NUCLEAR INNOVATION AND RESEARCH ADVISORY BOARD

NIRAB Annual Report 2014

NIRAB-35-4

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Foreword from the Chair

I am delighted to present this first annual report for the Nuclear Innovation and Research Advisory Board (NIRAB). Our aim is to advise on where research and innovation is needed to underpin Government and industry's vision of a vibrant nuclear sector that plays a significant role in delivering a secure, sustainable and affordable low carbon energy future, creating an industrial sector that makes a positive contribution to the economy through high value jobs and exports over many decades.

The UK has the ability to realise this vision, and research and innovation will be the foundation for our success going forward. We pioneered the nuclear industry over half a century ago, breaking new ground with our research, and our international standing today is based on this heritage. However, the 20 year gap from the mid 1990s in funding for targeted mission led R&D into next generation systems has led to a vulnerable and fragile skill base in key areas of our nuclear capability. NIRAB has focused on identifying targeted R&D interventions which will both yield long term opportunities for our industry and secure the skill base. Reinvigorating our high end skills across the fuel cycle will not only enable us to make informed choices to decide our own nuclear future, it will help our companies attract and develop the scientists and engineers who will lead future advances in technologies that will see the UK back at the top table of nuclear nations.

NIRAB has over 2014 assessed the UK's current R&D position and identified the areas in which research and innovation is needed as a priority to achieve our ambitious vision. With the right programmes in place we can play a key role in developing safer, accident tolerant nuclear fuels, our advanced manufacturing capability can help to design reactors that are cheaper and easier to build and operate, and our innovations in recycling and waste management can make sure there is an optimal solution to long term disposal, minimising the impact on future generations.

In formulating our advice the industry and academic communities have contributed significant effort and enthusiasm, working well together. I would like to express my gratitude to all those that have given their time supporting NIRAB's efforts, demonstrating the huge amount of goodwill behind NIRAB. It is disappointing that, even though NIRAB's advice was welcomed by Ministers, the Government has not been able to allocate the funds necessary to enable a programme of R&D to commence this coming year.

The emphasis must now shift to 2015 as the Government sets out the budget for the next Parliament. We will all work hard to ensure that momentum is not lost and key existing and emerging gaps in the UK's skill and capability base are addressed in the next Comprehensive Spending Review. NIRAB is looking forward to a busy and crucial year developing advice on the future direction of nuclear research and innovation in the UK.

Dame Sue Ion

Chair, NIRAB

Executive Summary

NIRAB was established in January 2014 to advise Ministers, Government Departments and Agencies on publicly funded research and innovation required to underpin Government policy in the civil nuclear sector. This first annual report details the activities NIRAB has undertaken to date. The main focus has been to identify where investment is urgently needed to address current gaps in funding, specifically in areas not addressed by the Nuclear Decommissioning Authority (NDA), Research Councils, and Innovate UK. NIRAB has engaged widely in formulating its advice, which aims to meet the UK's objectives to:

- Develop data to inform strategies that maintain energy security and meet the Government's commitment to manage climate change
- Deliver the research required to drive down the cost of energy to the consumer
- Enable UK companies to develop a competitive edge in the global nuclear market, leading to high value science and engineering jobs, products and manufacturing capability that will be catalysts for economic growth.

There is a clear gap in the UK's current R&D activity, if these objectives are to be met, in relation to next generation nuclear reactor technologies and their associated fuel cycles - an area of increasing activity in leading nuclear nations worldwide, and where the UK would be welcomed into international programmes, securing a position at the top table of nuclear nations. NIRAB has identified and made the following recommendations for R&D that play to the UK's strengths:

Nuclear Fuel Fabrication - investment in the development and manufacture of the next generation of safer, accident tolerant and more efficient nuclear fuels, with the ultimate goal of large scale manufacture of fuels from within the UK servicing the future global market.

Advanced Reactor Development - investment in R&D in areas that aim to give UK companies a competitive edge in the design and manufacture of significant reactor components for Small Modular Reactors (SMRs) and Generation IV reactors, creating the Intellectual Property (IP) crucial to win high value manufacturing contracts. Success would secure a share in the global market forecast to see an investment of $1.2 trillion by 2030.

Recycle and Waste Management – investment in R&D into advanced recycle and waste management technologies, which is particularly important for Generation IV fast reactors, with the aim of increasing security of supply by recycling irradiated fuel, reducing waste volumes and minimising the burden on geological disposal facilities. The UK currently has world leading expertise in this area and through R&D we can play a significant and influential role internationally in evolving reactor and fuel cycle systems, substantially increase our international profile, generate the evidence we need to inform energy policy and determine the feasibility of closing the fuel cycle.

It is crucial that these areas of research are supplemented with investment in R&D in a number of enabling technologies such as remote handling and modelling and simulation which in themselves also offer commercial opportunities for exploitation by industry once developed.

Provision must also be made to develop tools to assess and compare a range of different technologies effectively and to evaluate emerging nuclear technologies such as Molten Salt Reactors and U-Battery to enable the UK to remain informed of advanced developments on the global stage and take advantage of completely new market opportunities.

> ***Small Modular Reactors*** - NIRAB agrees with the recommendations from the recent feasibility study published by the National Nuclear Laboratory (NNL) to conduct further technical and economic assessment on current designs to inform any UK decision to enter the SMR market. It also noted the very different opportunities presented by innovative proposals for nuclear batteries and the need to further explore potential markets.

Development of next generation technologies will not be driven by the private sector. The risks and uncertainties associated with potential deployment of SMRs and the timescales and costs to commercialise Generation IV systems are too great to justify private investment in the short term. This kind of technology simply will not come to fruition without Government intervention, a position adopted by leading nations worldwide.

The need for investment is now, with this urgency driven by two main factors:

- An increasingly pressing need to underpin the existing skill base and develop the next generation of subject matter experts. Many of the current UK experts reached their level of expertise carrying out R&D in the 1970s, 80s and 90s and are now approaching retirement. The normal pipeline for development of subject matter experts was broken in the mid 1990s when Government investment in next generation systems ceased.
- Windows of opportunity currently exist that will not remain indefinitely. Several countries are keen to collaborate with the UK in the development of advanced fuels, Generation IV technologies and SMRs. If the UK does not engage now others will seize the opportunities, denying our industry base the chance to get a foothold in a market that has intergenerational implications of economic success for those in at the outset.

Further inaction in reinvigorating the UK R&D skill base will jeopardise the success of the Nuclear Industrial Strategy, a sentiment echoed by the Nuclear Industry Council. The UK would lose credibility on the international stage and with it the potential economic benefits from inward investment and exports. We will continue to be passive recipients of nuclear technology as we are for the current new build projects with no opportunity to create high value jobs and limiting our ability to reduce costs.

The forthcoming year will see NIRAB further develop and strengthen the case for its recommendations. It will work with Government to prioritise leverage gained from international collaboration. It will target efficiency reviews of the existing Public Sector R&D and identify where further investment in safety and security related R&D may be appropriate.

Key Recommendations

- **A programme of R&D across the range of priority areas outlined in this report must be put in place as a matter of urgency.** While capital funding allocated to date has been welcome it is not on its own sufficient to deal with the looming high end skills crisis or to plug the gaps identified in R&D which would preclude realisation of the Nuclear Industrial Strategy.
- **Sustained R&D funding in the broad region of £50 million per year is required to establish the UK at the top table of nuclear R&D nations.** This should be in addition to that already funded by the NDA, Research Councils and Innovate UK. This level of funding can assist the UK in gaining a significant stake in a future nuclear reactor market which could include SMRs in the near term leading on to Generation IV technologies in the longer term.
- **The identified priority R&D areas must be seen as an interconnected integrated case for investment to realise the full range of benefits.**

Specific Themed Recommendations

Small Modular Reactors

- Commission the next phase of SMR technical and economic analysis with the aim of maximising the opportunity to create the IP required to strengthen the UK negotiating position in any collaboration with international partners (Recommendations 32 to 35).

Fuel Fabrication

- Commission the R&D required to gain a position in the emerging market for the fabrication of Accident Tolerant Fuels (ATF) (Recommendation 1).
- Use existing facilities to develop a fabrication route that would enable the UK to become the fuel supplier of choice for the French ASTRID reactor (Recommendation 2).
- Develop IP in the fabrication of robust coated particle fuels that would support the commercialisation of the U-Battery and other High Temperature Reactors (Recommendation 3).

Advanced Reactors

- Establish the UK as a partner of choice in commercialising advanced reactors by building on existing UK expertise to:
    - Develop the high temperature radiation tolerant materials required to construct the next generation of reactors (Recommendations 7 and 8)

- Further develop the ability to predict heat transfer in the reactor core (Recommendation 9).

- Enable UK suppliers to secure a stake in the market to manufacture high value components for both current and future reactors by developing advanced manufacturing techniques (Recommendation 11).

Fuel Recycling and Waste Management

- Establish the UK as a world leader in the development of safe, proliferation resistant and economic technologies that could be deployed to improve energy security and sustainability (Recommendations 12 to 14).
- Develop the waste management technologies required to deal with any novel waste streams produced by advanced proliferation resistant recycle technologies (Recommendations 13 and 14).

Essential Enablers

These main fuel cycle areas need to be complemented by research activities in the following essential enabling areas:

- Strategic assessment tools to investigate the impact of adopting a range of reactors and fuel cycles. (Recommendation 19)
- Modelling and simulation tools and capabilities (Recommendations 20, 21 and 22)
- Public engagement strategies (Recommendations 23 and 24)
- Processes to enable the use of modern control and instrumentation systems (Recommendation 25 and 26)
- Assets to enable the development of robotics and remote managing equipment (Recommendation 27)
- Knowledge management of historical nuclear data, knowledge and materials (Recommendations 28, 29 and 30).

NIRAB also recommend that provision is made to evaluate emerging nuclear technologies, such as Molten Salt Reactors (Recommendation 31).

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1 Introduction

NIRAB was established in January 2014 and met four times in the course of the year. NIRAB was set up by Government to advise Ministers, Government Departments and Agencies where additional public funded innovation and research in the nuclear sector is required to enable the objectives set out in the Nuclear Industrial Strategy[1] (NIS).

This document is NIRAB's 2014 annual report and provides:

- A summary of the work NIRAB has undertaken in 2014, including recommendations for research and innovation priorities and capital infrastructure (Sections 2 to 7 and 9)
- A description of the proposed future work for NIRAB and the Nuclear Innovation and Research Office (NIRO) (Section 8)
- A description of NIRAB and NIRO including Terms of Reference, membership and structure (Appendix).

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 Background to NIRAB

NIRAB was established in January 2014 as a direct result of an action within the NIS published in March 2013. NIRAB's primary purpose is to advise Government on the level, approach and coordination of nuclear innovation and R&D that will keep future energy options open and enable both domestic and international commercial opportunities to be realised by the UK.

The NIS was published alongside a suite of supporting documents including an R&D Roadmap[2], and sets out aims for nuclear energy to play a significant role in the UK's energy mix by 2050 (up to 75 GW of nuclear energy[3]), with an emphasis on reducing the cost of electricity to ensure nuclear is competitive with all sources of low carbon energy.

R&D features prominently in the NIS, which captures the Government's response to a highly critical 2011 report from the House of Lords on the UK's nuclear R&D capabilities[4] and the

1 Nuclear Industrial Strategy: The UK's Nuclear Future, URN BIS/13/627, March 2013

2 Nuclear Energy Research and Development Roadmap: Future Pathways - URN BIS/13/632, March 2013

3 DECC Carbon Plan, 2011

4 House of Lords Select Committee on Science and Technology, 3rd Report of Session 2010-2012, Nuclear Research and Development Capabilities. ISBN 978 0 10 847395 1, November 2011

recommendations of the Ad-Hoc Nuclear R&D Advisory Board[5]. Prior to the Government's recent re-commitment to new nuclear build, spending on nuclear energy focussed R&D in the UK had fallen to historically low levels. The NIS and R&D Roadmap recognise that Government funded research is required in the near term to ensure that the UK has the right skills, knowledge and infrastructure base from which to make informed decisions on the future direction. Government must take a lead and make suitable investment due to the long term nature of commercially deploying new nuclear technologies.

1.2 Objectives for Nuclear R&D and Innovation

R&D and innovation is the foundation to sustaining and enhancing capability in nuclear engineering. A substantive, broad ranging programme of nuclear R&D is needed to enable both the Department of Business, Innovation and Skills (BIS) and the Department of Energy and Climate Change (DECC) to meet their objectives.

Contribute to UK economic growth:

- Enable the UK to engage in international collaborations to deliver future nuclear energy technologies where these are considered valuable to UK long term interests, and leverage funding from international programmes
- Maintain and enhance the UK's international standing in the nuclear field that will in turn lead to inward investment and exports
- Enable the UK research base to be involved in early stages of design development and secure IP that can be exploited in future global markets
- Create high value jobs in the UK.

Ensure nuclear energy is cost-competitive:

- Enable the UK to reduce the cost of nuclear ownership, which will in turn reduce energy prices to consumers.

Maintain energy security and manage climate change:

- Provide a secure form of low carbon energy which will help meet CO_2 reduction commitments.

Inform future Government policies:

- Provide the evidence base needed to inform the Government's future energy, environmental and security policies.

Sustain nuclear security and safeguards:

- Sustain the UK's credibility and expertise when supporting nuclear non-proliferation and nuclear security on the international stage

5 Ad Hoc Nuclear Research and Development Advisory Board - Summary of the Recommendations and Work of the Board - URN BIS/13/628, March 2013

- Ensure safeguards and security is built in by design to any future systems and fuel cycles.

Improve nuclear safety:

- Deliver continual improvements in nuclear safety and maintain the UK's ability to effectively manage the consequences of a major nuclear incident here or abroad.

