

Clean Growth Through Innovation - the need for urgent action

A Report for the Department for Business,
Energy and Industrial Strategy (BEIS)



Foreword from the Chair



Mike Tynan
NIRAB Chair

I am delighted to chair the Nuclear Innovation and Research Advisory Board (NIRAB) and to present this first report from the newly re-convened Board. NIRAB has a vital role to play in providing current, accurate and independent advice to Government on where research and innovation is needed to enable nuclear energy to be cost competitive, be investible and thus make a significant clean growth contribution to the UK in line with Government and industry's ambitions, set out in the Nuclear Sector Deal.

I believe that nuclear energy can and needs to make this significant contribution to an integrated low carbon energy system. Such a system will be a cornerstone in the UK's effort to combat climate change whilst also ensuring that projected increases in the demand for energy are met. Recent developments have shown that new, large Gigawatt scale nuclear power stations in the UK are proving a challenge for investors; whilst mechanisms need to be found to resolve this issue it also highlights the potential value of small and advanced modular reactors (Advanced Nuclear Technologies). These provide an additional route to transition to an affordable clean energy strategy. This transition, it goes without saying, needs to take place alongside efficient legacy clean-up.

This report presents our findings to date and highlights our work on the overall challenges and long-term goals for nuclear power in the UK. It is clear from our work over the last year that there is need for urgent action. The nuclear industry in the UK must develop products that are cost competitive, attractive to investors, create economic value for the UK, and use best in class programme

controls to ensure timely, cost effective delivery. International collaboration will be a key to success.

I was pleased to see the launch of the Nuclear Innovation Programme (NIP), the first significant public investment in future civil nuclear fission research and innovation for a generation. This is already having an impact in rejuvenating UK capability and increasing the UK's international standing, complementing the programmes sponsored by the NDA, UKRI and industry. To maximise value for money, Government will now need to ensure that the necessary arrangements are in place to coordinate all publicly funded civil nuclear research and to set strategic direction.

Beyond the timeframe of the current NIP, we need to transition to a 'demonstration' phase in which new technology and product development is accelerated and the scale of investment ramped up if our ambitions for nuclear energy are to be met. Government has a continued role to play in supporting capability development and creating an enabling framework that allows and attracts the private sector in the UK and overseas to develop and commercialise new technologies here.

Finally, I would like to thank those who have contributed to the work of NIRAB over the last year in what is a challenging but exciting time for the nuclear sector. Our work continues through 2019 and NIRAB has a broad reach across UK industry to ensure that the advice provided to Government is underpinned by learning, experience, research, and innovation across industrial sectors and international boundaries.

Executive Summary

This is the first report summarising the work undertaken by the newly convened Nuclear Innovation and Research Advisory Board (NIRAB). NIRAB was re-established in 2018 to provide independent expert advice to Government on the publicly funded civil nuclear research and innovation, across the full nuclear life-cycle, necessary to underpin energy policy and industrial strategy, and with fostering cooperation and coordination across the sector. In particular Government has asked that NIRAB:

- ▶ Monitor the delivery and impact of the Department for Business, Energy and Industrial Strategy (BEIS) Nuclear Innovation Programme (NIP) and recommend any amendments that may be necessary in the light of outputs from the programme and developments in the nuclear landscape.
- ▶ Advise where innovation could drive down costs across the whole nuclear life-cycle
- ▶ Identify opportunities for greater collaboration with industry and international partners

This report sets out the progress made by NIRAB in addressing these questions in the 2018/19 financial year. It highlights recommendations formulated to date and an outline of the planned work programme beyond April 2019.

The clean energy and growth challenge - urgent need for action

Affordable clean energy will be vital to the prosperity of the UK. To decarbonise the UK energy system cost effectively requires a methodical consideration of the future UK energy system as a whole, including all potential contributory technologies and the role that they can play in achieving a fully optimised, integrated clean energy system. Meanwhile, clean energy demands are expected to rise as progress is made in decarbonising road transport and domestic and industrial heat.

In 2017, the Government articulated its commitment to decarbonising all sectors of the UK economy in its Clean Growth Strategy. This significant challenge sets a need for urgent and immediate action - as outlined by the Committee on Climate Change which warns that the UK is no longer on track to meet the fourth and fifth carbon budgets. The UN Emissions Gap Report states that a more ambitious net zero emissions target may be required.

Nuclear energy technologies have the potential, if they are cost competitive, to play a broader role in decarbonising a future energy system. In addition to generating baseload electricity through large and small reactors, new advanced reactors could

be developed for the provision of high grade heat (over 500°C) for industrial processes and are well suited to the production of hydrogen. Flexible generation and supply of electricity to the grid, as well as remote off grid locations, are additional applications nuclear technologies could target.

Government and the private sector each has a role to play in defining and realising nuclear energy's future potential. A key principle of Government's Clean Growth Strategy is for it to create the best possible environment for the private sector to innovate and invest in low carbon technologies, processes and systems. Nuclear energy has the opportunity to play a central role in achieving these clean growth aims, in the UK and overseas, but urgent action is required by Government and industry to provide solutions on timescales that will make a difference and for economic growth to be maximised. This will require innovation and significant deployment of a range of nuclear technologies between now and 2050.

Recommendation 1

Government should, as a matter of urgency, work with private industry to define a roadmap for future nuclear new build to meet the clean energy and growth challenge out to 2050.

An enabling framework for clean growth

A sustained cost competitive build programme (Gen III+, Small Modular Reactor (SMR) and Advanced Modular Reactor (AMR)) is required to meet the objectives set out in the Clean Growth Strategy. In particular, there are significant opportunities for the UK in relation to Advanced Nuclear Technologies (SMRs and AMRs) both domestically and globally. UK involvement at an early stage maximises the prospects for UK jobs, Intellectual Property (IP) and supply chain development.

If the UK is to contribute to the deployment of attractive solutions in the clean energy market timeframe there is a real need to accelerate the programmes, collaborate effectively, and realise the benefits of delivering and evaluating demonstrators in the UK.

Government is an essential partner in facilitating technology development and innovation for new nuclear technologies. Government support for the demonstration of new, advanced concepts is essential for attracting and making feasible the necessary scale of private investment. No matter how promising or potentially cost effective it is, a new reactor design can only go to market with the benefit of Government cooperation on a range of issues.

Recommendation 2

Government should continue to develop and implement energy policy to foster technologies that deliver significant impact through Clean Growth. This policy development should include an enabling framework for the manufacture, testing and evaluation, and commercial deployment of Advanced Nuclear Technologies which deliver economic growth and energy system value in decarbonisation.

Recommendation 3

Government should invest with private industry to facilitate an Advanced Nuclear Technologies build programme in the UK (operation of a mature commercial advanced nuclear technology by 2030 and a demonstrator of a lower maturity technology by mid 2020s).

The first significant public investment in future nuclear fission research for a generation

NIRAB welcomes the investment by BEIS in the Nuclear Innovation Programme (NIP) and the Government's investment in nuclear R&D facilities and equipment over recent years. The BEIS NIP represents the first significant public investment in future nuclear fission research and innovation for a generation. It was commissioned by BEIS in response to advice given by the previous NIRAB in 2016, and focusses on closing gaps in the nuclear research and innovation 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 associated with low carbon nuclear energy. The programme is designed to equip the UK with skills and capability to capitalise on both near term and longer term market opportunities. The Government vision of success from which the current NIP is derived has been reviewed in the light of current policy statements including those in the Industrial Strategy, The Clean Growth Strategy and the Nuclear Sector Deal. NIRAB concludes that the vision remains valid. Key elements of that vision are that by 2050:

- ▶ The UK will be a key partner of choice in commercialising Generation III+, SMR and AMR technologies worldwide
- ▶ The UK will be supplying the fuel needs of Generation III+ and any SMRs and AMRs
- ▶ UK nuclear industry will have a strong domestic capability from fuel enrichment and manufacture, reactor technology, operations to recycling and waste minimisation, storage and disposal

Future Government investment in a Nuclear Innovation Programme (NIP)

2019-21 – Delivery of the current NIP: Initial phases of the NIP (2016 – 2021) focus on 're-starting' the industry in relation to nuclear new build and future systems - the investment is already having an impact in rejuvenating capability and enabling the UK to participate in international programmes. NIRAB assess that the BEIS NIP is aligned to previous NIRAB recommendations and with current policy, and is appropriately focussed against the funding made available. Although the investment in the BEIS NIP is welcome NIRAB notes that the scale of investment is significantly less than that recommended previously. When NIRAB was originally established in 2014 there was an urgent need to maintain and build capability. That urgency has increased in the intervening five years.

The level of funding from BEIS in the NIP is projected to increase to around £50 million per year from 2019 to 2021. It is imperative that funding is maintained at no less than this level, building on the initial phases of the programme, to maintain and grow UK capability and energise the supply chain to meet the strategic ambitions.

Recommendation 4

Government should commission without delay the remainder of the prioritised programme recommended previously by NIRAB and deliver on the commitment to spend £180 million on nuclear innovation over this spending review period to 2021

2021-26 – Technology demonstration: The period following the current Spending Review needs to focus on accelerating technology development and moving into demonstration of multiple technologies as outlined in Recommendations 2 and 3 above. This will require significant Government and private sector investment to realise the stated vision for nuclear energy to play a broader role whilst achieving economic growth for the UK. A preliminary high level assessment by NIRAB and NIRO suggests that future Government investment through the NIP between 2021 and 2026 (the assumed next Spending Review Period) should be considered split across three areas:

- ▶ Research and innovation to develop key UK capabilities and supply chain aligned to market opportunities (around £300 million)
- ▶ An Advanced Nuclear Technologies demonstration programme (around £600 million)
- ▶ Critical infrastructure to support prototyping and demonstration of reactor concepts (around £100 million)

Over the next year, NIRAB will work with a broad range of stakeholders to clearly define and underpin the scope and

scale of the proposed public and private investment required, including where inward investment could be leveraged through working in collaboration with international partners.

