years, with the option to extend the contracts by two further 1 year periods (i.e. 2+1+1 years). Originally, the DRP was subdivided into 4 categories, or “Lots”, that aligned with the four NDA key strategic themes identified in NDA’s 2011 Strategy. The scope of the Lots is aligned with the NDA key strategic themes and have been updated for NDA Strategy 2016.

Up to end of FY 2015/16	From FY 2016/17 onwards
Lot 1: University Interactions	Lot A: University Interactions
Lot 2: Integrated Waste Management	Lot B: Integrated Waste Management & Site Decommissioning and Remediation
Lot 3: Site Restoration	
Lot 4: Spent Fuels & Nuclear Materials	Lot C: Spent Fuels & Nuclear Materials

This is to ensure consistency of approach and enable the full range of NDA’s R&D requirements to be met. The Integrated Waste Management & Site Decommissioning and Remediation strategic themes have been combined in recognition that the projects typically require contractors with the same capabilities. The University Interactions Lot is awarded to a single contractor in order to ensure co-ordination of our interactions with Universities across the NDA’s remit.

A standard mini-tender process using a defined scope and technical and commercial scoring criteria is used to select the preferred supplier for each work package⁴. This contractual mechanism provides:

- a good balance between ease of placing work, commercial competition and getting a good range of technically competent and cost-effective R&D proposals;
- an opportunity to develop relationships and capability within the supply chain; and
- a good range of suppliers to provide R&D expertise across the NDA mission (there are over 60 organisations involved including SMEs, universities and international organisations).

R&D proposals are developed in line with the three drivers (Inform Strategy, Deliver Innovation, Maintain and Develop Skills) and a variety of different approaches are used to refine the proposals. R&D proposals can be developed by NDA Strategic Authorities⁵ or with support from the Nuclear Waste and Decommissioning Research Forum (NWDRF), the

⁴ NDA (2016), Technology / Research Investment Process, EGPR04 Revision 7

⁵ Strategic Authorities are responsible for developing and maintaining NDA’s strategy in their Topic, acting as NDA’s Intelligent Customer and subject matter expert in that regard and articulating NDA’s strategic vision on their topic.

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NWDRF Working Groups, SLC or NDA subsidiary technical experts and the Theme Overview Groups (TOGs).

The DRP is managed within the NDA Strategy & Technology Directorate and is regularly reviewed to ensure that the portfolio is balanced across the key themes and that any synergies with other R&D programmes are identified. This oversight role also includes the publication of annual reviews of the DRP looking at the value and nature of the work placed and the status of the framework contracts. Regular updates of the ongoing portfolio are published on NDA's website.

DRP projects that focus on informing strategy are identified by the relevant NDA Strategic Authorities who are responsible for strategy within their specific area of accountability *e.g.* Site Decommissioning and Remediation, Integrated Waste Management and Spent Fuels and Nuclear Materials.

Through the DRP, the NDA also supports early technical innovation to address identified needs, risks or opportunities at multiple SLCs. These multi-site needs, risks and opportunities are identified through engagement with our SLCs (*e.g.* NWDRF and the associated Working Groups) or estate-wide analysis (*e.g.* analysis of SLC Technical Baseline and underpinning R&D (TBuRD) submissions). Individual projects are sponsored by the relevant NDA Strategic Authorities, typically with technical support from members of the relevant NWDRF Working Group.

Where there is an estate-wide need to maintain or develop key technical skills, the NDA may support relevant R&D projects that sustain and progress these skills. A specific DRP Framework Contract (Lot A: University Interactions) has been set up to deal with university interactions and is the main mechanism by which the DRP supports the maintenance and development of generic high-level skills relevant to nuclear decommissioning.

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Table 1: Current drivers for direct NDA sponsorship of R&D across the different Framework Contracts (the darker the blue colour the more important the driver)

Lot	A	B						C					
Theme	University Interactions	Integrated Waste Management & Site Decommissioning and Remediation			Site Decommissioning and Remediation			Spent Fuels			Nuclear Materials		
Underpinning Strategies		Radioactive Waste	Liquid and Gaseous Discharges	Non-radioactive Waste	Decommissioning	Land Quality	Site Interim and End States	Land Use	Magnox	Oxide	Exotics	Plutonium	Uranics
Inform Strategy													
Deliver Innovation													
Maintain & Develop Skills													

Table 1 has been updated since Issue 1 of the 5 year plan to reflect the changes to the R&D topics, account for the intent behind the work that has been performed over the last 3 years in each topic area, and in expectation of the work that is to be performed over the next 2 years.

4a. University Interactions (Lot A)

R&D Objective: To ensure there is relevant and sufficient academic technical capability available on the required timescales to facilitate delivery of the NDA mission.

R&D is a supplemental function for the NDA as specified in the Energy Act (2004). As such the NDA is required to promote and, where necessary, carry out research in relation to its primary function of decommissioning. The NDA also has an obligation within the Energy Act (2004) to ensure that there is a skilled workforce available to undertake the work of decommissioning. University R&D performs an important role in fulfilling the NDA's R&D obligations and delivering a skilled workforce.

The NDA's University R&D strategy is derived from two of its critical enabling strategies, R&D and People (including Skills and Capability). In order to successfully deliver its mission the NDA needs to ensure that its mission is technically underpinned by sufficient and appropriate R&D and that the NDA estate has the skills and capability to carry out the mission efficiently and effectively.

