

NIRAB Final Report

2014 to 2016

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Foreword from the Chair

2016 was another landmark year for the UK nuclear sector, not least with the final investment decision and Government approval for the first new reactors of a generation at Hinkley Point. This is most welcome and will provide a much needed boost to the sector.

I am delighted to see the first steps have been taken which will eventually lead to aspects of the £250m research and innovation programme announced in the 2015 Spending Review being commissioned. However my delight is tempered by the time taken to secure funding and the subsequent delay in converting the commitment into research activity. Nuclear energy policy has not changed and NIRAB's recommendations remain valid. When NIRAB was established there was an urgent need to maintain and build capability and to re-engage in major international development programmes. That urgency has not diminished in the intervening three years.

A positive development for the UK nuclear sector has been the Small Modular Reactor competition, launched by Government in March. The level of global interest has been encouraging and demonstrates the promise that the small nuclear concept holds, and the perception of the UK as a viable nation who can lead SMR commercialisation. In order to reach a successful outcome to the competition, Government will need to clarify its vision of success and describe the criteria it will use to evaluate the wide range of options available. I urge Government to focus on a solution that will secure long term jobs and exports in advanced nuclear design and manufacturing applicable to both current and advanced nuclear technologies, with the aim of building a bedrock UK capability that can develop successive generations of reactor technology.

I would like to reiterate a message that has been at the forefront of NIRAB's mission from day one: research and development activity in universities, national laboratories and industry is crucial in developing capability and capacity and in advancing technology. Without a base level of research we cannot expect to design, build, operate, regulate or decommission large or small nuclear reactors (be they current or future systems). I am pleased to say once the promised funds are committed we will be in a better position, with the new research programmes complementing those sponsored by the NDA, Research Councils, Innovate UK, and industry, but this position needs to be kept under constant review.

As NIRAB's term draws to an end, Government should put in place the arrangements necessary to oversee the totality of publicly funded nuclear research programmes, to review outputs and set strategic direction. NIRAB has reached consensus in its advice to Government, and Government should ensure that it can continue to access such independent advice.

Finally I would like to thank the NIRAB members and all those who have directly supported NIRAB with its work for their goodwill and giving up time and contributing invaluable to formulating and delivering advice to Ministers. The future is bright for the nuclear sector, and the trajectory that our advice has set will result in thousands of exciting and secure careers for future generations.

Dame Sue Ion

NIRAB Chair



Executive Summary

This is the final report summarising the work undertaken by the Nuclear Innovation and Research Advisory Board (NIRAB). NIRAB was established in January 2014 as a temporary advisory board for a period of up to three years. It is charged with advising Ministers on the publicly funded civil nuclear research necessary to underpin policies (particularly industrial and energy policies) and with fostering cooperation and coordination.

Since its inception NIRAB has provided clear, evidence based recommendations to Government which represent a consensus between universities, national laboratories and industry. NIRAB has engaged with the broad UK research community and developed recommendations for a programme of research and innovation spanning the period of the current Spending Review.

NIRAB research programme recommendations are focussed on closing gaps in the current nuclear Research and Development (R&D) landscape; in particular those gaps associated with new reactor systems which, in the absence of action, would prevent the UK realising the economic and industrial potential in low carbon nuclear energy. The recommended programme is designed to equip the UK with skills and capability to capitalise on both near term and longer term market opportunities, whilst reducing the cost of decarbonisation and the effects of climate change by increasing the nuclear contribution to the UK's energy mix. Capability developed through the recommended research will support the new build fleet and Small Modular Reactor (SMR) development and, importantly, creating a platform to support advanced reactor development in the longer term. The recommended research programme, of approximately £250m over a five year period, covers:

- ▶ **The UK's Strategic Toolkit:** Generating the tools to critically assess emerging nuclear technologies and deployment scenarios, providing an evidence base to enable quicker and more effective decisions in nuclear policy
- ▶ **Future Fuels:** Making more efficient and safer fuels for current and future reactors, crucial if the UK is to retain an indigenous fuel manufacturing capability
- ▶ **21st Century Nuclear Manufacture:** Developing new and improved manufacturing, joining and modularisation techniques that will increase UK competitiveness and reduce the cost and risk of nuclear projects
- ▶ **Reactor Design:** Developing digital tools and fundamental scientific understanding needed to design and build future generations of reactors in an accelerated and cost effective way, with emphasis on ever increasing safety
- ▶ **Recycling Fuel for Future Reactors:** Building capability and knowledge of nuclear technologies with enhanced safety and sustainability by virtue of fuel recycling and reduced wastes

NIRAB delivered this advice to Ministers in 2015, and welcomed the announcement in the Spending Review and Autumn Statement 2015 of the intention to allocate at least £250m to fund an ambitious nuclear research and development programme including an SMR competition. This is in addition to investments in new research infrastructure with a proposed enhancement to the National Nuclear User Facility (NNUF). This commitment sent a strong signal to both the UK nuclear industry and potential international collaborators of the UK's intent to remain a leading nuclear nation. The funding will act as a catalyst for future private investment to commercialise cutting edge technologies.

Prioritisation has been a focus in NIRAB's final year of operation. NIRAB has supported Government by prioritising its research recommendations as part of the process to commission the initial phase of a new research programme. Elements of NIRAB's recommended £250m five year programme that target immediate market opportunities and develop skills and capability to increase UK competitiveness are afforded the highest priority: advanced materials and manufacturing, Accident Tolerant Fuel (ATF) research and reactor design.

Recommendation 1

Government should commission without further delay the first stages of the programme recommended by NIRAB and subsequently deliver on its commitment to fund at least £250m for an ambitious nuclear R&D programme over this spending review period.

Success of new research programmes is dependent on having effective mechanisms in place to implement, oversee and review outputs. This is necessary to ensure that quality outputs are delivered, impact is maximised and the implications for the future direction of the programme are identified.

Recommendation 2

Government should put in place arrangements to integrate and review the output of publicly funded civil nuclear research programmes.

Several Government departments and agencies currently fund civil nuclear research. Commissioning additional research programmes will increase the complexity of the landscape of publicly funded nuclear research. In order to achieve value for money it will be necessary to ensure that all publicly funded civil nuclear research is coordinated effectively.

Recommendation 3

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

Access to expert independent advice is crucial to inform policy decisions. The NIRAB model has successfully delivered against its brief to provide independent expert advice to Ministers. NIRAB has offered such advice with a single voice representing universities, national laboratories and industry. It is important that new arrangements are put in place to ensure that Government continues to have access to independent expert advice.

Such advice is a valuable resource and will support key policy decisions as the global nuclear landscape evolves.

Recommendation 4

Government should put in place arrangements to retain access to independent expert advice on nuclear research and innovation to inform policy decisions in this area.

The nuclear R&D landscape has evolved over the last three years during NIRAB's tenure. During 2016 NIRAB, on behalf of Government, produced an update to the 2013 review of the civil nuclear R&D landscape which summarises existing funding sources and the capability of the UK research base. Compiling such information on the civil nuclear R&D landscape on a periodic basis enables an objective assessment of the landscape and to determine the impact of Government interventions.

Recommendation 5

Government should periodically commission updates of the civil nuclear R&D landscape as a means of monitoring the health of the landscape and the effectiveness of Government interventions.

The UK's research infrastructure base has improved over the preceding three years as new state of the art facilities have come on line. There has also been an increase in the number of high calibre graduates and PhDs engaging in nuclear research and a noticeable uptake in talented entrants to the industry from our internationally renowned universities. In addition, non-nuclear researchers are increasingly engaging in nuclear research challenges in areas such as robotics, micro-electronics and high performance computing. However, despite recent funding commitments, the level and scope of funding for nuclear research programmes has changed very little over the past three years. Significant delays between funding announcements and work being commissioned means progress in addressing concerns about the perilously low level of research activity in future nuclear technologies, initially highlighted in 2011 by the House of Lords Select Committee on Science and Technology, has yet to be realised. This is now in hand with preparations to commission a new research programme which will complement the publicly funded research currently commissioned by Research Councils UK, the Nuclear Decommissioning Authority and Innovate UK. It will be vital going forward that all of these initiatives are sustained.

Recommendation 6

Existing nuclear R&D programmes funded by Research Councils UK, the Nuclear Decommissioning Authority and Innovate UK should continue at no lower than current levels.

International collaboration will be an important aspect of future nuclear research. The UK is now more visible on the international stage with the perception of an ambitious nuclear programme through, for example, investment in new nuclear research facilities and a competition to deploy SMRs. However, the current level of international activity across the whole sector is not sufficient to place the UK at the top table of nuclear nations, in particular in the development of future reactor and fuel cycle technologies. NIRAB's recommended

programme of research would enable the UK to enter into major international initiatives, including resuming active participation in the Generation IV International Forum (GIF).

Recommendation 7

Government should develop a plan to resume active membership of the Generation IV International Forum.

It is important that Government provides guidance on its international research collaboration priorities. An international collaboration strategy needs to take into account both technical opportunities and diplomatic priorities in order to maximise benefit.

Recommendation 8

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

Government should also assess potential implications of the UK leaving the European Union with a view to putting in place mechanisms to ensure that researchers can continue to enter international collaborations where there is benefit to the UK.

Recommendation 9

Government should assess the potential impact of the UK exiting the European Union on nuclear innovation and research activity and mitigate accordingly.

Small Modular Reactors present a major opportunity for the UK to gain a stake in a potentially significant new global market. The prioritised NIRAB research recommendations target development of generic reactor design capabilities and cost reducing innovations in modularisation that will be advantageous irrespective of reactor technology. As the UK's SMR position evolves in the coming months and years it will be important there is continued alignment of the wider underpinning research programmes with SMR priorities and that an appropriate strategic direction is maintained.

Recommendation 10

Government should make clear its aims for SMR development in the UK, ensuring that these are used in evaluating the SMR competition. It will be important there is continued alignment of the wider underpinning research programmes with SMR priorities and that a strategic direction is maintained.

The current outlook for nuclear research is bright. Preparations are in hand to commission a new programme of nuclear research, which will complement existing programmes, and to further enhance the research facilities base. The combination of these positive actions by Government, together with full implementation of the recommendations outlined in this report, will rejuvenate the UK research landscape and serve to underpin the ability of UK companies to achieve the nation's ambitious long term objectives for nuclear energy.

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1 Introduction

This document provides a summary of the activity of the Nuclear Innovation and Research Advisory Board (NIRAB) over the last three years. It reflects on how the civil nuclear research and innovation landscape has changed during that time. It also sets out NIRAB's recommendations and the rationale for those recommendations.

1.1 NIRAB Remit

NIRAB is an independent expert advisory board. It was established in accordance with Cabinet Office guidance as a temporary advisory board, by Ministerial appointment, for a period of up to three years. NIRAB first met on 30th January 2014 and has now completed its third and final year.

The details of NIRAB's role and ways of working are defined in its Terms of Reference which are reproduced in Appendix A. In summary NIRAB is charged with:

- Advising Ministers, Government Departments and Agencies on issues related to nuclear research and innovation in the UK
- Overseeing a regular review of the nuclear research and innovation capability, portfolio and capacity in the UK
- Supporting the development of new research and innovation programmes in the UK to underpin priority policies including energy and industrial policies
- Fostering greater cooperation and coordination across the whole of the UK's nuclear research and innovation capability, portfolio and capacity
- Overseeing the development of an international engagement strategy (both bilateral and multilateral) for nuclear research and innovation.

NIRAB does not have responsibility for managing or delivering Research and Development (R&D) programmes or for directing or managing R&D budgets. These responsibilities remain with Government. NIRAB has been supported by the Nuclear Innovation and Research Office (NIRO) which has provided a secretariat function. NIRAB member and observer profiles are provided in Appendix B. Details of NIRO are included in Appendix C.

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.