Without this scale of Government investment and support, in a timely fashion, the UK will not be able to secure the potentially significant economic benefit through clean growth and fail to meet the overall strategic ambitions.

Recommendation 5

Between 2021 and 2026, to meet ambitions for nuclear to play a broader decarbonisation and Clean Growth role, Government should consider investment in a Nuclear Innovation Programme in the region of £1 billion and include support for the construction of Advanced Nuclear Technology demonstrators. In return, Government should expect to attract significant private sector leverage as a direct result of this support.

Delivery body: With the projected increase in funding per annum of the next phase of the NIP, in order to achieve value for money it will be necessary to ensure not only that all elements of the NIP are coordinated, communicated and delivered effectively, but that it is coordinated with other publicly funded civil nuclear research.

Recommendation 6

Government should ensure value for money by assigning a strategically focussed expert delivery body to actively manage and integrate public investment in civil nuclear innovation through a Nuclear Innovation Programme.

Driving down the cost of nuclear through innovation

Successful deployment of new nuclear, whether current or new technologies, will depend on projects being 'investible'; delivered on time, to budget, and operating successfully throughout their lifetimes. This is equally applicable to waste management and decommissioning projects. Addressing cost and programme risk challenges is urgent if a future energy system which fulfils nuclear energy's potential is to be realised. The Nuclear Sector Deal recognises this, with industry committing to achieving cost reduction targets of 30% reduction in new nuclear projects, and savings of 20% in the cost of decommissioning by 2030. Government has tasked NIRAB with identifying how innovation can drive down costs across the full nuclear lifecycle.

In addressing this challenge the nuclear sector needs to think and act differently. As well as commercialising technical innovation which can design in cost reduction from the outset,

innovation in culture, the regulatory process, delivery models, contracting practices, financing structures, and programme risk management are vital and can result in incremental cost reduction realisation over more immediate timeframes. Key to this will be to maximise learning and increasing productivity; learning from other sectors and nations that have demonstrated cost reduction and programme certainty, and importantly taking a programmatic approach which maximises learning across successive projects. The latter requires clarity of a forward programme of projects across the sector, and a coordinated, planned approach to delivery which allows for the development of a consistent supply chain.

Industry's cost reduction targets set out in the Nuclear Sector Deal are considered by NIRAB to be eminently achievable, and efforts should focus on raising productivity which can deliver efficiencies and cost savings on the 2030 timescale. Government can facilitate this through adhering to the enabling cost reduction principles outlined by NIRAB.

Recommendation 7

New build 30% cost reduction by 2030 – Government support for new build should be contingent on the application of cost and risk reduction best practice, with full transparency on how industry intends to deliver these strategies and where innovation will increase productivity and result in cost savings.

Recommendation 8

Decommissioning cost savings of 20% by 2030 – Government should ensure that the waste management and decommissioning sector baseline cost estimates from which the cost reduction targets are to be measured are transparent and publicly available, and that the sector's strategy of how targets are to be met is understood and articulated such that it can work with industry to deliver the requisite cost savings through targeted innovation and productivity increases.

NIRAB recognises and welcomes that Government is actively exploring real and perceived risks across all aspects of nuclear projects, and how innovative finance models may be applied in an effort to make civil nuclear projects investible. NIRAB considers this to be a critical activity in allowing new nuclear projects to come to fruition.

Recommendation 9

Government should identify the role it needs to play in de-risking civil nuclear projects, including innovative finance models, such that they are investible to the private sector.

The need for international collaboration

International collaboration will be instrumental in ensuring that nuclear energy plays a significant role in the UK achieving its ambitions for clean growth. International collaboration is the only credible route by which the UK can play a significant role in the commercialisation of Advanced Nuclear Technologies.

An effective international collaboration strategy needs to be shaped by multiple factors including diplomatic considerations, export opportunities and research and development programmes. Further work is required to establish a collaboration strategy which appropriately balances these factors.

Recommendation 10

Government should establish an effective international collaboration strategy which balances goals relating to diplomatic relations, trade ambitions and research and development programmes.

BREXIT and BREXATOM will change the dynamic for research and innovation collaboration with Europe. It is important to ensure that the mechanisms are in place to ensure that disruption to ongoing programmes involving UK participants is minimised.

Recommendation 11

Government should review the impact of BREXIT and BREXATOM on UK nuclear research and innovation programmes once the new arrangements are clear.

Looking forward

NIRAB will continue its work over the next year building on initial observations, advice and recommendations. This will include clearly outlining the range of roles that nuclear energy can play in meeting the demand for cost effective clean energy in the UK by evaluating the impact of a range of variables on the extent to which nuclear could contribute to clean energy needs.

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1. Introduction

This document provides a summary of the activity of the Nuclear Innovation and Research Advisory Board (NIRAB) since April 2018. It reflects the progress made by NIRAB in formulating advice to Government, and highlights recommendations arrived at to date and an outline of the planned focus for NIRAB beyond April 2019.

1.1. NIRAB Remit

NIRAB has been re-convened to provide independent expert advice to Government. Government tasked the Nuclear Innovation and Research Office (NIRO) with convening a reconstituted and restructured NIRAB able to draw on a wide range of expertise. The re-convened NIRAB first met on 4th April 2018 and has now completed its first year.

The role of NIRAB is set out in its terms of reference (Appendix 1). Government has asked that NIRAB:

- ▶ Monitor the delivery and impact of the BEIS Nuclear Innovation Programme and recommend any amendments that may be necessary in the light of outputs from the programme and developments in the nuclear landscape
- ▶ Advise where innovation could drive down costs across the whole nuclear cycle
- ▶ Identify opportunities for greater collaboration with industry and international partners
- ▶ Support the development of recommendations for new research and innovation programmes required to underpin priority policies including energy policy and industrial policy
- ▶ Oversee a regular review of the nuclear research and innovation landscape which may include facilities, capability, portfolio and capacity in the UK
- ▶ Foster greater cooperation and coordination across the whole of the UK's nuclear research and innovation capability, portfolio and capacity

NIRAB does not have responsibility for managing or delivering research and innovation programmes or for directing or managing budgets.

NIRAB works with the NIRO to advise Ministers, Government Departments and Agencies on issues related to civil nuclear research and innovation in the UK. NIRAB member profiles are provided in Appendix 1. Details of the role of NIRO in supporting the operation of NIRAB are included in Appendix 3.

NIRAB, supported by NIRO, have primarily operated through smaller working groups, holding workshops to consider specific areas of focus. The structure of these Working Groups is detailed in Appendix 4.

1.2. Background

The first incarnation of NIRAB was established as a temporary advisory board with a three year term, operating from January 2014 to December 2016. The advice provided by NIRAB was used, along with other inputs, to inform the decision by Government to invest in an ambitious Nuclear Innovation Programme (NIP) and revitalise the nuclear fission research landscape in the UK. In its final report to Government in February 2017 NIRAB provided a number of recommendations, which are detailed in Appendix 5 along with some commentary of progress against these recommendations.

1.3. NIRAB focus in 2018/19

The NIRAB scope of work includes the full civil nuclear lifecycle. However, as there are established programmes and organisations accountable for ensuring appropriate research and innovation in existing generation (EDF Energy), waste management and decommissioning (Nuclear Decommissioning Authority (NDA), EDF Energy) and fusion (UKAEA); the main focus for NIRAB has been on the gap the BEIS Nuclear Innovation Programme is looking to address. This gap relates primarily to research and innovation in supporting future new nuclear build in both the short and medium term. The recommendations in this report are therefore dependent on and complementary to the ongoing programmes as currently envisaged in these other areas.

NIRAB and NIRO have also worked to foster greater cooperation and coordination across the whole of the UK's civil nuclear research and innovation capability, portfolio and capacity, including:

- ▶ Communication through NIRAB members who have expertise spanning all aspects of the nuclear lifecycle. Observers from NDA, UK Research and Innovation (UKRI) and the Office for Nuclear Regulation (ONR) attend full NIRAB meetings and Working Group meetings
- ▶ The NIRAB Chair is a member of the Nuclear Industry Council (NIC) and chairs the NIC Innovation Working Group which is overseeing implementation of the innovation aspects of the Nuclear Sector Deal

- ▶ The NIRO Executive Director Chairs the Nuclear Skills Strategy Group which is overseeing implementation of the skills aspects of the Nuclear Sector Deal
- ▶ NIRO is represented as observer on both the NDA Research Board and Nuclear Waste and Decommissioning Research Forum (NWDRF)
- ▶ The NIRO Executive Director is the Vice-Chair of OECD-NEA's Steering Committee and Chairs the OECD-NEA Nuclear Innovation 2050 Initiative.

1.4. Structure of report

NIRAB has focussed on understanding the role that nuclear could play in meeting the clean energy challenge and identifying where publicly funded research and innovation is required to underpin Government policy. In Chapter 2 the clean energy challenge is set out and the current landscape described. Following the Government investment in the NIP, Chapter 3 considers the enabling framework and role for Government in supporting the deployment of Advanced Nuclear Technologies (i.e. Small Modular Reactors (SMR) and Advanced Modular Reactors (AMR)). Chapter 4 provides an overview of the background and current scope of the NIP. Based on an understanding of the current BEIS NIP and the evolving landscape, Chapter 5 considers the impact of the current NIP and also proposes how it should develop to support the attainment of Government strategic ambitions. An overview of the role of innovation in reducing the cost of civil nuclear is considered and outlined in Chapter 6. An international perspective is detailed in Chapter 7, particularly the role of international collaboration. Finally, priorities for NIRAB over the coming year are summarised in Chapter 8.