University R&D plays an important role in this delivery through:

- maintenance and/or development of key technical skills required to deliver the decommissioning plans;
- early-stage development of decommissioning technologies (*e.g.* technology at low technology readiness levels);
- informing the development of strategy and policy;
- advancement and transfer of knowledge with regard to decommissioning; and
- providing fundamental understanding of underpinning science and engineering of key processes or technologies deployed on the NDA sites.

The NDA University R&D strategy is that, where possible, SLCs (and their supply chain) influence and where necessary fund relevant University R&D programmes to support delivery of site plans. The NDA will look to influence relevant funding bodies (*e.g.* Research Councils) and where necessary provide direct funding for a strategic University R&D programme to support delivery of the NDA mission.

The NDA will ensure that its funded strategic University R&D is identified and prioritised to:

- address multi-site technical needs, risks and opportunities;
- support key strategic decisions; and
- support development of key technical skills and knowledge.

Delivery of the NDA funded strategic University R&D is via a single source competed framework contract.

Evaluation of University R&D outputs is an important step in the NDA's University R&D strategy as this is where the NDA assesses the impact that University R&D is having on its mission. The NDA will assess and demonstrate the impact of its funded strategic University

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R&D to key stakeholders using a structured approach, such as a Value Scorecard Framework and associated metrics.

The role of University R&D in successfully delivering the NDA's mission can only be realised if the R&D outputs reach its stakeholders, the wider research community and the supply chain. Therefore, the NDA believes that the results of University R&D should be available in the public domain through effective publication and dissemination, taking account of any commercial or security considerations.

The short-term targets of the University R&D strategy are to:

- review the SLC approach to University R&D to support delivery of their site plans;
- improve dissemination of the NDA funded strategic University R&D outputs to the SLCs and the supply chain.

There is strong stakeholder support for the NDA to maintain a strategic University R&D portfolio. A suite of high priority R&D topics suitable for University projects has been identified via the NWDRF and NDA will continue to work with the NWDRF Working Group on University Interactions to determine and share common University R&D needs, risks and opportunities and share good practice in engaging with universities across the NDA estate and with other interested organisations. The NDA works with Government and other stakeholders to steer and coordinate research towards decommissioning related activities.

The NDA works closely with the research councils and universities to encourage and leverage investment in University R&D relevant to the NDA mission with a target that it achieves at least matched funding for future University R&D programmes.

Key NDA Estate R&D Interactions

NWDRF and NWDRF Working Group: University Interactions

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Direct support of capability in targeted areas
 - Annual Bursary Call that aligns with the scope of the NWDRF Working Groups and Spent Fuels & Nuclear Materials Strategic Themes.
2. Direct support of industrial supervisors for NDA funded PhD projects
 - Developing knowledge exchange between NDA Estate and academia
3. Support the development and delivery of Research Council programmes
 - Centres for Doctoral Training (*e.g.* Next Generation Nuclear)
 - Managed calls (*e.g.* EPSRC funded DISTINCTIVE consortium)
 - iCASE awards
4. Support the development and delivery of nuclear decommissioning specific academic capability
 - Support to existing programmes where appropriate
 - Working with other interested parties to identify and support appropriate areas of academic technical capability

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5. Support the access to specialist facilities (*e.g.* facilities capable of handling radioactive materials) for academia to ensure the benefit of individual projects is maximised
6. Management of contracts with Universities
7. Monitoring the impact of the NDA's University R&D Strategy

4b. Integrated Waste Management (Lot B)

Two of the Integrated Waste Management (IWM) Lot topic headings have been modified from their previous designations of “Higher Activity Waste” and “Lower Activity Waste” to “Radioactive” and “Liquid and Gaseous Discharges” respectively. Whilst the content of the Key R&D Topics in each category remain largely unchanged, the new section headings better reflect the target areas of the underpinning strategies of the IWM theme. An additional topic of “Waste Retrievals” has been added to the Radioactive Waste area following a review of the IWM programme by the NDA Research Board.

Radioactive Waste

The NDA is committed to moving towards a single radioactive waste strategy for its estate that will need to demonstrate how it will support all relevant policies in the UK. Whilst this will not replace the use of existing waste categories, it will take into account the nature of the wastes, (radiological, chemical & physical properties) and the most appropriate waste management route while recognising the challenges posed by waste classification boundaries.

R&D Objectives: To support the NDA in its development and analysis of strategic options for radioactive waste management. To enable the NDA to act as an informed strategic body by sponsoring R&D activities that allow the NDA to respond to decisions on government policy and oversee SLC activities with regard to radioactive waste retrieval, treatment, storage and disposal. To support the development of innovative technologies for the retrieval, treatment, storage and disposal of radioactive waste.

Radioactive waste encompasses Higher Activity Wastes and Solid Low Level Wastes, (HAW & LLW).

HAW is High Level Waste (HLW), Intermediate Level Waste (ILW) and a relatively small amount of Low Level Waste (LLW) that is not suitable for disposal in the current LLW facilities. It arises from historical waste storage practices, management of spent nuclear fuel, decommissioning, research facilities and reactor operations. Long-term management within a Geological Disposal Facility (GDF) is the preferred approach for managing these wastes in England and Wales, supported by safe and secure storage arrangements and a programme of underpinning research. The Scottish Government has stated its policy is for the long-term management of HAW in near-surface facilities. The availability of a GDF is significant for site decommissioning and remediation schedules, although it should be noted that the strategy is supported by a programme of safe and secure interim storage that is capable of accommodating changes to the delivery timescale of the GDF. Alternative options for some HAW, such as near surface disposal for reactor decommissioning wastes is also being considered.