Ensure the UK is able to deliver an increased level of nuclear energy:

- Sustain critical UK capabilities in areas that are at risk if no action is taken
- Attract new entrants into the nuclear sector through cutting edge R&D
- Develop new and leading capabilities for the UK
- Increase public understanding and confidence in nuclear energy generation.

NIRAB's recommendations to Government directly relate to achieving these departmental objectives and to the objectives of the NIS.

1.3 NIRAB Meetings in 2014

Four NIRAB meetings were held in 2014; January, March, July and October. Full details of each NIRAB meeting including the minutes are available on the NIRAB website (www.NIRAB.org.uk)

2 Recommendations for Priority Nuclear Research and Innovation

NIRAB's main focus in 2014 was to make recommendations to Government on the priority areas for research and innovation investment to re-invigorate the UK nuclear industry and start the journey to deliver objectives of the NIS and Government's energy policy.

The details of the recommendations were established through a process of consultation with members of NIRAB and the wider nuclear community. This included a series of workshops and meetings focusing on a range of detailed topic areas.

The workshops used the NIS and its underpinning documents to guide the long term strategic direction for the R&D activities. In addition a series of near term aims and objectives were established by NIRAB to provide a more focussed direction for the programme. These five and ten year aims and objectives are presented in Figure 1.

The resultant series of recommendations consist of a number of technical components across the nuclear energy generation landscape, together with cross-cutting enabling activities. The series of recommendations should be viewed as an integrated suite of activities, all of which in totality is required to meet the objectives of the NIS. The entirety of the recommended activities is outlined in Figure 2 with the detail of the priority elements, required to be completed in financial year 2015, described in the remainder of this section.

This process also identified a number of recommended R&D activities that are not required to start until after 2016. These are not reflected in this report with only NIRAB's priority recommendations being detailed. The details of these activities have been recorded within NIRO and will be used when establishing longer term programmes.

NIRAB provided to Government in 2014 its recommendations on initial high priority research areas with the advice that circa £37 million of funding be secured for research infrastructure and programmes for a one year period from April 2015 to March 2016. DECC has secured £7 million for some aspects of the capital infrastructure and funding to conduct further technical and economic assessment of SMRs. Funding for the remainder of the NIRAB recommended programme of work has not been secured. The recommendations and work done to date will now be recast into a longer term package of work and submitted to Government as part of the Comprehensive Spending Review (CSR) process. An indicative cost estimate in the region of £50 million a year is considered necessary to deliver the work. This figure has been derived whilst developing the R&D recommendations for each individual activity.

<table>
<tr><th colspan="2">Technology Focussed Themes</th><th colspan="3">Cross Cutting Themes</th></tr>
<tr><th></th><th></th><th>Strategic Assessment</th><th>Modelling and Simulation</th><th>Public Engagement</th></tr>
<tr><td>Fuel</td><td>Within 5 years the UK will have manufactured one or more test pins for an advanced reactor for irradiation in a materials test reactor.

Within 10 years the UK will be the manufacturer of choice for fuel for a demonstration reactor, providing a basis for future fabrication on a commercial scale.</td><td rowspan="4">Within 3 years the UK has developed and demonstrated appropriate tools and techniques to evaluate a range of potential fuel cycles. The tools will have been used to generate the information required to make informed decisions, to shape future research programmes and to understand the potential impact of alternative fuel cycles on geological disposal.</td><td rowspan="4">Within 5 years the UK will have an integrated modelling and simulation capability that supports all aspects of fuel cycle research.
Within 3 years to establish a virtual prototyping centre using state of the art computing techniques. Within 5 years of establishing this centre to have developed new codes that will make the UK a leading nation in this area.</td><td rowspan="4">Within 5 years further research will have been completed which identifies the tools and techniques that can be used to communicate effectively with the public on all aspects of nuclear power. Within a further 2 years these tools and techniques will be routinely used to engage with the public.</td></tr>
<tr><td>Reactors</td><td>Within 10 years the UK will:
• Be a key partner in the development and demonstration of an advanced reactor system
• Be a supplier of selected significant reactor components.</td></tr>
<tr><td>Recycle/ Waste Management</td><td>Within 5 years the UK will demonstrate:
• A safe, economic, efficient and proliferation resistant aqueous LWR fuel recycle technology at lab scale (active)
• Components of a fast reactor fuel pyroprocessing recycle technology (inactively)
• Effective waste immobilisation technologies for the waste forms generated by advanced recycling technologies.

Within 10 years the UK will have demonstrated a novel overall flowsheet (likely to involve aqueous and pyroprocessing) to underpin a fast reactor system.</td></tr>
<tr><td>Techno-economic assessment of emerging technologies</td><td>Within 5 years the UK will:
• Have IP in relevant emerging technologies
• Have relevant supply chain expertise and capacity to develop SMR / emerging technologies in the UK
• Implemented necessary regulatory and site-related procedures to enable deployment of SMR / emerging technologies
• Have international collaborations in place for emerging technology development.</td></tr>
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Figure 1 - NIRAB Near Term Aims and Objectives

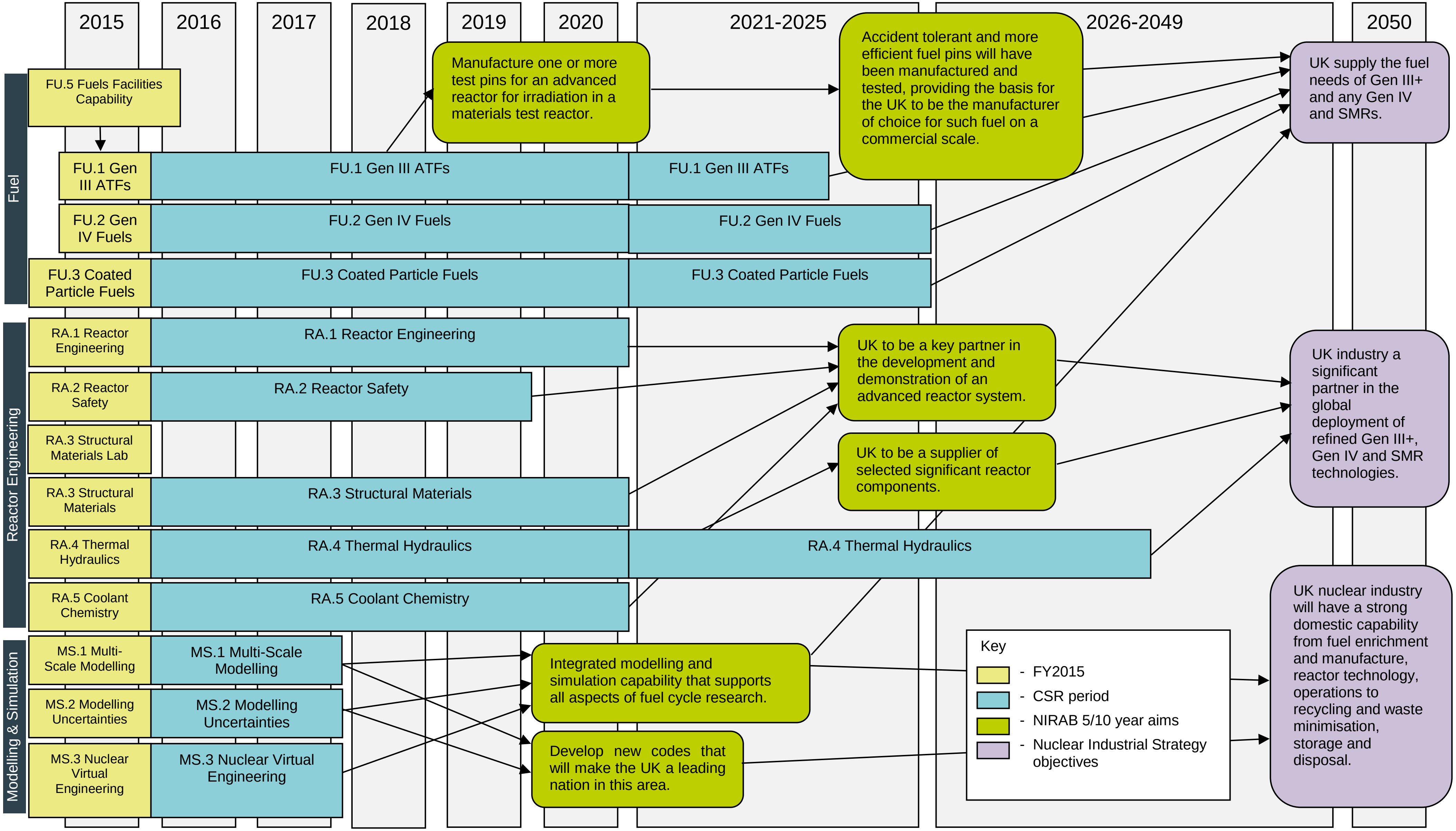

Figure 2 – R&D Recommendations

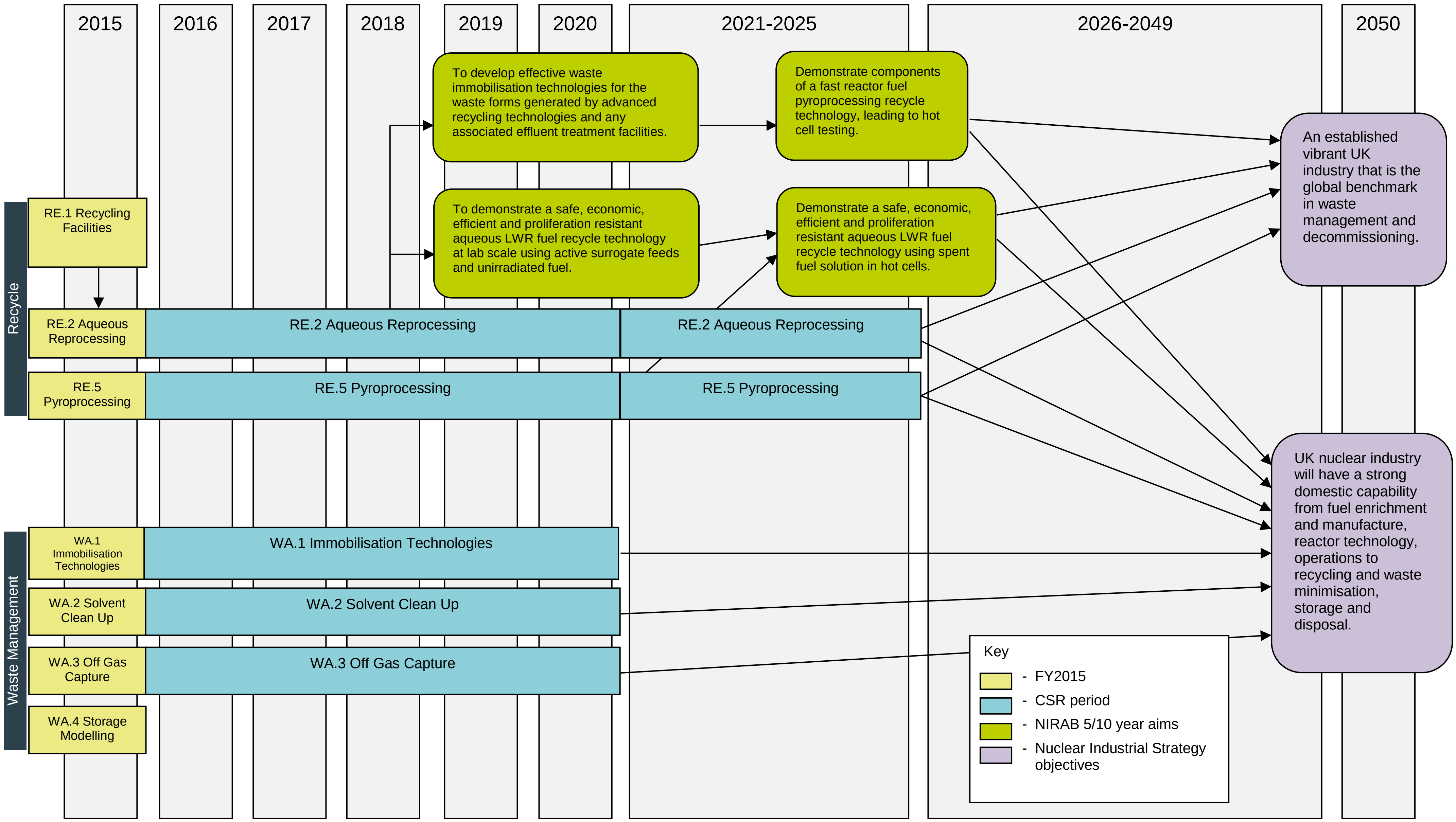

Figure 2 – R&D Recommendations (cont)