1.5. NIRAB Meetings

NIRAB met three times in 2018/19 (in April, October and January). The minutes are available on the NIRAB website (www.NIRAB.org.uk/our-work/meeting-minutes). In addition there have been more than 20 NIRAB Working Group meetings.



2. The Clean Energy Landscape

This section describes the context within which NIRAB's advice and recommendations have been developed. It summarises the broader clean energy challenge and discusses the evolving landscape.

2.1. The clean growth challenge

In 2017, the Government articulated its commitment to decarbonising all sectors of the UK economy in its Clean Growth Strategy^[1]. All sectors of business and society depend on access to affordable and reliable energy. In this context energy is more than electricity; it includes domestic heating, fuelling the transport sector, industrial processes and much more. A key principle of the Clean Growth Strategy is to create the best possible environment for the private sector to innovate and invest in low carbon technologies, processes and systems. Nuclear has the opportunity and should play a central role in achieving these clean growth aims delivering low carbon energy and creating new high value jobs.

The Climate Change Act 2008 commits the UK to a reduction of greenhouse gas emissions by at least 80% of 1990 levels by 2050, with associated carbon budgets in the intervening years as stepping-stones along the way. However, in 2018 the UN Energy Emissions Gap Report^[2] highlighted the fact the sum of the current worldwide national commitments will fall short of the action required to ensure that Global Warming stays below 2°C. More ambitious targets may be required and the prospects of the need for net zero carbon emissions has been raised.

The need for urgent and immediate action has been confirmed by the Committee on Climate Change^[3] which warns that the UK is no longer on track to meet the fourth and fifth carbon budgets. If the UK were to target net zero emissions by 2050 the gap would be even wider.

In order to decarbonise cost effectively, innovative ways of realising an integrated national clean energy system must be considered. In the absence of long-term sustainable solutions that can address not just carbon-free electricity but, for example, heat and hydrogen generation, the UK will have to continue its reliance on oil and gas.

Government has a three-fold role in enabling this low carbon energy system as follows^[4]:

- ▶ Providing coordination and reducing uncertainty in delivering future outcomes,
- ▶ Ensuring a diverse reliable energy system which ensures cost-effective low-carbon energy security,
- ▶ Investing to ensure that the UK has the capability and flexibility to deliver low-carbon energy

2.2. The evolving landscape

The landscape in which the nuclear sector exists has continued to evolve since December 2016, when the first NIRAB stood down. This evolution has been considered when formulating advice and recommendations over the past year and described in this report.

Going hand in hand with the Clean Growth Strategy is the UK's Industrial Strategy^[5], published in 2017, which puts forward the Government's long-term plan to boost the productivity and earning power of people throughout the UK. The Industrial Strategy sets out Grand Challenges to put the UK at the forefront of the industries of the future. Clean Growth is one of the first four Grand Challenges to be tackled. In addition falling under the Industrial Strategy are Sector Deals jointly owned by industry and government. The Nuclear Sector Deal^[6], published in 2018, has the stated aim of ensuring that the UK's nuclear sector remains cost competitive with other forms of low-carbon technologies to support our Clean Growth Strategy and Grand Challenge. Under the Nuclear Sector Deal, the UK nuclear industry has signed up to commitments on cost reduction, diversity and a target to win £2 billion of new domestic and international contracts by 2030.

At the end of 2016, Government commissioned the Nuclear Innovation Programme, committing to fund around £180 million for civil nuclear innovation over the spending review period to 2021. £40 million has been contracted so far. The Nuclear Innovation Programme forms an integral part of the Nuclear Sector Deal. The Nuclear Innovation Programme is discussed in more detail later in this report. Other notable Government actions include:

- ▶ An Advanced Nuclear Technologies Policy Paper^[7]
- ▶ The Generic Design Assessment (GDA) process for small and advanced modular reactors was opened for expressions of interest
- ▶ Government are considering a proposal for a small modular reactor from a UK Consortium led by Rolls-Royce that could lead to significant joint investment^[8]
- ▶ The UK has recently joined the Generation IV International Forum as a full participating member with an active participation in Sodium Fast Reactor (SFR) and Very High Temperature Reactor (VHTR) systems
- ▶ Government committed an initial £20 million for conceptual design development of the Spherical Tokamak for Energy Production (STEP) project through UKAEA^[9]

There have also been changes in the broader nuclear landscape since 2016. These include the financial difficulties and subsequent restructuring of established reactor vendors (e.g. AREVA NP/Framatome and Westinghouse), and withdrawal of Toshiba from the new build project at Moorside and suspension by Hitachi of their project at Wylfa in the UK.

State backed programmes continue to deliver around the world and programmes delivering Generation IV reactors for commercialisation are mainly state backed.

2.3. The role of nuclear energy - understanding a range of possible futures

Nuclear has a long and proud history of reliably supplying carbon-free baseload electricity; it has operated at high capacity factor preventing billions of tons of CO₂ emissions. As the demand for clean electricity generation increases with decarbonisation of transport and domestic and industrial heating, nuclear technologies can be pivotal in ensuring that the UK achieves its moral and legal obligation to decarbonise.

Decarbonisation is a huge challenge and will require all 'the tools in the box'. Nuclear sits alongside power generation technologies such as wind and solar in having an important role to play as part of a diverse low carbon energy system; the UK only has to look to Sweden and France for examples of where sustained nuclear build has delivered significant decarbonisation. It is recognised that for nuclear to play a significant part in the clean energy future it will need to be cost competitive with the full system cost of other clean energy technologies. Recent studies^[e.g. 10] have identified huge potential for innovation to reduce financial, project and construction risk in a way that reduces costs and provides the certainty required to make nuclear investible. Looking

beyond these mechanisms to reduce baseload electricity cost, Advanced Nuclear Technologies (Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs)) could, in addition, maximise cost-competitiveness by satisfying a range of other needs within a wider decarbonised clean energy system, including:

- ▶ Supply of low grade heat for domestic heating
- ▶ Supply of high temperature process heat to energy intensive industries
- ▶ Providing a source of energy to manufacture hydrogen
- ▶ Electricity supply to accommodate the intermittency of electricity generated from renewable sources

Changes in the political, nuclear industry, UK energy and nuclear power generation landscapes need to be considered to ensure that any Government intervention is appropriately focussed. Any current or future Government intervention and investment must seek to ensure, in partnership with industry, that the UK has the capability to support the successful delivery of a range of possible nuclear energy futures. All of these futures include successful delivery of decommissioning, waste management and waste disposal programmes. It is important to understand the characteristics of the technologies that could meet various decarbonisation needs in a cost effective manner, and the relative technical maturity of the technologies. Generation III+ large reactors are available now. Advanced Nuclear Technologies are a range of technologies with different technical maturities and associated deployment timescales, see Table 1.

1. [The Clean Growth Strategy: Leading the way to a low carbon future, October 2017](#)
 2. [Emissions Gap Report, 2018, United Nations Environment Programme, November 2018](#)
 3. [2018 Report to Parliament, Committee on Climate Change](#)
 4. [Greg Clark speech, The End of the Trilemma, November 2018](#)
 5. [Industrial Strategy: Building a Britain fit for the future, Cm9528, November 2017](#)

6. [Industrial Strategy: Nuclear Sector Deal, June 27th 2018](#)
 7. [BEIS Policy paper, Advanced Nuclear Technologies, Update December 2018](#)
 8. [Greg Clark statement to the House, 17th January 2019](#)
 9. [Science Minister speech at UKAEA, 25th January 2019](#)
 10. [The ETI Nuclear Cost Drivers Project: Summary Report, Energy Technologies Institute, 20th April 2018](#)

Table 1. An assessment of the time to technical maturity of SMR and AMR concepts¹¹⁾

		First of a Kind (FOAK) Commercial	Nth of a Kind (NOAK) Commercial
SMR	SMR (light water)	Before 2030	2030 – 2050
	HTGR, SFR ^a	Early 2030s	2030 – 2050
AMR	Other Gen IV	2040s	Beyond 2050

a - HTGRs and SFRs could possibly progress directly to commercial offerings as these technologies are already operating or under construction in Russia and China, clearly this will be dependent on the actual concept design and the amount of read across.

Figure 1 provides an illustrative example of a theoretical deployment profile; this is not a forecast but is used to highlight that a range of technologies could be deployed to decarbonise different aspects of the energy sector; that these technologies are complementary and additive; and that the timing of deployment differs.

Nuclear has an opportunity to play a critical role in the UK meeting its clean growth ambitions. To do this will require **urgent action and a planned, programmatic approach** to underpin the deployment of a range of technologies focused on meeting market needs between now and 2050.