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The majority of UK LLW is generated by the nuclear industry, with the largest proportion arising at our sites. The Low Level Waste Repository (LLWR) is part of the NDA estate and a key asset for the management of LLW in the UK. NDA was tasked with producing a strategy⁶ for managing solid LLW from the UK nuclear industry, to establish treatment and disposal routes to:

- support past, present and future site decommissioning and remediation activities; and
- manage the operational LLW that continues to be created by the nuclear industry

In the five years since the publication of the strategy LLW Repository Ltd, on behalf of the NDA, have worked with a wide range of stakeholders, including the NDA, Regulators, LLW generators and the supply chain on its implementation. Significant improvements have been made to how LLW is managed, including:

- The establishment of a waste services framework by LLW Repository Ltd, enabling waste generators to access a range of alternative treatment and disposal facilities.
- The application of the waste hierarchy across the industry, resulting in the diversion of significant quantities of waste from disposal to the repository.
- The establishment of the LLW National Programme, enabling the implementation of the UK Solid LLW Strategy through the coordination of the implementing activities of NDA and non-NDA estate waste generators; the communication and sharing of best practice; the identification of opportunities for improvement; and the engagement of the wider stakeholder group within the process.

These changes have realised benefits to the UK nuclear industry as a whole and have resulted in the diversion of significant quantities of waste from disposal at LLWR.

Key NDA Estate R&D Interactions

LLWR, NWDRF and NWDRF Working Groups: Characterisation, Waste Packaging & Storage

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Application of the Waste Hierarchy
 - Development of technologies to improve the application of the Waste Hierarchy (e.g. waste characterisation technologies, sorting and segregation technologies, understanding technical barriers to material re-use)
2. Waste retrievals

⁶ UK Strategy for the Management of Solid Low Level Radioactive Waste from the Nuclear Industry

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- Review of available waste retrieval technologies that may be suitable for use within the nuclear industry.
- 3. Alternative waste treatment, with a particular focus on volume reduction
 - Understanding and, where appropriate, addressing the technical barriers to implementation of new thermal, mechanical and chemical treatment technologies across the NDA estate
 - Understanding and, where appropriate, addressing the technical barriers to implementation of mobile and/or modular treatment technologies
 - Technologies that may lead to better treatment of unique waste streams at an NDA estate-wide level (*e.g.* contaminated oils and solids)
- 4. Alternative encapsulants
 - Consolidate work and understanding on improving existing encapsulation technology (*e.g.* use of superplasticisers)
 - Understand options and technical barriers to implementation of alternative encapsulants (*e.g.* alternative cements or polymers)
- 5. Underpinning of interim storage
 - Material and design of package (*e.g.* improve fundamental knowledge of relevant underpinning science)
 - Store environments and their impact on long-term interim storage
 - Understanding the evolution of waste packages during long-term interim storage
 - Technologies for monitoring waste packages and stores
 - Technologies for remediating damaged ILW packages
- 6. Alternative disposal approaches
 - Understanding and, where appropriate, addressing the technical barriers to implementation of alternative disposal approaches (*e.g.* decay storage, near surface)

Liquid and Gaseous Discharges

R&D Objective: To enable the NDA to act as an informed strategic body by sponsoring R&D activities that allows the NDA to respond to decisions on government policy and oversee SLC activities with regard to liquid and gaseous discharges.

Liquid & gaseous discharges are generated by SLCs during operations and decommissioning. We require our SLCs to implement the UK Strategy for Radioactive Discharges⁷ and comply with relevant UK legal requirements. These requirements are driven by a number of principles including the use of Best Available Technique (BAT) in England

⁷ UK Strategy for Radioactive Discharges, July 2009

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and Wales and Best Practicable Environmental Option (BPEO) and Best Practicable Means (BPM) in Scotland.

Key NDA Estate R&D Interactions

LLWR, NWDRF and NWDRF Working Groups: Characterisation, Waste Packaging & Storage, Aqueous Effluents

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Alternative liquid and effluent treatment technologies
 - Understanding and, where appropriate, addressing the technical barriers to implementation of new liquid and effluent treatment technologies across the NDA estate (e.g. modular and mobile treatment technologies)

Non-Radioactive Waste

R&D Objective: To enable the NDA to act as an informed strategic body by sponsoring R&D activities that allow the NDA to respond to decisions on government policy and oversee SLC activities with regard to Non-Radioactive and Hazardous wastes.

NDA sites generate non-radioactive waste including demolition rubble, packaging, paper and food waste. Some non-radioactive waste from nuclear sites is hazardous, such as asbestos, process chemicals and oil. The nuclear industry's contribution to total UK waste volumes is very small compared to that of UK households and industry. The UK has a well-established, comprehensive and prescriptive regulatory regime for the management of waste. Waste management strategies have also been developed at UK, regional and local level by UK Government and Devolved Administrations, local and regional authorities. The NDA has collated the established practices and principles that underpin these strategies and they are being implemented across the NDA estate. There may be areas where greater co-operation between sites could yield benefits and there is an expectation for sites to work with other waste producers and local authorities to engage with local waste management planning activities.

Key NDA Estate R&D Interactions

NWDRF and NWDRF Working Groups: Characterisation, Waste Packaging & Storage

Key DRP R&D Topics (FY2016-17 to FY2018-19)

None currently identified – Technology improvements are likely to be driven by multi-sector needs and commercial opportunities. The situation will continue to be monitored by NDA via its industry groups.

