NUCLEAR INNOVATION AND RESEARCH ADVISORY BOARD

NIRAB Annual Report 2015

NIRAB-88-3

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Foreword from the Chair

As expected 2015 was a crucial year for nuclear research and innovation as the Government carried out its Spending Review and set budgets for the next Parliament. To support this process NIRAB provided advice to Government on the investment needed to underpin delivery of the Nuclear Industrial Strategy, a key element of this advice is the NIRAB UK Nuclear Innovation and Research Programme Recommendations.

I was delighted when the Government allocated much needed funds to implement a new programme of ambitious nuclear research and innovation, based on advice given by NIRAB. This programme will address the growing skills gaps, prevent further loss and attract the brightest minds into the field of nuclear science and engineering. It will also deliver new laboratories to complement the UK's existing assets, providing a network of world-class national research facilities that can allow the UK to carry out internationally competitive research and development.

The Government's signalled investment in innovation supporting SMR technologies presents an opportunity for the UK to play a significant part in the ongoing worldwide development of SMRs. This will support the country's long-term energy policy and should be used to provide a stepping stone for the UK to develop its capability in the design and development of the next generation of nuclear power plants.

This investment demonstrates to industry that the Government understands the importance of the long-term future of nuclear power in the UK, giving confidence to the industry and providing opportunities for UK universities to carry out science and engineering at the highest level.

2015 has seen significant strides taken to secure overseas investment in the UK nuclear new build programmes and although we may not have maximised the opportunity for UK suppliers to deliver the initial units, the Government's investment in UK high end manufacturing skills and capability will provide opportunities for the UK to supply a greater proportion of future plants.

The challenge for 2016 now becomes delivering the ambitious new programme of innovation and research, coordinating with and maximising synergies across the publicly funded nuclear research landscape. It is critical for Government to maintain the work as an integrated programme and to put the correct governance and delivery mechanisms in place to ensure that the research objectives are successfully achieved.

Finally I'd like to thank all of those who have contributed towards the work of NIRAB over the last year in what may turn out to be a significant turning point for the UK nuclear industry.

Dame Sue Ion
NIRAB Chair

Executive Summary

This annual report provides a summary of the work undertaken by NIRAB in 2015. During its second year of operation the primary focus for NIRAB has been to review the nuclear research and innovation capability, portfolio and capacity in the UK and recommend where future activity is best directed to maximise benefit to our industrial and energy policies.

Current public sector research in the UK is predominantly in the waste management and decommissioning sector, commissioned by the Nuclear Decommissioning Authority estate to underpin its mission. This research should continue at no less than current funding levels.

Fundamental nuclear research is well served by our internationally renowned universities, with Research Councils providing essential programme and infrastructure funding to develop the scientists and engineers needed for the future. The UK has a world-class research facility base that continues to be enhanced through Government investment.

Innovate UK continues to stimulate the UK supply chain to develop new technologies and services that provide our smaller companies with the competitive edge needed to break into the domestic and global marketplace.

However to fully meet Government and industry's vision for the future as outlined in the Nuclear Industrial Strategy, we need to be more active in research into the next generation of reactor technologies that will be deployed globally. This includes gaining a stake in Small Modular Reactor development in the near term and playing a leading role in the development of advanced reactors in the longer term.

NIRAB has engaged widely with UK companies, universities and national laboratories and defined an initial five year programme of research and innovation tailored to address this mismatch between our ambition and current level of research activity. It encompasses the full fuel cycle and is designed to deliver the UK with the skills and capability to capitalise on future market opportunities. The research covers:

- **The UK's Strategic Toolkit:** Underpinning decisions on which emerging nuclear technologies are brought to market to give the best economic return for the UK
- **Future Fuels:** Making more efficient, safer fuels of the future
- **21st Century Nuclear Manufacture:** Advanced manufacturing and 'plug and play' modular build in nuclear factories of the future
- **Reactor Design:** Delivering the people, processes and tools to make the UK the partner of choice as the world designs SMRs and 4th generation nuclear power plants
- **Recycling Fuel for Future Reactors:** Cost effective technologies to deliver a secure and sustainable low carbon fuel supply.

The strategic direction of these programmes is intended to guide future departmental funding including Research Council and Innovate UK calls. There will also be synergies with NDA estate, fusion and defence programmes. Adopting a fully coordinated approach to direct research across Government will be required in future to maximise industrial impact whilst achieving value for money.

NIRAB delivered this advice to Government in 2015 and is delighted that the Chancellor of the Exchequer has acted to allocate funding for ambitious new research programmes. In the 2015 Autumn Statement it was announced that at least £250m will be invested over the next five years, aiming to revive the UK's nuclear expertise and position the UK as a global leader in innovative technologies. Government has also signalled its intent to be at the front of the global race to deploy SMRs in the 2020s. This support from Government is precisely what our industry needs, and a crucial next step will be for Government to express its aims for UK involvement in SMR development so that future research programmes can be defined appropriately and industry can align with a national strategy.

Given this exciting new prospect for the UK's research base, it will be vital that we approach implementation of the programmes in a strategic and coordinated way. Priority research needs to be identified and commissioned without delay, and adequate preparation needs to be carried out, especially with potential international collaborators. NIRAB outline some key principles for governance of new research programmes and for developing an international collaboration strategy, and are keen to work with Government in finalising these early in 2016.

Key Recommendations

NIRAB make the following key recommendations to Government Ministers, Departments and Agencies:

Recommendation 1: Existing nuclear R&D programmes funded by NDA, Innovate UK and RCUK should continue at no lower than current levels.

Recommendation 2: Government should develop and implement a comprehensive and coordinated international collaboration strategy for nuclear research and innovation to enable research to be implemented to the greatest effect.

Recommendation 3: Government should implement a transparent and effective mechanism to coordinate and, where necessary, direct, all publicly funded nuclear R&D activities in order to achieve the desired industrial impact and maximise value for money.

Recommendation 4: The programme of research outlined in this document should be commissioned by the Government over the next five years to ensure the UK can remain on track to deliver Nuclear Industrial Strategy 2020 objectives.

Recommendation 5: Government should commission high-priority research immediately to deliver the most urgent aspects of NIRAB's recommended 5 year programme.

Recommendation 6: NIRAB's research recommendations are used to help shape future calls for directed programmes or capital investment issued by Research Councils and Innovate UK.

Recommendation 7: Government should put in place the governance arrangements required to commission and integrate the new programme of research with a view to commissioning research early in 2016/17.

Recommendation 8: Government should make clear its aims for SMR development in the UK, ensuring that these are used in evaluating the SMR competition and setting the technical priorities for both SMR development and the scope of wider nuclear research and innovation programmes.

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1 Introduction

The Nuclear Innovation and Research Advisory Board (NIRAB) has completed its second year and continues to provide advice to Ministers, Government Departments and Agencies.

This document provides a summary of the work undertaken by NIRAB in 2015 in delivering its remit against the Terms of Reference[1], including:

- A review of the nuclear research and innovation capability, portfolio and capacity in the UK and an assessment of progress against the objectives set out in the Nuclear Industrial Strategy[2] (NIS) - (Section 2)
- Development of new specific research and innovation programmes in the UK underpinning priority policies including energy policy and industrial policy - (Section 3)
- Recommendations for implementing future research programmes and fostering greater cooperation and coordination across the whole of the UK's nuclear research and innovation capability, portfolio and capacity - (Section 4).

All appointments to NIRAB are unfunded with the exception of the Chair, who receives the standard Government rate for committee chairs and reimbursement of travel expenses. NIRAB does not control a budget and it is therefore not necessary for this document to report any accounts or provide financial statements.

1.1 NIRAB Meetings

NIRAB met four times during 2015 in January, March, June and October. The minutes are available on the NIRAB website (www.NIRAB.org.uk).

2 Review of the UK Nuclear Research and Innovation Landscape

2.1 Background

The UK's Nuclear Industrial Strategy[2] published in March 2013 is the latest policy statement for the nuclear sector. NIRAB has been tasked by Government with overseeing a regular review of the nuclear research and innovation capability, portfolio and capacity in the UK and in doing so assessing progress against the objectives set out in the NIS.

During 2015, NIRAB has reviewed the milestones and objectives set out in the NIS with the aim of understanding where progress has been made and where further R&D and innovation is needed for the objectives to be realised. This section provides a summary of that review, with section 3 summarising the subsequent recommendations for new research and innovation programmes made by NIRAB to underpin Government energy and industrial policies.

2.2 Progress against NIS Research Objectives

The NIS sets out the following research and innovation objectives:

- To have the right level of nuclear innovation and R&D to ensure near-term as well as long-term commercial success in domestic and global markets
- For the research base to be underpinned by world-leading facilities which are fully utilised by both national and international customers and which conduct a programme of fission-related research whose scale is consistent with the UK's nuclear aspirations
- To be a respected partner contributing significantly to appropriate international research programmes undertaken with selected international collaborators
- To have a joined up approach to nuclear R&D across government, industry and academia, which serves to benefit the UK economy and ensure security of supply.

Each of these is reviewed in turn as follows.

2.2.1 Level of Nuclear Fission Research and Innovation

In reviewing this objective, NIRAB has collated information on public and private R&D investment across the sector since publication of the NIS in March 2013. In summary investment in civil nuclear R&D in the UK has occurred through:

- Capital investment by BIS, DECC and the Research Councils in building a world-class research facility base in the UK (approximately £60m in total since March 2013)
- Continued programme spend across the NDA estate to support the decommissioning mission and geological disposal of the order of £90-100m per year
- Continued investment in academic research through the Research Councils Energy Programme, typically around £12m per year

- Innovate UK supply chain development competitions totalling approximately £30m
- Industry investment in R&D (approximately £40m per year), predominantly in support of ongoing operations and life extension of current reactors
- A series of studies commissioned by DECC, BIS, Innovate UK and ETI into the feasibility of the UK being involved with the design of and deploying SMRs in the UK and overseas. The studies have included technical, economic and siting assessments.

Specific highlights include:

DECC Funded Research

- £12.5m in March 2013 for the UK to join the Jules Horowitz Research Reactor programme
- £1.5m in December 2013 for a research programme in future nuclear reactor technologies, fuel and fuel cycles, delivered by a consortium of organisations coordinated by NNL
- £4.5m in 2015 for a techno-economic assessment of SMRs
- A total of £7m invested in 2015 in new nuclear research infrastructure, comprising:

  Accident Tolerant Fuel Facilities - A £1.5m capital grant awarded to NNL in conjunction with a £1m grant to the University of Manchester to deliver a suite of equipment to support research into accident tolerant fuel and accident tolerant fuel cladding.