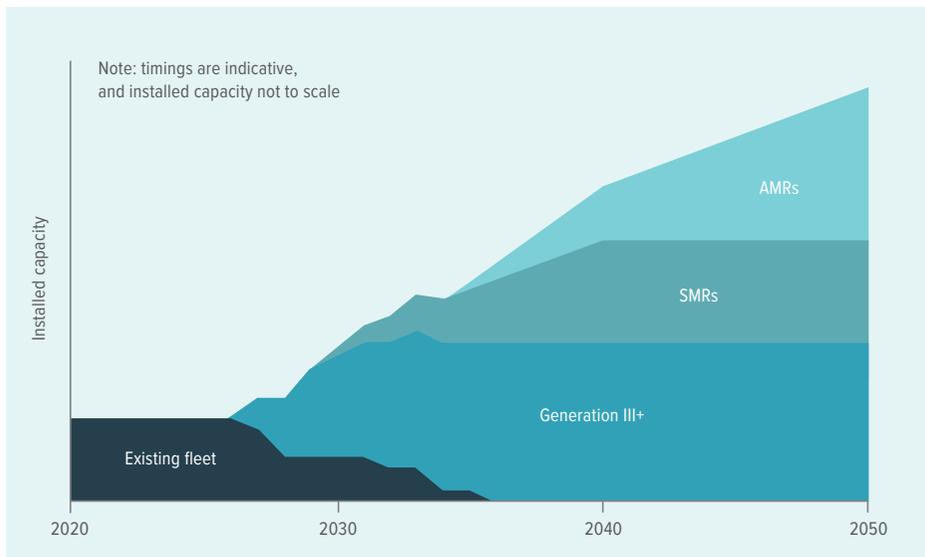
NIRAB has begun and will continue to identify and quantify the role that nuclear energy could play in meeting all identified

clean energy system needs in a range of future scenarios. The output from this exercise will be used to inform future recommendations on research and innovation (see Section 8.1).

Recommendation 1

Government should, as a matter of urgency, work with private industry to define a roadmap for future nuclear new build to meet the clean energy and growth challenge out to 2050.

Figure 1. An illustrative deployment profile for a range of nuclear technologies



11. The Future of Nuclear Energy in a Carbon-Constrained World; An interdisciplinary MIT study, 2018

3. Enabling the path to deployment of Advanced Nuclear Technologies (SMRs and AMRs) - the need for demonstrators

Nuclear has an important role to play in a clean energy future in the UK; but for this to be realised there needs to be an enabling framework to support the development, demonstration and deployment of multiple cost-competitive reactor systems (large and small) delivering products to the energy market in a timely fashion.

Government investment through the Nuclear Innovation Programme (NIP) (see Section 4) is helping to build capability in the UK; this capability now needs to be mobilised to underpin the sustained cost competitive build programme (Gen III+, SMR and AMR) required to meet the objectives set out in the Clean Growth Strategy.

There are significant opportunities for the UK in relation to SMRs and AMRs both domestically and globally, UK involvement at an early stage maximises the prospects for UK jobs, Intellectual Property (IP) and supply chain development. The role of public investment in nuclear innovation in supporting the commercialisation of these technologies is considered in the following sections.

3.1. Research, Development and Demonstration of Advanced Nuclear Technologies

BEIS developed the AMR Feasibility & Development project (see Section 4) to explore the potential for UK involvement in the commercialisation of AMRs for deployment in the UK and abroad, with a view to informing how emerging nuclear technologies can meet broader long term energy and economic policy objectives. Indeed, without implementation resulting in benefit (to the UK) the NIP is a technology development programme rather than an innovation programme. Without a route to market and a good business model, a good idea

becomes good technology but doesn't become a successful product.

The NIP (and broader industry investment in the UK) needs to enable the successful deployment of nuclear products into the clean energy market. If the UK is to contribute to the availability of attractive solutions in the clean energy market timeframe there is a real need to accelerate the programmes, collaborate effectively, and recognise the benefits of delivering and evaluating demonstrators in the UK. In particular, the benefits and opportunities of international collaboration to deliver timely solutions need to be considered.

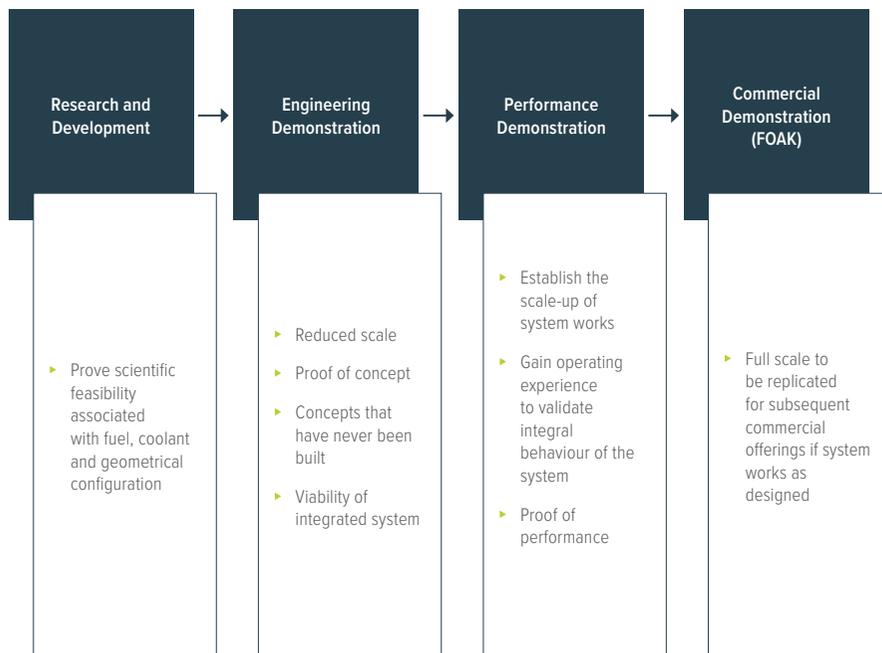
Innovation should be prioritised towards designs that are optimised for lower costs and aimed at delivering successful products into the clean energy market, i.e. commercially directed technology development. Private industry is best placed to deliver this, but Government has a critical role as an enabler. Great value can be gained through harnessing commercial interests to select among technology options and drive key technology choices through development to deployment.

3.2. Process for bringing a reactor concept to commercial deployment

To bring a reactor concept to commercial deployment involves many steps; the resources required to bring new designs to market are large and the time horizons lengthy.

The steps will, at a high level, include those outlined in Figure 2. Technology demonstration is the central process on this route to commercialisation.

Figure 2. Schematic representation of the high level process for developing a reactor concept towards commercialisation^[10]

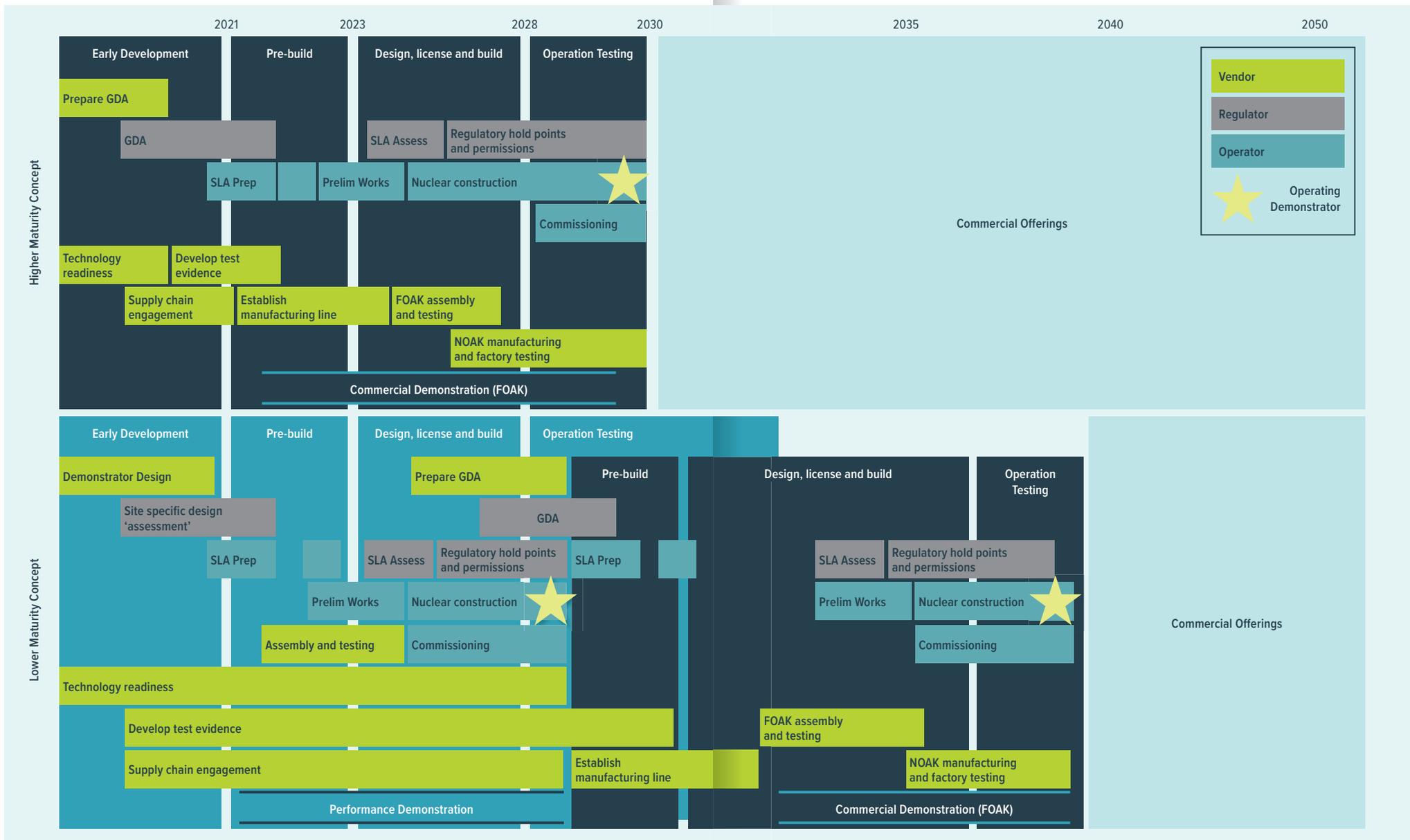


There is the need for demonstrators, particularly for the less mature advanced technologies; the AMR F&D project aims to understand the maturity of some of these technologies and proposed timelines for commercialisation. Figure 3 provides an example high level schematic representation of a notional timeline to commercialisation of a higher and lower maturity concept. The level of maturity determines the level of development and demonstration work required (Figure 2). In Figure 3 the lower maturity example assumes that an engineering demonstrator is not required (i.e. only a performance demonstrator, see Figure 2). If engineering demonstration is required clearly this adds additional time and cost to the development programme. The timelines are not intended to be 100% accurate but to provide an illustration of the elements and work required to move from a paper based reactor to an operating commercial system. **It is clear that urgent action is required now to accelerate programmes if technology is to be deployed in the 2020/30s.**

It is important that an enabling innovation framework is put in place to support technologies at different levels of maturity. The less mature concepts will require access to capabilities and sites to prototype and undertake engineering and performance demonstrators. The UK should aim to play an active role in the demonstration

phases for advanced technologies, given the potential additional functionality of these systems, and should provide sites to host these demonstrators enabling the UK supply chain to actively engage in the early stages; with the ultimate aim to accelerate the process towards commercialisation for advanced nuclear technologies where possible.