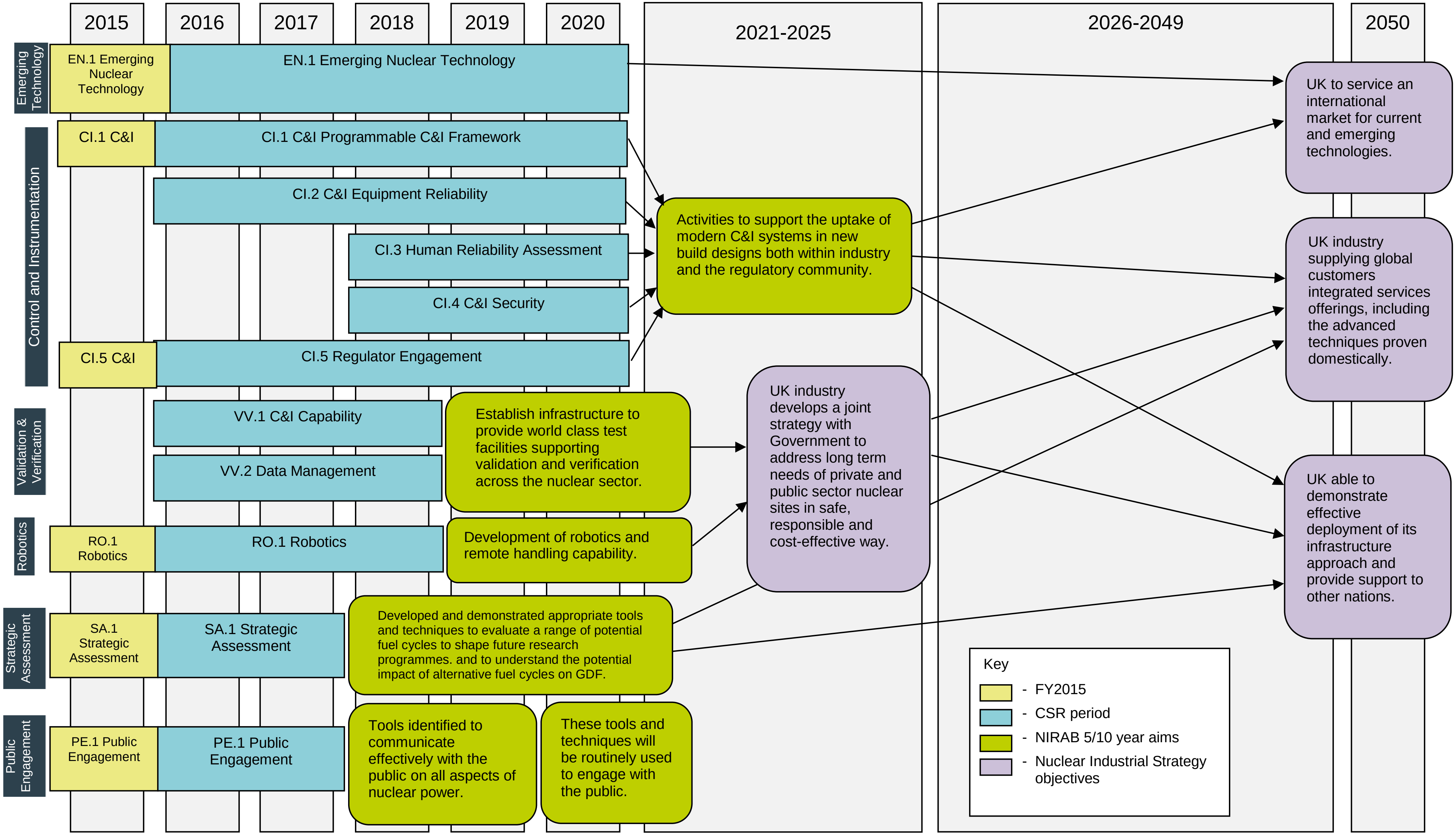

Figure 2 – R&D Recommendations (cont)

2.1 Advanced Nuclear Fuel

2.1.1 Accident Tolerant Fuels (FU.1)

The principal aim of ATF is to develop fuels that are more tolerant of temperature excursions that may occur under accident conditions, and, in the case of severe accidents, to extend the period of time over which fuel integrity is maintained, providing operators with an extended window of response time. In practice, this is achieved through advanced cladding materials, either modifications to existing Zirconium-based claddings, such as coatings, or novel materials such as ceramic composites. In order to compensate for the higher cost of adopting such cladding materials, ATF developments include advanced fuel materials that could improve fuel efficiency. There is significant international interest in this area: most notably in the USA where several national programmes are underway, and in Europe under Horizon 2020, providing opportunities to collaborate internationally and leverage funding.

Recommendation 1

Gain an understanding of the mechanics involved in joining advanced cladding materials to nuclear fuels, develop techniques to enable ATF manufacture and gain an understanding of the performance of ATFs.

The successful development of ATF provides a significant opportunity for exploitation within Generation II, Generation III, and SMR systems, and the knowledge and capability generated are expected to provide a significant stepping stone towards establishing the capability to develop fuels for Generation IV reactors.

ATF are a significant business opportunity and have the potential to create high value employment and IP that can be exploited worldwide, stimulating growth and exports. Their use within Generation III or SMR reactors would lead to continuous safety and efficiency improvements and help reduce the cost of nuclear ownership, which in turn can contribute to reductions in energy prices.

The operation of ATF could also increase public confidence in nuclear power which could be the catalyst to increasing the level of nuclear generated electricity within the UK.

2.1.2 Generation IV Reactor Fuels (FU.2)

One of the key milestones set out in the NIS is for the UK to be capable of supplying fuel for Generation IV reactors and there is a window of opportunity approaching to provide fuel for fast reactor prototypes programmes such as the French ASTRID reactor.

Recommendation 2

Develop and test a Mixed Oxide fuel pellet production line capable of small scale production of fuel for use in research reactors, demonstrators for emerging reactor systems and prototype Gen IV reactors. This could be delivered by an extension to existing facilities within the UK.

This capability would greatly enhance the UK international standing, allowing the UK to establish a stake in the leading international Generation IV programmes (such as ASTRID) and generate significant IP. The future Generation IV fuel manufacture will be a multi-billion pound market which the UK could have a significant stake if the opportunity to build on our current fuel manufacturing capability is taken.

2.1.3 Coated Particle Fuels (FU.3)

Coated Particle Fuels (CPFs) are exceptionally robust, and offer the prospect of reactor systems that are inherently safe (i.e. where no safety systems are required to protect the fuel). This technology has been proposed for near to medium term SMR deployment (e.g. the U-Battery system) and is also expected to be employed by the Generation IV Very High Temperature Reactor (VHTR) system.

Recommendation 3

Complete commissioning of a CPF kernel manufacturing lab at the NNL Preston facility, investigate novel dual coatings using the chemical vapour deposition coater at Nuclear Fuel Centre of Excellence (NFCE), and conduct preliminary research into compacting for fuel element manufacture.

This capability would allow the UK to generate significant IP in the production of CPFs, a technology that could be the mainstay of advanced future fuel types for all generations of reactor systems. CPFs would share many of the business opportunities and benefits as those seen from ATFs, developing them in parallel would provide diversity of approach for the UK.

2.1.4 Advanced Fuels Facilities (FU.5)

In order to carry out research to develop advanced nuclear fuels, a number of supporting active and non-active facilities are required. Facilities have been proposed at the NNL Central Lab and within universities that will be open access to researchers.

Recommendation 4

Deliver equipment to enhance the UK's advanced nuclear fuel manufacturing capability and support the programmes developing ATFs.

In addition to being vital to support the UK's own research and fuel development programmes this suite of facilities will attract interest from international researchers and lead to inward investment and collaboration.

2.2 Advanced Reactors

The reactors component of the proposed research programme is designed to contribute to the objective in the NIS of the UK being a key partner of choice in commercialising advanced reactor technologies worldwide, including Generation III+, IV and SMRs.

Advanced Reactors has been categorised into six topics comprising reactor engineering, thermal hydraulics and reactor physics, structural materials, reactor safety, coolant chemistry and advanced manufacturing.

2.2.1 Reactor Engineering (RA.1)

Reactor engineering encompasses all the practical aspects of turning reactor concepts into safe, technically sound and commercially viable systems. This includes the topics of structural integrity, core instrumentation, in-service inspection, repair, energy conversion systems, interfaces with the reactor and development of codes and standards.

One of the challenges facing UK manufacturers supplying components into the worldwide market is ensuring that their products and services meet the requirements of the codes and standards in each regulatory jurisdiction. This is often where indigenous manufacturers that are familiar with local standards and focus solely on them can again a competitive advantage.

Recommendation 5

Facilitate UK supply chain qualification and competitiveness by providing guidance for UK manufacturers on how to achieve the requirements of a wide range of codes and standards.

Building to a superset of world standards that UK manufacturers could qualify their components or services to once would remove the high costs of having to requalify everything differently for customers from different regulatory jurisdiction. This will increase UK industry's competitiveness and enable more overseas orders to be won. This will contribute towards economic growth and sustain UK high value engineering capability.

2.2.2 Safety Engineering (RA.2)

In addition to the design of reactors it is important to have expertise in the design and implementation of safety assessment methodologies. Probabilistic Safety Assessment (PSA) methods currently in use in the UK nuclear industry are well-established and broadly consistent with international best practice. However, safety assessment and licensing regimes worldwide have recently been reviewed and several updates are expected, to take account of lessons learned from Fukushima, new Safety Assessment Principles are due along with new international PSA guidance. These will require new PSA approaches, taking more account of uncertainties and also human actions.

Recommendation 6

Assess and develop the UK's capability in nuclear safety engineering alongside a review of the international opportunities and global capability. This should then be used to provide targeted development for the UK's safety capability to realise future opportunities.

Developing the UK's nuclear safety engineering capability will allow the UK to capitalise upon reactor developments planned in the near future across the world. This includes the application of human factors and human machine interfaces in the nuclear field, a current area of strength within the UK that could be developed into a world-class commodity. This will enhance the UK's international standing, which in turn would lead to inward investment.

The UK safety community must have new PSA approaches and tools in the longer term in order to be able to meet revolutionary changes associated with Generation IV technologies and allow safety cases to be produced for Generation IV reactors. This will allow the UK to maintain its international standing in the fields of safety engineering and regulation.

Development of the UK's safety engineering capability will also drive continuous improvement into nuclear safety within the UK and the UK's ability to effectively manage the consequences of any nuclear incident.

2.2.3 Structural Materials (RA.3)

Radiation damage of structures surrounding a reactor core is a particular engineering challenge and is common to both fission and fusion reactors. A number of potential degradation mechanisms need to be understood in the high temperature high radiation environment of a reactor.

These mechanisms include corrosion, radiation-induced swelling, creep, other ageing mechanisms, fault initiation and fault growth mechanisms. These can be a determining factor in overall lifetimes and economics of nuclear power components.

Recommendation 7

Develop a better understanding of high dose radiation damage by establishing the capability to handle radioactive materials at the Diamond light source and establish an electron microscope at the Dalton Cumbria Facility.

This R&D would develop an understanding that would inform life extension decisions for today's fleet and the design of efficient and reliable fission and fusion systems for future deployment. This can support the continued level of nuclear energy production within the UK, supporting energy security and affordability.

The new facilities introduced as part of the Government funded National Nuclear User Facility (NNUF) initiative will allow the most up-to-date experimental techniques to be used on irradiated material, yielding greater understanding for both fission and fusion, particularly when combined with the latest simulation capability. Use of these facilities will attract international attention and attract new entrants to the nuclear sector.

Recommendation 8

Maximise value from the NNUF by targeting research to establish the long term effects of temperature, chemistry and radiation on the properties of a range of structural materials.

2.2.4 Thermal Hydraulics and Reactor Physics (RA.4)

All currently planned and proposed new reactor systems rely on 'passive' thermal hydraulics both under normal operations and under design basis and severe accident conditions. This characteristic crosses essentially all coolant types, including water, gas, liquid metal and molten salt coolants and air for passive post-accident secondary cooling. It is critically important to be able to predict thermal hydraulic performance when both designing and assessing the safety of a proposed reactor design.

Thermal-hydraulics is an area in which the UK has traditionally been strong, with many of the codes used across the worldwide nuclear industry originating within the UK. However, this capability has not been sustained and has seen a substantial reduction in recent years. There is a threat to maintain any UK capability in this area without an increase in R&D activity and attract new entrants to this field as current experts approach retirement.

Recommendation 9

Reinvigorate UK thermal hydraulic capability by delivering validated analysis techniques to predict buoyancy-driven 'passive' flows used within new Generation III+/Generation IV reactor systems and SMRs. This will require both the use of computer models and the generation of data to validate those models via delivery of thermal hydraulics test rigs.

These activities will sustain and develop a key suite of thermal hydraulic capabilities within the UK nuclear workforce, an area that is relevant across all facets of nuclear reactor safety and performance.

The development of codes that can be used to predict passive flows in reactor systems and the methodologies, skills and facilities to validate them will contribute valuable IP and opportunities for the UK to attract leverage from international R&D programmes.

An independent UK thermal hydraulic capability is vital for the UK to act as an informed licensor and operator or nuclear facilities, even if they are designed internationally. The availability of flexible, supporting thermal hydraulics facilities will be a vital asset to manage any in-service issues in the way the Wythenshawe boiler rig has provided invaluable support to the UK Advanced Gas-cooled Reactor (AGR) fleet. This will contribute towards long term energy security and affordability of energy prices for the UK.

2.2.5 Coolant Chemistry (RA.5)

Within the suite of Generation III+ and Generation IV reactor systems there is a wide range of coolants including water, gases and liquid metals. Having an understanding and being able to control the coolant chemistry in both primary and secondary coolant circuits is vital in managing the lifetime of reactor components and inhibiting life-limiting mechanisms such as corrosion. The UK currently has world leading capability in managing the chemistry of gas cooled reactors from experience of operating the current fleet of AGRs and metal cooled reactors from the Dounreay Fast Reactor programme. This capability should be sustained and built upon to service opportunities in the development of Generation IV reactors.

Recommendation 10

Develop knowledge and capability on the chemistry regimes for Generation III and Generation IV reactor systems to position the UK with expertise that can be leveraged into a maximum number of future systems.

This will enable the UK to establish IP both with the operational side of chemistry control but also in the design, development and manufacturing of new reactor components, opening up opportunities within international markets to UK industry.

Development of the UK knowledge in nuclear chemistry and corrosion will sustain key UK skills and deliver continuous improvements in nuclear safety throughout the current and future reactor fleet.