  High Temperature Materials Testing Facilities - A £2m capital grant was awarded to a consortium led by AMEC Foster Wheeler to deliver a high temperature environmental testing suite for advanced Gen-IV reactor materials performance.

  Advanced Recycling and Waste Management Facilities - £2.5m capital grant for a network of facilities to support advanced recycle and waste management research. This comprises the following three facilities:

  - Materials for Innovative Dispositions from Advanced Separations (MIDAS) Facility at the University of Sheffield (see box below).
  - U/Th/beta-Gamma Active process chemistry R&D facilities (UTGARD) Laboratory at the University of Lancaster to support fundamental and application driven research of recycle and waste management technologies, including scale up to industrial application.
  - Pyrochemical Reprocessing Laboratory at Edinburgh University to establish and demonstrate integrated pyrochemical reprocessing of fuel using fuel-relevant compositional mixtures at laboratory scale.

MIDAS Laboratory - In 2015 investment from the University of Sheffield in conjunction with a grant from DECC was used to establish the state of the art MIDAS laboratory to support world leading research in the management and disposal of radioactive wastes from the nuclear fuel cycle.

The MIDAS lab has been established as a national user facility and is part of a network of facilities required to enable the UK to deliver internationally competitive R&D in nuclear waste management.

The facility is operated as an open facility, available for use by academic, public and private sector organisations and is staffed by an experienced team of researchers who provide advice and guidance on utilising the equipment.

BIS Funded Research

- £5.5m in December 2013 towards the costs of commissioning the **High Active, Phase 3 facilities at the NNL Central Laboratory**.
- £8m in December 2013 to establish a **Nuclear Fuel Centre of Excellence**, providing shared equipment across the UK nuclear energy community, located in facilities run by NNL and the University of Manchester.
- £7.8m investment announced in 2014 by BIS and the Oxford Local Enterprise Partnership, match funded by industry for the **Remote Applications in Challenging Environment (RACE)** Research Centre (see box below).

RACE Research Centre - 2015 saw the completion of the RACE research centre based at the UKAEA's Culham site.

The centre will be involved in exploring many areas of remote operations including inspection, maintenance and decommissioning and will be instrumental in developing new remote tools and techniques with academia and industry. RACE occupies a dedicated new building at the Culham Science Centre which opened in Q1 2016.

The Research Councils currently fund £10-15m of nuclear projects annually as part of the EPSRC led RCUK Energy Programme. Some of the main nuclear energy research the EPSRC has recently funded is given below.

Nuclear Centres for Doctoral Training

The EPSRC support two Centres for Doctoral Training (CDT) in nuclear engineering along with contributions from partner organisations. The aim of the CDTs is to develop future subject matter experts and technical leaders to support the UK's strategic nuclear programmes across the fuel cycle, including nuclear new build and decommissioning. The two CDTs are:

Next Generation Nuclear - based at the University of Manchester and operating in partnership with the Universities of Lancaster, Leeds, Liverpool and Sheffield, and with a number of industrial and regulatory bodies including AMEC-Foster Wheeler, Areva, AWE, EDF Energy, NDA, NNL, Rolls-Royce and Sellafield Ltd. The CDT will train up to 24 PhD students per year with the first cohort of students having started in September 2014.

Nuclear Energy - based at Imperial College London operating in partnership with the University of Cambridge and the Open University. The CDT will train 62 PhD students in five cohorts and involves a one year Masters in Nuclear Engineering at Imperial followed by three years of PhD study at any one of the partner Universities. In addition to the EPSRC funding CDT students are sponsored by industry and international partners including; AWE, EDF Energy, Hitachi, Rolls-Royce and Westinghouse. The first cohort has now graduated from the Masters component and are beginning their PhD studies.

New Nuclear Manufacturing (NNUMAN)

NNUMAN is a major programme delivering new long-term research into innovative manufacturing techniques for the future needs of the UK nuclear industry. The programme focuses on early-stage research into a range of manufacturing technologies.

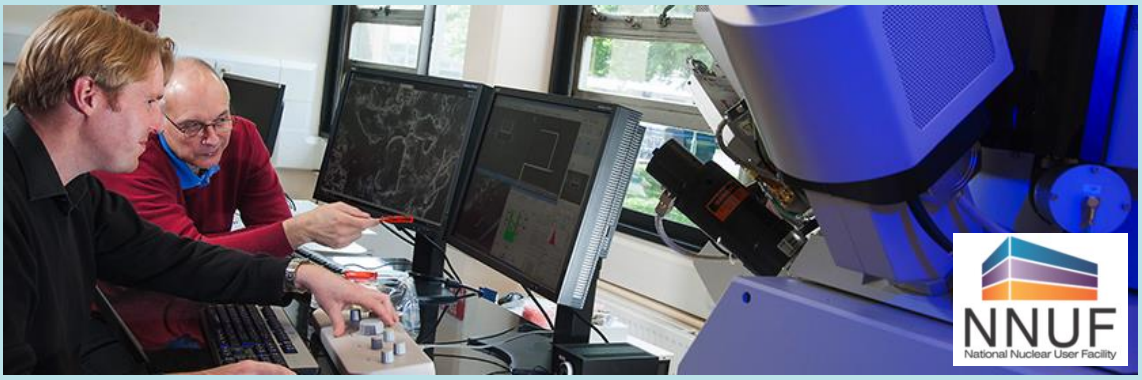
The programme, managed by the Dalton Nuclear Institute at The University of Manchester and supported by the NAMRC at the University of Sheffield, has £4m funding from EPSRC, with the two universities committing a further £4m, and further financial and in-kind support coming from industry. The current round of NNUMAN funding is due to complete in 2017.

Decommissioning, Immobilisation and Storage Solutions for Nuclear Waste Inventories (DISTINCTIVE).

The £5m DISTINCTIVE programme coordinates the EPSRC supported research in decommissioning and waste disposal, undertaking world leading fundamental scientific research to address the decommissioning and waste disposal challenges that the UK faces. The programme is supported by additional funding from NDA, Sellafield Ltd and NNL. This research is due to complete in the last quarter of 2017.

National Nuclear User Facility (NNUF)

The NNUF is a multi-site facility that provides academia and industry with access to internationally leading experimental equipment for nuclear research on radioactive materials at levels greater than can be handled in university laboratories. The EPSRC in collaboration with DECC and BIS has provided £16m of funding for the purchase of a range of equipment that is centred at NNL's Central Laboratory, the Culham Centre for Fusion Energy (CCFE) (see box below), the University of Manchester's Dalton Cumbrian Facility and the Advanced Digital Radiometric Instrumentation for Applied Nuclear Activities (ADRIANA) facility for nuclear instrumentation at the Universities of Lancaster and Liverpool, and CCFE.



Materials Research Facility - The Materials Research Facility has been established to analyse material properties in support of both fission and fusion research. It is part of the National Nuclear User Facility initiative, funded by EPSRC and has recently moved to purpose built facility at Culham.

The MRF provides academic and industry users with a unique resource for micro-characterisation of materials. It bridges the gap between the university or industrial laboratory and large facilities at nuclear licensed sites, with affordable, convenient lab access. With hot cells for processing and micro-characterisation of neutron-irradiated samples, it has the capacity to cut, polish and encapsulate individual samples up to the Tera-Becquerel level for analysis either on-site or back at the user's institute.

The facility supports research in lifetime extension for today's power stations, nuclear new build, Generation IV and fusion.

Innovate UK funded research

Innovate UK has funded a number of nuclear related development programmes each year focusing on exploiting innovation in the UK supply chain, particularly in SMEs. Funding announced since publication of the NIS includes:

- £13m for a nuclear supply chain development competition in March 2014, co-funded by DECC and NDA
- £3m from 2015-18 for two nuclear projects as part of the Energy Catalyst Round 1
- SMR feasibility study in 2014, co funded by BIS, DECC and industry, and delivered by a consortium led by NNL.

Current research activity

Civil nuclear R&D expenditure in the UK across the public and private sector for the 2014/15 financial year is approximately £150m. A breakdown is given by funder in Figure 1 and by sector in in Figure 2[3,4].