Figure 3. Notional advanced nuclear technologies (higher and lower maturity) development timelines



3.3. Government support for technology development

Government is an essential partner in facilitating technology development and innovation for new technologies. Government support for the demonstration of new, advanced concepts is essential for attracting and making feasible the necessary scale of private investment. No matter how promising or potentially cost effective it is, a new reactor design can only go to market with the benefit of Government cooperation on a range of issues. The substantial upfront investment and long-time horizons before return on investment, means that Government buy-in is important to attract private investors. The structure through which Government support is channelled will be important to maximise the likely success and impact of public funding. The Expert Finance Working Group (EFWG) – tasked by BEIS to provide an independent view - considered this in relation to small nuclear and reported to Government in Summer 2018^[12]. Examples of government support around the world vary and it is important to understand the global market landscape and for the UK to learn from some of these examples. These include: the development of the AP1000 (Westinghouse – then owned by British Nuclear Fuels Ltd (BNFL)), the European Pressurised Water Reactor (EPR) (French state ownership of AREVA NP/Framatome), all Chinese designs (state owned), all Russian designs (state owned), the Japanese High Temperature Gas Reactor (HTGR) programme (state delivered with a plan for commercialisation and transfer to private sector), the NuScale Power SMR (privately delivered but Federally co-funded).

A number of studies have estimated the costs for particular designs to achieve First of a Kind (FOAK); the AMR feasibility and development programme aims to elucidate more detailed

costs for systems to achieve commercialisation. For more mature technology, the EFWG suggested costs in the region of £2 billion to construct first full-scale SMR (light water) plant^[12], not including up-front R&D and design costs which could total in the region of £500 million dependent on the design. In addition, developing a supply chain for fuel and other equipment could also be in the region of £500 million. A total investment in the region of £3 billion over the life of the project could be expected. For less mature technology this figure is likely to be in the region £4 billion – 6 billion when the cost of the additional performance demonstration phase required (Figure 3) is factored in.

The next stage is to consider what the Government support and investment could and should look like. Table 2 shows an example, using figures from a recent MIT study^[11]. This presents the potential breakdown of costs for high maturity (not requiring performance demonstration) and lower maturity (requiring performance demonstration) concepts to deliver a FOAK. These figures are illustrative; Government will receive more detailed cost estimates and timings through the AMR F&D study. The important consideration is the role of public funding in supporting the development and innovation of new technologies. The examples show that, for these scenarios and assumed Government contributions at various stages through the development process towards commercialisation, to support two reactor concepts – one high maturity and one lower maturity – Government investment in the region of £50 million to £100 million per annum could help accelerate the commercialisation of these technologies and attract significant private investment. This represents a significant leveraging of investment, while the deployment would bring major economic benefits together with meeting the needs for clean energy.

Table 2. Illustrative costs for ANTs to achieve commercial demonstration and an example of cost sharing between public and private investment^[11]

		High Maturity		Lower Maturity		
		Duration / years	Cost / £ mill	Duration / years	Cost / £ mill	Government Investment / %
Early Development	R&D	3	40	8	230	50
	Design Development	3	80	8	160	50
	Supply Chain	3	80	8	160	50
Performance Demonstration	Design Completion			2	230	50
	Licensing			2	160	50
	Construction			7	1800	30
	Operational testing			5	310	30
Commercial Demonstration	Design Completion	2	80	2	80	50
	Licensing	2	160	2	80	50
	Construction	5	1350	5	1380	20
	Operational testing	2	160	2	160	20
	Total	12	1930	31	4740	
	Government investment over the project		530		1650	
Industry investment over the project		1400		3090		

Conversion to £'s from \$'s of values taken from reference with assumed exchange rate of 0.78.

3.4. Competition and international context

The objective of the ANT programme, and the broader NIP, should be to attract developers of innovative nuclear technologies to the UK at an early stage (rather than them establishing themselves in, for example, Canada or the US). This maximises the opportunities for UK involvement, IP and supply chain development. This must be started before IP is secured elsewhere, other nations such as the US and Canada are moving at pace in this space. For example Canada has delivered an SMR roadmap and the Canadian Nuclear Laboratories (CNL) has proposed the use of their facilities to host a demonstration or prototype reactor by 2026.

Although there are inherent risks of investing in lower maturity nuclear technology, targeted Government investment in innovation can help vendors and operators leverage much higher levels of private funding for their designs. A Government enabling framework will help to de-risk investment and build capacity in the UK supply chain.

Recommendation 2

Government should continue to develop and implement energy policy to foster technologies that deliver significant impact through Clean Growth. This policy development should include an enabling framework for the manufacture, testing and evaluation, and commercial deployment of Advanced Nuclear Technologies which deliver economic growth and energy system value in decarbonisation.

In addition to progressing delivery of Gen III+ and SMR technologies, the UK should target hosting the construction of an AMR (engineering/performance) demonstrator by the mid-2020s by accelerating work in this area; AMRs offer the capability to target different applications to current light water based technologies. Any AMR demonstrator must be based around product development with a clear understanding of the future market - which is likely to necessitate targeting both heat and power with consideration of industrial applications.

Recommendation 3

Government should invest with private industry to facilitate an Advanced Nuclear Technologies build programme in the UK (operation of a mature commercial advanced nuclear technology by 2030 and a demonstrator of a lower maturity technology by mid 2020s).

The urgency required around AMR product development, to ensure that commercial offerings are available to the market within the timescales necessary to actively contribute to Clean Growth in the UK, will necessitate international collaboration. The UK should actively and urgently consider how international collaboration can be used to move towards delivery of a technology demonstrator on the path to a commercial AMR offering by the mid-2030s - ensuring clarity around the opportunities for the UK supply chain.

4. BEIS Nuclear Innovation Programme (NIP)

The BEIS Nuclear Innovation Programme (NIP) represents the first significant public investment in future nuclear fission research and innovation for a generation. Aspects of the NIP are based on the recommendations set out previously by NIRAB between 2014 and 2016; the following sections provide more detailed background on the NIP.

4.1. NIRAB (2014 – 2016) Recommendations

The first incarnation of NIRAB offered advice to Government on the publicly funded research and innovation required to underpin policy¹³. NIRAB's original recommendations were made in the context of the Nuclear Industrial Strategy published by Government in March 2013¹⁴. This was developed jointly with industry and identified not only a vision for the industry, but also a series of strategic objectives addressing power generation, waste management and decommissioning, fuel fabrication and the supply chain for all parts of the industry. The strategic objectives spanned timeframes from 2020 to 2030 and 2050. The level of ambition described in these objectives set the basis for NIRAB to develop its original recommendations.

It was clear that a broader programme of publicly funded research would be needed to support the delivery of these long term objectives. Hence, one of the main focuses of NIRAB's work over the period of 2014 – 2016 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.
- ▶ Fundamental nuclear research is well served by our internationally renowned universities, with Research Councils UK (now part of UKRI) providing essential programme and infrastructure funding to develop the scientists and engineers needed for the future.
- ▶ Innovate UK (now part of UKRI) 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 be maintained at no lower than the then current levels (see Appendix 5).

There was, however, still a gap in the UK's research activity in relation to future nuclear technologies, and so NIRAB recommended research be commissioned in this area. The urgency and rationale for identifying the recommended research was predominantly due to two factors:

- ▶ An increasingly pressing need to underpin the "at-risk" 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 recommended programme was 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 was aimed to support the new build fleet and SMR development and, importantly, creating a platform to support AMR development. The recommended research programme, of approximately £250 million over a five year period, covered:

- ▶ **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
- ▶ **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

4.2. Evolution of the Nuclear Innovation Programme

In the Spending Review and Autumn Statement 2015, Government committed to invest in an ambitious nuclear research and development programme over the period 2016 to 2021¹⁵. Further clarification around this commitment has been made since 2015; the current understanding is that within the current BEIS Energy Innovation Programme, BEIS expects to invest around £180 million in nuclear innovation¹⁶ between 2016 and 2021 - the Nuclear Innovation Programme – building on the recommendations of NIRAB.

As part of the NIP commitment, an initial phase of over £20 million of funding was launched in November 2016, supporting innovation in the civil nuclear sector across five major areas from 2016-18:

- ▶ £6 million towards maintaining the UK's leading edge work on advanced nuclear fuels which could provide greater levels of efficiency.
- ▶ £5 million for research that underpins the development, safety and efficiency of the next generation of nuclear reactor designs.
- ▶ £6 million to develop the UK's capability in nuclear materials, advanced manufacturing and modular build for the reactors of the future.