4c. Site Decommissioning & Remediation (Lot B)

Site Decommissioning and Remediation, including decommissioning and land remediation, is the NDA's driving strategic theme and all other strategic themes support or enable its delivery. We can only complete our decommissioning and remediation mission if we secure and integrate final management solutions for spent fuels and nuclear materials. Site decommissioning and remediation must take account of non-NDA liabilities located on our sites, such as those owned by the Ministry of Defence (MoD) or EDF Energy.

The decommissioning and remediation of the NDA sites presents a number of major challenges:

- Legacy plants in excess of 60 years old containing significant quantities of corroding radioactive material which represent our highest risk and some of our largest hazards;
- Infrastructure which has been deteriorating for several decades; and
- Ground and groundwater contamination resulting from a variety of past uses, including non-nuclear activities.

Decommissioning

R&D Objective: To technically underpin the development of the NDA's Decommissioning Strategy and enhance its delivery by SLCs.

The strategy remains to decommission our sites as soon as is reasonably practical, taking into account relevant factors such as lifecycle risks to people and the environment. Our preference is for continuous decommissioning except where there are clear benefits from deferring the work, for example to realise the benefits of radioactive decay or from earlier reuse of the facility.

Guidance is required to inform the assessment of options by SLCs, comprising key principles and a discussion of relevant factors as set out in our Value Framework.

Some of the approaches and techniques required to deliver the preferred decommissioning strategy are common to multiple sites and as such could be advanced through R&D funded via the DRP.

Key NDA Estate R&D Interactions

NWDRF and NWDRF Working Groups: Land Quality, Decommissioning and Characterisation

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Strategic approach to prioritisation of decommissioning and remediation activities
 - Influence of different factors such as using asset condition to determine decommissioning priority
2. Improved characterisation to support decommissioning
 - Improving the approach to in-situ characterisation
 - Improving characterisation technologies to increase the value of information obtained (e.g. improved accuracy, lower limit of detection)
 - Improved remote characterisation technologies
3. Improved decommissioning (e.g. decontamination, dismantling)
 - Improving the approach to decommissioning (e.g. pipeline decommissioning, pond decontamination)
 - Improving decommissioning technologies (e.g. laser cutting)
 - Improving remote decommissioning technologies (e.g. robotics)

The only significant change in the key Decommissioning R&D topics since the original version of the 5 year R&D plan is the omission of the “In-situ disposal of structures and waste” topic. Some aspects of this topic are covered by the Land Quality Management theme described below, and other elements were deemed more appropriate for inclusion in the NDA strategic funding portfolio, as opposed to the DRP.

Land Quality Management

R&D Objective: To technically underpin the development of the NDA’s Land Quality Strategy and enhance its delivery by SLCs.

Land quality management involves managing risks to people and the environment (including flora and fauna) from radioactive and non-radioactive contamination in ground and groundwater. The challenge is to demonstrate that risks are being managed appropriately and to prevent them from increasing. Also, the most appropriate way to manage large volumes of lightly contaminated material (which is around ten times greater than the LLW disposal capacity in the UK) needs to be determined as it represents a significant liability. The NDA’s Strategy is to employ early risk-based decision-making to ensuring remediation is proportional to the level of risk and evaluated on a case by case basis. The strategic issues are understood and identical to decommissioning:

- When do we remediate contamination (e.g. continuous or deferred to allow for natural attenuation)?
- When is in-situ management / disposal appropriate?

Many of the techniques and skills required to deliver the strategy already exist so the focus needs to be on improving these techniques where appropriate, as well as maintaining skills and collating and disseminating good practice.

Key NDA Estate R&D Interactions

Nuclear Industry Group for Land Quality (NIGLQ), NWDRF and NWDRF Working Groups: Land Quality, Decommissioning and Characterisation

Key DRP R&D Topics (FY2016-17 to FY2018-19)

Work in recent years has supported the technical underpinning of the land quality management strategy. Therefore, the focus of R&D over the next three years is to improve the tactical application of land quality management and to continue to facilitate knowledge dissemination. In collaboration with the NIGLQ the following R&D themes have been identified:

1. Addressing the barriers to on-site and in-situ disposal of waste (including for beneficial reuse) and the management of residual land contamination as part of final Site End States
2. Improving characterisation of ground and groundwater
 - Improving the approach to ground and groundwater characterisation to improve effectiveness and efficiency (e.g. new or improved application of existing technologies, development of new processes and procedures)
 - Improving characterisation technologies to increase the value of information obtained (e.g. improved accuracy, lower limit of detection)
 - Improving long-term and remote monitoring technologies for ground and groundwater
3. Assessing risk from land and groundwater contamination
 - Understanding the behaviour of contaminants associated with wastes (including sub-surface structures) and residual land contamination managed in situ
 - Improving data interpretation (including long-term monitoring data) to support assessment of ground and groundwater contamination (overlap with site interim and end states).
 - Defining human health exposure scenarios relative to generic land use (see Land Use section below)
4. Improving management and remediation technologies for ground and groundwater contamination (including the application of the Waste Hierarchy)

Several of the key Land Quality Management R&D topics have been modified in this issue of the 5yr R&D plan. The topics of “Improved treatment of land and groundwater” and “Improved application of the Waste Hierarchy” have been consolidated into topic No. 4 above. The specific subjects of “Deriving generic assessment criteria” and “Modelling of land and groundwater contamination” are topics that are being addressed at the Site Licence Company level, and thus do not currently need to be addressed by the DRP.