2.2.6 Advanced Manufacturing (RA.6)

High value manufacturing is widely understood to be a key part of future growth for the UK and advances in manufacturing techniques will position UK industry to gain a stake in component manufacture for current and future reactor designs (including SMRs and Generation IV systems). There is a narrow window of opportunity approaching for the UK to gain involvement in SMR and Generation IV reactor developments as the design and manufacturing engineering is completed. Once the development is complete over the next two to five years, it will be very difficult for UK industry to usurp the incumbent overseas manufacturers.

Over recent years significant investment has been made in capital facilities to support advances in manufacturing, most notably the Nuclear Advanced Manufacturing Research Centre (NAMRC) at Rotherham. It is imperative that programmes of research are funded to fully utilise these facilities and allow them to release their potential.

Recommendation 11

Deliver advanced manufacturing capabilities in the following areas:

- Advanced joining technologies
- Hot isostatic pressing for dissimilar materials
- Manufacturing process inspection technologies
- Fabrication, machining and assembly of large nuclear components

These development programmes will integrate with the on-going Engineering and Physical Sciences Research Council (EPSRC) funded New Nuclear Manufacturing (NNUMAN) programme and build upon the Nuclear Sharing in Growth programme at the NAMRC.

Advances in manufacturing capability are likely to attract international attention and opportunities for the UK to collaborate in projects such as the ASTRID fast reactor prototype.

New manufacturing technologies and processes will create significant amounts of valuable, transferable IP for UK industry and increase the competiveness of UK companies. This will lead to high value engineering jobs within the UK manufacturing base, contributing to UK economic growth.

2.3 Recycling

Research is required to develop proliferation resistant recycle processes which could be economically deployed within a future closed fuel cycle. This includes the development of improved Generation III recycling processes and processes for recycling Generation IV reactor fuel. Initial research in this area is required to generate the requisite technical knowledge to underpin policy decision on whether a closed fuel cycle is desirable whilst at the same time maintaining a critically fragile skill base which is in imminent danger of disappearing with no new R&D activity due to the pending cessation of the UK's current recycling activities.

2.3.1 Nuclear Fuel Recycling Facilities (RE.1)

To support recycling R&D an integrated network of facilities should be established in which non-active, active and highly active experimental work can be carried out to develop new, safer, more proliferation resistant and cost effective processes.

Recommendation 12

Deliver equipment to enhance the UK's recycling capability and support the programmes developing new recycling techniques:

- Uranium active facilities to investigate the engineering aspects of aqueous separation technologies including, for example, centrifugal contactors.
- A laboratory facility capable of carrying out experiments on solutions containing higher inventories of plutonium and minor actinides to focus on actinide separations and conversion.
- A laboratory equipped to carry out small scale alpha active fundamental chemistry and spectroscopic studies on both aqueous and molten salt media.
- Facilities to study the thermodynamics and kinetics of molten salt systems.
- Facilities to develop head end dissolution options for thermal and fast reactor mixed oxide fuels and other candidate fast reactor fuels.

These facilities will build on existing investments and provide world class capabilities to support the NIRAB recommended research programmes and would invite international collaboration from overseas researchers.

2.3.2 Aqueous Recycling (RE.2)

Aqueous recycling has been operated within the UK at industrial scale and UK scientists and engineers have world class expertise in aqueous recycling technologies. The UK is one of only three countries that offer commercial recycling on an industrial scale. Plans are in place for this to cease in 2018, which creates a risk that the UK irretrievably loses a unique and internationally respected set of skills and capability in aqueous recycling technologies. These capabilities are an intellectual and potentially commercial asset for the UK that is in need of safeguarding.

Recommendation 13

Develop innovative aqueous recycling technologies to Technology Readiness Level (TRL) 6 and provide data for evaluating the aqueous process against alternative options and optimising advanced fuel cycle strategies.

An advanced aqueous recycling technology would allow the UK maintain a world leading position, sustain key skills and generate IP and services that could be applied to the worldwide nuclear fuel recycling market. This will contribute towards energy security and the level of nuclear power reduction within the UK.

Use of the technology would deliver improvements in the economics, proliferation resistance and environmental impacts, and minimisation of wastes generated, especially those sent to a Geological Disposal Facility (GDF).

This development work would also provide data for evaluating the aqueous process against alternative options and optimising the advanced fuel cycle strategies, supporting future policy decision making.

2.3.3 Pyroprocessing Fuel Recycling (RE.5)

High temperature reprocessing (pyroprocessing) is an emerging less well developed technology and the UK does not hold the same position in world expertise as the current aqueous recycling technology. This type of technology is required to recycle some fast reactor fuels. This area is open to development and the establishment of UK owned IP.

The UK currently has a developing capability in pyroprocessing that has been created by EPSRC's multidisciplinary REFINE project (2011-2015). Whilst this capability is a good foundation for future research, it will need to be extended and enhanced in order to underpin a programme that leads to construction of a facility based on pyroprocessing.

Recommendation 14

Understand the fundamental principles behind pyroprocessing as a mechanism to recycle used nuclear fuels and build on this to deliver economic pyroprocessing methods that can be scaled up to an industrial scale.

The use of pyroprocessing has the potential to provide significant commercial opportunities in the future global nuclear fuel recycling market. Developing processes and acquiring IP that can be scaled to industrial level will position the UK to be able to exploit this new potential global market.

This will also develop skills and capability in the recycling and waste management field that can complement other elements of the recycling programme developing the UK's capability and attracting new entrants into the field.

There are a number of future European research projects in pyroprocessing and a complementary UK programme of research would enable UK academia to collaborate, providing significant funding leverage.

2.4 Waste Management

Waste management is a key element of the nuclear fuel cycle. R&D supporting the management of the UK's legacy waste is under the remit of the Nuclear Decommissioning Authority (NDA), subsequently the NIRAB priority programme has focussed on the waste management of future nuclear fuel cycles.

New recycle processes are likely to generate new or novel wastes arising either directly from the processes themselves or from the management of liquid or gaseous effluents. Research will need to be done to develop processes to manage these wastes. In addition, research should develop waste management capabilities for new fuel types, including fast reactor fuel.

Recommendation 15

Develop immobilisation technologies for new waste forms generated by advanced recycle processes, including salt clean up, recycle and salt immobilisation from pyroprocessing.

Recommendation 16

Develop innovative technologies and processes for solvent clean-up for recycle and solvent destruction.

Recommendation 17

Develop methodologies for off gas capture from voloxidation and dissolution steps.

Recommendation 18

Develop GDF modelling and storage technologies to support final waste disposal.

Delivering advances in waste management technologies and processes would allow the UK to maintain a world leading position in nuclear waste management. This will also lead to continual improvements in the safety of waste management helping to address one of the public's key concerns over nuclear energy.

Developing these technologies will generate valuable IP for the UK that can be developed into commercial service offerings that could be applied to the worldwide waste management market.

The modelling of GDFs and the development of storage facilities will provide evidence around some of the key policy decisions to be taken by the UK when debating the most appropriate future nuclear energy scenarios for the country. This should support clear, data driven policy decisions.

2.5 Strategic Assessments

The long lead times associated with delivering a reactor design, manufacture and construction mean that a long term view must be taken when formulating policy decisions on how nuclear power should support the UK energy needs. Tools are required to assist in the strategic assessment used to inform Government policies on the strategic direction of the nuclear industry in the UK.

Recommendation 19

Deliver a suite of modelling and assessment tools and techniques that can be used to provide data to inform future Government policy decisions.

This will be a key source when identifying future research and innovation requirements, where activities can be carried out to answer specific questions and generate the information required to underpin strategic decisions. The outputs from this activity are considered critical to ensure that appropriate decisions are taken on the future of the UK nuclear energy research and will provide the evidence base needed to inform the Government's future energy, environmental and security policies.

This work will be of particular importance in determining the R&D funding required to provide robust data that will be foundation of the submissions to Government for a national programme of R&D.

2.6 Modelling and Simulation

Modelling and simulation within the nuclear industry covers a wide range of activities from very detailed neutronics modelling to analysis of whole fuel cycles and various energy scenarios. Maximum use needs to be made of modelling and simulation across this entire range of activities to reduce costs and optimise systems.

This is an area where in the past the UK has been very strong, developing codes that have been used worldwide in the nuclear industry. New, validated codes, focussed on passive flows in new reactor systems are an opportunity for innovation. There is a general need to update or develop models to run on modern computers and architecture and to provide, where possible, open source software in the way that the US Consortium for Advanced Simulation of LWRs (CASL) project has done. Emphasis needs to be on software development rather that development of new high performance computing hardware as it is felt that the current computing facilities within the UK are adequate.

Recommendation 20

Develop a capability for multi-scaled modelling to allow coupling of microstructure stress models to environmental models.

This will reduce the need for large amounts of expensive environmental testing which would increase the competitiveness of UK industry. These techniques would also be applicable to other modelling scenarios both within and outside of the nuclear industry and therefore have the potential to generate UK owned IP.

Recommendation 21

Develop an understanding of how uncertainties in current reactor models e.g. turbulence in thermal hydraulics models, can be reduced.

This research would initially be applied to existing nuclear models but also provide a framework for how future models should be developed. Reducing modelling uncertainties can increase the efficiency and economics of reactor operations and to increase safety margins.

The management of uncertainties is a significant challenge in all high-end engineering fields that utilise computer modelling. These techniques would also be applicable to a range of other engineering modelling disciplines and therefore have the potential to generate significant UK owned IP supporting economic growth.

Recommendation 22

Establish a Nuclear Virtual Engineering Centre featuring state of the art virtual engineering tools and techniques.

This would enhance capability and improve business performance and competiveness in the nuclear industry through the evaluation, application and adoption of virtual engineering tools and techniques. This would lead to manufacturing IP, increase the competitiveness and effectiveness of UK industry, leading to export potential.

2.7 Public Engagement

The NIS recognises the importance of public awareness of nuclear energy's capacity to help meet the UK's energy needs now and in the longer term. The NIS includes an action for the Nuclear Industry Council (NIC) to "work with universities, research institutes and others on programmes that improve understanding of radiation and how it is used in society and managed within the nuclear industry". A communications strategy has been developed by the Public Understanding of Nuclear Energy work stream of the NIC and this recommends research is undertaken to inform the development and delivery of the public engagement and communications strategy on nuclear energy[6].

Recommendation 23

Develop new understanding of the underlying reasons for public attitudes to nuclear energy at national, regional and individual level, how these have emerged over time and how these are shaped by events.

This work will provide research-based evidence to inform the development and delivery of the NIC's strategy for public engagement and building wider international links to strengthen the UK programme.

6 Nuclear Industry Council, In the Public Eye: Nuclear Energy and Society, July 2014

Recommendation 24

Develop evidence-based tools to inform and enhance the delivery of a national strategy on public engagement in nuclear energy and embed these within the delivery programme for the NIC communications strategy.

While these specific activities will be carried out on understanding the public perception of the nuclear energy industry all R&D activities and the overall programme itself will be used to engage the public and improve the image of the industry. Public acceptance is important if the level of nuclear energy production is to significantly increase towards the aspirations given in the NIS and to meet the UK future energy needs in a sustainable, low-carbon manner.

2.8 Control and Instrumentation

The use of programmable electronics should be considered for all aspects of Control and Instrumentation (C&I) within the nuclear industry, including high integrity protection systems within reactors and nuclear facilities. This includes updating of existing analogue C&I systems as well as implementation of new C&I systems in new plants. The increased functionality that is capable by using programmable C&I systems can also open up new possibilities to better support the operation and maintenance activities in the plant.

Many sensors and actuators used within nuclear plants are now only available with embedded processors (smart valves and sensors). This leads to a particular type of obsolescence where the original ‘dumb sensors/valves’, that feature in the reactor plant safety justification, are no longer available. This drives an inevitability of needing to have the capability within the nuclear industry to be able to use such digital based equipment in high integrity C&I safety systems.

The electronics industry will lead the bulk of the development of new C&I technologies and equipment. The challenge for the nuclear industry is to develop a framework to allow successful regulation of these technologies for implementation within nuclear plants.

Recommendation 25

Develop an approach to providing a safety justification for programmable C&I systems that will meet the expectations of global regulators and the requirements for new nuclear build.

Recommendation 26

Promote R&D activities within the regulator community to ensure that advancements in C&I technology are well understood in order that future safety cases can be adequately scrutinised.

Achieving a C&I capability will allow the UK to capitalise on a niche market in the supply of safety critical, secure programmable C&I within a well respected regulatory framework. This would establish significant IP that could be exploited across the international nuclear industry and throughout the high reliability electronics markets in other industries.

2.9 Robotics and Remote Handling

Several parts of the fuel cycle already make and will need in the future to make use of remote handling and robotics systems; it is an obvious candidate for future in situ inspections of radioactive plants. However this is an area in which there is already a great deal of activity spanning the needs of several industrial sectors including aerospace, transport, oil and gas. This includes the Autonomous and Intelligent Systems Partnership (AISP) and the Growing Autonomous Mission Management Applications (GAMMA).

The Robotics and Autonomous Systems Special Interest Group is a cross sector industrial initiative set up by Innovate UK and is developing a strategy for robotics. This is being done to address one of the UK Government's Eight Great Technologies.

Recommendation 27

Establish a nuclear focussed asset that can be used to develop robotic and remote handling systems for use in the nuclear sector.

Robotics and remote handling capabilities are key to the nuclear industry and an improvement in capability will be an enabler to other advancements in fuel manufacture and waste management. An improved capability will generate UK owned IP and feed across into other industries that utilise robotic technology situating economic growth and develop a leading capability.