- ▶ £2 million to research fuel recycling processes that may reduce future environmental and financial burdens.
- ▶ £2 million to continue with the development of a suite of tools and underpinning data that will enhance Government's knowledge basis for future decision making in the nuclear sector, up to 2050.

A second phase of innovation funding was announced by BEIS in December 2017, providing up to £8 million for work on modern safety and security methodologies and advanced fuel studies.

In addition to an R&D programme, the 2015 announcement outlined that a competition to identify the best value small modular reactor design for the UK would be launched. In March 2016 Government launched the first phase of an SMR competition with the goal of evidence gathering and gauging market interest among technology developers, utilities, and potential investors. Following engagement with industry, the competition closed in December 2017 without any 'winners' or 'prizes'. In March 2015, Government commissioned an independent Techno-Economic Assessment (TEA) of SMRs in order to contribute to the evidence base and help inform policy decisions. There were seven projects involved in the TEA, including a comprehensive analysis of SMRs, cost reduction studies, assessment of the UK regulatory regime and more. The TEA was published in December 2017.

In December 2017, following closure of the SMR competition and publication of the TEA, BEIS announced that it was to invest up to £44 million in an Advanced Modular Reactor (AMR) Feasibility and Development (F&D) project. AMRs were defined by BEIS as a broad group of advanced nuclear reactors which differ from conventional reactors that use pressurised or boiling water for primary cooling. It was stated that AMRs aim to maximise the amount of off-site factory fabrication and can target:

- ▶ generating low cost electricity
- ▶ increased flexibility in delivering electricity to the grid
- ▶ increased functionality, such as the provision of heat output for domestic or industrial purposes, or facilitating the production of hydrogen
- ▶ alternative applications that may generate additional revenue or economic growth.

13. UK Nuclear Innovation and Research Programme Recommendations, NIRAB-75-10, March 2016
14. The UK's Nuclear Future: Industrial Strategy; government and industry in partnership, BIS/13/267, March 2013

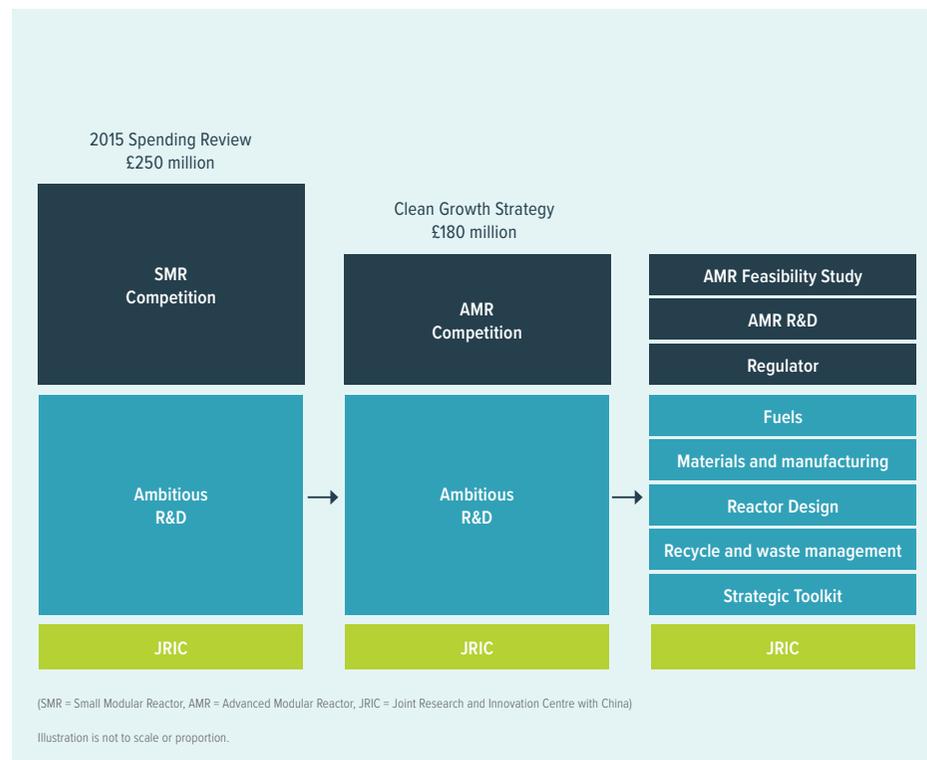
15. Spending Review and Autumn Statement 2015
16. Funding for nuclear innovation; Government web site

The BEIS AMR F&D project has two phases:

- ▶ Phase 1: funding (up to £4 million) to undertake a series of feasibility studies for AMR designs with individual contracts of up to £300,000 available. Eight contracts were awarded in May 2018.
- ▶ Phase 2: subject to Phase 1 demonstrating clear value for money and Government approval, a share of up to £40 million could be available for selected projects from Phase 1 to undertake development activities.

In addition, Government announced that it is providing up to £7 million of funding to regulators to build the capability and capacity needed to assess and license AMRs. This funding will also provide support for pre-licensing engagement between vendors and regulators. In addition, up to a further £5 million may also be made available to regulators to support Phase 2 of the AMR F&D project.

Figure 4. Assumed breakdown of Nuclear Innovation Programme funding and evolution from the announcement in the 2015 Spending Review (£250m)



Finally, it is also assumed that the NIP incorporates the plans for a Joint Research and Innovation Centre (JRIC) with China; at the Spending Review and Autumn Statement 2015 it was announced that there would be £25 million of UK funding for a JRIC, to be based in the North West. There have not been any recent announcements in relation to the JRIC.

The NIP is, hence, made up of a number of constituent parts. The evolution and current understanding of the elements of the NIP funding is shown schematically in Figure 4.

The Nuclear Sector Deal (NSD) published in 2018 represents an important milestone for the nuclear sector^[6]. The NIP is intrinsically linked with the NSD. Indeed, the NSD directly incorporates and mentions parts of the NIP:

- ▶ £56 million to support the design of advanced nuclear technologies. This is the AMR F&D project and to fund upskilling of regulators in relation to advanced technologies.
- ▶ Government contribution to the £40 million investment in a new thermal hydraulics facility is part of the Digital Reactor Design element of the NIP.
- ▶ £20 million for an advanced manufacturing and construction programme is part of the Materials and Manufacturing element of the NIP.

4.3. Nuclear Innovation Programme objectives

The strategic objectives set out in the 2013 Nuclear Industrial Strategy^[14] were originally used to shape an ambitious research and innovation programme that would position the UK nuclear industry to be a:

- ▶ Key partner of choice in commercialising Generation III+, IV and Small Modular Reactor (SMR) technologies worldwide
- ▶ 'Top table' nuclear nation, working in international partnerships leading the direction of future technology advances across the fuel cycle
- ▶ Respected partner contributing significantly to appropriate international research programmes undertaken with selected international contributors

These were considered in conjunction with indicative milestones set out, as follows, in the same document:

- ▶ UK supplying the fuel needs of Generation III+ and any Gen IV and SMRs
- ▶ UK nuclear industry will have a strong domestic capability from fuel enrichment and manufacture, reactor technology, operations to recycling and waste minimisation, storage and disposal

As a precursor to an evaluation of the effectiveness of the BEIS NIP it is important to first consider whether these objectives remain relevant and adequate. NIRAB therefore reviewed more recent policy statements including the Industrial Strategy^[5], The Clean Growth Strategy^[1] and the Nuclear Sector Deal^[6].

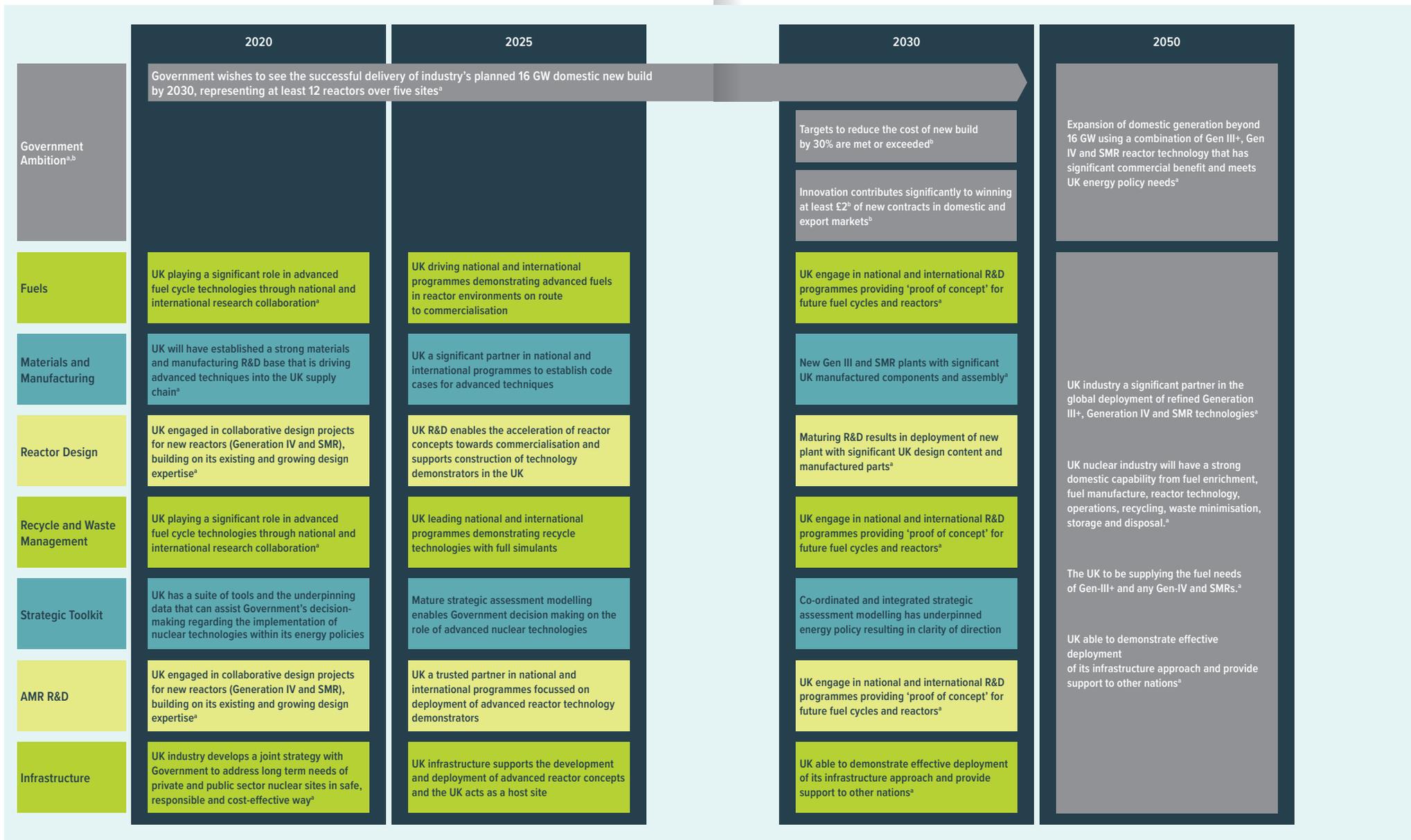
NIRAB has concluded that the original drivers for the Nuclear Innovation Programme remain valid. Two factors have risen to greater prominence, but both are consistent with the programme commissioned to date;