1.2 Structure of report

NIRAB has spent a significant proportion of its effort in identifying the publicly funded research and innovation required to underpin Government policy. This work culminated in a consensus view on a series of recommendations relating to the need to commission programmes of research. Chapter 2 describes the process by which the recommendations were developed and their current status.

In 2013 Government published a review of the civil nuclear R&D landscape¹. This summarised the range of organisations carrying out civil nuclear research, the level of public funding for such research and the number of Full Time Equivalent (FTE) people engaged in that research. In the second half of 2016 NIRAB has overseen the production of an update of this document with a view to identifying how the landscape has changed in the interim. This will form the benchmark for future comparisons, enabling Government to assess the effectiveness of any intervention measures. A summary of key changes to the UK nuclear research and innovation landscape since NIRAB was established and an assessment of progress against research and innovation objectives is given in Chapter 3.

In parallel with NIRAB formulating its advice over the past three years, Government has been establishing an evidence base to determine a possible course of action to develop a UK Small Modular Reactor (SMR) programme. NIRAB has regularly been asked for its advice related to SMRs; the research recommendations NIRAB has made are associated with future reactor capability, including SMRs. Chapter 4 gives a commentary from NIRAB on Government progress on SMR policy, a view on what the key objectives and criteria should be for the UK, and identifies research that can help to overcome challenges in deploying SMRs.

1.3 NIRAB Meetings

NIRAB has met 13 times over a period of three years, including five times during 2016 (in January, March, June, October and December). The minutes are available on the [NIRAB website](#).



NIRAB

Recommendations

for Civil Nuclear R&D

2 NIRAB Recommendations for Civil Nuclear R&D

This section describes the process by which NIRAB's recommendations have been developed and prioritised. It summarises the progress made by Government in addressing recommendations made in previous NIRAB annual reports and details new (final) recommendations which reflect the current landscape and future priorities.

2.1 Development of NIRAB recommendations

When NIRAB was established at the start of 2014 civil nuclear research programmes funded by a range of organisations including the Nuclear Decommissioning Authority (NDA), Research Councils UK and Innovate UK were already underway. These programmes were primarily aligned to the NDA clean-up and decommissioning mission, and to developing supply chain capability in advance of new nuclear build. Research Councils UK programmes had a broader base which included a very low level of research into future reactors.

In order to formulate its advice NIRAB took into account energy and industrial policy objectives for nuclear which set an appropriate level of ambition. These can be summarised as follows:

- The UK to be a key partner of choice in commercialising Generation IIIⁱ, IVⁱ and SMR technologies worldwide
- UK industry to be established as a global leader in waste management and decommissioning, securing a significant share of high value contracts globally
- The UK to be a 'top table' nuclear nation and a respected partner in international collaborations leading the direction of future technology advances across the fuel cycle.

It was clear that a broader programme of publicly funded research would be needed to support the delivery of these long term objectives. NIRAB convened a series of sub-groups involving NIRAB members and a wider range of subject matter experts. The sub-groups were tasked with:

- Assessing the current landscape and identifying gaps in the UK nuclear research and innovation capability, portfolio and capacity
- Proposing interim research objectives and developing recommendations for specific innovation and research areas/programmes for NIRAB to consider where:
 - New Government funding is required to meet the objectives
 - Government funding can be redirected to better meet the objectives
- Prioritising the recommendations, considering both short term programmes as well as longer term programmes

ⁱ Generation I: prototypes and first realisations (~1950-1970)

Generation II: current operating plants (~1970-2030)

Generation III: deployable improvements to current reactors (~2000 onwards)

Generation IV: advanced and new reactor systems (2030 and beyond)

The sub-groups reported through Board members to NIRAB; NIRAB reviewed, updated where appropriate, and endorsed the sub-group research recommendations. These were formally delivered to Ministers at the end of 2014 and 2015. The recommendations are published in the 2014 and 2015 NIRAB Annual Reports^{2,3} and, accompanying the latter, in a detailed programme recommendations document⁴.

2.2 Progress against NIRAB recommendations

The following sections provide a summary of the current status of the research and innovation recommendations published by NIRAB in 2014 and 2015.

2.2.1 NIRAB 2014 recommendations

The 2014 NIRAB Annual Report² contained recommendations that identified specific components of a research and innovation programme related to next generation nuclear reactor technologies and their associated fuel cycles. These included nuclear fuel fabrication, advanced reactor development and recycle and waste management, as well as several cross cutting enabling activities. It was recommended at the time that sustained research funding of the order of £50m per year across these themes, in addition to existing publicly funded R&D, was required to fulfil policy objectives. Appendix D replicates the recommendations in full and provides a brief statement of progress.

It was considered that Government support through provision of research funding was required as development of next generation technologies would not be driven by the private sector, particularly in the initial stages, due to commercialisation timescales, technical and policy uncertainties and costs being too great.

The urgency and rationale for identifying the recommended research was predominantly due to two factors:

- An increasingly pressing need to underpin the existing skill base and develop the next generation of subject matter experts with many of the UK experts approaching retirement
- Windows of opportunity to collaborate on international research in the development of advanced fuels, Generation IV technologies and SMRs that would not remain open indefinitely, and where gaining an early foothold would give the best chance to secure Intellectual Property (IP) and return long term economic gains.

The majority of these initial programme recommendations were not addressed and were subsequently reviewed, updated and reiterated in the 2015 annual report (see 2.2.2). Some recommendations related to new infrastructure were addressed by The Department of Energy and Climate Change (DECC) (see Chapter 3).

Alongside the specific new research programme recommendations, NIRAB recommended a technical appraisal of prospective international collaboration partners, which has yet to be addressed.

NIRAB also recommended the continuation of Government's SMR technical and economic assessment with the aim of maximising the opportunity to create the IP required to

strengthen the UK negotiating position in any collaboration with international partners. This recommendation has been addressed.

2.2.2 NIRAB 2015 recommendations

The recommendations made in the 2015 NIRAB Annual Report³ were high level in nature, and accompanied by a more detailed UK Nuclear Innovation and Research Programme Recommendations Report⁴. Appendix E replicates in full the recommendations from the 2015 Annual Report and provides a brief statement of progress.

One of the main focuses of NIRAB's work was to review the level and effectiveness of existing publicly funded research. It concluded that:

- Waste management and decommissioning sector research commissioned by the NDA estate to underpin its mission is at minimum levels and should continue at no lower than that
- Fundamental nuclear research is well served by our internationally renowned universities, with Research Councils UK providing essential programme and infrastructure funding to develop the scientists and engineers needed for the future
- Innovate UK stimulates the UK supply chain to develop new technologies and services that provide our smaller companies with the competitive edge needed to break into the domestic and global marketplace.

It was recommended that each of these is maintained at no lower than current levels, this action has been addressed to date and NIRAB continues to stress the importance of this. Chapter 3 provides further details of funding levels over the past three years.

There was, however, still a gap in the UK's research activity in future nuclear technologies, and so NIRAB continued to recommend research be commissioned in this area. The recommended programme was effectively an evolution of the 2014 recommendations in the absence of any significant progress in the intervening year, but with its structure, objectives and milestones defined over a five year period. The resultant five year programme recommendations⁴, with approximate scale of £250m, comprised five interlinked themes:

- ▶ **The UK's Strategic Toolkit**
- ▶ **Future Fuels**
- ▶ **21st Century Nuclear Manufacture**
- ▶ **Reactor Design**
- ▶ **Recycling Fuel for Future Reactors**

The rationale for Government funding remained the same as for the original 2014 programme, but with the urgency heightened in critical skill maintenance areas and where collaboration opportunities still existed.

New funding was announced in 2015¹⁰ for “*an ambitious nuclear research and development programme intended to revive the UK’s nuclear expertise and position the UK as a global leader in innovative nuclear technologies. This includes a competition to identify the best value Small Modular Reactor design for the UK*”. This now forms part of the energy innovation budget held by the Department for Business, Energy and Industrial Strategy (BEIS). Many of the programme recommendations, whilst to date not fully implemented, are in hand as BEIS has begun the process to commission the initial phases of research programmes in the areas NIRAB recommend. However some aspects have necessarily had to be delayed due to the availability of funding and are therefore not addressed (see Section 2.3 below).

NIRAB also recommended that governance arrangements be put in place to ensure technical integration across the programme areas and strategic review of research outcomes. Presently the initial stages of a new programme are being commissioned directly by BEIS as six thematic strands; it is not clear at present how integration of the programme will be managed.

The public funding landscape is complex and with the potential inclusion of a new programme, SMR initiative, National Nuclear User Facility (NNUF) enhancement (see Chapter 3) and continuation of existing publicly funded research, NIRAB emphasised the importance of having an effective mechanism to coordinate public sector funding to maximise value for money. The Government is in the process of establishing a new cross department energy innovation board, and so is addressing this recommendation.

NIRAB highlighted the need to develop an international collaboration strategy to enable research to be implemented to the greatest effect. This recommendation is yet to be addressed, and as new programmes are about to commence, identifying and establishing appropriate future international collaboration remains of utmost importance.

NIRAB welcomed the announcement of an SMR competition in parallel with the ambitious research programme. NIRAB recommended Government clarify its aims for SMRs, ensuring these are used in setting evaluation criteria for the SMR competition, setting the technical priorities for both SMR development and the scope of wider nuclear research and innovation programmes. This recommendation has yet to be fully addressed, but NIRAB recognise that Government has been developing its evidence base further over the last year to be in a position to articulate its objectives (SMRs are discussed further in Chapter 4).

2.3 Prioritising NIRAB research recommendations

NIRAB has over the last year worked with BEIS to prioritise its 2015 research programme recommendations to better match the availability of funding, particularly in the first one to two years of a programme with the expectation that funding levels will increase throughout the five year period.

A series of prioritisation principles, illustrated in Figure 1, were agreed and applied to the recommendations in order to categorise the proposed research as:

- Research that needs to begin as a matter of urgency, or
- Research that could initially be reduced in scope or slightly delayed, or

- Research that could be delayed more significantly.

For example, elements of the research recommendations addressing at risk skills and capability were assigned a high priority. In addition to the five key principles, opportunities to enter into collaborations were also considered, especially in circumstances where the opportunity is known to be time limited.

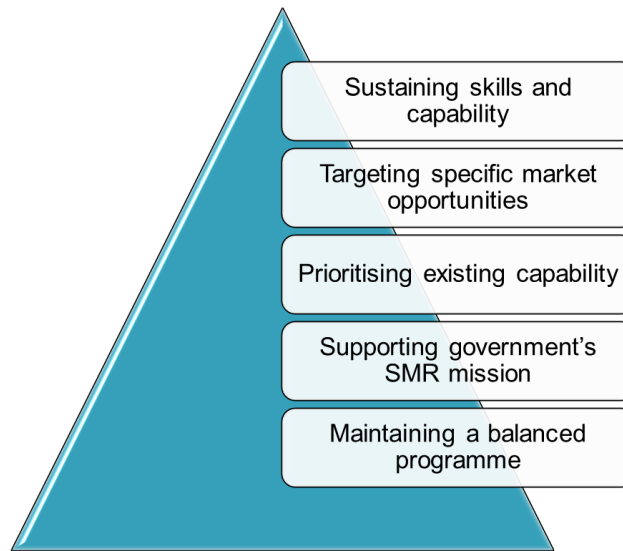


Figure 1 - Hierarchy of research prioritisation principles

The resulting prioritised programme retains some level of activity in each of the research themes of the 2015 programme, and has since been considered by BEIS when developing its calls for research proposals, see Table 1 for a summary of the prioritised programme. Full details of the prioritisation process, rationale and final outcome are reported separately⁵. To communicate the recommendations more widely, the Knowledge Transfer Network (KTN) facilitated a stakeholder briefing event in May 2016 at which the prioritised recommendations were described. Copies of the briefing slides and a video of the event are available on the KTN web site⁶.