Developing an asset at a nuclear licensed site will give developers a training ground that will present some of the challenges faced in providing robotic products into such locations. This will include some of the environments challenges as well as the administrative barriers and safeguards.

2.10 Knowledge Management

Effective knowledge management is of particular importance to the nuclear industry given the long product/project lifecycles and high cost of producing nuclear information and materials. The looming high end skills crisis within the UK nuclear community provides a stark realisation of the importance of knowledge management as irreplaceable capability is lost from industry and academia.

It is widely recognised that the UK's rich nuclear heritage should be leveraged to inform future programmes and provide opportunities for international collaboration and exploitation. To enable this some specific areas for knowledge capture and management have been identified by NIRAB that are considered vital to support future UK R&D programmes.

2.10.1 Nuclear Energy Agency Data Bank (KM1.1)

Much of the nuclear R&D carried out within the UK relies on continued access to nuclear data. Full details of this issue can be found in Section 6 of this report.

Recommendation 28

Ensure continued access for the UK nuclear community to the Nuclear Energy Agency (NEA) Data Bank.

2.10.2 Dounreay Fast Reactor Knowledge Capture (KM2)

For decades Dounreay was the centre of fast reactor research in the UK with many of the technologies employed being the basis for Generation IV reactors. All of the active reactor research projects at Dounreay are now complete and the site has moved into a decommissioning phase under the ownership of the NDA.

Recommendation 29

Ensure that historical fast reactor data from the Dounreay project is captured and made available to future R&D programmes.

It is expected that much of the research carried out at Dounreay will be directly applicable to the development of Generation IV fast reactors and a valuable asset. This knowledge will be a catalyst to UK involvement in many international projects developing fast reactors.

2.10.3 Nuclear Materials Archive (KM3.1)

All of the nuclear projects and reactor operations within the UK have produced nuclear materials. This includes irradiated and non-irradiated sample of structural steels, graphite and samples of exotic isotopes. All of these have potential value to future research projects and it would be cost-prohibitive to recreate many of them. It is important that the UK secures access to samples of such materials to ensure they are not disposed of during scheduled decommissioning activities.

Recommendation 30

Carry out a survey of existing nuclear materials and establish a national materials archive.

Establishing an archive will help to ensure that nuclear materials that have value to future projects are not disposed of as part of on-going decommissioning activities at current nuclear sites. It will also enable research organisations to understand what materials are available which could be a catalyst to future development opportunities.

The national archive will provide the potential to collaborate internationally. Indications have already been made from international bodies that a quid quo pro arrangement could be put in place that gives the UK access to nuclear materials held overseas.

2.11 Emerging Nuclear Technologies

The NIRAB recommendations for a programme of R&D have been directed to achieve the aims and objectives of the NIS. This has resulted in a targeted suite of R&D activities around the traditional areas of reactors and the fuel cycle. NIRAB recognise that a sustainable and fully effective programme of R&D should include a diverse range of technologies and those at all levels of maturity.

Recommendation 31

Provision should be made for investigations into low TRL technologies and systems which are applicable to the nuclear industry.

It is important to evaluate emerging technologies, such as Molten Salt Reactors, in order to understand their potential benefits as a basis for deciding whether or how these should be developed to a greater level of maturity.

3 Small Modular Reactor Feasibility Study

3.1 Background to the Study

In 2014, the Government sponsored a feasibility study on the implementation of SMRs within the UK. The aim of the study was three-fold; to determine whether SMRs are economically and technically viable, the potential role for UK industry in SMR delivery and the possible role that Government might play in supporting the industry in securing a stake in a potential SMR market. The study focused on the following areas and looked towards a ten year horizon:

- An assessment of the potential global market for SMRs
- A technical assessment of the current leading SMR designs
- Any opportunities within the SMR market for innovation that warrants UK investment
- A financial assessment of the potential costs of energy production from SMRs and any potential areas for cost reduction
- An assessment of how, and in which areas the UK can secure commercial value from SMRs.

3.2 Conclusions of the Study

The study concluded that if the forecasted large future global market for nuclear generated electricity is realised then there will also be a substantial market for SMRs, as they fulfil a market need that cannot always be met by large reactors. In addition it is considered that the price of electricity production from SMRs could become cost-comparable with large reactors and have the potential for further cost reduction, if they are manufactured and operated in sufficient volume.

The last three to four years has witnessed a significant acceleration in the pace of SMR development, however none of the current SMRs are ready for deployment. This presents a narrow window of opportunity for UK industry to work with SMR vendors to complete the design and manufacturing development, enabling them to secure a stake in SMR technology.

All of the leading SMR designs are led by overseas vendors and it is seen that Government influence is key to ensure that indigenous industry is involved in SMR deployment within the UK. It is considered unlikely that UK industry will wish to or have the opportunity to participate in the development of these reactors without a partnership with Government involving a significant aspect of public funding support.

The cost of completing the development for any of the leading SMR designs is estimated to be in the range of £0.5 billion to £1.0 billion over a seven to ten year period. The exact figure and programme is dependent of the specific technologies used within the various designs and the outstanding challenges that must be overcome to enable UK regulation.

3.3 Recommendations from the Study

The technical and economic reviews carried out during the study have not been sufficient to justify and understand the magnitude and exact nature of any further Government involvement in promoting SMRs in the UK. There is a clear need for deeper investigation into the individual technologies and the capability required to deliver them to market, further financial analysis to clarify the economic case, and a testing of the possible engagement models for the UK to partner with an SMR technology vendor.

The study recommends that a more detailed techno-economic review is carried out on a limited number of SMR designs. The output of this next phase should aim to provide the evidence to inform a decision on which, if any, route to commercialisation of SMR technology the UK should follow.

3.4 NIRAB Recommendations for SMRs

An initial view of these conclusions and recommendations, along with some detail of the supporting analysis, were presented to NIRAB at its third meeting. The following recommendations are made by NIRAB:

Recommendation 32

NIRAB fully supports the proposed second phase of the SMR study. The Board considered that any future SMR development work greatly complements an R&D programme for advanced reactor systems, with many of the material and manufacturing research being equally applicable. The two elements of any subsequent programme (i.e. R&D and SMR development) should be seen as a single, integrated programme.

Recommendation 33

The second phase of the SMR study should be funded alongside and not displace funding for the wider R&D programme.

Recommendation 34

A UK led SMR option should be considered during the second phase of the study to provide a baseline to compare with other options.

Although the UK has the capability to develop its own SMR design, given the maturity and investment already made in overseas SMR projects, it would be a challenge for the UK to 'go it alone' given the fiscal constraints and time to market. Nevertheless, NIRAB recommend that the proposed techno-economic study includes a UK led SMR option to provide a baseline against which to the review of alternative options.

Recommendation 35

The market analysis undertaken by the study is not applicable to micro reactors, such as the U-Battery concept, and a specific market analysis is needed to inform progression of such designs.

4 NIRAB Engagement

4.1 UK Stakeholder Engagement

Throughout 2014 NIRAB and NIRO have been interacting and providing coordination between a number of UK official bodies and organisations involved in nuclear and R&D fields. A brief summary of the key interactions is given below.

4.1.1 House of Lords/Commons

In July the NIRAB Chair provided evidence to the House of Lords Select Committee on Science and Technology. Dame Ion answered members' questions on nuclear R&D and the establishment and ways of working of NIRAB.

The Chair has also met with Baroness Worthington to exchange views on the national and international nuclear landscape, in particular emerging nuclear technologies. This was followed up by a meeting on The Potential of Thorium and Advanced Reactors at the House of Lords, which was sponsored by Baroness Worthington and attended by NIRO. An assessment of emerging technologies is recommended as part of the programme of R&D.

4.1.2 Government Departments (DECC, BIS, Treasury, Ministry of Defence, Foreign and Commonwealth Office)

NIRAB has supported DECC and BIS through providing its recommendations for future R&D funding, and NIRO subsequently in providing the technical content required for business cases.

NIRO has also established a dialogue with the Ministry of Defence's (MoD) submarine nuclear reactor plant technical authority to understand the R&D work going on to support the naval propulsion programme. The aims of these discussions have been to ensure that, where possible, the civil and defence R&D programmes funded by Government are complementary. Potential areas for collaboration include modelling and simulation, control and instrumentation, chemistry and structural materials.

4.1.3 NHS England

NIRO held a meeting with the National Clinical Director for Diagnostics from NHS England to understand the issues with the supply chain of radioisotopes for medical diagnostics, how the NIRAB community may assist with making this more robust and where there may be opportunities to collaborate. The more in-depth study into medical isotopes being carried out by NIRAB (see Section 5) is as a result of this meeting. NIRAB intend to continue the ongoing dialogue with NHS England to maintain this link.

4.1.4 Low Carbon Innovation Coordination Group

NIRAB and NIRO have worked closely with the Low Carbon Innovation Coordination Group Nuclear Sub-group (LCICG NSG), with the outputs of the NIRAB work to date reported into the group. This includes NIRAB's recommendations for the main R&D programme which were presented to the LCICG meeting in July.

4.1.5 Innovate UK and Research Councils

Representatives from Innovate UK and EPSRC sit as observers at NIRAB meetings. NIRO have worked closely with Innovate UK and EPSRC to help understand the current landscape for Government funded nuclear research delivered through these two organisations. This information has been used to help determine priority areas for R&D funding for the 2015 period and also to ensure that there is as much coordination between the fundamental research carried out by the Research Councils and the NIRAB recommended programme.

NIRAB has recommended that funding for the fundamental research carried out by the Research Councils be maintained as this is required to support the directed nuclear R&D programme recommended.

4.1.6 Nuclear Industry Council

The NIC's principle remit is to oversee delivery of the NIS. NIRAB provides advice to the NIC on research and innovation required to underpin NIS objectives as described in the Appendix of this report.

NIRAB and NIRO have maintained close engagement with the NIC throughout 2014. Over half of the organisations represented on the NIC have had a direct involvement in NIRAB's work, principally through attendance at NIRAB/Subgroup meetings or NIRO led workshops. This has helped to ensured synergy between the activities being carried out on behalf of the NIC and NIRAB.

To keep the NIC informed on the development of the R&D programme NIRAB and NIRO have provided briefs to the April, July and November Council meetings. This included providing a detailed overview of the recommended R&D programme outlined in Section 2.

NIRO has also collaborated with the relevant NIC subgroups and work streams on innovation to coordinate specific R&D activities across the two organisations.

4.1.7 Nuclear Decommissioning Authority

Decommissioning, legacy waste management and geological disposal of radioactive waste are very important and strategically significant issues that fall within the accountabilities of the NDA. Through their Research Board the NDA govern a number of research programmes to address these issues. There is significant cross-representation between this board and NIRAB (seven members/observers of NIRAB are also members of the NDA Research Board).

The NDA are represented as an observer of NIRAB and have played an active role with representation on the supporting subgroups and NIRO led workshops. The aim has been to ensure that synergies and opportunities for collaboration between R&D programmes focusing on the management of legacy wastes and wastes arising from potential future systems are identified and coordinated.

This link is to be continued through strong coordination between the NDA Research Board and the recycling and waste management elements of the NIRAB Advanced Systems Subgroup.

4.1.8 Nuclear Fusion Research

An objective within the NIS is to maximise synergy across the fission and fusion research and development landscape. Indeed, a recommendation of the Ad Hoc Nuclear Research and Development Advisory Board which preceded NIRAB was "that Government acts to ensure that synergies between fusion and fission R&D are fully exploited for the benefit of both communities".

The work done to date in identifying the priority R&D activities to support the fission sector has not explicitly addressed synergies with fusion research, although representatives from the Culham Centre for Fusion Energy (CCFE) have played an active role in the process, through membership on NIRAB and representation at NIRO led workshops.

Areas of the initial recommended programme that are expected to have benefit within the fusion field are high temperature materials research and funding of the NEA Data Bank.

Other technologies where there are strong overlaps and a combined research programme would yield benefits to both fission and fusion include: nuclear instrumentation, remote handling, remote maintenance, safety/accident analyses, safety/accident systems, 3D visualisation, simulation, non-destructive examination, non-destructive testing and tritium technology. These areas are expected to be pursued as part of the R&D programme recommended by NIRAB for the CSR period.

4.1.9 National Nuclear Laboratory

Representatives from NNL have been directly involved with NIRAB through a number of different routes including membership on NIRAB and involvement at NIRO led workshops.

4.1.10 National Physical Laboratory

The National Physical Laboratory (NPL) is the UK's National Measurement Institute and one of the world's top measurement institutes. NPL receives a significant proportion of its income through block funding that is used to develop measurement techniques including the measurement of radioactivity, radiation dosimetry and neutron metrology as well as properties such as temperature and mass. NIRO has met with NPL to allow the two organisations to better understand each other and how they may contribute to each other's aims.

4.1.11 Nuclear Advanced Manufacturing Research Centre

Representatives from the NAMRC have been directly involved with NIRAB through a number of different routes including membership on NIRAB and involvement at NIRO led workshops and subgroup meetings.

4.1.12 National Nuclear User Facility

The NNUF is a recently established, 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 provided £15 million of funding in 2013 for the NNUF to purchase a range of equipment that will be centred at the three complementary hubs of the Central Laboratory of NNL, CCFE and The University of Manchester's Dalton Cumbrian Facility. A further £1 million has been invested in nuclear instrumentation at the Universities of Lancaster and Liverpool, and at CCFE.

There has been good collaboration between NIRO and the NNUF with NIRO attending NNUF steering meetings and NNUF members contributing towards NIRAB, subgroups and NIRO led workshops. The aim of this collaboration has been to maximise effectiveness of Government funded equipment by linking it to programmes of R&D and ensuring that the most suitable facilities are recommended as part of the programme.