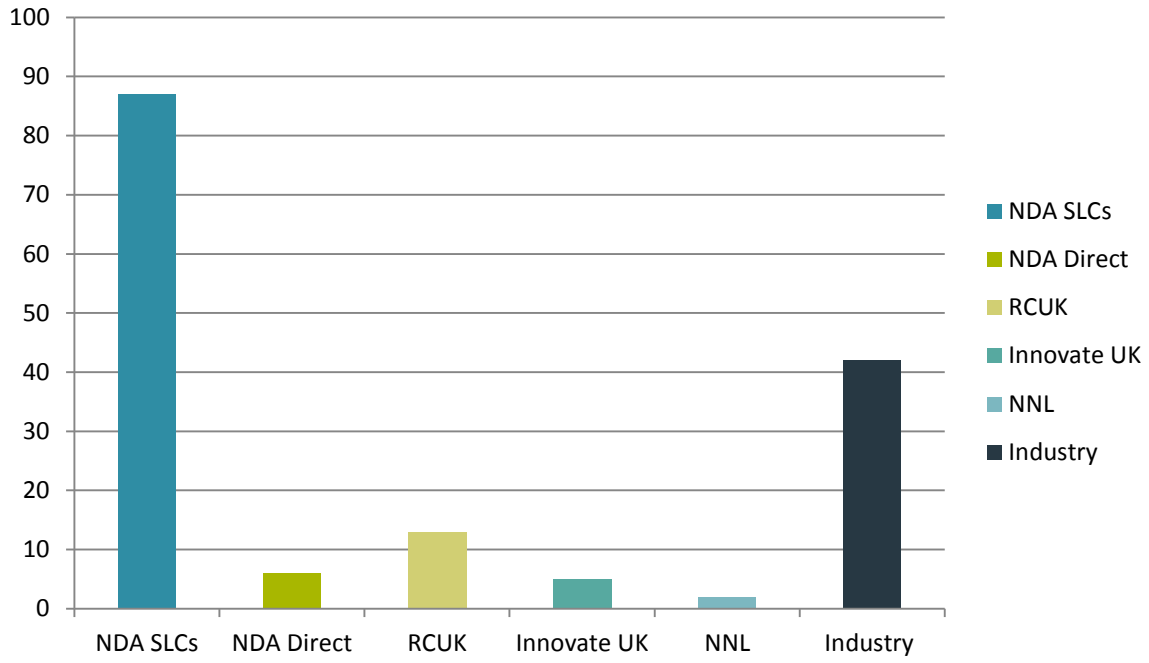


Figure 1 2014/15 UK nuclear R&D funding

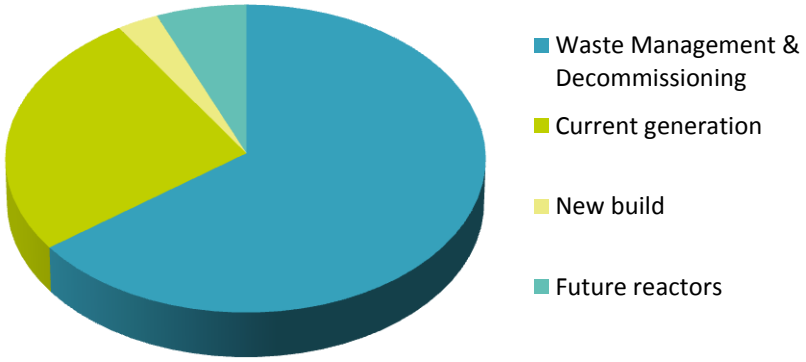


Figure 2 Indicative 2014/15 UK nuclear R&D funding by area of the sector

During 2015, NIRAB carried a review of publicly funded nuclear R&D[10]. In part this review was carried out to determine whether any of the funding could be redirected to address gaps in the current funding landscape. Figure 2 shows that public nuclear R&D funding is dominated by research carried out by the NDA estate and in particular by Sellafield Ltd. The vast majority of R&D expenditure across the NDA estate is needs driven and funds the late stage development of technologies that have already been selected for deployment on decommissioning projects[5]. In addition NDA funds a strategic portfolio focussing on estate-wide R&D to inform strategy, deliver innovation and maintain technical skills (around £6m per year)[6,7]. It was concluded that R&D expenditure across the NDA estate is running at the minimum levels required to support the NDA's decommissioning mission and mitigate the

key risks associated with that mission. No opportunity was identified to make significant savings within the NDA R&D budget or to redirect funds to better support the R&D programme recommended by NIRAB.

An examination of Research Council funded nuclear R&D concluded that the majority of current projects align with either the NDA mission or the research needs identified by NIRAB despite the fact that most grants were let prior to the establishment of NIRAB.

Recommendation 1

Existing nuclear R&D programmes funded by NDA, Innovate UK and RCUK should continue at no lower than current levels.

Research related to current generating reactors is predominantly funded by industry and is focussed on lifetime extension.

The amount of UK funded research into the proposed Generation III+ new build reactors is low as the research needs are low – the bulk of the costs will be borne by overseas investors in constructing and deploying the proposed new reactors and not in R&D. UK spend in this area is related to developing UK capabilities through academic research and Innovate UK supply chain development.

A key gap in UK research activity remains in relation to research into future nuclear reactor technologies, including SMRs, and their associated fuel cycles. This gap is mentioned in the NIS and will be crucial in sustaining nuclear skills and facilitating a significant expansion of nuclear energy in the UK by 2050.

There has been insufficient progress in addressing this area since publication of the NIS. Research is happening in universities at the lower Technology Readiness Levels and this should continue. This is in addition to one off capital infrastructure projects funded by BIS and DECC, and evidence gathering for the potential of SMRs through a series of techno-economic assessments (see below). However there is a market failure preventing industrial organisations from investing in research into next generation nuclear technologies. Upfront development costs and timescales for commercial returns are too great for commercial organisations to be able to justify investment to shareholders. Nuclear research globally is characterised by state backed programmes and international collaborations for this very reason, and which is why UK Government funding is needed to progress research in new technologies to a point where industry will take over.

Section 3 outlines the areas of research NIRAB recommend are necessary to plug this gap in UK nuclear research activity.

Small Modular Reactors

In December 2014 a consortium led by NNL published a report[8] which concluded that:

- There is a very significant market for SMRs where they fulfil a market need that cannot, in all circumstances, be met by large nuclear plants
- Current estimates suggest that the overnight capital cost of SMRs is broadly in line with current market estimates for First Of A Kind (FOAK) large scale nuclear projects in the UK, with the potential for being comparable with Next Of A Kind (NOAK) costs for large nuclear projects in the UK

- There is an opportunity for the UK to regain technology leadership in the ownership and development of low-carbon generation and secure energy supplies through investment in SMRs by partnering with an existing vendor to complete the detailed design and secure IP. The greatest opportunity may be associated with IP relating to manufacturing and modular construction.

2015 has seen a further increase in interest in the UK and globally regarding SMR development. During 2015 DECC commissioned a techno-economic assessment with the aim of establishing a robust evidence base to inform a potential policy decision on SMR development or deployment. In addition, a recent study published by the Energy Technologies Institute[9] has shown that SMRs could be constructed on a wider range of sites than those suitable for large reactors, thus giving the potential for SMR deployment to increase the maximum contribution that nuclear power could make to the grid.

2.2.2 World-leading Research Facilities

There has been good progress against delivering this NIS objective with welcome capital investment by BIS, DECC and the Research Councils totalling approximately £60m since March 2013. Figure 3 illustrates the breadth of new world class facilities in the UK, which have added to an already significant research infrastructure in UK national laboratories, industry and universities.

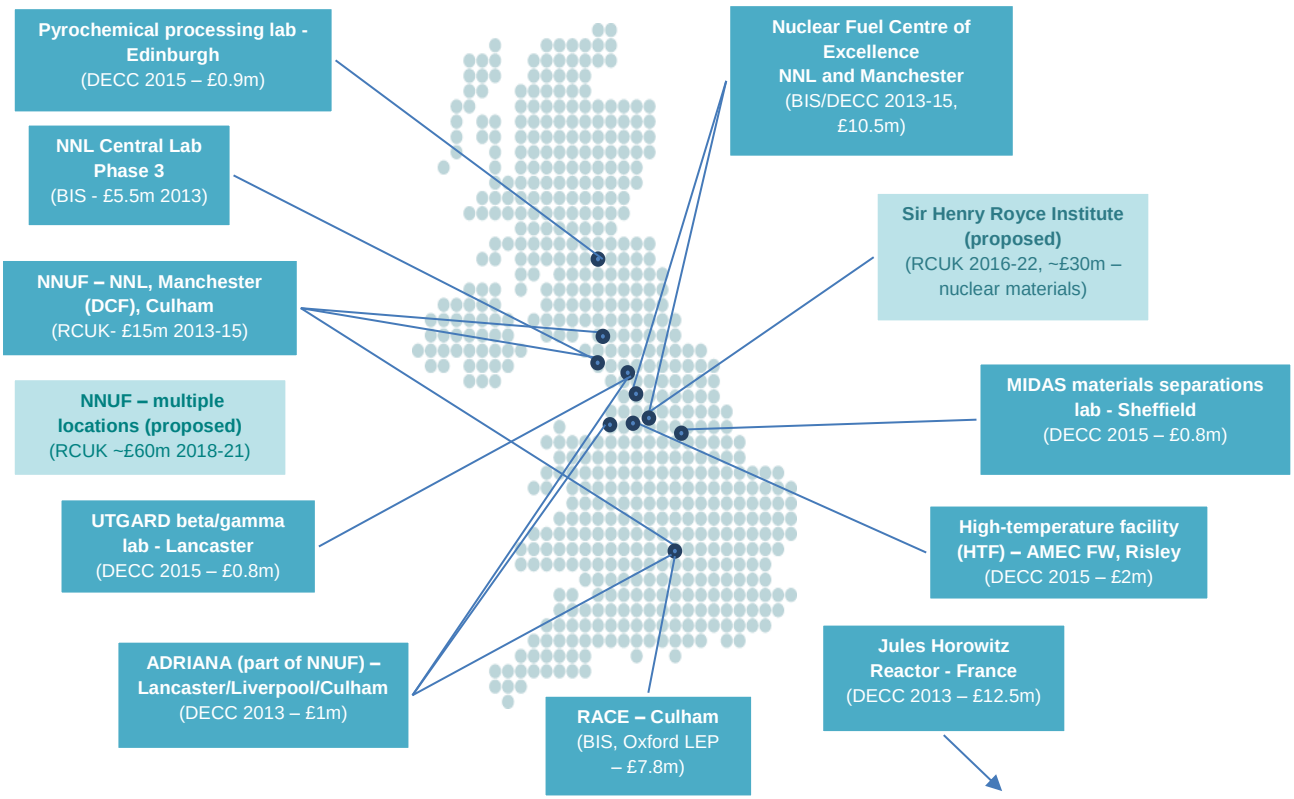


Figure 3 Map of UK research facilities where Government has invested since 2013

2.2.3 UK Involvement in International Research

The NIS places a strong emphasis on international engagement, including research collaboration. Collaboration with other nations offers an affordable route for developing nuclear technologies such as new reactor designs, due to the substantial investment required by such programmes. In addition few nations have retained the technical capability to deliver an entire nuclear development as the drive to sustain a wholly indigenous nuclear industry has diminished.

There are a number of benefits associated with international collaboration including:

- Gaining access to international best practice to challenge and benchmark the UK's research capability
- Gaining access to technologies and facilities for the UK to meet its research objectives, in particular research reactors and irradiation facilities
- Sharing the cost of nuclear R&D and achieves intellectual gearing
- Taking opportunities to test technologies in different countries, increasing the UK's technical maturity and shortening development timescales
- Improving access for UK industry to overseas markets
- Understanding political and legislative developments.

The UK has a long history of international collaboration on major nuclear research and development projects and continues to forge new relationships and agreements each year,

for example the recently announced Joint Research and Innovation Centre to be formed with China.

Existing collaborations include the projects recently funded by EPSRC and NDA with the Republic of Korea, India and Japan, alongside the longer term strategic collaborations with the US and the European EURATOM framework. Radioactive Waste Management in particular is actively involved in international research programmes on waste disposal.

However, the current level of UK activity is not sufficient to place the UK at the top table of nuclear nations, with the exception of the waste management and decommissioning arena and so increasing the UK's international profile related to future reactor development is crucial. The recommended programme of research outlined in section 3 would enable the UK to enter into major international initiatives, including resuming active participation in the Generation IV Forum.