Table 1 - NIRAB recommended themes, objectives and prioritised research

Theme	Objectives	Prioritised Programme
The UK's Strategic Toolkit	Generating the tools to critically assess emerging nuclear technologies and deployment scenarios, providing an evidence base to enable quicker and more effective decisions in nuclear policy.	Fuel cycle modelling and strategic assessment tool development are prioritised, but at a reduced scale, in order to further generate an evidence base to assess the potential of emerging technologies and future fuel cycle options. Research into public engagement prioritised, but at a reduced scale.
Future Fuels	Making more efficient and safer fuels for current and future reactors, crucial if the UK is to retain an indigenous fuel manufacture capability.	Highest priority given to Accident Tolerant Fuel research due to the significant, yet time limited, opportunity to engage with major international programmes. The programme also includes Coated Particle Fuel and Plutonium fuel research, associated physics modelling and nuclear data generation.
21st Century Nuclear Manufacture	Developing new and improved manufacturing, joining and modularisation techniques that will increase UK competitiveness and reduce the cost and risk of nuclear projects.	High priority given to this theme to drive innovation and increase competitiveness in UK nuclear manufacturing. Techniques to be developed have potential to lower build costs and project risk through increased use of off-site modular, factory production, in line with SMR philosophy. The programme includes new material research, advanced component manufacturing and joining techniques, large scale component assembly and off site modularisation.
Reactor Design	Developing digital tools and fundamental scientific understanding needed to design and build future generations of reactors in an accelerated and cost effective way, with emphasis on ever increasing safety.	High priority for developing digital reactor design tools to accelerate future reactor development using, for example, virtual prototyping, with the aim of reducing costs. Thermal hydraulics experimental facilities and associated model development are also prioritised to further understand reactor operational behaviour and passive flow regimes. Development of safety, security and safeguards associated with future reactors is also included.
Recycling Fuel for Future Reactors	Building capability and knowledge of nuclear technologies with enhanced safety and sustainability by virtue of fuel recycling and reduced wastes.	Priority afforded to advanced aqueous recycling aimed at developing more cost effective and proliferation resistant options for closing the fuel cycle. This will allow the existing world class skill base, otherwise at imminent risk, to be maintained. Other future recycle options (fast reactor fuel and pyroprocessing) are deferred.

2.4 Looking forward

The NIRAB members welcome the fact that BEIS has begun the process that will culminate in a new research programme being commissioned. It is important that this process is taken to a conclusion, that programmes are actually commissioned and that there should be continuity in funding for such programmes over the period of the current spending review.

Recommendation 1

Government should commission without further delay the first stages of the programme recommended by NIRAB and subsequently deliver on its commitment to fund at least £250m for an ambitious nuclear R&D programme over this spending review period.

Technical integration across programme areas and a strategic review of research outcomes will be essential to ensure that quality outputs are delivered, maximum value/impact is achieved and the implications for the future direction of the programme are identified.

Recommendation 2

Government should put in place arrangements to integrate and review the output of publicly funded civil nuclear research programmes.

NIRAB continues to emphasise the importance of having an effective mechanism to coordinate public sector funding. Commissioning additional research programmes will increase the complexity of the landscape of publicly funded nuclear research. In order to achieve value for money it will be necessary to ensure that all publicly funded civil nuclear research is coordinated effectively.

Recommendation 3

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

In parallel with embarking on new research programmes it is important that new arrangements are put in place to ensure Government continues to have access to independent expert advice post-NIRAB. Such advice is a valuable resource and will support key policy decisions as the global nuclear sector landscape evolves.

Recommendation 4

Government should put in place arrangements to retain access to independent expert advice on nuclear research and innovation to inform policy decisions in this area.

UK Civil Nuclear R&D Landscape

3 UK Civil Nuclear R&D Landscape

NIRAB's remit includes overseeing a regular review of the nuclear research and innovation capability, portfolio and capacity in the UK, with the aim of understanding where progress has been made and where further action is needed.

NIRAB has, on behalf of Government, updated the civil nuclear R&D landscape survey which provides a quantitative assessment of the evolution of the research landscape since data was last published in 2013¹. The 2013 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 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. The new 2016 landscape survey⁷ is currently in preparation and will be published in early 2017; some data and emerging conclusions from the 2016 landscape survey are included in the following sections, where appropriate, to illustrate how the research and innovation landscape has changed in the three years since the inception of NIRAB. NIRAB recommends compiling such information on the civil nuclear R&D landscape on a periodic basis to enable an objective assessment of the landscape and to determine the impact of Government interventions.

Recommendation 5

Government should periodically commission updates of the civil nuclear R&D landscape as a means of monitoring the health of the landscape and the effectiveness of Government interventions.

3.1 Objectives for Nuclear Research and Innovation

Research and innovation is the foundation to sustaining and enhancing capability in the nuclear sector. Objectives for nuclear research and innovation in the UK, aligned to the ambitions outlined by Government, include:

- To have the right level of nuclear research and innovation to ensure near-term as well as long-term commercial success in domestic and global markets
- For the research base to be underpinned by world-leading facilities which are fully utilised by both national and international customers and which conduct a programme of fission-related research whose scale is consistent with the UK's nuclear aspirations
- To be a respected partner contributing significantly to appropriate international research programmes undertaken with selected international collaborators

- To have a joined up approach to nuclear research and innovation across government, industry and academia, which serves to benefit the UK economy and ensure security of supply.

The following sections discuss progress against each of these objectives in turn.

3.2 Level of Nuclear Research and Innovation

The right level of research and innovation is critical if nuclear is to achieve a growing contribution to the UK's energy mix, as well as ensuring commercial opportunities are realised. In reviewing this objective, NIRAB has collated information on public and private R&D as part the process of producing the 2016 civil nuclear R&D landscape survey on behalf of Government.

Overall the nuclear R&D landscape in terms of research programme activity has changed very little since 2013. The issues that were a concern in 2013 remain a cause for concern, in particular the limited amount of research into future nuclear technologies and their associated fuel cycles. Steps have been taken to address this through the recently commissioned BEIS research programme based on NIRAB recommendations, as outlined in Chapter 2. In contrast the research landscape infrastructure base has improved as new facilities have been commissioned. The following sections provide more details.

3.2.1 Government Spending on Civil Nuclear R&D

The annual level of publicly funded civil nuclear R&D in 2015/16 was less than in 2010/11 as reported in the 2013 Landscape documentⁱ, see Table 2. This is mainly due to a reduction in the overall spending for the NDA Estate Site Licence Companies (SLCs) as a consequence of progress in establishing their technical baseline for decommissioning, see discussion below on NDA Estate funding. Funding for fission research (excluding NDA Estateⁱⁱ) had increased by over £12m relative to 2010/11, this increase is largely dominated by one off capital (£7m) and strategic investments by DECC in 2015/16. Fusion spending was £8m less in 2015/16 when compared to 2010/11 dataⁱⁱⁱ.

Table 2 - UK Government Expenditure on Nuclear R&D in 2010/11 and 2015/16

	2010/11	2015/16
Fission NDA Estate	£82.5m ^{iv}	£64.7m
Fission Other	£18.1m	£30.5
Fusion	£33m	£24.6
Annual Total	£133.6m	£119.8m

ⁱⁱ NDA Estate includes NDA, RWM, Sellafield Ltd, LLWR, Magnox Ltd, DSRL.

ⁱⁱⁱ Fusion research funding appears to have reduced by around £8m between 10/11 and 15/16. However, this is an anomaly in the 10/11 data due to a grant payment being held over from 09/10 and paid in 10/11. Correspondence with RCUK indicates that public funding for fusion has actually been stable at around £25m per annum for the past ten years.

^{iv} The 2013 Civil Nuclear R&D Landscape Survey incorrectly reported an R&D spend for NDA SLCs of £121.3m. This value was actually for the total NDA Estate (direct and indirect) 09/10 spend as reported in the House of Lords Select Committee on Science and Technology Report on Nuclear Research and Development Capabilities published in 2011. In addition, the 09/10 value was based upon the best available information at the time and utilised spend that could qualify for R&D Tax Credits. Subsequently an improved methodology for identifying R&D spend (which more accurately reflects the level of research taking place) has been implemented by the NDA and updated values using this new methodology are now reported for 10/11 in line with the methodology used for the 15/16 values.

A high level summary and timeline of public investment in nuclear fission research and innovation since 2013 is shown in Figure 2. A breakdown of civil nuclear fission R&D expenditure in the UK across the public and private sector for the 2015/16 financial year is given in Figure 3 (by funder) and in Figure 4 (by sector). In summary public investment in civil nuclear fission R&D in the UK has occurred through:

- Investment by the Department for Business, Innovation and Skills (BIS), DECC and Research Councils UK (RCUK) in building a research facility base (approximately £60m in total since March 2013)
- Continued programme spend across the NDA estate to support the decommissioning mission and geological disposal of the order of £60 - 80m per year (the majority of this is spent each year by NDA subsidiaries and SLCs⁸ mainly focussed on development for deployment with the remainder being NDA Direct R&D)
- Continued investment in academic research through Research Councils UK Energy Programme, typically around £13m per year
- Innovate UK supply chain development competitions totalling approximately £30m (competition funding comprises funds from Innovate UK, DECC, NDA and EPSRC)
- A series of studies commissioned by DECC, BIS, Innovate UK and the Energy Technologies Institute (ETI) into the feasibility of the UK being involved with the design of and deploying SMRs in the UK and overseas. (These studies are discussed in more detail in Chapter 4)
- Annual re-investment in research and facilities by the Government owned and operated National Nuclear Laboratory (NNL), including between £2 - 5m in research activities of strategic importance to the UK nuclear industry: nuclear energy, waste management, decommissioning and disposal and nuclear security.

In addition to committed funding, announcements of further public funds for nuclear research have been made over the past three years:

- £60m to extend the capabilities of the National Nuclear Users Facility (NNUF), announced in December 2014⁹
- Nuclear materials research infrastructure as one of the nine research areas that form part of the £235m Sir Henry Royce Institute for Advanced Materials, announced in December 2014⁹
- £250m for an ambitious nuclear research and development programme and a competition to identify the best value Small Modular Reactor design for the UK, announced in November 2015¹⁰. £30m of this commitment is for an SMR-enabling advanced manufacturing R&D programme to develop nuclear skills capacity¹¹ and £25m is for a Joint Research and Innovation Centre (JRIC) with China with the expectation of £25m match funding from the Chinese Government.

These announcements provide optimism for the industry and it is important that Government deliver on these commitments so the UK can continue to develop the research base required to grow capability and capacity and to advance technology.