One good example of on-going collaboration in this area is the potential to establish a national archive of nuclear materials. This is requiring collaboration between NIRO, CCFE, the Universities of Oxford and Bristol and the NDA. The output of this work is expected to feed into the NIRAB recommendations for R&D in the CSR period.

4.1.13 The Carbon Trust

On behalf of the LCICG, The Carbon Trust is in the process of refreshing the Nuclear Technology Innovation Needs Assessments (TINA)[7], first published in 2013. NIRO has been liaising and sharing information with The Carbon Trust to ensure that this refresh is consistent with NIRAB's recommendations.

4.1.14 Industry

NIRO has engaged with a range of industrial organisations both within and outside of the nuclear field. This includes organisations not represented on NIRAB. This has provided insight into innovations and programmes that may be brought to bear within the nuclear industry and enable collaboration across industries, potentially maximising leverage for Government investments.

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7 Technology Innovation Needs Assessment, Nuclear Fission Summary Report, April 2013

4.2 International Collaboration

One of the functions of NIRAB is to facilitate the development of an international engagement strategy and recommend a national programme of R&D that enables UK involvement in international research programmes. Involvement in international research programmes gives the UK a number of benefits, most notably leverage of funding.

Throughout 2014 members of NIRAB and NIRO have interacted with a number of international organisations in the nuclear field to foster collaboration. A brief summary of the key interactions is given below.

4.2.1 US Department of Energy

In May 2014 NIRO and DECC met with representatives from the US Department of Energy (US DoE) to discuss potential areas of collaboration. The following areas were discussed:

- Fuel cycle technologies
- Advanced modelling and simulation tools
- Research resources and materials libraries
- Studies on the public perception of nuclear energy
- University cooperation

In response to these discussions a joint statement was signed by the US DoE's Assistant Secretary for Nuclear Energy and DECC's Chief Scientific Advisor affirming their commitment to implementing this bilateral cooperation.

4.2.2 Republic of Korea

The EPRSC, in collaboration with the Ministry of Science, ICT and Future Planning of the Republic of Korea, has recently led a call for collaborative research applications in nuclear decommissioning nuclear waste treatment and disposal. This call represents the first phase of this new collaboration and is intended as a springboard for deeper and larger collaborations in the future.

Members of NIRAB and NIRO have been involved in the associated workshops to help ensure that the nature of the work carried out complements NIRAB's programme of R&D.

4.2.3 Establishment of an International Collaboration Strategy

In recent years a large number of Government sponsored Memoranda of Understanding, Nuclear Cooperation Agreements and other declarations have been made that state the UK's intent to collaborate with international partners in the field of nuclear energy.

These agreements have been made with a number of nations and cover the full spectrum of nuclear fuel cycle and nuclear technologies.

International collaboration is one of the key considerations in determining the content and priorities for the R&D programme. R&D activities need to be identified that complement international programmes or direct funding for UK participation is required.

The large numbers of agreements mean that it has not been clear what the Government's priorities are for overseas collaboration that could be used to influence the content of the R&D programme. It has not been clear who Government deem to be the most desirable overseas collaborators and to which areas of nuclear technology priority should be given.

It has been requested that Government provide NIRAB with an indication of priorities for international collaboration on nuclear R&D that can be used as a guide during the establishment of the full national nuclear R&D programme. This will ensure that R&D activities are carried out to the most effect.

The international strategy should identify who are the long term strategic international partners that the UK Government would want the nuclear industry to be collaborating and any specific technologies that should or should not be included. A strategy should also consider how the UK will proactively manage approaches from other nations on the collaboration of nuclear R&D. The strategy should recognize that geopolitical changes can take place during the execution of a long term programme and responsiveness to these changes is important.

The international strategy is expected to be developed in 2015, along side the development of the R&D programme for the period after 2016.

Recommendation 36

Determine from a technical perspective, which overseas organisations/areas would be the most attractive for collaboration and where international agreements should be focused.

5 Medical Isotopes

Although NIRAB's primary focus is nuclear energy there are a number of synergies with the current problems facing the supply of medical isotopes so at the request of Government NIRAB has worked with the medical physics and health care communities to evaluate options for a potential way forward to address the anticipated supply issues.

The principle radioisotope used for medical diagnostic imaging is Technetium-99m (^{99m}Tc) produced via separation from Molybdenum-99 (^{99}Mo). The worldwide production of $^{99m}Tc/^{99}Mo$ is dependent on a small number of research reactors and a similarly small number of organisations producing the irradiated targets and associated processing facilities.

Between 2016 and 2020 there is expected to be a global shortage of ^{99}Mo as several of main research reactors producing 99Mo shut down. Beyond 2020 it is expected that new reactors and alternative technologies will redress the anticipated global shortage.

On the world stage the Nuclear Energy Agency within the Organisation for Economic Co-operation and Development has formed a High Level Group that has made a series of recommendations. Unfortunately, these have not been adopted widely enough to address the shortage in a timely fashion. Although mitigation measures are being prepared there remains a need for a longer-term solution to ensure that the impact on the UK of fluctuations in the global supply is minimised.

Recommendation 37

Establish an independent committee to investigate the potential solutions to ensure a secure supply of medical isotopes and make recommendations to Government via NIRAB.

6 Nuclear Data

The UK nuclear industry relies on significant modelling and simulation capability to support safe operation for current plants and economic cases for future advanced reactors and fuel cycles. Underpinning this modelling of the nuclear physics aspects (e.g. neutron transport, nuclear reactions, radioactive waste production, radiation heating and shielding) are parameters referred to as nuclear data.

Currently available nuclear data is largely adequate for existing safety cases for operating nuclear plants; predicted improvements in safety margins are not expected to benefit commercial operations significantly, once the cost of implementation is included. However, it is known that current nuclear data is not adequate for the assessment of advanced fuels (even in current reactors); advanced reactors (Generation IV and beyond); and especially in understanding the waste from these systems and how this can be dealt with most economically and practically. Access to nuclear data for the UK's research community is therefore necessary to allow the research and innovation programmes recommended by NIRAB to be implemented.

Nuclear data is derived from the following five-stage process and to be considered an active participant, the UK should be involved in each stage:

1. Analysis of differential experiments based on the understanding of nuclear physics theory. The academic development of theory and experiment is therefore the foundation of this field.
2. Evaluation, in which a best estimate of parameters needed for modelling is generated; this is usually done by national laboratories and then accreditation through evaluation projects.
3. Processing of the data so that it is suitable for nuclear methods. Again, this is often done by national laboratories or code developers.
4. Use of the data within application codes to calculate important engineering properties, either by commercial organisations or by national laboratories.
5. Most importantly, the validation of the data by comparison of results with integral experiments. This is often done by code developers or, in the UK, by and for licensees (with review by regulators).

Recommendation 38

Establish a UK committee to manage the UK's approach to Nuclear Data.

This committee would bring together academia, national laboratories, industry, regulators and Government bodies. As it is very difficult for any one individual research programme or organisation to justify providing a funding route for UK access to nuclear data, it is considered that funding is requested centrally through Government.

From a UK industry viewpoint, a co-ordinated UK programme for nuclear data, with effective leadership and a clear definition of work and benefits, is an essential foundation on which to base long term research and innovation programme aspirations and budget. The present situation in the UK does not allow this.

7 UK Nuclear R&D Snapshot

7.1.1 Background

When developing the NIS in 2012, the Ad-Hoc Nuclear R&D Advisory Board carried out a review of the complete civil nuclear R&D landscape[8]. This review investigated and mapped the following:

- Government policies that had given rise to research needs
- Existing funding sources that support R&D programmes
- The capability of the research base in the UK to meet the government and private sector demands.

The output of this review was used to provide the baseline from which the future aspirations for the UK's R&D capability were drawn.

To understand if the landscape had evolved since this review at the end of 2014 NIRO took a 'snapshot' of UK nuclear R&D funding. This included a review of work on-going in 2014 and work planned for 2015. This review was not intended to be as comprehensive as that carried out in 2012, and focused mainly on the R&D ongoing within the organisations directly represented on NIRAB. It does however include both R&D funded by Government alongside that funded privately by industry.

This expectation of this review was that it could be used to validate that the areas of work recommended in NIRAB's priority programme of R&D were appropriate given an understanding of the work currently on going.

7.1.2 Output and Conclusions

A summary of the funding levels for each of the technical research areas is presented in Figure 3. Funding has been split into research supporting current reactors and that supporting future systems.

The snapshot demonstrates:

- The priority areas recommended in the NIRAB programme for 2016 are in areas that do not have significant private funding
- Some private investment is being made in nuclear related R&D although this is primarily in the support of current operations.

8 A Review of the Civil Nuclear R&D Landscape in the UK – URN BIS/13/631

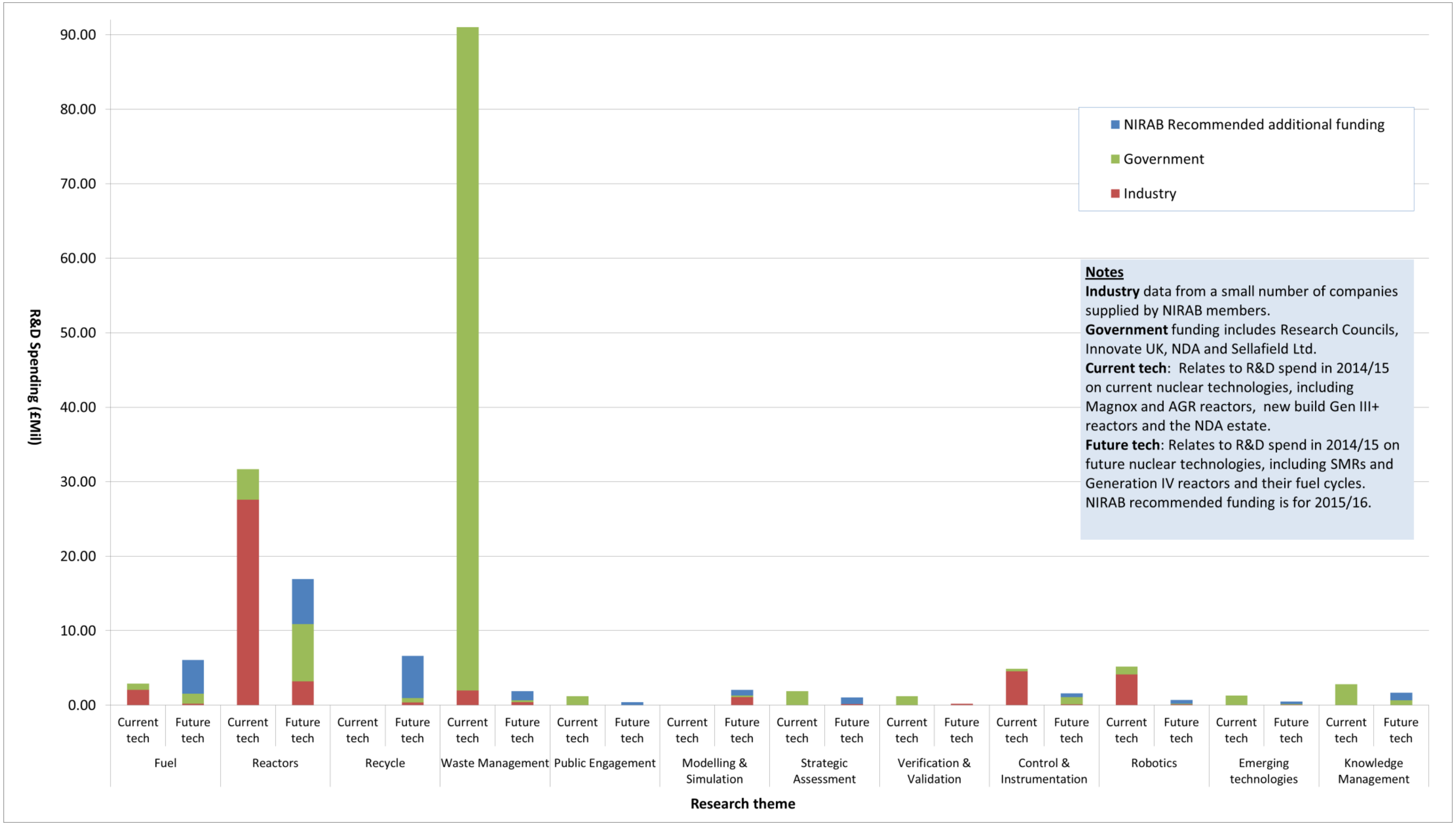

Figure 3 - 2014 R&D Snapshot

8 Future Activities

The work carried out within NIRAB throughout 2014 has been to identify gaps in R&D and make recommendations for targeted interventions to enable the UK to meet the challenges of the NIS. This section outlines some of the specific future activities that NIRAB and NIRO will be carrying out during the coming year.

8.1 NIRAB Meetings

NIRAB will continue to meet in 2015, with four main board meetings currently scheduled. In addition the subgroups will continue to meet to support the development of the future R&D programme.

8.2 Supporting Delivery of On-Going R&D Programmes

As any Government funded nuclear research and innovation programme progresses, NIRAB will give technical advice on the conclusions and outputs of the work. This will help ensure that all Government funded work is directed towards meeting the aims and objectives of the NIS.

This will involve continue coordination between NIRAB and groups such as the NNUF, CCFE, NDA, Innovate UK and the Research Councils.

8.3 Recommendations for a National Programme of R&D

The main focus for NIRAB in 2015 will be recommending to Government a substantial programme of R&D that will allow the UK to achieve the aims set out in the NIS.

The next programme of R&D that NIRAB recommends will cover the period from 2016 to 2021 and is expected to be presented in May/June 2015. This is in order to inform Government Departments prior to the CSR.