Site Interim and End States

R&D Objective: To technically underpin the development of the NDA's Site End States Strategy and enhance its delivery by SLCs.

The site end state describes the condition to which the site will be taken. The key to describing the condition of the site is deciding what is left behind (e.g. building, infrastructure, in situ disposals, on-site disposals and residual contamination) and how residual risks will be controlled from any hazards that are left behind (e.g. physical barriers and / or administrative controls). Site interim states are natural milestones and decision points on the way to achieving the site end state. The Site End State could range from removing the hazard entirely to leaving the hazard and controlling the risks to people and the environment.

Key NDA Estate R&D Interactions NWDRF

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Technically underpin approach to defining and optimising Interim and Site End States (for land, structures and infrastructure)
 - Influence of land use (e.g. development of generic exposure scenarios)
 - Influence of asset management (e.g. tools to support decision making)
 - Understand the appropriateness of when to implementation on-site or in-situ disposal of waste across the NDA estate
2. Technically underpin approach to controls of in situ waste disposals and residual contamination
 - Improving long-term and remote monitoring technologies for ground and groundwater (overlap with land quality management)
 - Identifying and improving technologies for long-term record management

The Site Interim and End States theme has been amended in this issue of 5yr R&D plan. The wording of some of the bullet points in key topic No. 1 has been modified to better address the specific issues at hand, and the "Value of different land uses" subject has been moved into the Land Use theme described below. Under topic No. 2, the "Influence of maintaining or revoking regulatory controls" has been transferred from the DRP remit to the NDA strategic funding portfolio. Topic numbers 3 and 4 from issue 1, "Translating site end states into restoration targets for decommissioning and remediation" and "Mechanisms for communicating Site End States and the preceding journey", have been followed up by individual SLCs where they were required, and so no longer require addressing by the DRP.

Land Use

R&D Objective: To technically underpin the development of the NDA's Land Use Strategy and enhance its delivery by SLCs.

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To support defining the site end state it is necessary to understand how a site can be used. There may also be opportunities for interim use(s) where decommissioning and remediation activities allow. Many things can affect how a site can be used; for example the location of the site or the proximity of environmentally designated sites. Understanding how a site can be used also supports identifying an approach to land quality management and the extent to which controls can be used to manage residual hazards.

Key NDA Estate R&D Interactions

Nuclear Industry Group for Land Quality (NIGLQ), NWDRF and NWDRF Working Groups: Land Quality and Decommissioning

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Technically underpin factors that influence land use
 - Understand the value of different land uses (e.g. monetary value, social value, environmental value)
 - Understand the physical attributes that make a site suitable for a particular land use

This topic incorporates some aspects that were previously acknowledged in other areas of the Site Decommissioning and Remediation theme but were considered better to address as a specific topic area, so as to allow greater focus on the development of the NDAs land use strategy.

4d. Spent Fuels (Lot C)

Magnox Spent Fuels

R&D Objective: To enable the NDA to act as an informed strategic body by sponsoring R&D activities which allow the NDA to set the Magnox Spent Fuel Strategy, to monitor its delivery by the SLC, and to respond appropriately to external factors.

The current UK strategy is to reprocess all spent Magnox fuel. However, in the event of sudden or gradual loss of reprocessing capability, there are a number of fallback options being considered. Options include interim dry storage (containerised and in-reactor) and extended wet storage at Sellafield. If reprocessing of some Magnox fuel is not technically or economically viable, work will be needed to support strategic decisions and options for its longer term management.

Key NDA Estate R&D Interactions

Sellafield Ltd, Magnox Ltd, RWM Ltd.

Key DRP R&D Topics (FY2016-17 to FY2021-22)

Further R&D will be commissioned depending upon the progress of the Magnox Operating Programme (MOP) and the condition of the relevant assets. Improved interim dry and wet storage will provide contingency against the current strategy.

1. Interim wet storage capability for Magnox
 - Improve and underpin mechanistic understanding of the behaviour of spent Magnox fuel under wet storage conditions,
 - Understand the basis of a technical and safety case for extended interim wet storage of spent Magnox fuel.
2. Options for long term management of spent Magnox fuel
 - Explore alternative options to wet storage for long term management of unprocessed spent Magnox fuel,
 - Establish options for disposal of spent Magnox fuel, including treatment if appropriate.

The second research topic area for spent Magnox fuel has been broadened somewhat since the first issue of the 5yr R&D plan in recognition that options other than drying may become feasible for any unprocessed residual material.

Oxide Spent Fuels

R&D Objective: To enable the NDA to act as an informed strategic body by sponsoring R&D activities which allow the NDA to set the Oxide Spent Fuel Strategy, to monitor its delivery by the SLC, and to respond appropriately to external factors. Key in this is ensuring

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that skills in spent fuel management are maintained in light of the long timescales for continued receipt and then storage of the spent AGR (Advanced Gas-cooled Reactor) fuel.

The strategy for Oxide Spent Fuels is to complete the reprocessing contracts and place the remaining AGR fuel, including any future arisings, into storage pending a decision to dispose to a GDF. In the event that reprocessing of some spent LWR oxide fuel is not technically or economically justified, work will be needed to support strategic decisions and options for its longer term management.

This strategy requires the safe and secure storage of spent AGR fuel for a long period prior to packaging for disposal. There are over 25 years of experience of storing AGR spent fuel and there is high confidence in the pond storage approach that Sellafield Ltd is now implementing. Storage of residual intact LWR fuels is sustainable for periods considerably in excess of those planned under the proposed wet storage conditions proposed for spent AGR fuel.