There are several other parties currently interested in engaging with the UK research base, and great care will be needed when entering into new international collaboration agreements. Complex geopolitical issues may mean that some collaboration opportunities will be mutually incompatible. There is an urgent need to develop an overarching strategy and set of principles for establishing new research collaborations. This should be done in a structured manner and account for both proactive and reactive interactions with overseas agencies and tie in with existing UK nuclear R&D international collaborations.

Key outputs from this strategy would include determining the technical areas in which the UK needs to collaborate and identifying the countries on which the collaboration should focus. This will allow the implementation of the R&D programme to be tailored to facilitate collaboration and for the necessary agreements and delivery mechanisms to be put in place.

International collaboration can be categorised in two ways; firstly developing significant future technologies, such as advanced reactors, in which case collaboration must be with established nuclear nations running large nuclear R&D programmes such as the USA, China, France and Japan. Secondly, advancing science diplomacy may be undertaken with a wider range of established and emerging nuclear nations based on the provision of services, rather than research collaborations.

International research collaboration can be challenging to administer and can carry a substantial financial overhead, but can be very rewarding. NIRAB recommend that the UK should focus on a small number of strategic partners whose capability and long-term challenges and technical direction closely match those of the UK and which offer the potential for significant mutual benefit.

Recognising the UK's standing and the aim to sustain a world-leading position in nuclear research capability NIRAB recommend that the main focus for the UK should be collaboration with technically advanced partners with significant programmes.

Recommendation 2

Government should develop and implement a comprehensive and coordinated international collaboration strategy for nuclear research and innovation to enable research to be implemented to the greatest effect.

2.2.4 Coordination of UK Research and Innovation

There is a clear need for a coordinated approach to implementing NIS initiatives given the numerous stakeholders interested in nuclear R&D from both within and outside the sector. There has been some progress in addressing this issue since publication of the NIS through the formation of the Nuclear Industry Council (NIC), NIRAB, NIRO and the Low Carbon Innovation Coordination Group (LCICG) Nuclear Sub Group, which is a forum for the public funders of nuclear research.

In practice establishing these new bodies has led to an improvement in communication and sharing of information. NIRAB and NIRO have over the course of 2015 interacted with industrial and academic stakeholders and provided coordination between a number of UK official bodies and organisations involved in nuclear R&D. This includes a wide range of UK companies, select committees in the House of Lords and the House of Commons, the Defence Research Programme Group, The Carbon Trust, NIC and its subgroups, the Nuclear Energy Skills Alliance and Cogent Sector Skills Council.

Given the complex range of nuclear R&D funding routes shown in Figure 4, and that there are many areas of synergy between existing and potential future programmes (shown in Figure 5), It is important that Government adopts governance arrangements which ensure a fully coordinated and managed approach to delivery of the programmes is adopted. This has not always been evident when defining and commissioning programmes, and the logic for prioritisation of capital investment has not always been apparent.

Recommendation 3

Government should implement a transparent and effective mechanism to coordinate and, where necessary, direct, all publicly funded nuclear R&D activities in order to achieve the desired industrial impact and maximise value for money.

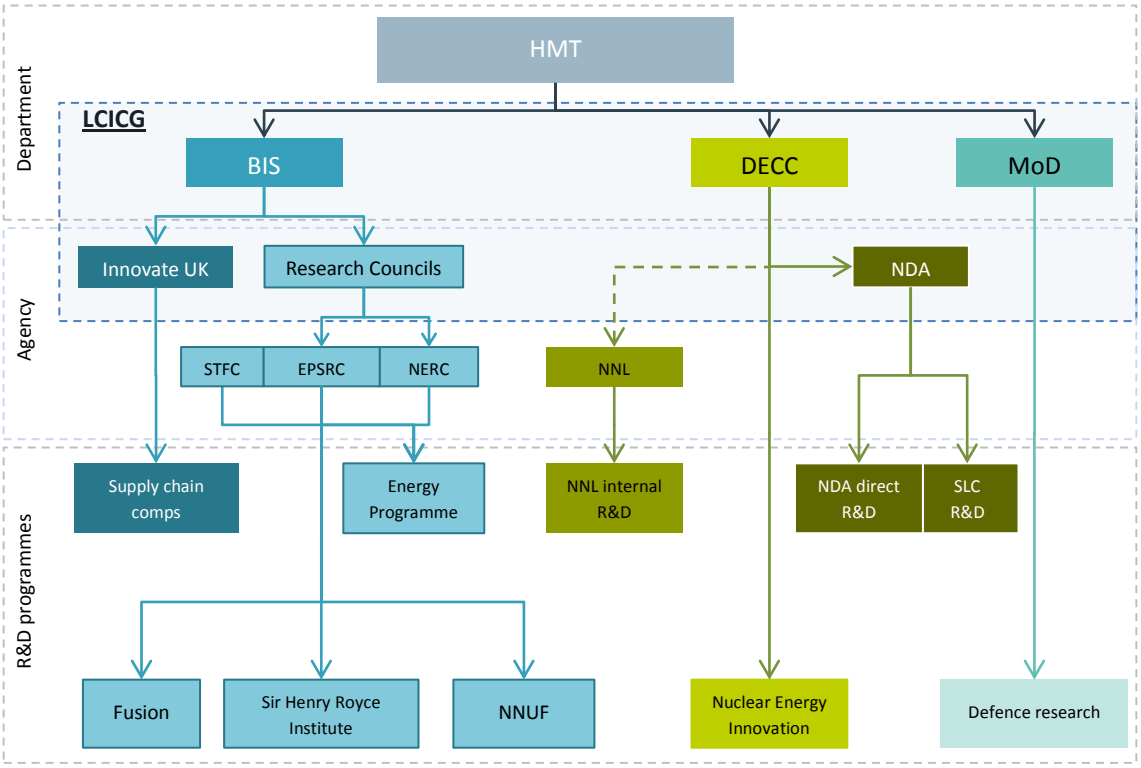


Figure 4 Government funding routes for nuclear research and innovation

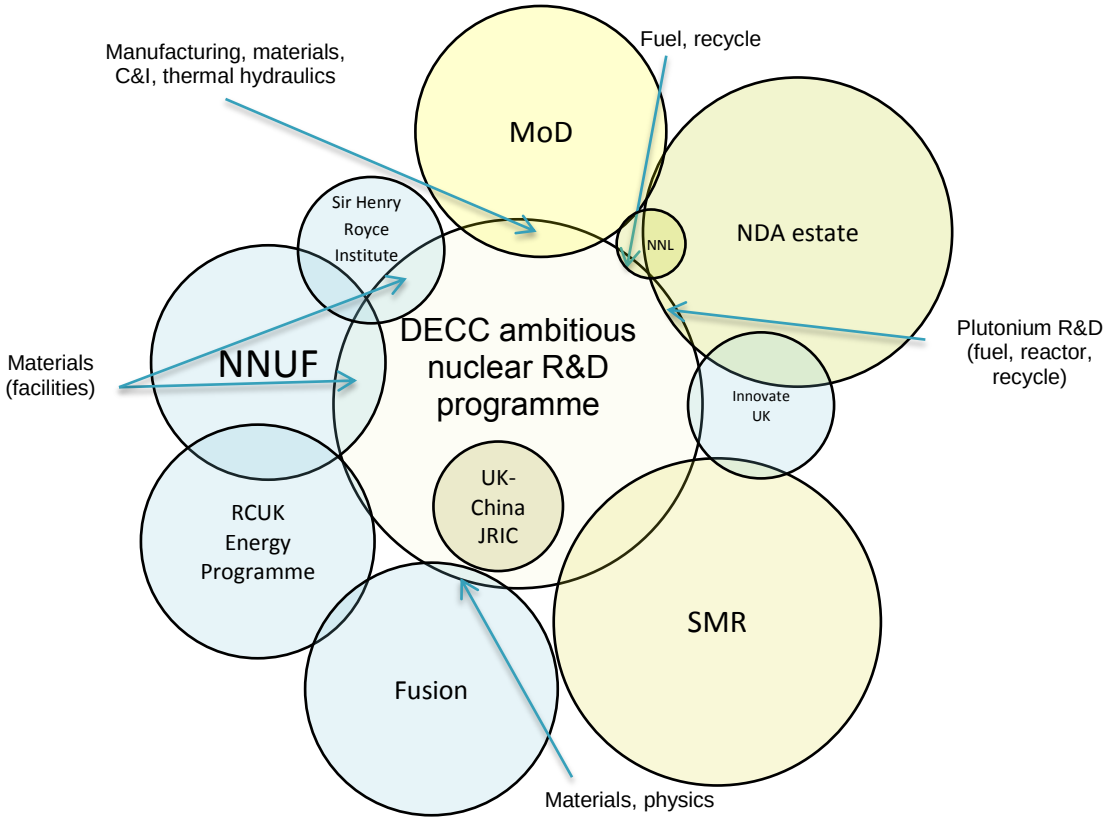


Figure 5 Indicative programme synergies

3 Recommendations for a New Programme of Research and Innovation

During 2015, NIRAB has produced a UK Nuclear Innovation and Research Programme Recommendations document [10] which is published alongside this Annual Report. This identifies additional publicly-funded programmes of R&D needed to underpin the Nuclear Industrial Strategy which sets out the shared vision held by Government and Industry of a vibrant nuclear industry that is an area of economic and strategic national strength providing the UK with safe, reliable and affordable low carbon electricity.

The recommendations have been aligned to the needs of the Government, the nuclear industry, academia and national laboratories to promote economic growth, skills development and scientific excellence. The recommended programme aims to provide a long-term strategic technical view giving direction to the UK's nuclear funding and research community. Coordination of R&D programmes is critical and these recommendations are intended to provide an additional guide to investment in energy innovation, Innovate UK in future supply chain competitions, shape the nuclear aspects of the Research Councils Energy Programme and inform the provision of new capital investments.

NIRAB's recommendations identify the R&D and innovation required in the five year period up to 2020 which is critical in stabilising the nuclear R&D community and providing a strong footing on which to base a long-term programme that can deliver the NIS vision. NIRAB's aim is by 2020 to have established the high-level skills and leading-edge facilities needed to set the UK on course to deliver its 2050 vision for nuclear energy, creating a renowned capability contributing to economic growth and achieving a strong international presence. Success over this period will be determined by practical outcomes which might include, but not be limited to the following:

- The UK has the capability to deliver a FOAK SMR in the 2020s and a UK consortium is actively engaged in the design and construction of a FOAK SMR
- The UK manufacturing base is delivering a wider range of components for new build programmes both in the UK and internationally
- Fuel manufacturing capabilities will have been secured and the UK will play a key role in manufacturing ATF test pins
- The reprocessing skill base will be secure and the UK will be leading the development of a proliferation resistant flowsheet
- The UK will be a partner of choice in international collaborations, securing significant gearing on UK R&D budgets.