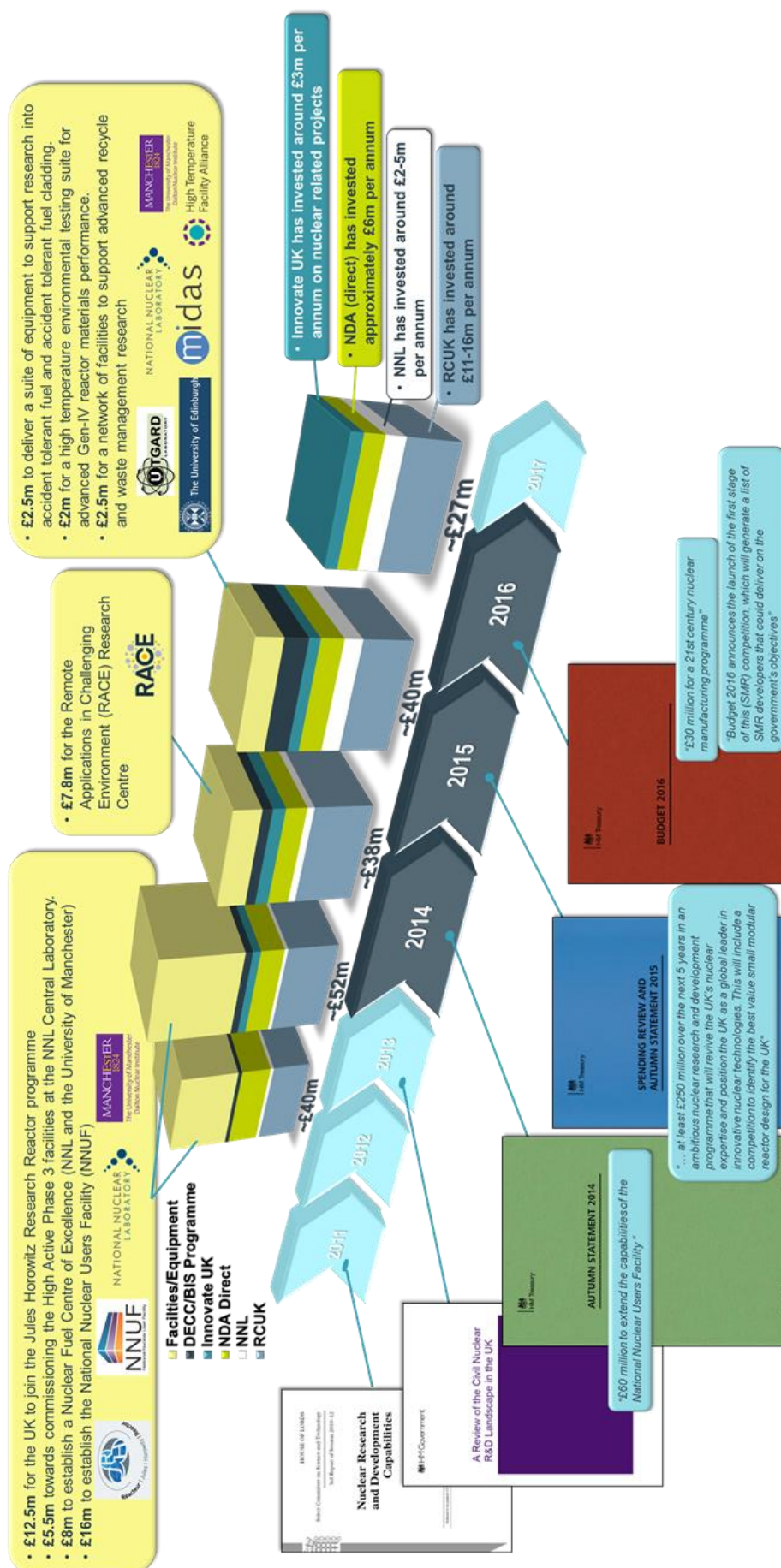


Figure 2 - Public investment in nuclear R&D and timeline of some key publications

NOTE: Investment totals are per financial year (Apr – Mar) and do not include NDA indirect R&D spend (i.e. NDA direct R&D only). The values for 2016/17 are forecasted spend based upon best available information.

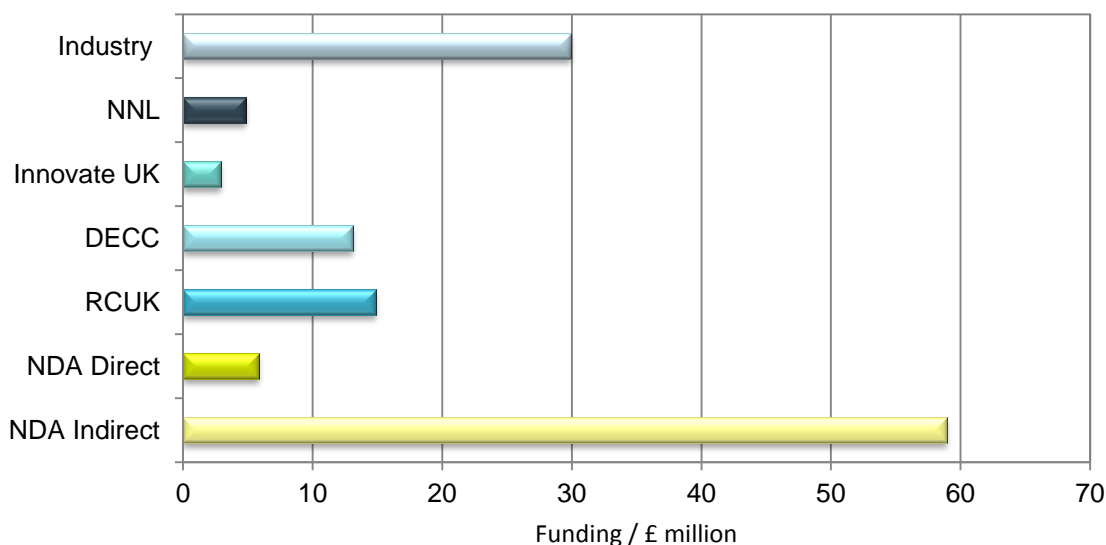


Figure 3 - 2015/16 UK civil nuclear fission R&D funding

Research Councils UK

Assessment of Research Councils UK funding in nuclear over the last three years shows it has been consistent and aligned to either the NDA mission or the research needs identified by NIRAB. Sustained funding from the Research Councils has been important in maintaining and developing the university nuclear science base; the Energy Programme funding for nuclear research has grown from almost nothing 10 years ago and has now plateaued at around £10 – 13m annually, which is considered an appropriate level. The following are examples of two nuclear energy research programmes funded over the past three years:

- **New Nuclear Manufacturing (NNUMAN)** - NNUMAN is a programme delivering research into innovative manufacturing techniques for the future needs of the UK nuclear industry. The programme focuses on early-stage research into a range of manufacturing technologies. The programme, managed by the Dalton Nuclear Institute at The University of Manchester and supported by the Nuclear Advanced Manufacturing Research Centre (NAMRC) at the University of Sheffield, has £4m funding from Engineering and Physical Sciences Research Council (EPSRC), with the two universities committing a further £4m, and further financial and in-kind support coming from industry
- **Decommissioning, Immobilisation and Storage Solutions for Nuclear Waste Inventories (DISTINCTIVE)** - the £5m DISTINCTIVE programme coordinates the EPSRC supported research in decommissioning and waste disposal, undertaking fundamental scientific research to address the decommissioning and waste disposal challenges that the UK faces. The programme is supported by additional funding from NDA, Sellafield Ltd and NNL.

Innovate UK

Innovate UK funding over the last three years has helped to develop the UK supply chain and supported small and medium-sized enterprises (SMEs) in relation to the NDA estate and

nuclear new build. In 2016, over £50m was made available through competitions including the Energy Catalyst, a First of a Kind demonstrator programme and the general Infrastructure Systems call for proposals; up to £8m of this is likely to go towards nuclear R&D. Civil nuclear R&D has been prioritised as part of Innovate UK's strategy for the next four years delivered as part of its Infrastructure Systems programme which will continue to support the development of the nuclear supply chain.

NDA Estate

Public nuclear R&D funding is dominated by research carried out by the NDA estate and in particular by Sellafield Ltd (Figure 3). There has been a reduction in the overall spending for the NDA Estate (Site Licence Companies (SLCs)) when comparing 2010/11 and 2015/16, Table 2. This is mainly due to reductions in R&D spend at Dounreay Site Restoration Ltd (DSRL), Magnox Ltd (MxL) and Low Level Waste Repository Ltd (LLWR) reflecting the progress made by these SLCs in establishing a technical baseline for their missions. The R&D spends at Sellafield Ltd, NDA direct and Radioactive Waste Management Ltd (RWM) have not changed significantly. The vast majority of R&D expenditure across the NDA estate is needs driven and funds the late stage development of technologies that have already been selected for deployment on decommissioning projects¹². In addition, there is likely to be a shift in focus in the future to support broad front cross site decommissioning at Sellafield. NIRAB reviewed in detail the R&D³ expenditure across the NDA estate in 2015 and concluded that it is running at the minimum levels required to support the NDA's decommissioning mission and mitigate the key risks associated with that mission; NIRAB continue to support this assessment and have not identified any areas for significant savings or where funds could be redirected to support the R&D programme recommended by NIRAB.

Recommendation 6

Existing nuclear R&D programmes funded by Research Councils UK, the Nuclear Decommissioning Authority and Innovate UK should continue at no lower than current levels.

3.2.2 Balance of Research across the Nuclear Sector

Figure 4 shows an indicative breakdown of UK nuclear fission R&D funding by research area. Each of the areas is discussed in more detail below.

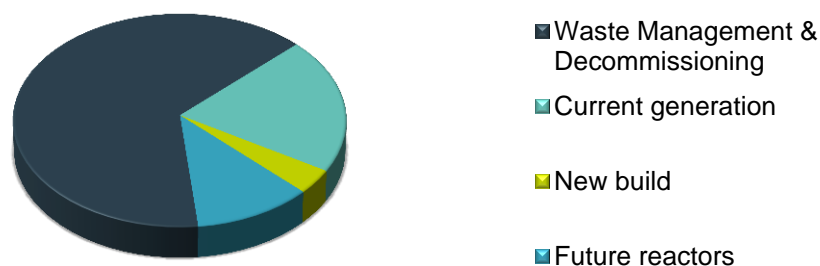


Figure 4 - Indicative 2015/16 UK nuclear fission R&D funding by research area

Waste Management and Decommissioning

Research into waste management and decommissioning accounts for the majority of UK research activity as was the case in 2013. Funding is primarily from the public sector with NDA, NDA SLCs, Innovate UK, Research Councils UK and NNL all funding research in this area.

Current Generation

Programmes of innovation and R&D related to operational reactors are predominantly funded by industry (approximately £30m annually) and are focussed mainly on lifetime extension. The Office for Nuclear Regulation (ONR) commission a small amount of research in support of its independent regulatory decision making (approximately £500k annually) described in the Regulatory Research Register¹³.

New Build

Publicly funded research in the UK supporting the proposed new build reactors (Generation III+) is low, and is likely to be appropriate due to the limited research needs associated with overseas reactor technology. The majority of the costs will focus on constructing and deploying the reactor technology rather than R&D and will be borne by the overseas vendors and operators. UK spend is focussed on developing UK capabilities through Innovate UK supply chain development and through some opportunities for academic research.

Future Reactors

UK research activity on future nuclear energy technologies, including SMRs, is essential to meet the objectives of developing nuclear skills, facilitating a significant expansion of nuclear energy in the UK by 2050 and ensuring long-term commercial success in domestic and global markets. Some research is happening in universities at the lower Technology Readiness Levels (TRLs) and this should continue. There has, however, been insufficient progress in this area over the past three years and, hence, it is still a key gap for the UK. There has been Innovate UK investment in capability development for advanced manufacturing for nuclear; however industry take up for matched funding has been weak.

NIRAB has provided advice to Government on the areas of research necessary to plug this gap and, as described in Chapter 2, published detailed recommendations in March 2016⁴ for a £250m five year programme. Over the last year NIRAB has supported Government by prioritising its recommendations⁵ and the process is now in hand which will culminate in an initial programme being commissioned by BEIS. This is the first stage of a five year plan and is great progress; however, continuity of public funding is critical given the vulnerability of the community, the lack of programme investment over the preceding years and the level of ambition. This is crucial if the UK is to achieve its nuclear ambitions, realise the full benefits of the previous investment in capital assets and ensure that the UK has the capability to deliver a range of possible nuclear power scenarios over the medium and longer term.