Future decisions are needed on whether to continue with the current storage arrangements, and when and how to prepare and package the fuel for disposal. These decisions will be influenced by such factors as the performance of fuel and storage facilities over the timescales pending availability of a GDF, and the disposal system requirements for fuel acceptance.

It is RWM Ltd's responsibility to undertake the research supporting the disposability of fuels and the performance of the disposal system.

Key NDA Estate R&D Interactions

Sellafield Ltd, RWM Ltd.

Key DRP R&D Topics (FY2016-17 to FY2021-22)

1. Options for improved wet storage
 - Explore novel technologies to improve monitoring of spent fuel to identify incipient conditions potentially affecting fuel integrity and trace fugitive radioactivity sources at very low levels.
 - Underpin confidence in selection of routine and contingency water treatment options as the spent fuel inventory is increased by ongoing pond receipts.
2. Potential strategic option to extend wet fuel storage beyond 25 years
 - Improve understanding of the impact of extended wet storage on fuel condition, notably of mechanisms and influential factors controlling corrosion rates during storage of AGR fuel,
 - Evaluate the potential for improved techniques to monitor condition of pond containment structures.

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3. Potential fuel drying and dry storage
 - Understand fuel drying characteristics and process options, including potential technical basis for dry storage of AGR, typically drying process options and achievable dryness levels,
 - Understand fuel behaviour in dry storage environments and options for short or extended dry storage periods.
4. Fuel storage strategy alignment with disposal
 - Develop spent fuel strategy alignment with emerging disposal concepts,
 - Modelling the impact of strategic options and operational changes on the oxide spent fuel strategy

The Oxide spent fuel R&D topics above include those from issue 1 of the 5 year R&D plan (albeit in a re-ordered fashion to better group relevant topics together), but have also been added to. The second bullet points noted in topics 1 and 2 reflect the understanding that the wet storage environment will be a significant factor in the development of a spent oxide fuel strategy and thus needs to be well defined and characterised to underpin strategy development.

Exotic Spent Fuels

R&D Objective: To enable the NDA to act as an informed strategic body by sponsoring R&D activities which allow the NDA to set the Spent Exotic Fuels Strategy, to monitor its delivery by the SLC, and to respond appropriately to external factors.

The NDA manages several hundred tonnes of non-standard fuels, commonly referred to as 'Exotics'. They are often fuels from prototype reactors or experimental fuels used to support the development of nuclear power in the UK. They include significant quantities fuel material from R&D programmes to examine irradiated fuels, and some irradiated metallic residues and ceramic spent fuel material unsuitable for reprocessing.

Where technically feasible and cost effective the way to manage these fuels is to treat them alongside bulk fuels. The strategy for some fuels is still under development. A number of options are possible and, for fuel which cannot be technically or economically reprocessed, may include packaging for interim storage pending disposal, conditioning or immobilisation for storage and/or disposal, as appropriate.

Although smaller in quantity than our bulk fuels they have diverse properties that cause management challenges. Future work will focus on technically underpinning options to consolidate these fuels and materials in storage and on developing options to manage them over the long-term including, where appropriate, conditioning them to enable future disposal.

Key NDA Estate R&D Interactions

Sellafield Ltd, DSRL.

Key DRP R&D Topics (FY2016-17 to FY2021-22)

1. Improved technical options for long term storage of exotic fuel materials.
 - Control of residual moisture and radiolytic product impacts on containment systems, including hydrogen capture or recombination,
 - Novel concepts to improve containment packages.
2. Improving our understanding of potential long term behaviours of additive materials and exotic fuel claddings under wet or dry storage conditions.
 - Cladding sensitisation and corrosion potential of very highly irradiated materials,
 - Potential behaviours of alloy or non-standard fuel claddings,
 - Behaviours of non-standard fuel composition or additives used in experimental fuels or fuel examination.
3. Identify functional requirements and candidate treatments to facilitate storage and disposal exotics fuel materials.
 - Drying of failed fuel and fuel residues,
 - Encapsulation, immobilisation or chemical process stabilisation of potentially reactive or mobile fuel material residues.

The R&D topics for Exotic spent fuels have been made somewhat more specific in this issue of the 5 year R&D plan, reflecting a more advanced understanding of the challenges and potential options for remediation. However, as the bulk fuels management options are likely to solve many of the Exotics fuels challenges, these topics will likely remain a lower priority for R&D.

4e. Nuclear Materials (Lot C)

Plutonium

R&D Objective: To support the NDA in its development and analysis of strategic options for the management of the UK's stockpile of separated plutonium. To enable the NDA to act as an informed strategic body by sponsoring R&D activities that allow the NDA to respond to government policy decisions and oversee SLC activities with regard to plutonium management.

The UK-owned stocks of civil, separated plutonium have arisen from the reprocessing of Magnox and AGR spent fuels. The current strategy for plutonium is safe and secure long-term storage. The NDA also holds stocks of civil plutonium from commercial reprocessing operations for overseas customers which have been undertaken primarily in Sellafield Ltd's Thermal Oxide Reprocessing Plant (THORP) and to a lesser extent at Magnox reprocessing and Dounreay.