NIRAB's recommendations are targeted on areas where publicly funded nuclear R&D and innovation can address the current market failure by strengthening the UK nuclear industry's capability and capacity to play an increasingly significant role in current and future nuclear markets. Supporting in the early stages of developing new, disruptive technologies and methods that can make an impact on existing supply chains will provide the bridge to subsequent investment by industry to commercialise those technologies enabling the UK to

grow its domestic and global market share. The key future nuclear reactor markets being targeted by UK businesses are:

- Nuclear new build manufacture for Gen-III Pressurised Water Reactors (PWRs) and Boiling Water Reactors (BWRs)
- SMR design, manufacture and implementation
- Gen-IV reactor design.

In producing these recommendations NIRAB have consulted with individuals from the full spectrum of academia, industry and national research organisations that have expertise in the entire range of nuclear technologies. NIRAB and NIRO have a remit to represent the best interests of the UK and in delivering this adopt an open and transparent policy for collating views for consideration in formulating advice. Throughout 2015, NIRO has engaged with a range of industrial organisations both within and outside of the nuclear field. Interaction has occurred through the NIRAB Industry and Advanced Systems subgroups, technical visits to a number of company sites, conferences, one to one meetings and correspondence through the NIRAB website portal. The wide range of industry stakeholders has included many companies not represented on NIRAB, from major established players to new start-up SMEs.

To ensure close alignment with the UK nuclear industry the recommendations have also been reviewed by representatives from across the sector including: a nuclear utility, a fuel enrichment company, a fuel manufacturer, a major nuclear engineering consultancy, a manufacture of nuclear technologies, a nuclear decommissioning company and a nuclear engineering Small and Medium Enterprise.

NIRAB's recommendations have been grouped into the following five programme areas:

- **The UK's Strategic Toolkit:** Underpinning decisions on which emerging nuclear technologies are brought to market to give the best economic return for the UK.
- **Future Fuels:** Making more efficient, safer fuels of the future.
- **21st Century Nuclear Manufacture:** Advanced manufacturing and 'plug and play' modular build in nuclear factories of the future.
- **Reactor Design:** Delivering the people, processes and tools to make the UK the partner of choice as the world designs SMRs and 4th generation nuclear power plants.
- **Recycling Fuel for Future Reactors:** Cost effective technologies to deliver a secure and sustainable low carbon fuel supply.

These programmes cover the full range of the fuel cycle and play to the strengths of the UK nuclear sector. There is broad alignment between these areas and the product streams required to exploit each of the future nuclear markets identified.

Full details of the recommended activities in each of these programme areas are given in the separate recommendations document[10] and a brief description of each is given below.

3.1 Overview of Recommended 5 year Programme

3.1.1 The UK's Strategic Toolkit

The long lead times associated with delivering major nuclear infrastructure, such as reactor plants or recycling facilities, mean that a long term, strategic view must be taken when formulating policy decisions on how nuclear power should support the UK energy needs. There are many key decisions to make between Government and industry that will determine the future direction of the UK nuclear sector. Providing a structured set of credible data that can be responsive to changes in governing factors will allow policy makers to understand their potential impacts and determine the most appropriate route for the UK.

A programme of research is recommended to develop tools to assist decision making and provide credible data to inform which reactor technologies should be developed by the UK, directing future R&D funding allocations. This research is essential to enable a credible and cost effective national programme of new nuclear focussed R&D within the UK.

Public support through engagement is crucial if the level of nuclear energy production is to meet the UK future energy needs. Research is needed that draws together the nuclear community with social sciences and humanities to understand the underlying reasons for public attitudes to nuclear energy, how these attitudes are shaped by events and the underlying perceptions that have developed over time. Research should also address how communications on nuclear matters can become more effective, what industry can learn from others and what communication channels and tools can help address current and emerging issues in the public eye to enhance public acceptance. This R&D will be used to enhance delivery of the UK nuclear sector's Concordat on Public Engagement[11], providing new understanding and approaches to better engage the public on current and future nuclear programmes including the range of R&D proposed by NIRAB.

3.1.2 Future Fuels

NIRAB's recommended programme of fuel R&D will deliver the UK a strong nuclear fuels R&D base that can attract international investment and, support retention of the UK's fuel manufacturing capability and subsequently deliver nuclear fuels to the domestic and international markets. This will be used as a launch pad for future fuel developments, stimulate economic growth and sustain key skills across the fuel cycle.

NIRAB's recommended programme of work will see the development of fuels for extant reactors that are more tolerant to accidents and more efficient, greatly improving the safety and economics of plant operation. This would be carried out in parallel to research and development into fuels for the next generation of reactor designs including fast reactor fuels and coated particle fuels.

Research and development into new fuel types, in conjunction with investment in new fuel lines, will support a transition from AGR fuel manufacture towards an increase in fuel manufacture capacity for new build Pressurised Water Reactor (PWRs) and a range of SMRs.

Accident tolerant fuels would be a game changing technology within the global nuclear fuel supply market and the existing installed reactor base. UK owned ATF design and

manufacture IP would help secure future private investment in UK fuel manufacturing, deliver a UK owned product that can be sold into a world market and act as a stepping stone for UK industry to supply Gen-IV fuels in the future.

3.1.3 21st Century Nuclear Manufacture

NIRAB's programme of advanced manufacturing R&D will establish a strong materials and manufacturing R&D base that is driving advanced techniques into UK industry allowing it to break into existing worldwide supply chains for high value nuclear components.

The programme includes developing new nuclear structural materials, machining and forming techniques, manufacturing, assembly and construction processes that can position UK industry to deliver a capability that is fit for the 21st Century. Technologies such as additive manufacturing and electron beam welding have the potential to make the UK nuclear manufacturing supply chain competitive in the growing international nuclear market. This will allow businesses to increase the proportion of UK content in high value reactor components for nuclear new build and SMRs production. Once the route into this market has been established this capability can be applied to the development and manufacture of Gen IV reactor technologies up to the end of the century.

This programme also addresses techniques for off-site modular assembly which could revolutionise the way power stations are built, making nuclear more attractive to investors and lowering the cost of electricity to consumers. These developments would be particularly beneficial in SMR development, but would also deliver benefit to the construction and delivery of the next tranche of new nuclear power stations and the design of Gen-IV reactors.

3.1.4 Reactor Design

Design engineering in the nuclear sector is a high value engineering proposition where the capability required to ensure compliance with the relevant nuclear codes, standards and ways of working presents a high barrier to entry. NIRAB's programme of R&D will develop a design capability that can operate in collaboration with international partners. The full range of design disciplines and capabilities required to deliver a reactor is very broad. NIRAB has identified four key areas where it believes that the UK can have the most impact and add significant value. These areas are:

- System and Component Design – The capability to provide new designs of systems and components into nuclear projects. Companies that are at the cutting edge of front end design of future nuclear plants systems and components will hold critical IP that they can exploit during product manufacture and in-service support for decades to come
- Design Analysis and Verification – The capability to provide sufficient analysis and verification to demonstrate that nuclear products can meet their requirements. The UK currently generates significant revenue from its world class modelling and simulation capability and licencing of previously developed thermal hydraulics codes. Targeted research will allow the UK to develop the next generation of these codes for PWR, BWR, SMR and Gen-IV reactors, expanding the UK's offering and maintaining a marketable resource base

- Design Justification – The capability to provide a formal justification for major safety case campaigns. Using modern safety engineering methods UK companies can become the partners of choice in the licensing of new reactor technologies worldwide
- Design for In-service – The capability to provide products and services to support the in-service operation of nuclear facilities. Innovative in-service inspection and support technologies will afford UK industry with the access to the significant reactor in-service operation and maintenance market, estimated at £260m a year for a typical large reactor. Having a credible "design-for-in-service" capability with innovative products, services and technologies would present the UK with a route to collaboration in future reactors developments and the reactor operations and maintenance market.

3.1.5 Recycling Fuel for Future Reactors

The UK is one of the very few countries to have recycled irradiated fuels from civil reactors on an industrial scale. This is the basis for a world-leading knowledge of recycling technologies, which has been built up over decades of research and operation. The planned cessation of spent fuel reprocessing at Sellafield poses a risk that the UK could irretrievably lose these unique, internationally respected skills and capability in recycling. These are valuable assets that the UK should safeguard at least until the medium term role of spent fuel recycling in the UK fuel cycle is clear.

NIRAB's programme of recycle and waste management R&D will sustain the UK's capability in spent nuclear fuel recycle technologies which has the potential to create commercial opportunities for UK companies in the global recycling market and maintain the UK's position as a 'top-table nation' in spent fuel reprocessing. The four key areas that NIRAB recommends the UK focuses its research and innovation in recycle and waste management are:

- Aqueous recycling of LWR fuel
- Aqueous recycling of fast reactor fuel
- Pyroprocessing of fast reactor fuel
- Waste management for new recycling waste streams.

3.1.6 Summary

Scheduling and cost estimates to achieve the recommended research and innovation aims have been generated with the NIRAB subgroups[10]. The total five year programme cost is approximately £250m. NIRAB has delivered this recommended programme to Ministers and would reiterate the importance of commencing research without delay.

Recommendation 4

The programme of research outlined in this document should be commissioned by the Government over the next five years to ensure the UK can remain on track to deliver Nuclear Industrial Strategy 2020 objectives.

4 Future Government Research and Innovation Funding

4.1 2015 Spending Review Outcome

NIRAB acknowledges and welcomes the recent commitment to nuclear research and innovation made by Government in the recent Spending Review[12]. It has come at a critical moment and signals a commitment to making real progress against the R&D ambitions set out in the NIS.

Government set out in its 2015 Spending Review a commitment to nuclear research and innovation in the following areas:

DECC:

£250m for DECC's Energy Innovation programme covering:

- An ambitious nuclear research programme that will revive the UK's nuclear expertise
- A competition to identify the best value SMR design for the UK
- SMR development relating to the winning design
- A co-funded UK-China Joint Research and Innovation Centre (JRIC) in nuclear technologies, to be based in the UK. The centre will be led in the UK by NNL who will collaborate with the China National Nuclear Corporation (CNNC). Programmes of research activities are currently being defined. The JRIC is due to begin operating in April 2016 and the UK has committed £25m of funding over a five year period to fund nuclear research and innovation. CNNC will match the UK funding for JRIC.