3.2.3 Number of Research FTEs

There has been an increase in undergraduates and PhDs in nuclear related research and a noticeable uptake in high quality entrants to the industry from our internationally renowned universities. Research Councils UK investment in two Centres for Doctoral Training (CDT)

and broader investment in nuclear training and skills is producing high quality graduates and PhDs. The aim of the CDTs is to develop future subject matter experts and technical leaders to support the UK's strategic nuclear programmes across the fuel cycle, including nuclear new build and decommissioning; the two CDTs are:

- **Next Generation Nuclear CDT** - based at the University of Manchester and operating in partnership with the Universities of Lancaster, Leeds, Liverpool and Sheffield, and with a number of industrial and regulatory bodies including Amec Foster Wheeler, Areva, AWE, EDF Energy, NDA, NNL, Rolls-Royce and Sellafield Ltd. The CDT will train up to 24 PhD students per year with the first cohort of students having started in September 2014
- **Nuclear Energy CDT** - based at Imperial College London operating in partnership with the University of Cambridge and the Open University. The CDT will train 62 PhD students in five cohorts and involves a one year Masters in Nuclear Engineering at Imperial followed by three years of PhD study at any one of the partner Universities. In addition to the EPSRC funding CDT students are sponsored by industry and international partners including; AWE, EDF Energy, Hitachi, Rolls-Royce and Westinghouse. The first cohort has now graduated from the Masters component and is beginning their PhD studies.

However, further Government investment is required in research programmes that include the participation of national laboratories and industry as well as academia to ensure that critical skills are maintained and developed, particularly in areas identified as at risk such as reactor design, fuel manufacture and recycling of spent fuel; Government support is crucial in acting as a catalyst for industry investment in skills development and research.

A shift in the landscape has been the number of non-nuclear researchers involved in nuclear research challenges (for example in robotics, micro-electronics and high performance computing). This may be down to the nuclear sector drawing in other researchers or other sectors being more proactive in sharing their technologies. Either way drawing the line on what is nuclear R&D is harder now than three years ago.

Continuing to attract and retain the best people within the industry is essential to deliver UK nuclear objectives. New entrants will join an industry which presents exciting challenges, but not one where there is a level of uncertainty about its future.

3.3 World-Leading Research Facilities

As outlined in the preceding Section and shown in Figure 2, investment of approximately £60m by BIS, DECC and Research Councils UK in new research facilities since March 2013 has resulted in good progress towards delivering world-leading capabilities in the UK. Figure 5 provides an overview of the breadth of new, Government funded, state of the art facilities and location. These have added to what was already a significant infrastructure in universities, UK national laboratories and industry. Further details of some of the new Government funded facilities are provided in boxes on the following pages.

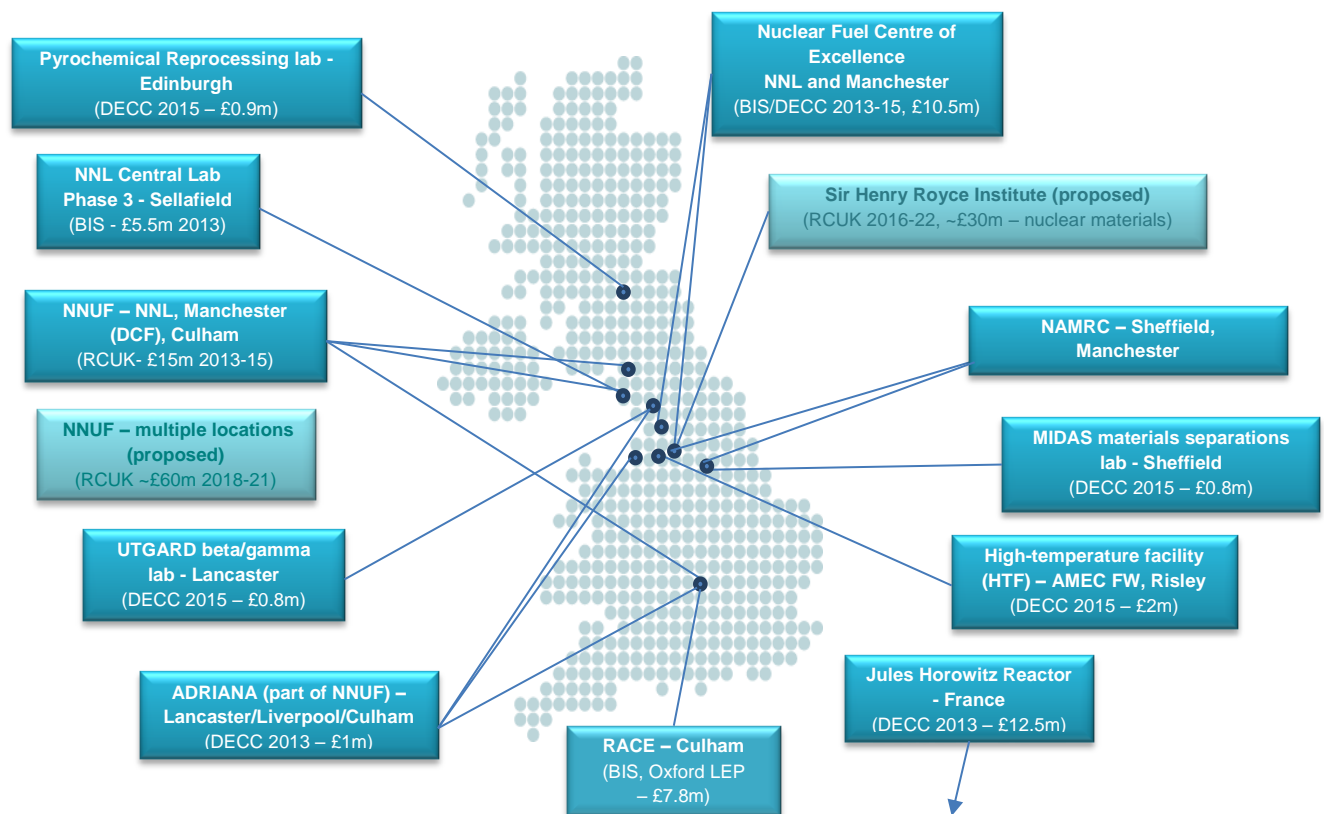


Figure 5 - Map of new Government funded nuclear research facilities

Figure 5 identifies a number of facilities associated with the NNUF. The NNUF was established in March 2013 to provide greater accessibility to world leading facilities for handling, testing and inspection of radioactive/irradiated materials as a collaborative effort from four complementary hubs: the NNL Central Laboratory, the Culham Centre for Fusion Energy (CCFE), the Dalton Cumbrian Facility (part of The University of Manchester) and Lancaster University. Delivery of the NNUF is a real step forward for the research community; coordination between the NNUF and other facilities will be essential to avoid duplication and ensure the potential of these capabilities is realised.

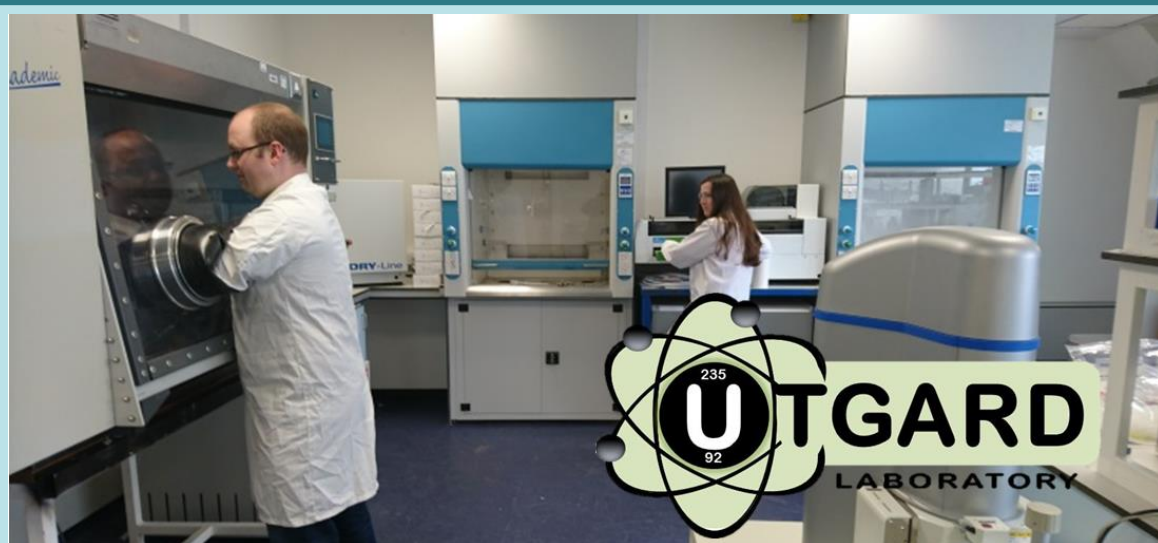
Delivery of the world class facilities over the last three years represents a great foundation for the UK R&D community. However, it is critical that these facilities are fully utilised undertaking high quality research aligned to the UK's nuclear aspirations. Continued investment in publicly funded R&D programmes is essential to maximise the return on investment in these capital assets and to stimulate private investment.



The High Temperature Facility (HTF) Alliance has built an open access materials testing laboratory using a grant from DECC. It was established to investigate, develop and advance structural materials technology for future systems applications such as Generation IV nuclear fission, nuclear fusion, advanced gas turbine materials and other advanced energy concepts. The HTF is housed in dedicated facilities at the Amec Foster Wheeler Technology and Innovation Centre, Warrington.

The HTF offers rigs capable of testing materials at temperatures up to 1000°C and with temperature cycling in a range of novel, demanding environments.

The HTF Alliance members are Amec Foster Wheeler, United Kingdom Atomic Energy Authority (UKAEA), EDF Energy, Imperial College London, NNL, The Open University, University of Bristol, University of Manchester, University of Oxford and U-Battery.



UTGARD (U/Th/beta-Gamma Active process chemistry R&D) Laboratory has been established for the study of chemical processes in support of spent nuclear fuel recycle and waste management. Funded by DECC, it is part of the EPSRC supported NNUF initiative and is an open access laboratory housed in dedicated facilities at Lancaster University.

UTGARD Laboratory provides academic and industry users with a unique resource for the study of the chemistry and engineering of spent fuel recycle and waste management processes. With glove boxes for the study of aqueous and non-aqueous samples, it has the capacity to study fully nuclear hydrometallurgical separations processes. It is licenced for work on β/γ active fission products, uranium, thorium and low level alpha tracers.



The Nuclear Fuel Centre of Excellence (NFCE) is hosted by the Dalton Nuclear Institute and NNL. NFCE's purpose is to create an advanced fuel R&D capability within existing facilities to enable the UK to be a world leader in fuel technology. A key focus is on growing UK talent specialising in advanced fuels.

Supported by £10.5 million of funding from Government to strengthen the existing fuel R&D facilities at NNL and The University of Manchester and create an integrated UK capability, the NFCE builds on unique fuel fabrication and performance experience from decades of research and development on past, present and future fuel types. It will support the creation of improved fuel for current reactors, a new Generation III+ fleet, small modular reactors and ultimately Generation IV fast reactor systems.



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

The MRF provides academic and industry users with a unique resource for micro-characterisation of materials. With hot cells for processing and micro-characterisation of neutron-irradiated samples, it has the capacity to cut, polish and encapsulate individual samples up to the Tera-Becquerel level for analysis either on-site or back at the user's institute. The facility supports research in lifetime extension, nuclear new build, Generation IV and fusion. The MRF is also part of the Sir Henry Royce Institute for Advanced Materials, which is investing in the facility in the years 2016-2019.



Remote Applications in Challenging Environments (RACE) Research Centre - 2015 saw the completion of the RACE research centre based at the UKAEA's Culham site.

The centre will be involved in exploring many areas of remote operations including inspection, maintenance and decommissioning and will be instrumental in developing new remote tools and techniques with academia and industry.



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

The MIDAS laboratory has been established as a national user facility and is part of a network of facilities which enable the UK to deliver internationally competitive R&D in nuclear waste management. The facility is operated as an open facility, available for use by academic, public and private sector organisations and is staffed by an experienced team of researchers who provide advice and guidance on utilising the equipment.



The Pyrochemical Reprocessing Laboratory (PRL) at the University of Edinburgh provides the facilities to develop and demonstrate integrated pyrochemical reprocessing of nuclear fuel using fuel relevant inactive compositional mixtures at laboratory scale, along with the required process monitoring.