R&D in this area continues to focus on the development and analysis of strategic options for the disposition of UK-owned plutonium but with a particular focus on the technical underpinning of the Government's preferred option of re-use of plutonium as Mixed Oxide (MOX) fuel. R&D is also funded to examine options for the immobilisation and subsequent disposal of plutonium - this covers both the plutonium which, for whatever reason, cannot be reused as MOX and also the entire UK-owned civil stockpile.

Key NDA Estate R&D Interactions

Sellafield Ltd, DSRL

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Understanding the suitability of the UK's plutonium inventory for re-use as MOX
 - Investigation of methods and strategies to enable the re-use of the vast majority of UK plutonium as MOX fuel
 - Demonstration that the vast majority of the stockpile can be converted into fuel qualified for use in new reactors
 - Approaches and strategies for MOX burning in modern reactors including core loadings and load factors
2. Immobilisation of plutonium
 - Development of immobilisation technologies for all types of plutonium including oxide powder, MOX manufacturing scraps and residues
3. Long-term storage of plutonium
 - Understanding the behaviour of plutonium in extended long-term storage including the behaviour of the plutonium and the storage package and compatibility with potential future management strategies.

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4. The disposability and disposal of relevant spent fuel and immobilised plutonium
 - o Establishing that the spent fuel and immobilised product generated from this programme can be disposed of.

Whilst the Pu R&D needs haven't changed over the last 3 years, the first two key R&D topics from issue 1 of the 5yr plan have been consolidated in recognition that "Understanding the suitability of the UK's plutonium inventory for re-use as MOX" and "Re-use of plutonium in modern reactors" require a similar R&D focus.

Uranics

R&D Objective: To support NDA in its development and analysis of strategic options for the management of the UK's uranics inventory. To enable NDA to act as an informed strategic body by sponsoring R&D activities that allow NDA to inform and respond to government policy decisions and oversee SLCs activities with regard to uranics management.

The NDA uranics inventory has largely arisen from the UK civil nuclear cycle research, development and operations over many decades. The current strategic approach is continued safe and secure storage pending the identification of opportunities for re-use (e.g. following sale). Some of the inventory requires processing into a suitable form for re-use. If no application for re-use can be found, some of the inventory may require conditioning to an appropriate form for disposal. The diverse nature of the inventory means there is no single preferred management option for all of it.

Key NDA Estate R&D Interactions

Sellafield Ltd, Springfields Fuels Ltd, Capenhurst Nuclear Services, RWM, INS.

Key DRP R&D Topics (FY2016-17 to FY2018-19)

1. Identification of ways to make re-use more attractive
2. Identification of alternative disposal methods and routes

The primary change to the uranics R&D topics is the deletion of the key topic "Identification of appropriate forms for disposal". This reflects the formation of a RWM Integrated Project Team on Depleted, Natural and Low-Enriched Uranium which will tackle that issue. The additional bodies listed under "Key Estate R&D Interactions" reflects the fact that re-use of uranics under the current strategic approach is primarily a market-driven activity as opposed to a technical R&D challenge.

5. Technical Innovation

R&D Objective: To support the supply chain in the development of innovative technologies relevant to the NDA's decommissioning mission.

Whilst the NDA supports innovation in the supply chain through the DRP, the NDA also engages the wider supply chain through open themed calls. Previously these open calls were managed directly by the NDA (Concepts Programme & Technology Demonstration Project), however recently the NDA has chosen to collaborate with the Innovate UK using their mechanisms for supporting supply chain innovation but with the NDA funding targeting projects aligned to its decommissioning mission. Innovate UK is the UK's innovation agency whose role is to stimulate innovation in order to accelerate economic growth. This collaboration benefits the NDA in a number of different ways:

- Increased funding for the nuclear supply chain through significant financial contribution to the call by Innovate UK and other collaborators – improves the attractiveness of the call to the supply chain;
- Significant leveraging of our investment from financial contribution by collaborators and industry – increases the amount of innovation that can be supported;
- Access to Innovate UK's capability in managing open innovation calls – improves the efficiency of programme delivery;
- Access to Innovate UK's wide network of innovation contacts in non-nuclear sectors – facilitates technology transfer from other sectors; and
- Access to Innovate UK's network of Monitoring Officers to support the monitoring of funded projects including reporting of project progress – improves the efficiency of programme delivery and increases overall programme impact.

Calls have taken place in 2012, 2014 and 2016 and have been co-funded by the NDA, Innovate UK, Department of Energy and Climate Change (DECC)⁸ and Engineering & Physical Sciences Research Council (EPSRC)⁹. Projects with a total value of over £50M were selected with £6.5M being provided by the NDA, a further £27M being provided by the other co-funders and the remainder being provided by the organisations involved in the actual projects. The calls supported projects in three areas:

- Feasibility Studies – single-company or collaborative R&D grant scheme that allows businesses the opportunity to test an innovative idea and its feasibility to be developed and eventually taken to market.
- Collaborative R&D (2012 and 2014 calls only) – encourages businesses and researchers to work together on innovative projects in strategically important areas of

⁸ DECC co-funded the 2012 and 2014 calls

⁹ EPSRC co-funded the 2012 call only

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science, engineering and technology – from which successful new products, processes and services can emerge, contributing to business and economic growth.

- Knowledge Transfer Partnerships (2012 call only) – helps UK businesses to improve competitiveness, productivity and performance by accessing the knowledge, technology and skills that are available within the UK’s world-class knowledge base (universities, colleges and research organisations), through the development of collaborative partnerships which stimulate innovation and can transform the participating organisations.

In future, NDA will look to continue to support Innovate UK calls related to decommissioning, and may also contract a third party to manage direct targeted innovation calls.