- ▶ There is currently an even greater emphasis on the need for cost reduction

- ▶ There have been major developments around advanced nuclear technologies (SMR enabling framework and AMR Feasibility and Development (F&D) initiative) and a greater recognition that nuclear energy could supply additional functionality (e.g. heat) in addition to baseload electricity.

Figure 5 provides a high level summary of the Government strategic objectives and a number of 'pathways' for the current Nuclear Innovation Programme areas, with the addition of infrastructure, indicating broadly the required evolution to meet the long term strategic goals. The subsequent sections of the document consider in more detail the role of Government investment and the evolution of the Nuclear Innovation Programme to meet these goals.

Figure 5. UK civil nuclear research and innovation pathways to achieving government strategic ambitions
 (References: a Nuclear Industrial Strategy 2013, b Nuclear Sector Deal)



5. NIRAB Review of the Nuclear Innovation Programme

NIRAB has been asked by BEIS to monitor the delivery and impact of the BEIS Nuclear Innovation Programme and recommend any amendments that may be necessary in the light of outputs from the programme and developments in the nuclear landscape. The following sections consider the current programme and assess how it should evolve, as the nuclear landscape evolves, to meet the overall objectives. A high level overview of the current contracted BEIS NIP is summarised in Appendix 6, which also identifies the lead contractors in each area and a selection of the many organisations (over 30) delivering the NIP.

5.1. Completeness and Efficacy of the Current programme

To assess the current programme, NIRAB gathered detailed information from the contractors delivering the NIP and also received feedback from the BEIS project delivery team. NIRAB were not able to comment on the AMR Feasibility and Development (F&D) project at this stage as outputs were not available and it was not considered appropriate given the relative immaturity of the project.

NIRAB reviewed the contractor's feedback in depth and held a series of interviews in order to assess the current programme. It should be noted that NIRAB did not perform an in depth technical review of the programme. NIRAB assess that the current NIP is aligned to previous NIRAB recommendations and is appropriately focussed against the funding made available. Organisations delivering the NIP appear competent and knowledgeable. Contracts seem to be delivering to existing scope, schedule, quality and budget. Indeed there are some excellent examples of where the investment is already showing considerable benefit and some case studies are included in Appendix 7.

There is, however, essential learning to be gathered from this initial investment to ensure maximum value for money:

- **Programme management** – Additional resource is required to ensure delivery of effective successful outcomes. Sufficient capability and capacity needs to be committed to programme definition, procurement, management and integration, including the management of Intellectual Property (IP).

- **Programme integration** – More integration will facilitate greater impact. To maximise the benefits of the programme, NIRAB recommend, as previously⁽¹⁷⁾ (Appendix 5), that the NIP should be treated and managed as a single integrated programme to maximise synergies and interactions across the individual projects and not delivered through a piecemeal approach which would severely curtail such interactions.
- **Demonstration** – A focus on technology demonstration will be required to realise the ambition of playing a significant role in the commercialisation of nuclear technologies. This, in turn, will require greater industry engagement and a focus on outcomes.

5.2. The level of current investment in the NIP

To date, around £40 million of research has been contracted under the NIP between 2016 and 2019. Table 3 provides a breakdown of the NIP areas and also the assumed funding breakdown (announced and contracted) based upon BEIS announcements and details published on the BEIS website⁽¹⁶⁾ also includes the original recommended R&D funding from NIRAB in 2015. The BEIS NIP is welcome investment but the scale of investment in R&D is significantly less than that recommended by NIRAB.

When NIRAB was originally established in 2014 there was an urgent need to maintain and build capability. **That urgency has increased in the intervening five years.** Without a base level of research the UK cannot expect to design, build, operate, regulate or decommission large or small nuclear reactors (conventional or advanced systems).

17. NIRAB Final Report, 2014 to 2016, NIRAB-117-3, February 2017

Table 3. Nuclear Innovation Programme (NIP) areas and assumed funding breakdown for 2016 – 2021

Nuclear Innovation Programme Area		Phase 1 Contracted (2016 – 2018)	Phase 2 Contracted (2018 – 2020)	Phase 3 Announced but not contracted (2019 – 2021)	Total BEIS NIP	Previous NIRAB Recommended Programme from 2015
AMR	Feasibility study		4		4	-
	AMR R&D			40	40	-
	Regulator capability and capacity		7	5	12	-
Ambitious R&D	Advanced Nuclear Fuels	6	4.3	12 ^a	22.3	44
	Advanced Manufacturing and Materials	6		20 ^b	26	52
	Reactor Design	5	3.7	26 ^c	34.7	74
	Fuel Recycle and Waste Management	2		12 ^d	14	75
	Strategic Toolkit	2			2	7.5
JRIC ^e	JRIC			25	25	-
Totals		21^f	19	140	180	250

a. Expect further funding to be announced, assume based on other announcements that will be £12m if remainder is equally split with recycle.

b. £20m announced in sector deal.

c. Assumed £40m for thermal hydraulics facility announced in Sector Deal is £20m from BEIS with match funding from Welsh Government (Welsh Government funding not included here). £6 million ITT announced in December 2018.

d. Expect further funding to be announced, assume based on other announcements that will be £12m if remainder is equally split with fuels

e. Joint Research and Innovation Centre with China

f. Initial phase was announced as £21 million, website also says that contracts for £12.5 million were awarded.

Table 3 also shows that Phase 3 of the BEIS NIP funding is a significant increase relative to the initial phases. NIRAB welcomes this but also continues to emphasise the importance of having an effective mechanism in place to coordinate public sector funding and that it is vital to improve programme management and delivery as investment increases; commissioning further programmes will increase the complexity of the landscape of publicly funded research.

In order to achieve value for money it will be necessary to ensure that all publicly funded civil nuclear research is coordinated effectively.

Government, and industry, structures are discussed in more detail in Section 5.4.4 when considering the future outlook of the Nuclear Innovation Programme.

5.3. The forward programme to 2021

It is important to deliver on the programme recommended previously by NIRAB and the full extent of the funding currently committed to the BEIS NIP. The basis for recommendations remains valid, and the investment in these capabilities is critical to maintain and develop capability to implement any future nuclear programme. The prioritisation of the NIRAB research recommendations⁽¹⁸⁾ also remains valid focussing on areas that target immediate market opportunities and develop skills and

capability to increase UK competitiveness. Elements of the programme of research addressing at risk skills and capability were previously assigned high priority, this should continue. In addition, there should be an increased focus and emphasis on innovation to reduce costs.

Recommendation 4

Government should commission without delay the remainder of the prioritised programme recommended previously by NIRAB and deliver on the commitment to spend £180 million on nuclear innovation over this spending review period to 2021

The basis for the NIRAB recommendations and prioritisation remains valid, but there have been changes in the landscape over the preceding three years that require consideration in Phase 3 of the NIP to 2021 and future programmes. Aspects to be considered across the current programme are included in Table 4. The increased emphasis on AMRs is highlighted and some possible adjustments to the programme suggested.