The laboratory consists of a suite of interconnected integrated controlled atmosphere dry-boxes, equipped with the necessary furnaces, cell systems and electrochemical and spectroscopic characterisation equipment required for research into and development of each of the essential elements of pyrochemical reprocessing at the laboratory scale. The PRL is an open access laboratory and is affiliated to the NNUF.

3.4 UK Involvement in International Research Programmes

International collaboration is the main route for developing nuclear technologies, such as advanced reactors, due to the substantial investment required by such programmes. In addition few nations have retained the technical capability to deliver an entire reactor development as the drive to sustain a wholly indigenous nuclear industry has diminished. International engagement and collaboration are therefore important and afford a number of benefits:

- Access to international best practice to challenge and benchmark the UK's research capability
- Access to facilities to enable the UK to meet its research objectives, for example, research reactors and irradiation facilities
- Leverage on investment in nuclear R&D
- Access for UK industry to overseas markets
- Improved understanding of political and legislative developments.

The UK is more visible on the international stage with the perception of an ambitious nuclear programme which has been created through investment in new research facilities, ambitions for deploying a SMR and the role of NNL in representing the UK on various international fora. The provision of research facilities, for example, provides credibility and a basis for finding mutual benefit in international research collaborations.

There are good examples of where the UK is working as a respected partner and contributing to international research programmes; spent fuel, waste management and decommissioning research for example. There has also been an increase in international academic engagement through Research Councils UK funding of programmes supporting collaboration with Japan, India, South Korea and the US. However, the current level of activity across the whole sector is not sufficient to place the UK at the top table of nuclear nations, in particular in the development of future reactor and fuel cycle technologies. NIRAB's recommended programme of research (Chapter 2) would enable the UK to enter into major international initiatives, including resuming active participation in the Generation IV International Forum (GIF).

Recommendation 7

Government should develop a plan to resume active membership of the Generation IV International Forum.

There remains a need for the UK to develop an overarching international collaboration strategy for nuclear. 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, for example:

- The 'Japan-UK Framework on Civil Nuclear Energy Cooperation' announced in April 2012¹⁴

- The UK and Republic of Korea signed two Memorandums of Understanding in November 2013 to develop closer cooperation in the fields of commercial civil nuclear energy and nuclear decommissioning¹⁵
- UK and France signed a declaration on nuclear energy in January 2014¹⁶
- In June 2015 the UK and Canada signed a Memorandum of Understanding concerning enhancing cooperation in the field of civil nuclear energy¹⁵
- UK and China signed a Statement of Cooperation in the field of civil nuclear energy in October 2015¹⁷.

NIRAB continues to recommend that the UK focuses on a small number of strategic partners whose capability and long-term challenges and technical direction closely match those of the UK and which offer the potential for significant mutual benefit. The focus for the UK should be collaboration with technically advanced partners with significant programmes.

Recommendation 8

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

Potential impact of exit from the European Union (EU)

The UK leaving the EU will inevitably have an impact on the UK's nuclear innovation and research activity. It is too early to fully understand what this will be, and Government should therefore assess the potential implications and mitigate accordingly.

An indication of the scale of current UK involvement in EU funded nuclear research can be gauged from UK involvement in Euratom programmes. A search was carried out on the European Commission (EC) Community Research and Development Information Service (CORDIS) database¹⁸ for projects that were live on 1st April 2016 and which met one of the following criteria: FP7-Euratom projects with UK participants or H2020-Euratom projects with UK participants. A total of 32 projects relevant to nuclear fission with UK involvement were identified (with 36 UK participants), a summary is provided in Table 3. The available data (Table 3) show that the UK participates in projects with an approximate total annual value of €57.5m, around €35m of this coming from the EU (€21m from participants) and of the €35m EU contribution approximately €3.5m in total per year is paid to UK participants.

Table 3 - UK Participation in Euratom (Fission) Research Projects live at 1st April 2016

<u>Number of Projects with UK Participants^a</u>	<u>Number of UK Participants^a</u>	<u>Approx. Combined Value of Projects per Annum^b</u>	<u>Approx. Total EU Contribution to Projects per Annum^b</u>	<u>Approx. Total EU Contribution to UK for Projects per Annum^b</u>
32	36	€57.5m	€35m	€3.5m

^a FP7-Euratom and H2020-Euratom projects live at 1st April 2016.

^b Projects live at 1st April 2016 have start dates from 2011 to 2016 and a range of project durations. The longest project duration is six years with an average project length of around 3.5 – 4 years. The annual value is calculated taking the total value for the duration of the project and assuming a linear spend profile: annual value per project = (total per project / project duration(years)). The total value presented in the table is the sum of the annual value per project for all live projects.

NIRAB welcomes the Chancellor's announcement on 13th August 2016:

"..where UK organisations bid directly to the European Commission on a competitive basis for EU funding projects while we are still a member of the EU, for example universities participating in Horizon 2020, the Treasury will underwrite the payments of such awards, even when specific projects continue beyond the UK's departure from the EU"¹⁹.

This provided much needed certainty and will enable UK participants to continue to bid for competitive EU funds while the UK remains a member of the EU. However, it is vital that the Government provide assurances that the level of funding for nuclear R&D currently provided by the EU will be replaced by Government following the UK's exit from the EU. It is essential that the UK continues to participate in key EU research programmes to maximise leverage.

Recommendation 9

Government should assess the potential impact of the UK exiting the European Union on nuclear innovation and research activity and mitigate accordingly.

3.5 Coordination of UK Research and Innovation

NIRAB was established to advise on the level, approach and coordination of civil nuclear innovation and R&D. The formation of NIRO and the Low Carbon Innovation Co-ordination Group (LCICG) Nuclear Sub Group (a forum for the public funders of nuclear research) has gone some way to addressing the need for coordination of UK nuclear research and innovation.

NIRAB and NIRO have interacted with industrial and academic stakeholders and provided coordination between a number of UK official bodies and organisations involved in nuclear R&D. NIRAB has, in part, fostered cooperation and coordination by providing a forum at which Government Departments and Agencies have been able to discuss priorities and share plans for funding research. In addition NIRAB has engaged, either directly or through NIRO, in the coordination of research by participating in a range of fora. These include, but are not limited to:

- The NDA Research Board
- The National Nuclear Users Facility Steering Group
- The nuclear sub-group of the Low Carbon Innovation Co-ordination Group.

This type of engagement has led to an improvement in communication and sharing of information over the past three years. It will be beneficial to retain such a forum for communication post-NIRAB.

There is a range of Government funding routes for nuclear R&D with many areas of synergy between existing and potential future programmes (shown in Figure 6 and Figure 7); hence, it is important that the Government has the necessary arrangements in place to ensure a fully coordinated and managed approach to delivery. The Government is now in the process of establishing a new cross department Energy Innovation Board which will succeed the LCICG in coordinating public research and innovation funds for all energy sectors - it will be important to continue to monitor how effectively public sector funding is coordinated with this

new arrangement in place. In addition, although defence research was not in scope for NIRAB, it is recognised there are synergies between the civil and defence programmes that should be coordinated where possible (Figure 7).

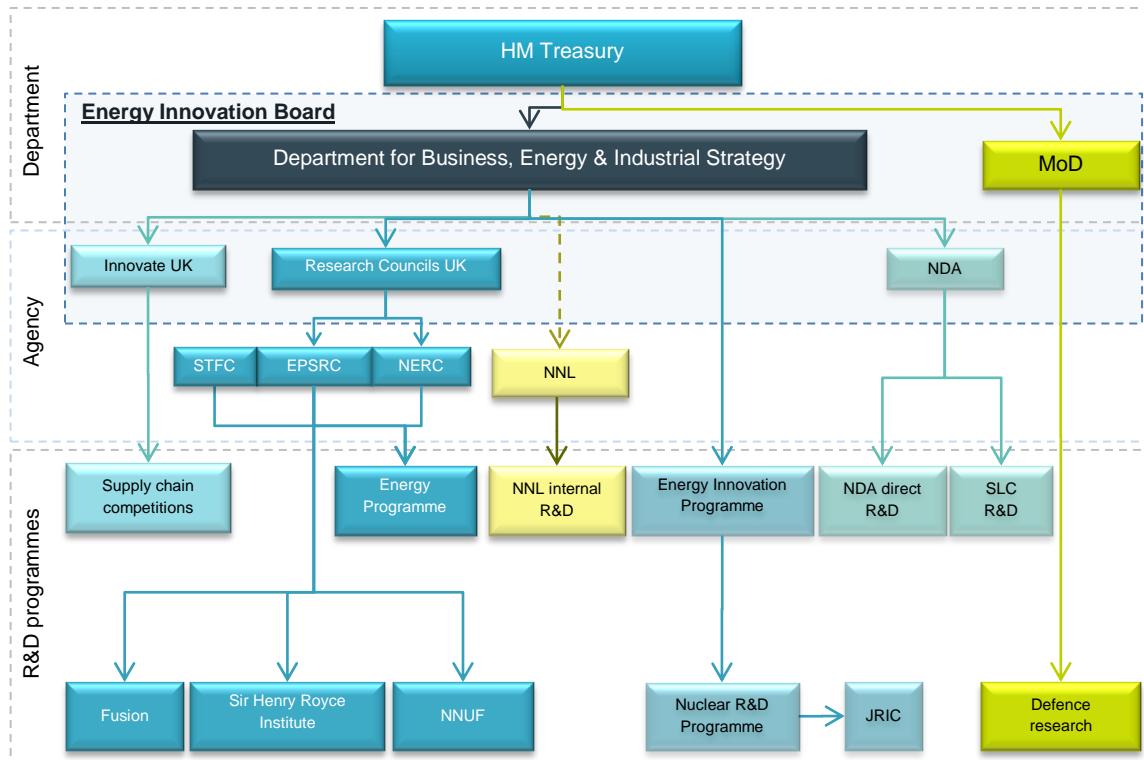


Figure 6 - Government funding routes for nuclear research and innovation

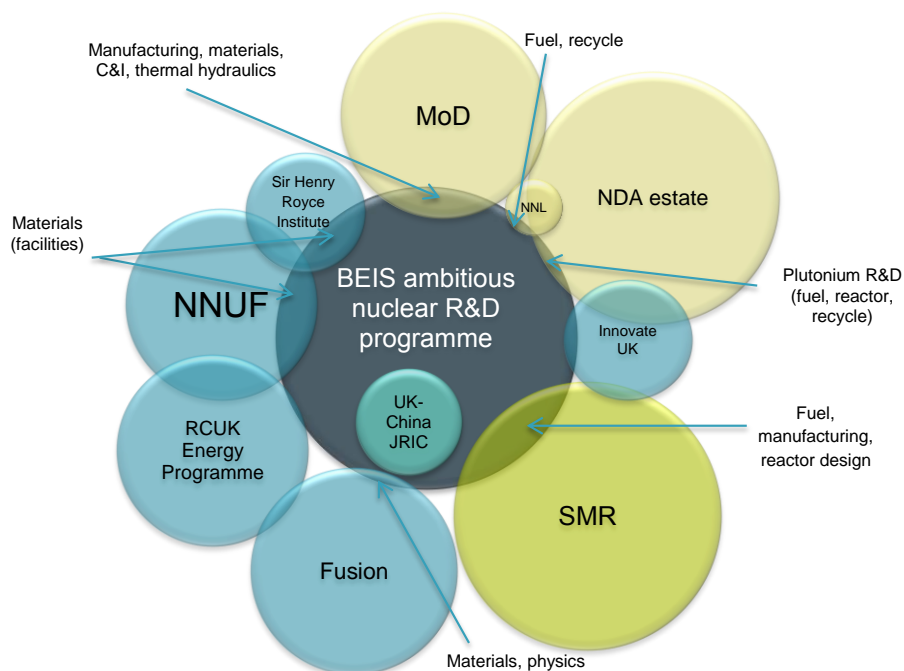


Figure 7 - Indicative public funded nuclear research programme synergies

Small Modular Reactors

4 Small Modular Reactors

Global activity in Small Modular Reactor (SMR) development continues at pace, with a variety of both near term established technologies and longer term concept designs being pursued. A future SMR market may develop internationally irrespective of the Government developing a policy position; the UK's position within this market will however be largely influenced by Government strategy and the support provided.