It is expected that NIRAB will take this forward using a similar approach to how the priority activities were identified in 2014, with recommendations being focussed through the NIRAB subgroups.

It is expected that this programme will greatly strengthen links into international programmes of nuclear energy R&D, such as the Generation IV Forum (GIF).

It is also crucial that the programme presented back to Government reflects the full suite of publically funded nuclear R&D and that this is coordinated and directed to meet the aims and objectives of the NIS.

8.4 Development of Processes and Success Measures

In order to support the construction of a robust national programme of research and innovation it is proposed that NIRO develop a framework of ways of working that can be applied to NIRAB's future work. This will provide transparency and clarity in NIRAB's operation and lead to more effective and efficient working.

This would extend to a series of metrics and success measures that could be used to monitor the effectiveness of NIRAB and the research and innovation programmes it is recommending.

9 Summary of NIRAB Recommendations

The primary function of NIRAB is to provide advice and recommendations to Government on the direction, implementation and coordination of research and innovation to support the UK nuclear energy generation community. This section summarises the recommendations that have been made throughout 2014.

9.1 R&D Programme and Funding

A programme of R&D across the range of priority areas outlined in this report must be put in place as a matter of urgency. While capital funding allocated to date has been welcome it is not on its own sufficient to deal with the looming high end skills crisis or to plug the gaps identified in R&D which would preclude realisation of the Nuclear Industrial Strategy.

Sustained R&D funding in the broad region of £50 million per year is required to establish the UK at the top table of nuclear R&D nations. This should be in addition to that already funded by the NDA, Research Councils and Innovate UK. This level of funding can assist the UK in gaining a significant stake in a future nuclear reactor market which could include SMRs in the near term leading on to Generation IV technologies in the longer term.

The identified priority R&D areas must be seen as an interconnected integrated case for investment to realise the full range of benefits. It will not be possible to progress certain parts of the programme in isolation to realise the NIS.

A number of detailed recommendations for R&D programmes have been made by NIRAB as follows.

ID	Recommendation
	Advanced Nuclear Fuels
1	Gain an understanding of the mechanics involved in joining advanced cladding materials to nuclear fuels, develop techniques to enable ATF manufacture and gain an understanding of the performance of ATFs.
2	Develop and test a Mixed Oxide fuel pellet production line capable of small scale production of fuel for use in research reactors, demonstrators for emerging reactor systems and prototype Generation IV reactors. This could be delivered by an extension to existing facilities within the UK.
3	Complete commissioning of a CPF kernel manufacturing lab at the NNL Preston facility, investigate novel dual coatings using the chemical vapour deposition coater at the NFCE, and to conduct preliminary research into compacting for fuel element manufacture.
4	Deliver equipment to enhance the UK's advanced nuclear fuel manufacturing capability and support the programmes developing ATFs.

ID	Recommendation
	Advanced Reactors
5	Facilitate UK supply chain qualification and competitiveness by providing guidance for UK manufacturers on how to achieve the requirements of a wide range of codes and standards.
6	Assess and develop the UK's capability in nuclear safety engineering alongside a review of the international opportunities and global capability. This should then be used to provide targeted development for the UK's safety capability to realise future opportunities.
7	Develop a better understanding of high dose radiation damage by establishing the capability to handle radioactive materials at the Diamond light source and establish an electron microscope at the Dalton Cumbria Facility.
8	Maximise value from the NNUF by targeting research to establish the long term effects of temperature, chemistry and radiation on the properties of a range of structural materials.
9	Reinvigorate UK thermal hydraulic capability by delivering validated analysis techniques to predict buoyancy-driven 'passive' flows used within new Gen III+/Gen IV reactor systems and SMRs. This will require both the use of computer models and the generation of data to validate those models via delivery of a series of thermal hydraulics test rigs.
10	Develop knowledge and capability on the chemistry regimes for Generation III and Generation IV reactor systems to position the UK with expertise that can be leveraged into a maximum number of future systems.
11	Deliver advanced manufacturing capabilities in the following areas: • Advanced joining technologies • Hot isostatic pressing for dissimilar materials • Manufacturing process inspection technologies • Fabrication, machining and assembly of large nuclear components

ID	Recommendation
	Fuel Recycling and Waste Management
12	Deliver equipment to enhance the UK's recycling capability and support the programmes developing new recycling techniques: • Uranium active facilities to investigate the engineering aspects of aqueous separation technologies including, for example, centrifugal contactors. • A laboratory facility capable of carrying out experiments on solutions containing higher inventories of plutonium and minor actinides to focus on actinide separations and conversion. • A laboratory equipped to carry out small scale alpha active fundamental chemistry and spectroscopic studies on both aqueous and molten salt media. • Facilities to study the thermodynamics and kinetics of molten salt systems. • Facilities to develop head end dissolution options for thermal and fast reactor mixed oxide fuels and other candidate fast reactor fuels.
13	Develop innovative aqueous recycling technologies to TRL6 and provide data for evaluating the aqueous process against alternative options and optimising the advanced fuel cycle strategies.
14	Understand the fundamental principles behind pyroprocessing as a mechanism to recycle used nuclear fuels and build on this to deliver economic pyroprocessing methods that can be scaled up to an industrial scale.
15	Develop immobilisation technologies for new waste forms generated by advanced recycle processes, including salt clean up, recycle and salt immobilisation from pyroprocessing.
16	Develop innovative technologies and processes for solvent clean-up for recycle and solvent destruction.
17	Develop methodologies for off gas capture from voloxidation and dissolution steps.
18	Develop GDF modelling and storage technologies to support final waste disposal

ID	Recommendation
	Essential Enablers
19	Deliver a suite of modelling and assessment tools and techniques that can be used to provide data to inform future Government policy decisions.
20	Develop a capability for multi-scaled modelling to allow coupling of microstructure stress models to environmental models.
21	Develop an understanding of how uncertainties in current reactor models e.g. turbulence in thermal hydraulics models, can be reduced
22	Establish a Nuclear Virtual Engineering Centre featuring state of the art virtual engineering tools and techniques.
23	Develop new understanding of the underlying reasons for public attitudes to nuclear energy at national, regional and individual level, how these have emerged over time and how these are shaped by events
24	Develop evidence-based tools to inform and enhance the delivery of a national strategy on public engagement in nuclear energy and embed these within the delivery programme for the NIC communications strategy.
25	Develop an approach to providing a safety justification for programmable C&I systems that will meet the expectations of global regulators and the requirements for new nuclear build.
26	Promote R&D activities within the regulator community to ensure that advancements in C&I technology are well understood in order that future safety cases can be adequately scrutinised.
27	Establish a nuclear focussed asset that can be used to develop robotic and remote handling systems for use in the nuclear sector.
28	Ensure continued access for UK nuclear community to the NEA Data Bank.
29	Ensure that historical fast reactor data from the Dounreay project is captured and made available to future R&D programmes.
30	Carry out a survey of existing nuclear materials and establish a national materials archive.
31	Provision should be made for investigations into low TRL technologies and systems which are applicable to the nuclear industry.

9.2 Small Modular Reactors

NIRAB considers SMRs to present an significant opportunity for the UK and makes the following recommendations:

ID	Recommendation
32	NIRAB fully supports the proposed second phase of the SMR study. The Board considered that any future SMR development work greatly complements an R&D programme for advanced reactor systems, with many of the material and manufacturing research being equally applicable. The two elements of any subsequent programme (i.e. R&D and SMR development) should be seen as a single, integrated programme.
33	The second phase of the SMR study should be funded alongside and not displace funding for the wider R&D programme.
34	A UK led SMR option should be considered during the second phase of the study to provide a baseline to compare with other options.
35	The market analysis undertaken by the study is not applicable to micro reactors, such as the U-Battery concept, and a specific market analysis is needed to inform progression of such designs.

9.3 International Collaboration

NIRAB recommend that a strategy is established for how the UK should engage in international collaborations on nuclear energy R&D. Developing this strategy will form part of NIRAB's forward work programme. Given the investments being made by overseas Governments including China, France, India, Japan, Republic of Korea and the US, it is vital that NIRAB determine the greatest opportunities for leverage and added value for the UK.

ID	Recommendation
36	Determine from a technical perspective, which overseas organisations/areas would be the most attractive for collaboration and where international agreements should be focused.

9.4 Medical Isotopes

NIRAB recommend that a small, independent committee is established to investigate the technical and commercial viability of the potential technologies available to the UK for the near term supply of medical isotopes. The work of this committee will be used to inform subsequent recommendations from NIRAB to Government.

ID	Recommendation
37	Establish an independent committee to investigate the potential solutions to ensure a secure supply of medical isotopes and make recommendations to Government via NIRAB.

9.5 Nuclear Data

It is recommended that a committee is established that can be the focus for the UK's involvement in nuclear data. This would coordinate the requirements of academia, national laboratories, industry, regulators and government bodies.

ID	Recommendation
38	Establish a UK committee to manage the UK's approach to Nuclear Data.

Appendix A – Details of NIRAB

The Role of NIRAB

The details of NIRAB's role and it ways of working are defined in a published set of Terms of Reference[9]. To summarise the role of NIRAB is:

- To advise Ministers, Government departments and agencies on issues related to nuclear research and innovation in the UK
- To oversee a regular review of the nuclear research and innovation capability, portfolio and capacity in the UK and, in doing so, assess progress against the objectives set out in the NIS
- To support the development of new specific research and innovation programmes in the UK underpinning priority policies including energy policy and industrial policy, including developing business cases for such activity
- To foster greater cooperation and coordination across the whole of the UK's nuclear research and innovation capability, portfolio and capacity and help NIRO to act as a repository of R&D knowledge
- To oversee the development of an international engagement strategy (both bilateral and multilateral) for nuclear research and innovation in the UK.

NIRAB does not have responsibility for managing or delivering R&D programmes or for directing or managing R&D budgets. This responsibility remains within the Government agency or department charged with delivering the programme. NIRAB is scheduled to meet up to four times each year.

NIRAB Membership

The role of the Chair of NIRAB is independent of Government. In addition to chairing the main meetings of NIRAB the Chair may be called upon to represent the Board in discussions with other key stakeholders such as Ministers, Parliamentary select committees and attending some meetings of the Nuclear Industry Council to discuss R&D issues.

Members are invited to join NIRAB, by Ministerial decision, for a period of up to three years. 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. Further appointments to, or removals from, the Board may be made by the Minister, on the advice of the Chair and officials from DECC and BIS.

The membership of NIRAB is structured to cover the entire civil nuclear sectors in order to provide credible, authoritative and expert advice and includes:

- Public bodies who engage in research, including the UK's national nuclear fission and fusion laboratories

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9 Terms of Reference for the NIRAB, NIRAB-9-1 , February 2014

- Universities with significant research centres and programmes, and who are able to represent the wider academic nuclear research interest
- Companies who conduct or fund significant innovation and research programmes and are representative of the key elements of the UK nuclear fuel cycle
- Representatives from other advisory bodies with significant interests.

Members are selected due to their credibility and position to best represent their fields and are expected to provide a cross section of part of the nuclear sector and subject matter expertise. Members are appointed as individuals and are expected to represent the interests of their sector rather than those of their employers.

The members are supported by a number of official observers and supporting staff that include Government Chief Scientific Advisors (CSA) and representatives from the Research Councils, the NDA, Innovate UK and the Office for Nuclear Regulation. Government officials from BIS, DECC and GO-Science may also attend as observers and by agreement with the NIRAB Chair, other participants may be invited to attend meetings as observers to provide support and information.

NIRAB Reporting Routes

NIRAB provides advice on R&D and innovation to both Government Ministers and to the NIC. In parallel the nuclear elements of the LCICG is also reporting into Government Ministers on nuclear aspects of innovation. The reporting and communication routes between the various groups are shown in Figure 4.

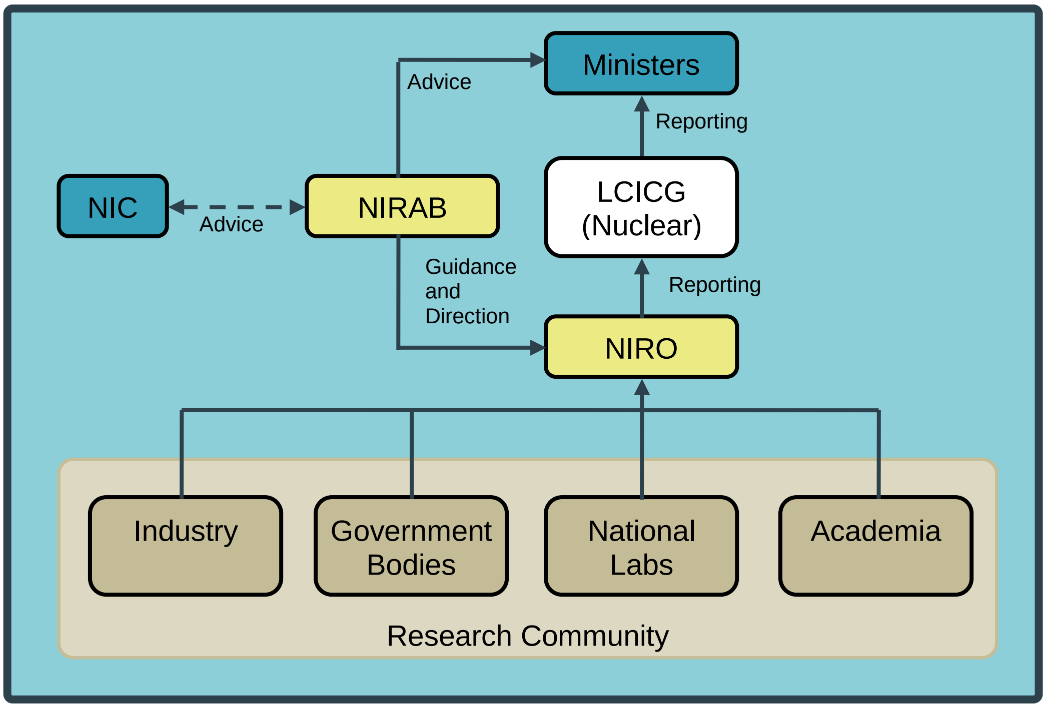


Figure 4 - Reporting Routes

NIRAB Subgroups

In addition to the main NIRAB board a number of subgroups have been established to engage with a wider range of views and to include a wider range of stakeholders than is possible within the main NIRAB meeting. There are currently two; an Industry Subgroup and an Advanced Systems Subgroup.