Research Councils:

- Further funding for NNUF announced as £60m in the 2014 Autumn Statement. Funding is expected to commence in 2018
- £235m for the Sir Henry Royce Institute for Advanced Materials Research, a component of which (approximately £30m) is for nuclear materials research. Nuclear related research facilities are expected to be located at the Universities of Manchester and Sheffield, the NNL's laboratory in Cumbria and CCFE. The detailed scope of the nuclear related research to be carried out at the institute is currently being defined.

In addition, funding of nuclear R&D for Innovate UK, NDA, MOD and CCFE are, at the time of writing, expected to continue at current levels.

4.2 Implementation – Next Steps

4.2.1 Prioritisation of Research Activities

The mismatch between the level of ambition embodied in the NIS and the level of programme funding made available to date now needs to be addressed through the commitments made by Government in the recent Spending Review. The extent to which the level of new funding announced for nuclear in the DECC Energy Innovation budget is

sufficient to deliver all of the NIRAB recommendations is not yet clear. There may be a need to prioritise critical research and innovation activities. NIRAB will assist Government as required with this process.

Recommendation 5

Government should commission high-priority research immediately to deliver the most urgent aspects of NIRAB's recommended 5 year programme.

Recommendation 6

NIRAB's research recommendations are used to help shape future calls for directed programmes or capital investment issued by Research Councils and Innovate UK.

4.2.2 Governance of New Research Programmes

It will be of vital importance to hit the ground running when new funding becomes available in April 2016. To facilitate this it is advised that Government establish an effective mechanism to commission and integrate the recommended R&D programmes. An appropriate implementation mechanism must:

- Provide access to the full range of technical skills required to:
    - Specify research programmes
    - Place research contracts
    - Monitor research programmes (technically as well as programmatically)
    - Evaluate research outcomes
    - Maintain integration of the elements of the programme
- Provide transparency and independence
- Minimise the risk of state aid issues arising
- Provide a mechanism to ensure that research of national or strategic importance can be delivered through the UK supply chain.

Recommendation 7

Government should put in place the governance arrangements required to commission and integrate the new programme of research with a view to commissioning research early in 2016/17.

4.2.3 Small Modular Reactor Competition

The Government have made clear in the 2015 Autumn Statement their intention to run a competition to identify the best value SMR design for the UK, paving the way towards building one of the world's first SMRs in the UK in the 2020s. This presents a fantastic opportunity for the UK to regain top table status and should be afforded due consideration. When the competition is launched it will be necessary for Government to identify the criteria against which the "best value" judgement will be made. There are a number of criteria that

could be used, either separately or collectively to differentiate between candidate designs. These criteria could include, but are not limited to, the following:

- The design estimated to give the lowest LCOE
- The design that offers the greatest economic benefit to the UK through the creation of high value jobs and / or Intellectual Property, including an indigenous supply of fuel
- The design that could result in the greatest certainty of earliest supply of power to the national grid
- The design with the potential to deliver the maximum power to the national grid
- The design that offers the greatest potential for flexibility or grid balancing.

Government needs to be clear which of these objectives will be used in its evaluation. This will determine not only the outcome of the competition, but will also set the strategic aims for SMR related research and innovation. A clear statement of objectives will enable NIRAB to tailor and prioritise its recommendations and identify any additional areas of research required to support the Government's SMR mission.

Recommendation 8

Government should make clear its aims for SMR development in the UK, ensuring that these are used in evaluating the SMR competition and setting the technical priorities for both SMR development and the scope of wider nuclear research and innovation programmes.

5 References

1 Nuclear Innovation and Research Advisory Board, Terms of Reference and Ways of Working, NIRAB-9-1, January 2014

2 The UK's Nuclear Future. Industrial Strategy; Government and Industry in Partnership, BIS/13/627

3 The Current Landscape for Publicly Funded Civil Nuclear R&D, NIRAB-70-4, August 2015

4 NIRAB Annual Report 2014, February 2015

5 The 2014/15 Technology Development and Delivery Summary, Sellafield Ltd, November 2015

6 NDA Research and Development Brochure 2014, NDA, November 2014

7 NDA Research and Development Brochure 2015, NDA, November 2015

8 Small Modular Reactors Feasibility Study, National Nuclear Laboratory, December 2014

9 Nuclear, The Role for Nuclear Within a Low Carbon Energy System, Energy Technologies Institute, October 2015

10 UK Nuclear Innovation and Research Programme Recommendations, NIRAB-75-7, March 2016

11 Nuclear Energy and Society: a Concordat for Public Engagement, Nuclear Industry Council, December 2015

12 Spending Review and Autumn Statement 2015, Cm 9162, November 2015

Appendix A: NIRAB Member and Observer Profiles

NIRAB Members

Dame Sue Ion, Chair, Independent

Dame Sue represents the UK on a number of international review and oversight committees for the nuclear sector including the Euratom Science and Technology Committee, which she Chairs, and the US Department of Energy Nuclear Energy Advisory committee. She was the UK's representative on the IAEA Standing Advisory Group on Nuclear Energy 2000-2006.

Dame Sue Ion was a non-Executive Director on the Board of the Laboratory of the UK Health and Safety Executive 2006-2015. She has been a member of the ONR's Technical Advisory Panel since 2014. She was a member of the UK Council for Science and Technology from 2004-2011, a member of the Particle Physics and Astronomy Research Council from 1994-2001, a member of Council for EPSRC between 2005 and 2010 and Chaired the Fusion Advisory Board for the Research Councils between 2006 and 2012.

Sue's background is in materials science/metallurgy. She gained a first class honours from Imperial College in 1976 and a PhD in 1979 before joining BNFL where she was Group Director of Technology 1992-2006. She was appointed Visiting Professor at Imperial College in 2006 and of London South Bank University in 2011 and has been a member of the Board of Governors at the University of Manchester since 2004 becoming Deputy Chair in 2015. She has held an Honorary Professorship at the University of Central Lancashire since the beginning of 2007.

Dame Sue was Vice President and Member of Council of the Royal Academy of Engineering between 2002 and 2008. She is Chair of the Royal Academy of Engineering's MacRobert Committee.

Professor Tim Abram, Professor of Nuclear Fuel Technology, University of Manchester

Tim joined the University in 2008 as the first holder of the Westinghouse Chair in Nuclear Fuel Technology. Prior to this appointment he gained over 21 years of experience in the nuclear fuels and research sectors, both in the UK and the USA. He led the team at BNFL responsible for the fuel rod design and safety analysis for the UK's most recent nuclear power station, Sizewell B, and for the UK's first export order for mixed (U,Pu) oxide fuel (MOX).

He has experience in the design, performance and safety analysis of all major fuel types, and in the development of computer codes for the analysis of in-reactor fuel performance. He has participated in over 15 European Framework research programmes in nuclear fuel and reactor technology, and is the UK's representative on the IAEA Technical Group on Fast Reactors and Accelerator-Driven Systems.

He was co-author of the Fuels and Materials section of the Generation-IV Roadmap, and has actively participated in the programme since its inception in 2000, most recently as the Euratom representative and Co-Chair of the VHTR Project Management Board for Fuel and Fuel Cycle research.

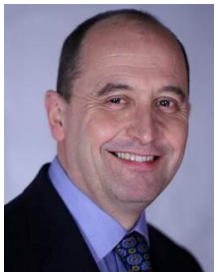
Prior to joining the University, Tim was the Senior Research Fellow for Fuels and Reactor Systems at the UK's National Nuclear Laboratory, where he retains the position of Associate Fellow.

Andrew Carlick, CEO, DBD Ltd

With almost 30 years experience in the nuclear industry, Andrew's career stems from a Chemical Engineering background with extensive experience in his early career in commissioning of nuclear plants.

Andrew established DBD in 2004 and he has developed and led them so they now operate successfully in the UK, France, Japan, the Middle East and US, mainly in the nuclear fission and fusion markets. Andrew is a keen supporter of R&D and has supported DBD in developing engineering solutions to key issues in the nuclear market.

Andrew is a Fellow of the Institute of Chemical Engineers.



Professor Richard Clegg, Managing Director, Lloyd's Register Foundation

Richard has 30 years of experience in the nuclear community within industry, government and academia in both the civil and defence sectors. His technical background is in radiation chemistry and environmental modelling

Richard is currently the Managing Director at the Lloyd's Register Foundation; shareholder of the LR Group and one of largest charitable foundations in UK in terms of revenue, focussed on engineering science, research and education. His previous roles include, Global Nuclear Director Lloyd's Register, MD UK National Nuclear Centre of Excellence, Chief Scientist UK Atomic Weapons Establishment, Professor and Director of Dalton Nuclear Institute, and Faculty Research Dean at The University of Manchester and Group Science Director British Nuclear Fuels.

Professor Steve Cowley, Director, United Kingdom Atomic Energy Authority Culham Laboratory

Steven became Director of the United Kingdom Atomic Energy Authority's Culham Laboratory in September 2008 and Chief Executive of the UK Atomic Energy Authority in November 2009. He received his BA from Oxford University and his PhD. from Princeton University. Professor Cowley's post-doctoral work was at Culham laboratory and he returned to Princeton in 1987. He joined the faculty at the University of California Los Angeles in 1993 rising to the rank of Full Professor in 2000. From 2001 to 2003 he led the plasma physics group at Imperial College London. He remains a part time professor at Imperial College. From 2004 to 2008 he was the Director of the Center for Multi-scale Plasma Dynamics at UCLA. His main research interest is in realising fusion power and has published over 150 papers on: the origin of magnetic fields in the universe, the theory of plasma turbulence and explosive behaviour in both laboratory and astrophysical plasmas.

Professor Cowley co-chaired the US National Academy's decadal assessment of, and outlook for plasma science. He is a Fellow of the American Physical Society and the Institute of Physics and the recipient of the IOP's 2012 Glazebrook Medal for leadership in physics. Currently he is also a member of the Prime Ministers Council on Science and Technology and in May 2014 he was elected a Fellow of the Royal Society.

Mick Gornall, Managing Director UK Fuel Operations, Springfields Fuels Limited

Mick was appointed to the role of Managing Director in April 2013 and has over 30 years' experience in the nuclear industry. He has a 1st Class Honours Degree in Electronic Engineering from Manchester University and has an engineering background in Control & Instrumentation Engineering. Mick has been involved in nuclear engineering projects at Dounreay, Sellafield, Heysham II, and more recently Springfields.