The Government first signalled its interest in investigating the potential for UK involvement in SMRs in 2013. Since then it has commissioned a series of studies to develop the evidence base needed to inform policy decisions, a timeline is shown in Figure 8. In parallel the Energy Technologies Institute, a public-private partnership between industrial organisations and the Government, has funded a number of studies looking at the role that SMRs could play in the UK's energy system^{20,21,22}. NIRAB welcome the continued Government interest in SMRs and view UK involvement in the near term development of all reactor designs, including SMRs, through to commercial deployment as a vital component in establishing the UK as leading nuclear nation.

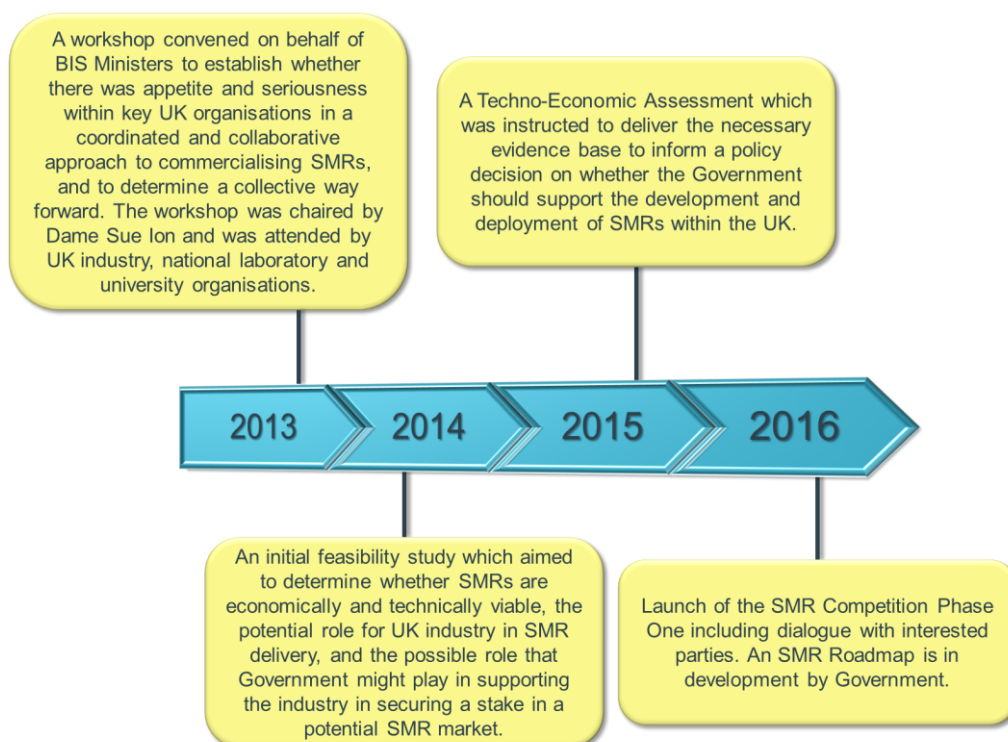


Figure 8 - Timeline of SMR studies commissioned by Government

Key objectives for a UK SMR programme

A UK SMR programme will be able to deliver against objectives related to both energy and industrial policy, and it will be important for Government to articulate what its aims and objectives are.

From an industrial policy perspective, it is the view of NIRAB that a UK SMR programme should aim to maximise the long term industrial growth and economic benefit to the UK associated with high value jobs and exports. The programme should support the UK

manufacturing sector by ensuring the involvement of UK companies in the completion of any design; thus enabling the development of Intellectual Property (IP) and know-how relevant to design, manufacturing, construction, fuel supply, through life support and decommissioning.

From an energy policy perspective, an SMR should aim to produce safe, secure and affordable low carbon electricity, and, where possible, process heat.

These energy policy objectives should be achievable through any of the leading SMR designs, and so it is the industrial policy drivers outlined above that will distinguish one design from another.

In order to achieve global success an SMR design, as part of a UK programme, must:

- Be first (or early) to market with timely regulatory approval and first deployment in the UK
- Achieve “nth of a kind” at an economically competitive price
- Have a route to export markets; be globalised such that it can be deployed overseas with little modification
- Have an acceptable level of technical and economic risk that will inspire confidence in investors.

Research and development to realise cost savings from SMRs

Many of the business concepts for SMRs are based on offering increased manufacturing efficiency and quality control in a factory setting, benefitting from repeatability across multiple sites. Comparable modularisation and flow line assembly construction techniques are widely used in a number of UK sectors, for example, aircraft, automotive and marine manufacturing. NIRAB programme recommendations related to the development of advanced materials, manufacturing and assembly processes, with best practice brought in from other sectors, should be an immediate priority (Chapter 2).

NIRAB programme recommendations also aim to revitalise the UK’s reactor design capability, which is particularly relevant to SMRs. UK companies should engage in the finalisation of any SMR design with a view to designing for ease of manufacturing and reduced construction costs. Engagement of UK companies will also develop and retain the IP and know-how that will contribute to the creation of high value jobs.

Focus should also be made on research activities that will accelerate licensing, for example the design features of SMRs that distinguish them from large scale nuclear plants. NIRAB’s prioritised recommendations include thermal hydraulics modelling and experimentation to develop understanding of passive cooling safety features.

In addition, it is worthwhile exploring the contribution that Accident Tolerant Fuel (ATF) designs could make towards cost reduction through being able to provide significantly higher levels of inherent fuel safety. The capability available within the UK’s fuel manufacturing sector could place the UK in a strong position to secure a significant role in ATF development and manufacture.

Government support to a potential UK SMR programme

If an SMR programme is launched, the supply chain needs a strong signal of sustained commitment along with associated investment for smaller businesses to prepare their infrastructure and technology to economically supply to the SMR requirements. Commitment to a programme will also trigger private investment.

Government should act on the commitment made in last year's Autumn Statement¹⁰ to provide at least £250m towards ambitious nuclear research. NIRAB has provided recommendations to BEIS Ministers for priority research programmes (Chapter 2). These are designed to equip the UK with skills and capability to capitalise on both near term SMR opportunities as well advanced reactor development in the longer term. It will be important to commission this research without further delay to maximise benefit to the SMR opportunity.

As the UK's SMR position evolves in the coming months and years it will be important there is continued alignment of the wider underpinning research programmes with SMR priorities and that a strategic direction is maintained.

Recommendation 10

Government should make clear its aims for SMR development in the UK, ensuring that these are used in evaluating the SMR competition. It will be important there is continued alignment of the wider underpinning research programmes with SMR priorities and that a strategic direction is maintained.

5 References

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Appendices and Glossary

Appendix A: NIRAB Terms of Reference and Ways of Working

NIRAB's Role

- 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 Nuclear Industrial Strategy
- 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.

The Chair

The role of 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 stakeholder such as Ministers, Parliamentary select committees and attending some meetings of the Nuclear Industry Council to discuss R&D issues.

Membership of NIRAB

Members are invited to join NIRAB, by Ministerial decision, for a period of up to three years. With the exception of the Chair, appointments will be unfunded. 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 (now BEIS).

The membership of NIRAB covers a range of sectors in order to provide credible, authoritative and expert advice:

- Public bodies who engage in research, including the UK's national nuclear fission and fusion laboratories
- Universities with significant research centres and programmes, and who are able to represent the wider academic nuclear research interests
- 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 will be individuals with the credibility and position to best represent their fields. Members are chosen to provide a cross section of sectoral and subject expertise. Members are appointed as individuals and are expected to represent the interests of their sectors rather than just their employer.

Observers and Supporting Staff

The Government Chief Scientific Advisors, Research Councils, NDA, Innovate UK and ONR will be represented at NIRAB meetings as Observers rather than full Members and will participate fully in NIRAB meetings. Government officials may also attend as observers.

By agreement with the NIRAB Chair, other participants may be invited to attend meetings as observers to provide support and information.

Meetings

It is anticipated that NIRAB will meet up to four times per year. As far as is reasonably possible Members will not deputise attendance.

Sub Groups

NIRAB may convene sub-groups to carry out specific workstreams as necessary. Sub-group participation is not limited to NIRAB members or their organisations, and will be at the request of NIRAB.

Relationship to NIRO

NIRO will act 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.

Appendix B: NIRAB Member and Observer Profiles

NIRAB Members



Dame Sue Ion, Chair, Independent

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

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

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

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



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

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

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

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

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



Andrew Carlick, CEO, DBD Group

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 set up, owns and is the CEO of DBD Group, a highly successful SME with a turnover of more than £10 million in 10 years. Operating primarily in the nuclear sector, DBD employs over 90 professional engineers, with a commitment to growing the next generation of engineers. Now DBD Group, the company operates internationally in six countries. 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 Royal Academy of Engineering and the Institute of Chemical Engineers.



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

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

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



Richard is a Fellow of the Royal Academy of Engineering.



Professor Steve Cowley, CEO, 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 Royal Academy of Engineers, 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, Retired (previously Chief Science and Technology Officer, National Nuclear Laboratory)

Graham retired from NNL in March 2015, following a long and illustrious career with NNL and its predecessor organisations. He joined BNFL (NNL's former parent company) in 1979 and spent his entire career working in R&D and technical roles in the civil nuclear sector. In his Chief Scientist role at NNL he was responsible for the longer term science and technical strategy for programmes covering the breadth of the nuclear fuel cycle as well as external technical collaborations in the UK and internationally.

Graham is a Fellow of the Royal Society of Chemistry and a Chartered Engineer and held a role as Visiting Professor at The University of Manchester in the Dalton Nuclear Institute.

Graham was awarded an MBE in June 2016 for services to UK nuclear energy research and development.

Graham was an active NIRAB member between January 2014 and March 2015.



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

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



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



Dr Paul Harding, Advisor to URENCO

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



Previously, Paul has been the Executive Commercial Director of the URENCO Group and Managing Director of URENCO UK.



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

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



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

Malcolm Joyce, 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 was until recently Director of the Centre for Nuclear Engineering and the Nuclear Energy Centre for Doctoral Training at Imperial College. 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 National Nuclear Laboratory Technical Advisory Board, the National Nuclear User Facility Working Group, the Project on Nuclear Issues (Royal United Services Institute) Board of Advisors, and the Scientific and Environmental Advisory Board Tokamak Energy plc.

Bill is a fellow of the Royal Academy of Engineering, the Institute of Materials, Minerals and Mining, the American Ceramic Society and the City and Guilds Institute.

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



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

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



Professor Andrew Sherry, Chief Scientist, NNL

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

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

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



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

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

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

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



Mike Tynan, CEO, Nuclear Advanced Manufacturing Research Centre



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

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

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

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



Professor Laurence Williams, Chairman, Committee on Radioactive Waste Management



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

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



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

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



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

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

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

Acknowledgement

The Chair would like to acknowledge the following individuals for providing significant contributions to the work of NIRAB over the previous three years:

John Molyneux, Rolls-Royce

Martin O'Brien, UKAEA

NIRAB Observers



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.



Professor Timothy Dafforn, Chief Scientific Adviser, Department for Business, Energy and Industrial Strategy

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

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

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

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



Professor John Loughhead, Chief Scientific Advisor, Department for Business, Energy and Industrial Strategy

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

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

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



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

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

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

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





Professor Melanie Brownridge, Head of Technology, NDA

Melanie has worked in the nuclear industry for 20 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.