It is accepted that the number and focus of these groups is likely to change throughout the duration of the NIRAB initiative. Initially three subgroups were established focusing on academia, industry and advanced systems. During the initial work of these subgroups it became clear that there was a great deal of overlap between the output of the advanced systems and academic groups with both making recommendations on future reactor and fuel systems. This consensus demonstrates the priority on the advance systems technology that is the mainstay of the recommended R&D. In response to this overlap the academic and advanced systems subgroups where combined into a single Advanced Systems subgroup.

The individual focus of the two subgroups are:

> ***Industry Subgroup*** - The focus of the industry subgroup is to identify appropriate Government funded research and innovation that can help to improve the competitiveness of UK industry in the areas of new build, current reactor operations, and decommissioning. The expected timeframe for implementation and exploitation of the work will be in a timeframe of less than ten years.
>
> ***Advance Systems Subgroup*** - The focus of the advanced systems subgroup is to improve the UK capability, capacity and portfolio of nuclear research across the full nuclear fuel cycle and keep the UK's future options open. The expected timeframe for implementation and exploitation of the work will be beyond ten years. This lends itself to targeting Generation IV reactors and their supporting infrastructure.

To keep meetings at a practical level the Advanced Systems Subgroup has been designed to meet in three parts; one part focusing on fuel and reactor technologies, another focusing on recycling and waste management and a third that will integrate the output of these groups into a coherent programme. The structure of the NIRAB subgroups is given in Figure 5 and a more detailed description of the scope of the subgroups and their ways of working is given below.

The invitations to be involved in the subgroups have been opened up to a wide range of individuals and organisations, beyond those represented on the NIRAB. The subgroup chairs have been keen to involve individuals with the relevant expertise to best inform the activities of each group. This has also helped to ensure that the wider UK nuclear community has representation with the on-going process and is not just limited to organisations that are part of the NIRAB. Two or three NIRAB members have typically attended each subgroup meeting to maintain sufficient consistency with NIRAB's aims and objectives.

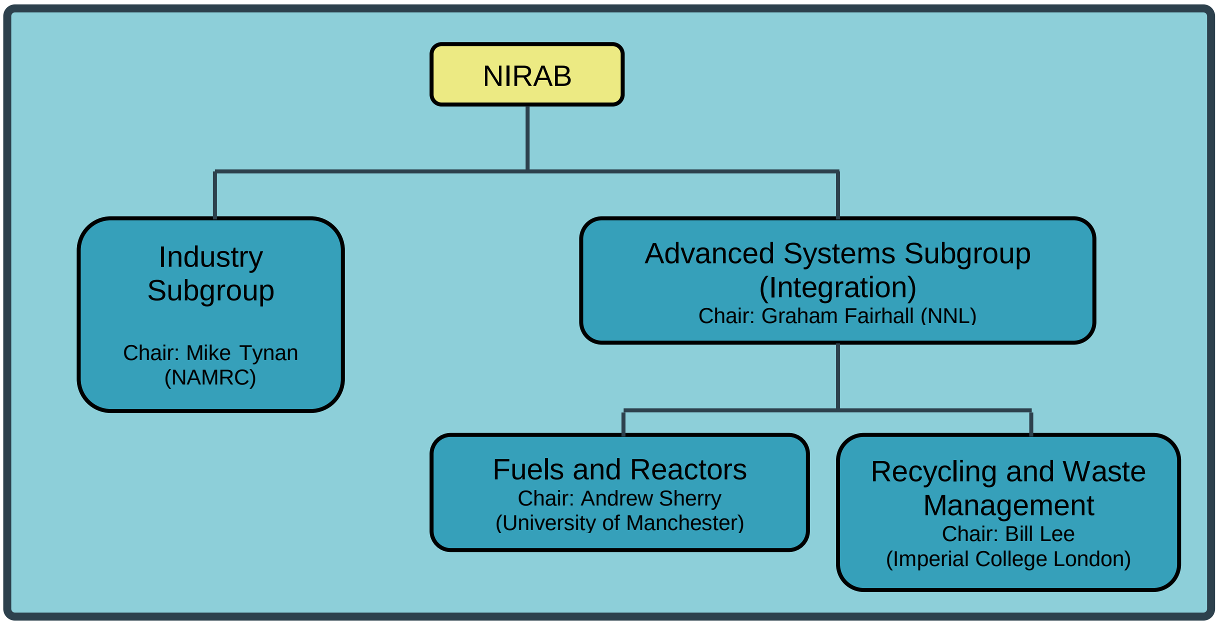


Figure 5 - Subgroup Structure

Recommendations made by the subgroups are expected to represent a consensus view from the subgroup members. Where consensus is not possible to achieve, these issues are highlighted for consideration and resolution by NIRAB.

For each of their specific areas the function of the subgroups is:

- To understand the current landscape and identify gaps in the UK nuclear research and innovation capability, portfolio and capacity.
- To develop recommendations for specific innovation and research areas/programmes for NIRAB to consider where:
  - New Government funding is required to better meet the NIS objectives.
  - Government funding can be redirected to better meet the NIS objectives.
- To prioritise the recommendations and to consider both short term programmes as well as longer term programmes.
- To fully justify the recommendations it puts forward by:
  - Identifying **what** the programme is intended to achieve and **why** it is regarded as a priority.
  - Providing sufficient information to underpin the development of a business case.
- To advise NIRAB on **how** the programmes could be delivered, including where international collaboration will be the best approach, and advise how UK Government can assist.

The subgroups are supported by NIRO in a similar way to NIRAB, providing secretariat duties, to ensure the subgroup meetings are run in an effective manner and are focused on meeting the aims of the NIS.

Appendix B - NIRAB Member Profiles

Dame Sue Ion, Chair, Independent

Dame Sue Ion is a non-Executive Director on the Board of the Laboratory of the UK Health and Safety Executive. 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. She has held an Honorary Professorship at the University of Central Lancashire since the beginning of 2007.

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 was Vice President and Member of Council of the Royal Academy of Engineering between 2002 and 2008. She is the Royal Academy of Engineering's representative on the UK Government's Energy Research Partnership.

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

MANCHESTER 1824
The University of Manchester
Dalton Nuclear Institute

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.

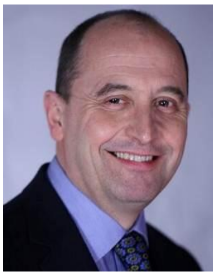
Prior to joining the University, Tim was the Senior Research Fellow for Fuels and Reactor Systems at the UK's National Nuclear Laboratory, where he retains the position of Associate Fellow.

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 and member of the UK Government's Nuclear Innovation and Research Advisory Board.



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.

Richard is a Member of Nuclear Advisory Board to UK Government on UK nuclear strategy and roadmap.

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.

Professor Graham Fairhall, Chief Science and Technology Officer, National Nuclear Laboratory

NATIONAL NUCLEAR LABORATORY

Graham joined BNFL, NNL's former parent company, in 1979 with a degree in chemistry and a PhD in the behaviour of liquid sodium. He has since spent more than 32 years working in Research and Development in the nuclear fuel cycle field.

In 1995 Graham was appointed to the role of Chief Technologist for Waste Immobilisation, the first appointment to senior level in BNFL based on technical contribution and since that time has held a number of senior technical positions in BNFL and NNL. He has recently led major R&D programmes supporting reprocessing, waste management, decommissioning and disposal activities, including advanced fuel cycle studies.

In his current role he is responsible for the Science and Technology strategy for NNL covering the breadth of the nuclear fuel cycle and leading NNL's self funded R&D programmes. Graham also leads NNL’s links with Universities, research councils and other external collaborations with national and international laboratories. He sits on a number of national and international committees and regularly gives invited presentations to meetings and conferences.

Graham is a Visiting Professor at the University of Manchester Dalton Nuclear Institute.

Mick Gornall, Managing Director UK Fuel Operations, Springfields ltd

Westinghouse

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.

Paul Harding, Advisor to the CEO, URENCO

urenco

Paul is currently working as Advisor to the CEO of URENCO specifically in the area of SMR development. Paul holds MA and D.Phil degrees in Chemistry from Oxford University and has worked for more than 33 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 Professor of Radioactive Waste Management at the University of Sheffield, 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

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, Director, Dalton Nuclear Institute, The University of Manchester

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. 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, EDF Energy

Neil has recently been appointed Senior Technical Advisor in the Generation Business of EDF Energy after holding the posts of Head of Research and Development and Head of Engineering for the last 7 years in the Nuclear Generation Business. His recent focus has been life extension of the AGR Fleet.

Neil has 35 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 Physics and a Fellow of the Institute of Mechanical Engineers.

EDF ENERGY

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.

NUCLEAR AMRC

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 the 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 Observer Profiles

Government Office for Science

Sir Mark Walport, Chief Scientific Adviser to HM Government and Head of the 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.

Department for Business Innovation & Skills

Professor John Perkins CBE, Chief Scientific Adviser, Department for Business Innovation and Skills

John took up his CSA appointment in January 2012. Prior to this he was Provost at the MASDAR Institute of Science and Technology, Abu Dhabi (2009-10), leading the development of this new institution.

Professor Perkins' distinguished academic career includes service as Vice President and Dean of the Faculty of Engineering and Physical Sciences, The University of Manchester (2004-9); Principal, Faculty of Engineering, Imperial College London (2001-4) and ICI Australia Professor of Process Systems Engineering, University of Sydney (1985-88), as well as a period at the beginning of his academic career at the University of Cambridge (1973-7). He has served as President of the Institution of Chemical Engineers (2000-1) and as Vice President of the Royal Academy of Engineering (2007-10). He has worked in industry for ICI and Shell, as well as acting as a consultant for a number of international companies.

Professor Perkins is currently an Honorary Professor at Manchester University, Visiting Professor at Imperial College London and a member of the EPSRC 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

Foreign & 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.

Jason Green, Head of Research Councils UK Energy Programme, Engineering and Physical Sciences Research Council (EPSRC)

Jason trained as an Organometallic Chemist at the Universities of Hull and Bristol. He joined EPSRC in 2000 and has worked in a variety of roles within the organisation including research facilities, international affairs, physics, and chemistry before moving to his current role as Head of Energy in April 2008.

Jason leads portfolio development in research and training capacity across the entire energy remit, setting strategy and managing a portfolio of research and postgraduate training with a value in excess of £1bn. His portfolio includes: Sustainable Power Generation and Supply, Nuclear fusion, Nuclear fission, Carbon Capture and Storage, Adaptation to Climate Change, Geoengineering, Demand Reduction, Transport, Energy and Equity, Security of Supply and International Collaboration.

EPSRC
Engineering and Physical Sciences Research Council

John Jenkins, Chief Executive Officer and Accounting Officer, Office For Nuclear Regulation

John has over 30 years of experience in private and, latterly, public sectors at a senior level. He was appointed to ONR as the Chief Operating Officer (COO) in June 2012 and subsequently Chief Executive Officer in April 2013.

He has led ONR through a significant programme of change, appointing senior staff to create a stable and mandated team and overseeing a successful IRRS Mission that received a commendation from the IRRS team. The creation of ONR as a Public Corporation pursuant to the Energy Act 2013 was the major milestone in his first two years at ONR. John’s role is to lead and protect the organisation in the coming years as the twin challenges of demographic-driven reduction in staff and increased regulating needs reach their peaks simultaneously.

John is a Chartered Engineer and Member of the Institution of Civil Engineers.

ONR Office for Nuclear Regulation

Appendix C - 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 (NNL) 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 D - Acronym Glossary

AGR	Advanced Gas-cooled Reactor
ATF	Accident Tolerant Fuels
ASTRID	Advanced Sodium Technical Reactor for Industrial Demonstration
BIS	Department for Business, Innovation and Skills
C&I	Control and Instrumentation
CCFE	Culham Centre for Fusion Research
CPF	Coated Particle Fuels
CSA	Chief Scientific Advisor
CSR	Comprehensive Spending Review
DECC	Department for Energy and Climate Change
EPSRC	Engineering and Physical Sciences Research Council
GDF	Geological Disposal Facility
IAEA	International Atomic Energy Agency
IP	Intellectual Property
LCICG NSG	Low Carbon Innovation Coordination group – Nuclear Sub-group
MoD	Ministry of Defence
NAMRC	Nuclear Advanced Manufacturing Research Centre
NDA	Nuclear Decommissioning Authority
NEA	Nuclear Energy Agency
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
NPL	National Physical Laboratory
OECD	Organisation for Economic Co-operation and Development
PSA	Probabilistic Safety Assessment
R&D	Research and Development
SMR	Small Modular Reactors
TRL	Technology Readiness Level
US DoE	US Department of Energy
VHTR	Very High Temperature Reactor

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To find out more about NIRAB visit:

www.nirab.org.uk

Contact NIRO at:

info@niro.org.uk

nirab NUCLEAR INNOVATION AND RESEARCH ADVISORY BOARD