Mick is a certified Lean Six Sigma Black Belt and has undertaken a number of key roles leading manufacturing operations at Westinghouse Springfields Nuclear Fuel facility, near Preston, and has significant experience in managing nuclear operations.

Dr Paul Harding, Advisor to URENCO

Paul is currently working as Advisor to URENCO in the area of SMR development. Paul holds MA and D.Phil degrees in Chemistry from Oxford University and has worked for more than 35 years in the Nuclear Industry in a variety of roles encompassing nuclear chemical plant management, commissioning and decommissioning project management, commercial and Nuclear Licensed Site General Management.

Professor Neil Hyatt, Nuclear Decommissioning Authority Research Chair in Radioactive Waste Management, University of Sheffield

Neil is the Head of the University of Sheffield's Department of Nuclear Material Chemistry supported by a Royal Academy of Engineering and Nuclear Decommissioning Authority Research Chair. He is also the Director of the Immobilisation Science Laboratory at The University of Sheffield and a co-Director of the EPSRC sponsored Nuclear First and Next Generation Nuclear Centres for Doctoral Training.

At the University of Sheffield, his research has focused on the conditioning of radioactive wastes and fissile materials, the performance of waste packages in storage and disposal, and the behaviour of actinides in the environment. He has served as an IAEA technical expert and provided advice and guidance to radioactive waste management organisations in the UK and overseas.

Malcolm Joyce, Head of Engineering Department, Lancaster University

Malcolm holds a Personal Chair in Nuclear Engineering at Lancaster University, and is currently Head of the Engineering Department at Lancaster. His area of research interest is in the field of Control & Instrumentation (C&I) and the development of radiation detection instruments including: portable neutron spectrometry; decommissioning-related analytical methods; nuclear policy and environmental consequences; medical radiotherapy and radiation effects.

Malcolm is author on over 100 refereed journal articles including 26 refereed outputs and two patents since 2008, primarily in the field of digital mixed-field radiation assay with fast, organic liquid scintillation detectors. Prior to this he spent four years in research in industry. He led the research team at Lancaster in 2010 that wrote the Nuclear Lessons Learned report on behalf of the Royal Academy of Engineering and Engineering the Future, which was commended by the Minister of State for Energy, HMG Chief Scientist and Lord Browne.

Professor WE (Bill) Lee, Director, Centre for Nuclear Engineering, Imperial College London

Bill is a member of the Leverhulme Trust Panel of Advisors, the Royal Academy of Engineering International Activities Committee, and the Scientific and Environmental Advisory Board Tokamak Energy plc. He was previously Deputy Chair of the Government advisory Committee on Radioactive Waste Management from 2007-2013, has acted as special advisor nuclear to the House of Lords Science and Technology Committee (2013) and was from 2006 to 2010 Head of the Department of Materials at Imperial. He is a member of the Board of Directors of the American Ceramic Society and an IAEA Technical Expert.

Bill is a fellow of the Royal Academy of Engineering, IOMMM, ACerS and the City and Guilds Institute.

Dr John Lillington, Chief Technologist - Nuclear Reactors, AMEC Foster Wheeler

John has worked for 40 years within the UK nuclear industry with the United Kingdom Atomic Energy Authority (UKAEA), its privatised sector, AEA Technology, Serco and most recently AMEC. He originally graduated in mathematics from the University of London (BSc, PhD). During his career, he has worked on all the major reactor systems (water, gas and fast reactor) as a theoretical physicist, safety analyst, technical programme, resource and project manager. He is a part-time lecturer and examiner at several UK universities and has published two books and numerous articles on nuclear power related subjects.

John is a Fellow of the Institutes of Physics and Mathematics (FInstP, FIMA) and a Chartered Engineer (CEng).

Professor Andrew Sherry, Chief Scientist, NNL

Andrew studied Metallurgy at Manchester where he did his PhD with Rolls-Royce before joining the United Kingdom Atomic Energy Authority in 1987 where he led research into materials ageing and structural integrity.

Andrew joined The University of Manchester in 2004 as Director of the Materials Performance Centre, and was appointed Director of the University's Dalton Nuclear Institute in 2009 where he established the flagship Dalton Cumbrian Facility, a partnership with the NDA in radiation science and decommissioning and led Manchester's partnership with Sheffield University to create the Nuclear Advanced Manufacturing Research Centre. In 2015, Andrew was appointed as Chief Science and Technology Officer at NNL. He is a member of the UK's Nuclear Industrial Council, leading work on public engagement and a member of the Nuclear Innovation Research Advisory Board.

Andrew is a Fellow of the Royal Academy of Engineering, a Fellow of the Institute of Materials Minerals and Mining and a Chartered Engineer.

Paul Stein, Chief Scientific Officer, Rolls-Royce plc

Paul Stein graduated in Electrical and Electronic Engineering from King's College London in 1978. After several positions in technology and general management serving the commercial and defence communications markets he moved to Roke Manor Research, and was appointed Managing Director in 1996.

From 2006 to 2009 Paul joined the Ministry of Defence as the Director General, Science and Technology, responsible for the technical direction, prioritisation and out-sourcing of the UK's £500m annual investment in Defence S&T. At the end of his three year contract with the MoD Paul joined Rolls-Royce as the group Chief Scientific Officer.

As Chief Scientific Officer, Paul helps the Rolls-Royce group set its technological and business direction in view of market and technology trends, and examine areas where alternative technological and innovative approaches could lead to competitive advantage for the company. He is also actively engaged in talent development for the company, ensuring that specialist engineering talent is promoted and sustained. Paul is also the independent chair of the Nuclear Engineering Executive and represents the Nuclear Sector at the Engineering Leadership Board.

Paul is a Fellow of the Royal Academy of Engineering, a Fellow of the Royal Aeronautical Society and a Fellow of the Institution of Engineering and Technology.

Neil Thomson, Senior Technical Advisor to EDF Energy and President of the Nuclear Institute.

Prior to his appointment as Senior Technical Advisor Neil spent 7 years as Head of Research and Development and Head of Engineering in the EDF-Energy Nuclear Generation Business. His recent focus has been life extension of the AGR Fleet.

Neil has 37 years experience in Power Generation involving senior technical and plant management roles; starting his career as a Research Officer in the CEGB in the area of inspection and structural integrity.

Neil is a Fellow of the Institute of Mechanical Engineers, Fellow of the Institute of Physics and a member of its Council.

Mike Tynan, CEO, Nuclear Advanced Manufacturing Research Centre

Mike was appointed CEO for the Nuclear AMRC in July 2013, having previously spent 5 years as CEO for Westinghouse in the UK. Prior to this Mike was Managing Director at Westinghouse Springfield's Fuels Limited, the UK's flagship nuclear fuel manufacturing facility.

Mike began his career in the nuclear industry at Calder Hall power station in West Cumbria in 1975 and has worked at numerous UK and international facilities, including Sellafield in West Cumbria and Oakridge in Tennessee.

Mike has been at the forefront of changes in the UK civil nuclear industry, including the restructuring of BNFL and the formation of Site License Companies for the Nuclear Decommissioning Authority. He established Westinghouse UK Ltd to integrate Westinghouse/Toshiba business interests in the UK and led the licensing of the Westinghouse AP1000 reactor through the Generic Design Assessment in the UK. Through the Nuclear AMRC, he leads the development of a UK supply chain for nuclear that competes in the global civil nuclear marketplace.

Mike is dedicated to the development of young people in the nuclear industry and is a founder Board member of the National Skills Academy - Nuclear (NSA-N). He is a Board member of Lancashire Local Enterprise Partnership, and is committed to the development of a new era of civil nuclear power.

Professor Laurence Williams, Chairman, Committee on Radioactive Waste Management

Laurence is currently the Chair of CoRWM which advises the Government and the Devolved Administrations on the geological disposal of radioactive waste.

For nearly four decades Professor Williams has contributed to improving nuclear safety in the UK and internationally. As Her Majesty's Chief Inspector of Nuclear Installations he was responsible for licensing all civil and some defence related nuclear installations in Great Britain. Laurence is regarded as one of the world's leading experts in nuclear safety regulation.

He was HM Chief Inspector of Nuclear Installations between 1998 and 2005. He was also, as the Director for Nuclear Safety, a member of the Health and Safety Executive Board. In 2005 Laurence joined the Nuclear Decommissioning Authority as the Director for Nuclear Safety and Security. As one of the founding Directors at the NDA he played a major role in its early development. He became NDA's Chief Engineer in 2007.

Laurence has extensively contributed to international nuclear safety. He has worked with the International Atomic Energy Agency (IAEA), the OECD's Nuclear Energy Agency, the European Commission, the European Bank for Reconstruction and Development, the International Nuclear Regulators Association, the Western European Nuclear Regulators Association and numerous national nuclear regulatory authorities. As Chairman of the IAEA Commission on Safety Standards he was responsible for overseeing the development of international standards in the areas of nuclear safety, radiation protection, radioactive waste management and the transport of nuclear materials.

Peter Wylie, Senior Manager in the Technical & Engineering Department, Sellafield Ltd

Peter works for Sellafield Ltd as a senior manager in the Technical & Engineering Department. Peter has over 30 years experience in the nuclear industry in a range of roles from research, nuclear design, nuclear operations and strategic planning. He has also worked in oil and gas, consultancy and process engineering design sectors of industry.

Peter's knowledge of nuclear research and development includes advanced reprocessing, control systems and process simulation, nuclear waste treatment and nuclear decommissioning.

NIRAB Observers

Sir Mark Walport, Chief Scientific Adviser to HM Government and Head of the Government Office for Science

Government Office for Science

Sir Mark is the Chief Scientific Adviser to HM Government and Head of the Government Office for Science. Previously, Sir Mark was Director of the Wellcome Trust, which is a global charitable foundation dedicated to achieving extraordinary improvements in human and animal health by supporting the brightest minds. Before joining the Trust he was Professor of Medicine and Head of the Division of Medicine at Imperial College London.

He has been a member of the Prime Minister's Council for Science and Technology since 2004. He has also been a member of the India UK CEO Forum, the UK India Round Table and the advisory board of Infrastructure UK and a non-executive member of the Office for Strategic Coordination of Health Research. He is a member of a number of international advisory bodies.

He has undertaken independent reviews for the UK Government on the use and sharing of personal information in the public and private sectors: 'Data Sharing Review' (2009); and secondary education: 'Science and Mathematics: Secondary Education for the 21st Century' (2010).