Innovate UK

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 Energy Catalyst, formed to accelerate 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.



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

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

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



David Senior, Deputy Chief Inspector, Office For Nuclear Regulation

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

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

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

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

Appendix 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 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.

Paul Nevitt, 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. Paul is on secondment from NNL.

Andrew Brown, Chief Technologist (May 2014 – March 2016).

Andrew was 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: Summary of progress against recommendations made in 2014

The 2014 NIRAB Annual report, published in February 2015, made a total of 38 recommendations spanning eight broad areas. These are reproduced below with a brief commentary and a traffic light indicator to illustrate which have been successfully addressed to date. Seven have been fully addressed and 18 have been partially addressed. The remaining 13 are outstanding.

Of the 38 recommendations 25 are reflected in the NIRAB recommendations document⁴ which sets out the detailed technical recommendations. These still reflect NIRAB's best advice. The Department for Business, Energy and Industrial Strategy (BEIS) recently issued invitations to submit research proposals. This is the first step in a process that will culminate in some work commissioned in each main area of the recommendations. Recommendations that are addressed through that competition are currently flagged with an amber status as the process of commissioning research programmes is currently incomplete. Recommendations which refer to research subjects that are not addressed in the current competition are flagged with a red status.

Key

Status of recommendation	
Complete	
Partially complete	
Incomplete	

Advanced Nuclear Fuels			
ID	Recommendation	Current Status	
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.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
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.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
3	Complete commissioning of a Coated Particle Fuel (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.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	

Advanced Nuclear Fuels			
ID	Recommendation	Current Status	
4	Deliver equipment to enhance the UK's advanced nuclear fuel manufacturing capability and support the programmes developing ATFs.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	

Advanced Reactors			
ID	Recommendation	Current Status	
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.	This recommendation has yet to be addressed and is incorporated in the "Nuclear Innovation and Research Programme Recommendations".	
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.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
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.	Priorities for academic research facilities are being addressed through National Nuclear User Facility proposals.	
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.	This recommendation has yet to be addressed and is incorporated in the "Nuclear Innovation and Research Programme Recommendations".	
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.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
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 recommendation has yet to be addressed and is incorporated in the "Nuclear Innovation and Research Programme Recommendations".	

Advanced Reactors			
ID	Recommendation	Current Status	
11	<p>Deliver advanced manufacturing capabilities in the following areas:</p> <ul style="list-style-type: none"> Advanced joining technologies Hot isostatic pressing for dissimilar materials Manufacturing process inspection technologies Fabrication, machining and assembly of large nuclear components 	Initial work in this area is part of the scope of the recently announced BEIS research programme.	

Fuel recycling and waste management			
ID	Recommendation	Current Status	
12	<p>Deliver equipment to enhance the UK's recycling capability and support the programmes developing new recycling techniques:</p> <ul style="list-style-type: none"> 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. Facilities to develop head end dissolution options for thermal and fast reactor mixed oxide fuels and other candidate fast reactor fuels. 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. 	These recommendations have yet to be addressed and are incorporated in the "Nuclear Innovation and Research Programme Recommendations"	
		Addressed through the award of a capital grant.	
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.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
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.	This recommendation has yet to be addressed and is incorporated in the "Nuclear Innovation and Research Programme Recommendations".	
15	Develop immobilisation technologies for new waste forms generated by advanced recycle processes, including salt clean up, recycle and salt immobilisation from pyroprocessing.	This recommendation has yet to be addressed and is incorporated in the "Nuclear Innovation and Research Programme Recommendations".	

Fuel recycling and waste management			
ID	Recommendation	Current Status	
16	Develop innovative technologies and processes for solvent clean-up for recycle and solvent destruction.	This recommendation has yet to be addressed and is incorporated in the “Nuclear Innovation and Research Programme Recommendations”.	
17	Develop methodologies for off gas capture from voloxidation and dissolution steps.	This recommendation has yet to be addressed and is incorporated in the “Nuclear Innovation and Research Programme Recommendations”.	
18	Develop Geological Disposal Facility (GDF) modelling and storage technologies to support final waste disposal.	This recommendation has yet to be addressed and is incorporated in the “Nuclear Innovation and Research Programme Recommendations”.	

Essential Enablers			
ID	Recommendation	Current Status	
19	Deliver a suite of modelling and assessment tools and techniques that can be used to provide data to inform future Government policy decisions.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
20	Develop a capability for multi-scaled modelling to allow coupling of microstructure stress models to environmental models.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
21	Develop an understanding of how uncertainties in current reactor models, for example, turbulence in thermal hydraulics models, can be reduced	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
22	Establish a Nuclear Virtual Engineering Centre featuring state of the art virtual engineering tools and techniques.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
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 recommendation has yet to be addressed and is incorporated in the “Nuclear Innovation and Research Programme Recommendations”.	

Essential Enablers			
ID	Recommendation	Current Status	
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.	This recommendation has yet to be addressed and is incorporated in the “Nuclear Innovation and Research Programme Recommendations”.	
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.	This recommendation has yet to be addressed and is incorporated in the “Nuclear Innovation and Research Programme Recommendations”.	
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.	This recommendation has yet to be addressed and is incorporated in the “Nuclear Innovation and Research Programme Recommendations”.	
27	Establish a nuclear focussed asset that can be used to develop robotic and remote handling systems for use in the nuclear sector.	The Remote Applications in Challenging Environment (RACE) research centre has been commissioned on the UKAEA site at Culham, however not primarily nuclear.	
28	Ensure continued access for UK nuclear community to the NEA Data Bank.	The research community has had continued access, but a mechanism is needed to ensure that this will continue into the future.	
29	Ensure that historical fast reactor data from the Dounreay project is captured and made available to future R&D programmes.	Initial work in this area is part of the scope of the recently announced BEIS research programme.	
30	Carry out a survey of existing nuclear materials and establish a national materials archive.	NDA has made progress in quantifying the range of existing materials, but arrangements have yet to be put in place to establish a national archive.	
31	Provision should be made for investigations into low TRL technologies and systems which are applicable to the nuclear industry.	Innovate UK has run competitions for such research.	

Small Modular Reactors			
ID	Recommendation	Current Status	
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 (R&D and SMR development) should be seen as a single, integrated programme.	DECC commissioned a Techno-Economic Assessment of SMRs in the spring of 2015, though the results have yet to be published.	
33	The second phase of the SMR study should be funded alongside and not displace funding for the wider R&D programme.	The Spending Review 2015 allocated funding for both research and SMRs.	
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.	The current SMR “competition” does not preclude a UK led design.	
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.	DECC commissioned such a study in 2015.	

Other			
ID	Recommendation	Current Status	
36	Determine from a technical perspective, which overseas organisations/areas would be the most attractive for collaboration and where international agreements should be focused.	Such an assessment has yet to be carried out from either a top down or bottom up perspective.	
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.	No progress.	
38	Establish a UK committee to manage the UK’s approach to Nuclear Data.	The recently announced BEIS programme includes nuclear data as a work element. STFC has funded The UK Nuclear Data Network	

Appendix E: Summary of progress against recommendations made in 2015

The 2015 NIRAB Annual report made a total of eight recommendations. These are reproduced below with a brief commentary and a traffic light indicator to illustrate which have been successfully addressed to date. A more detailed set of technical recommendations was published⁴ in parallel to the annual report.

One of the eight recommendations has been fully addressed to date. A further two recommendations are linked to implementing a programme of research; these are therefore partially complete. One further recommendation relates to coordination arrangements for publicly funded research. The Government is now in the process of establishing a new cross department Energy Innovation Board which will succeed the Low Carbon Innovation Coordination Group (LCICG) in coordinating public research and innovation funds for all energy sectors; therefore this recommendation is assessed to be partially complete. The remainder of the recommendations have yet to be addressed.

Key

Status of recommendation	
Complete	
Partially complete	
Incomplete	

ID	Recommendation	Current Status	
1	Existing nuclear R&D programmes funded by NDA, Innovate UK and RCUK should continue at no lower than current levels.	There is currently no indication that these programmes have been reduced in scale.	
2	Government should develop and implement a comprehensive and coordinated international collaboration strategy for nuclear research and innovation to enable research to be implemented to the greatest effect.	A strategy for international collaboration should take into account both a “bottom up” assessment of opportunities and “top down” guidance on diplomatic priorities. The latter is not currently available.	
3	Government should implement a transparent and effective mechanism to coordinate and, where necessary, direct, all publicly funded nuclear R&D activities in order to achieve the desired industrial impact and maximise value for money.	The Government is now in the process of establishing a new cross department Energy Innovation Board which will succeed the Low Carbon Innovation Coordination Group (LCICG).	

ID	Recommendation	Current Status	
4	The programme of research outlined in this document should be commissioned by the Government over the next five years to ensure the UK can remain on track to deliver Nuclear Industrial Strategy 2020 objectives.	The recently announced BEIS research programme addresses aspects of this.	
5	Government should commission high-priority research immediately to deliver the most urgent aspects of NIRAB's recommended 5 year programme.	The recently announced BEIS research programme addresses aspects of this.	
6	NIRAB's research recommendations are used to help shape future calls for directed programmes or capital investment issued by Research Councils UK and Innovate UK.	It remains to be seen whether this will be the case.	
7	Government should put in place the governance arrangements required to commission and integrate the new programme of research with a view to commissioning research early in 2016/17.	The governance arrangements for monitoring the effective implementation of nuclear research programme are yet to be made visible.	
8	Government should make clear its aims for SMR development in the UK, ensuring that these are used in evaluating the SMR competition and setting the technical priorities for both SMR development and the scope of wider nuclear research and innovation programmes.	Government has yet to communicate a clear vision of success for SMR development or deployment in the UK. Similarly it has yet to clarify the role that Government expects to play in facilitating that vision of success.	

Glossary

ADRIANA	Advanced Digital Radiometric Instrumentation for Applied Nuclear Activities	MIDAS	Materials for Innovative Dispositions from Advanced Separations
ATF	Accident Tolerant Fuel	MRF	Materials Research Facility
BEIS	Department for Business, Energy and Industrial Strategy	NAMRC	Nuclear Advanced Manufacturing Research Centre
BIS	Department for Business, Innovation and Skills	NDA	Nuclear Decommissioning Authority
C&I	Control and Instrumentation	NFCE	Nuclear Fuel Centre of Excellence
CCFE	Culham Centre for Fusion Research	NIC	Nuclear Industry Council
CDT	Centre for Doctoral Training	NIRAB	Nuclear Innovation and Research Advisory Board
CORDIS	Community Research and Development Information Service	NIRO	Nuclear Innovation and Research Office
DECC	Department of Energy and Climate Change	NNL	National Nuclear Laboratory
DISTINCTIVE	Decommissioning, Immobilisation and Storage Solutions for Nuclear Waste Inventories	NNUF	National Nuclear Users Facility
DSRL	Dounreay Site Restoration Limited	NNUMAN	New Nuclear Manufacturing
EC	European Commission	NWDRF	Nuclear Waste Decommissioning Research Forum
EPSRC	Engineering and Physical Sciences Research Council	ONR	Office for Nuclear Regulation
ETI	Energy Technologies Institute	R&D	Research and Development
EU	European Union	RACE	Remote Applications in Challenging Environments
FTE	Full Time Equivalent	RCUK	Research Councils UK
GIF	Generation IV Forum	RWM	Radioactive Waste Management
HTF	High Temperature Facility	SLC	Site Licence Company
IP	Intellectual Property	SME	Small and Medium-sized Enterprises
JRIC	Joint Research and Innovation Centre	SMR	Small Modular Reactor
KTN	Knowledge Transfer Network	STFC	Science and Technology Facilities Council
LCICG	Low Carbon Innovation Coordination Group	TRL	Technology Readiness Level
LLWR	Low Level Waste Repository Ltd	UTGARD	U/Th/beta-Gamma Active process chemistry R&D

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