Key Technical Innovation Activities (FY2016-17 to FY2018-19)

1. Collaborating with Innovate UK and other co-funders in the delivery of existing and new calls
2. Reviewing the delivery of the collaboration
3. Promoting selected projects in order to raise their impact
4. Evaluating the effectiveness and efficiency of this approach with regard to supporting innovation in the nuclear decommissioning sector
5. Identifying opportunities from new technologies outside of the nuclear industry.

6. International Collaboration

R&D Objective: To share and gain access to good practice, decommissioning experience and innovative technologies from our relationships with relevant organisations in other countries.

The NDA's international collaborations are guided by its International Relations Strategy. The NDA will engage at a high level with the International Atomic Energy Agency (IAEA), the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA) and the European Commission on R&D issues. The NDA will also engage with counterpart organisations in other countries (e.g. CEA (France), Department of Energy (USA), Japan Atomic Energy Agency (Japan)) to provide access to international good practice related to the delivery of its decommissioning mission. This may involve the NDA taking part in or supporting supply chain involvement in relevant internationally coordinated R&D projects, working groups and other collaborative mechanisms. Where appropriate, the NDA will also participate in targeted international conferences or events as a means of gaining access to good practice, third party review of its activities and promoting UK decommissioning expertise.

Key International Collaboration Activities (FY2016-17 to FY2018-19)

1. Supporting UK membership of OECD/NEA with respect to decommissioning
2. Identifying opportunities for international collaboration
3. Attendance at selected international conferences or events

7. Radiation Epidemiology and Radiobiology Research

R&D Objective: To ensure that our radiation epidemiology and radiobiology assets are appropriately managed and that research relevant to our mission is carried out.

Significant epidemiological and radiobiological research involving nuclear industry workers was previously sponsored by parts of the UK nuclear industry (e.g. British Nuclear Fuels Ltd and United Kingdom Atomic Energy Authority). This work generated important research assets which are now owned by the NDA. The NDA have continued to manage these assets and support research in these areas as it has a potential impact on the safety, cost, management, delivery and public acceptability of the NDA's decommissioning mission.

The NDA's R&D has focused on two specific areas:

- Radiation Epidemiology – using exposure (primarily radiation dose) and health (primarily cancer registration and cause of death) information collected for a nuclear worker population with statistical analysis to study the patterns, causes, and effects of health and disease outcomes within that population.
- Radiobiology – using biological samples from nuclear workers, with dosimetry information and laboratory techniques, to directly study the action of radiation on biological systems.

Following stakeholder engagement in 2013 the NDA published in 2014 a Preferred Option paper that concluded that its preferred option is to develop a strategic relationship with Public Health England (PHE) with the long-term aim of restructuring the ownership and management of the assets.

Key Radiation Epidemiology and Radiobiology Research Activities (FY2016-17 to FY2018-19)

1. Appropriate management of our radiation epidemiology and radiobiology assets
2. Delivery of radiation epidemiology and radiobiology R&D projects that inform our strategy
3. Further development of a strategic relationship with PHE

8. UK Inventory of Radioactive Waste & Materials

R&D Objective: To drive improvements in the quality of inventory data and efficiency of data collection to enable strategic decisions to be taken.

The UK Radioactive Waste & Materials Inventory (the Inventory) is a detailed catalogue of radioactive wastes at UK nuclear sites. The Inventory contains information about radioactive wastes that exist now, radioactive wastes that will arise in future and radioactive materials. Full details about the Inventory are available from the UK inventory website.

The Inventory is produced every three years and is a snapshot of wastes and materials at a specific point in time, called the 'stock date'. The latest Inventory was compiled in 2013 (based on a stock date of 1st April 2013). A contractor has been appointed for compilation of the 2016 Inventory. Work will involve:

- development of project plan and approach;
- development of data collection tools;
- preparation of supporting material;
- agreement of baseline scenarios;
- collection and quality checks of inventory data;
- data analysis and reporting; and
- project review.

Inventory Data Management – The NDA is currently in the process of reviewing options for improving the management of waste data across the NDA estate. The objective of the work is to *ensure that a single, approved waste and materials inventory data set is available when required to enable DECC and the UK to meet relevant international reporting requirements, to enable the NDA to develop strategy and deliver its mission, and to provide sufficient, accessible information suitable for use by our key stakeholders, including waste producers and the general public.* Work is currently being undertaken to review of credible options, in order to select a preferred option for implementation.

Materials & Samples – The NDA is also considering options for the effective management of materials and samples that exist across the NDA site. Work is ongoing to develop an overarching strategy for the management of material and samples and to develop supporting frameworks to help with decision making processes (e.g. whether to dispose of samples or transfer them to appropriate third parties). Work will involve the review of existing data relating to materials and samples, identification and assessment of credible options for management and selection of preferred options for implementation.

Key Activities (FY2016-17 to FY2018-19)

1. Delivering the 2016 Inventory (e.g. answering technical queries)
2. Managing the National Inventory Forum

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3. Reviewing credible options for new approach to Inventory data collection and management
4. Improvements to management of materials and samples across the NDA estate
5. Delivering the 2019 UK Inventory

9. Summary

This report gives a high-level summary of the components of the NDA R&D programme and key activities / R&D topics for financial years 2016-17 to 2018-19. Progress of the NDA's R&D programme will be reported in the NDA's annual R&D report and through the NDA's website. If you have further questions, please contact the NDA's R&D team via research@nda.gov.uk.