Sir Mark received a knighthood in the 2009 New Year Honours List for services to medical research and was elected as Fellow of The Royal Society in 2011.

Professor Timothy Dafforn, Chief Scientific Adviser, Department for Business Innovation and Skills

Department for Business Innovation & Skills

Professor Dafforn began his science career studying protein engineering at the Bristol University where he developed two different approaches to enzyme engineering based on forced evolution and rational design.

Tim has had a prestigious career in biological research including working at the Cambridge Institute of Medical Research and as the Director of Knowledge Transfer, Life and Environmental Sciences at the University of Birmingham.

In June 2015 Professor Dafforn took up his post as the CSA for the Department for Business, Innovation and Skills where he had previously acted as the entrepreneur in residence with a remit to champion activities in synthetic biology.

Tim is a Head of Policy and member of the executive at the Biochemical Society, a member of the Biotechnology and Biological Sciences Research Council new ways of working strategy panel and a Member of the Synthetic Biology Leadership Council.

Professor John Loughhead, Chief Scientific Advisor, Department of Energy and Climate Change

Department of Energy & Climate Change

John has been active in energy research for more than 30 years, predominantly in industrial development for the electronics and electrical power industries. Before joining UKERC, John was Corporate Vice-President of Technology and Intellectual Property at Alstom's head office in Paris.

He has been a member of the EPSRC Council and of the European Advisory Group on Energy, is presently the UK-China Science Focal Point for Energy and Renewables, and a member of the European Energy Research Alliance Executive Committee.

A Chartered Engineer, Professor Loughhead graduated in Mechanical Engineering from Imperial College, London, where he also spent five years in computational fluid dynamics research. He is Past-President of the UK's Institution of Engineering and Technology, Fellow of both the UK and Australian national Academies of Engineering, Professor of Engineering at Cardiff University and Fellow of Queen Mary University of London.

Professor Robin Grimes, Chief Scientific Adviser, UK Foreign and Commonwealth Office

Robin is the UK Foreign and Commonwealth Office Chief Scientific Adviser. He is also Professor of Materials Physics at Imperial College and was previously Director of the Imperial College Centre for Nuclear Engineering and the Rolls Royce University Technology Centre in Nuclear Engineering.

His primary research interest is the application and development of computer simulation techniques to predict structural and dynamic properties of inorganic materials for energy applications to improve performance of semiconductors for solar and electrolytes and electrodes for fuel cells, nuclear fuel for higher burn-up and waste forms of greater durability. He has published over 260 scientific papers.

He was the specialist adviser to the UK House of Lords for their 2011 review of Nuclear Research Requirements for the UK, a member of the Royal Society Working Group on nuclear non-proliferation and the Ad Hoc Nuclear Research and Development Advisory Board chaired by Sir John Beddington.

Derek Allen, Lead Technologist (Energy Generation & Supply), Innovate UK

Derek has over 30 years industrial and R&D experience in the Energy sector with large multinational organisations including GE, ABB and Alstom Power, his work has been primarily related to the technology development of turbines and generators for conventional fossil and nuclear power plants.

During his career he has managed a broad spectrum of technical and R&D business divisions, both in the UK and overseas, including Advanced Materials, Engine and Component Testing and Control & Instrumentation. He was also responsible for external collaborations, involving strategic technology partnerships with SMEs, large Companies, and Universities.

He originally joined the Technology Strategy Board (now Innovate UK) on a part-time secondment from Alstom Power in July 2007 and moved on a permanent basis in 2012. He is their Lead Technologist for Energy Generation & Supply, with specific responsibility for the nuclear sector and is also the programme manager of the newly created Energy Catalyst, formed to accelerated innovation in the energy sector from concept through to commercialisation.

He is a member of a number of national and international panels and committees including; Co-Chairman of the European Technology Platform for Advanced Materials, Chairman of the Materials UK Energy Group, member of the Energy Technologies Institute Technical Committee and Programme Management Board. In 2010 he was awarded the Institute of Materials, Minerals & Mining Gold Medal for his contribution to the industrial application of materials.

Professor Melanie Brownridge, Head of Research and Development, NDA

Melanie has worked in the nuclear industry for 18 years starting with BNFL (later National Nuclear Laboratory) focussing on effluent technologies and operational plant support. Melanie undertook a variety of roles including Programme Manager for legacy waste characterisation.

Melanie joined the Nuclear Decommissioning Authority in 2005 and is currently Head of Technology. She is responsible for development and implementation of the NDA's R&D strategy across NDA's estate. This includes the NDA's Direct Research Portfolio which sponsors strategic R&D work across NDA's mission linking innovation and skills. Melanie is a Non-Executive Director of Radioactive Waste Management Ltd, a wholly-owned subsidiary of NDA, since its formation in April 2014.

Melanie is also a visiting Professor at the School of Chemical and Process Engineering at the University of Leeds.

Dr Neil Bateman, Energy Portfolio Manager, Engineering and Physical Sciences Research Council (EPSRC)

Neil works in the RCUK Energy Programme which has a current portfolio in excess of £750M across the UK Research Councils. He has had responsibility for the Nuclear Fission portfolio at EPSRC for two and a half years, having previously administered the renewable energy portfolio for three years, looking after Bioenergy, Solar, Wind and Marine energy, Fuel cells, Hydrogen and Energy Storage. He was responsible for compiling data on the overall size and funding trajectory for the RC energy portfolio for planning future commitment profiles, and communicating this to BIS, between 2007 and 2014. In 2010 he organised the international review of UK energy research. Neil will be sharing the nuclear portfolio with Dr Jacqui Williams from September and will be taking over responsibility for the Whole Energy Systems research portfolio.

Neil originally trained as an engineer and worked in Industry for twelve years before retraining as a geochemist and subsequently moving to the Engineering and Physical Sciences Research Council in 2001. He has worked in a variety of roles within the EPSRC including Aerospace and Defence, Manufacturing, Cross Disciplinary Interfaces and Nuclear Fusion.

David Senior, Deputy Chief Inspector, Office For Nuclear Regulation

David Senior is a Deputy Chief Inspector with the United Kingdom's Office for Nuclear Regulation (ONR). David is an Executive Member of the ONR Board and currently Director of Regulatory Assurance.

Previously David was a Programme Director across two of ONR's front line operational programmes the Defence Programme and the Decommissioning, Fuel & Waste Programme. In this capacity David had responsibility for the regulation of nuclear safety at 26 nuclear licensed and non- licensed sites across the UK and the strategic interface with Government Departments and the Nuclear Decommissioning Authority.

David has also operated as a Deputy Director responsible for Nuclear & Radioactive Waste Policy the UK Government's Department of Energy & Climate Change. He was responsible for civil nuclear and radioactive waste policy both within the UK and Internationally, providing strategic direction and working closely with Government Ministers.

David is a Chartered Mechanical Engineer and has extensive regulatory experience across the wider nuclear industry acquired over 20 years. He was responsible for delivering a landmark regulatory policy that has secured a stage-wise reduction in stocks of heat generating highly active liquor stocks in the United Kingdom, and thus securing wider international confidence.

Appendix B: Nuclear Innovation and Research Office

NIRO is a dedicated expert secretariat for NIRAB and acts as the delivery arm of NIRAB by:

- Providing secretariat support and analytical capacity,
- Carrying out gap analysis in order to inform NIRAB's advice to Government on R&D programme priorities,
- Coordinating nuclear innovation and R&D activity and communications within and between Government and industry,
- Producing business cases to support NIRAB recommendations to specific nuclear R&D,
- Producing an annual report and other reports, as required, under the guidance of NIRAB.

NIRO is hosted within the National Nuclear Laboratory and is staffed by secondments from NNL and Industry. NIRO currently comprises the following four people:

Gordon Bryan, NIRO Director

The Director is responsible for the day to day leadership of NIRO, for maintaining strong links with key stakeholders including the NIRAB Chair, NIRAB members and Government officials. Gordon is on secondment from NNL.

Andrew Brown, Chief Technologist

The role of the Chief Technologist is to work with NIRAB members, NIRAB sub-groups and other stakeholders to ensure that the technical basis for NIRAB recommendations is clearly communicated. Andrew is on secondment from Rolls-Royce.

Andrew Howarth, Head of Technical Business Development

The Head of Technical Business Development is responsible for supporting Government Departments in the development of business cases for the research and innovation R&D programmes recommended by NIRAB, ensuring they meet the commercial objectives of Government and industry. Andrew is on secondment from NNL.

Simon White, Project Administrator

The Project Administrator leads the day to day activities required to operate the NIRO and to ensure that the administrative requirements of the Project are met effectively. Simon is on secondment from Rolls-Royce.

Appendix C: Glossary

ADRIANA	Advanced Digital Radiometric Instrumentation for Applied Nuclear Activities
ATF	Accident Tolerant Fuels
BIS	Department for Business, Innovation and Skills
BWR	Boiling Water Reactor
C&I	Control and Instrumentation
CCFE	Culham Centre for Fusion Research
CDT	Centre for Doctoral Training
DECC	Department of Energy and Climate Change
EPSRC	Engineering and Physical Sciences Research Council
FOAK	First of a Kind
IP	Intellectual Property
JRIC	Joint Research and Innovation Centre
LCICG NSG	Low Carbon Innovation Coordination Group – Nuclear Sub-group
LCOE	Levelised Cost of Electricity
MIDAS	Materials for Innovative Dispositions from Advanced Separations
MoD	Ministry of Defence
NAMRC	Nuclear Advanced Manufacturing Research Centre
NDA	Nuclear Decommissioning Authority
NESA	Nuclear Energy Skills Alliance
NFCE	Nuclear Fuel Centre of Excellence
NIC	Nuclear Industry Council
NIRAB	Nuclear Innovation and Research Advisory Board
NIRO	Nuclear Innovation and Research Office
NIS	Nuclear Industrial Strategy
NNL	National Nuclear Laboratory
NNUF	National Nuclear Users Facility
NNUMAN	New Nuclear Manufacturing
NOAK	Next of a Kind
NSAN	National Skills Academy for Nuclear
NWDRF	Nuclear Waste Decommissioning Research Forum
PWR	Pressurised Water Reactor
R&D	Research and Development
RACE	Remote Applications in Challenging Environments
RCUK	Research Councils UK
SMR	Small Modular Reactor
TRL	Technology Readiness Level

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Further information about NIRAB is available at:
www.nirab.org.uk

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