18. Prioritisation of UK Nuclear Innovation and Research Programme Recommendations, NIRAB-124-1, November 2016

Table 4. Potential impact on NIP areas of changes in the landscape since 2015 that should be considered in the NIP programme to 2021 and beyond

NIP Area	Aspects to consider as result of changes since 2015
Advanced Fuels	<ul style="list-style-type: none"> Greater urgency is now required if the UK wishes to have an indigenous fuel supply capability. Research needs to align with political/industry discussions in this space and ensure capability is maintained in the UK skill base to support future decision making. Re-focus of the SMR competition onto AMRs has underlined the need for development of advanced fuels on a shorter time-frame than was originally intended, in addition work on molten salt fuels should be considered as this is omitted from the current programme. In the absence of an ambition for an indigenous fuel manufacturing capability the programme should focus on critical skills maintenance and development essential if the UK wishes to deploy advanced reactor technology in the UK.
Reactor Design	<ul style="list-style-type: none"> Digital – Need to align with other national initiatives and focus on reducing the cost of nuclear through application of the technology. Opportunities to reduce the amount of prototyping and demonstration of advanced reactor concepts should be examined to complement the AMR F&D project. Thermal hydraulics - It can be expected that definition of these problems is more focussed but more expensive as specific designs for advanced reactors to be deployed in the UK develop. The programme needs to focus appropriately to enable the UK to contribute to demonstration programmes for advanced reactor technology. The investment in a thermal hydraulics facility will provide important infrastructure to support development of advanced nuclear technologies, the operating model for this needs to be carefully considered to maximise value for money, ensure UK involvement in programmes and support the demonstration of advanced reactor technologies on the path to commercialisation.
Spent fuel recycle and waste management	<ul style="list-style-type: none"> The UK will exit from commercial nuclear fuel reprocessing for the foreseeable future. The driver for recycle lacks any industrial pull; however decision timescales in this area make it essential to maintain capability and keep options open. The programme should therefore focus on skills maintenance and alignment to AMR and advanced technologies ambitions – fuel recycle is a necessary and integral part of the fuel cycle for some advanced reactor systems.
Materials and Manufacturing	<ul style="list-style-type: none"> It is not clear what industry pull has materialised from the current advanced manufacturing programme to support Gen III+ projects in delivery. The programme is more relevant to the scope and timing of SMRs and AMRs and should be orientated accordingly to develop the UK supply chain. Demonstrating materials performance in operationally relevant environments is a major challenge. The programme should focus on ensuring UK involvement in the demonstration phases for advanced technologies. Different fuels, coolants and moderators are used in AMRs and thus only some of the existing supply chain in the UK is relevant.
Nuclear facilities and strategic toolkit	<ul style="list-style-type: none"> There is now an increased focus on cost reduction and producing market relevant products; as such the strategic toolkit should include the ability to perform some level of economic assessment. Access to irradiation facilities will be essential to the development and demonstration of advanced reactor technologies, UK access to appropriate facilities (in the absence of a test reactor in the UK and the closure of Halden) must be considered.
Advanced Modular Reactors	<ul style="list-style-type: none"> The new focus on AMRs has profound implications across the programme: higher priority on advanced fuels, wider range of reactor technologies, different manufacturing challenges, some different materials, consideration of the balance between public and private investment to progress these technologies to commercialisation.

5.4. The future programme (post-2021) and public investment to achieve near and longer term objectives for the UK

5.4.1. NIP 2021 to 2026

The balance and focus of public and private funding will not be a 'one-size fits all' approach and will depend on a number of factors. But it is imperative that there is focus and urgency enabling a cost competitive build programme in the UK (as outlined in Section 6). If the UK (Government and industry) does not commit to investing in civil nuclear it will see a managed decline in capability and lose significant opportunities for the UK supply chain to be a first mover in new markets for SMR and AMR technologies. It will also struggle to meet the strategic ambitions that have been set out (Figure 5).

Initial phases of the NIP (2016 – 2021) focussed on 're-starting' the industry in relation to nuclear new build and future systems. The investment is already having an impact in rejuvenating the UK capability and enabling the UK to participate internationally (see case studies in Appendix 7). The increase in funding to around £50 million per year from 2019 to 2021 is much needed and will enable programmes to move up the readiness levels (be that technology or manufacturing) and enable the UK to engage and lead on international programmes. It is imperative that the projected level of funding is maintained in order to build on the initial phases of the programme and continue to reinvigorate the UK capability and energise the supply chain to meet the strategic ambitions (Figure 5). The UK capability and infrastructure has suffered from a lack of investment for a generation. The current NIP funding to 2021 will not resolve this and the timelines are such that significant industry investment in the absence of Government investment and policy direction is unlikely.

A preliminary high-level assessment by NIRAB and NIRO suggests that Government should consider investment in the region of £1 billion through the NIP between 2021 and 2026 (the assumed Spending Review period). The suggested investment is split into three areas as shown in Table 5 and detailed further in sections 5.4.2 and 5.4.3. Over the next year, NIRAB will work with a broad range of stakeholders to clearly define and underpin the scope and scale of the proposed public, and private, investment required (see Section 8.2). NIRAB will also work with BEIS and NIRO as required to assess options and provide further evidence needed for a detailed cost/benefit analysis.

Table 5. Initial Assessment of Required Funding Levels

Research Area	Initial assessment of the magnitude of Government investment (2021 – 2026) /Approx. £ mill
Research and innovation to maintain and develop key UK capabilities and supply chain aligned to market opportunities (see section 5.4.2 and Table 6)	300
An Advanced Nuclear Technologies Demonstration programme (see section 5.4.3 and Table 7)	600
Critical infrastructure to support prototyping and demonstration of reactor components (see section 5.4.3 and Table 7)	100
Total	1,000
Active management of the programme will require dedicated skilled resource. BEIS should consider committing 5-10% of the total programme investment on expert resource to manage the delivery on behalf of BEIS	

To reiterate, Government is an essential partner in funding technology development and innovation for new technologies. In particular, Government support for the demonstration of new, advanced concepts is essential for attracting and making feasible the scale of private investment (see Section 3.3). In addition, this level of public funding (around £200 million per annum) would move the UK investment closer to other OECD nuclear nations involved in developing reactor technologies⁽¹⁹⁾ elevating the UK standing on the international stage and enabling international collaboration.

Without this level of Government investment and support, in a timely fashion, the UK will struggle to secure the potentially significant economic benefit in early engagement with Advanced Nuclear Technologies and risk failing to meet the overall strategic ambitions (Figure 5). Opportunities for the UK in relation to SMRs and AMRs both domestically and globally would be impacted with the UK failing to secure involvement at an early stage; hence, the prospects for UK jobs, Intellectual Property (IP) and supply chain development will be limited.

5.4.2. Research and innovation to maintain and develop key UK capabilities

An initial assessment, to be underpinned by further work, suggests that Government investment of around £300 million (between 2021 – 2026) should be focussed on innovation to continue to support key capabilities that are relevant to multiple reactor technologies, maintain optionality and stimulates the UK supply chain. Investment around this magnitude is required to ensure research and innovation is applied at a commercially relevant scale and enables the UK to engage and lead international programmes. Further details are provided in Table 6.

Recommendation 5

Between 2021 and 2026, to meet ambitions for nuclear to play a broader decarbonisation and Clean Growth role, Government should consider investment in a Nuclear Innovation Programme in the region of £1 billion and include support for the construction of Advanced Nuclear Technology demonstrators. In return, Government should expect to attract significant private sector leverage as a direct result of this support.

19. The UK Civil Landscape Survey, NIRAB-123-4, February 2017

Table 6. Initial consideration of NIP work areas for 2021 to 2026 programme

NIP Area	Proposed Broad Work Areas	Projected funding from 2017 to 2021 / £million	Initial assessment of the magnitude of Government investment between 2021 – 2026 / Approx. £ million
Advanced Fuels	<ul style="list-style-type: none"> ▶ Active involvement in international programmes in Advanced Technology Fuels, including irradiation and Post Irradiation Examination (PIE) of test fuels. Optimising fuel and cladding fabrication for commercial deployment. ▶ Optimised production of Coated Particle Fuels (CPF) using active UK capability. Active engagement and contribution to international performance testing programmes – including irradiation testing. Supporting the application of CPF. ▶ Reactor physics underpinning the development of advanced fuels and optimised to minimise, as far as, possible the requirement for irradiation testing. 		
Reactor Design	<ul style="list-style-type: none"> ▶ A focus on innovative architectures for Advanced Nuclear Technologies, particularly around innovative component areas and applications. Supporting the development and demonstration of advanced reactor concepts towards commercialisation. UK actively engaged in design programmes for advanced reactor systems. ▶ Embed the nuclear virtual engineering capability and expand to drive down costs in new areas through application, focussing on accelerating designs and reducing the need for technology demonstration and prototyping where possible. ▶ Thermal hydraulics modelling and experimental work to develop world leading capabilities in the UK to support deployment of future reactor systems and attract international investment in the UK National Thermal Hydraulics Facility. The UK actively engaged in the design and testing of advanced reactor designs. ▶ Work on in-service and operational challenges for new reactor systems, to include fuel route engineering, inspection and repair and health monitoring 	124 ^a	300
Spent fuel recycle and waste management	<ul style="list-style-type: none"> ▶ Focus on clarifying options and scale up of experimental work. To progress from development into a testing phase – to include flow sheet tests with full simulants. To also include scale up of work on pyroprocessing, fast reactor fuel recycle, waste management challenges for advanced reactors and development of key infrastructure. 		
Materials and Manufacturing	<ul style="list-style-type: none"> ▶ Progress advanced manufacturing techniques to enable deployment through international collaboration and code case development. ▶ Coolant chemistry research focussed on material compatibility with new fuel, coolant and moderator combinations for advanced concepts. UK actively engaged in demonstration testing for advanced reactor concepts. ▶ Implementing in the supply chain and build programmes advanced manufacturing techniques that demonstrate reduced costs particularly in a factory environment 		
Nuclear facilities and strategic toolkit	<ul style="list-style-type: none"> ▶ Advances in strategic assessment tools to include incorporation of economic modelling and whole system modelling integration. ▶ Knowledge capture to build on the fast reactor knowledge capture exercise and developing the UK database of operational experience across all Generation IV reactor types to support the future development and deployment of AMRs in the UK. ▶ Continue NEA databank membership and coordination of access to irradiation facilities. 		

a - Projected spend for phases 1, 2 and 3 of the NIP, excluding the AMR F&D project and regulatory upskilling

5.4.3. Advanced Nuclear Technologies Demonstration Programme

An initial assessment of the magnitude of Government investment required, to be underpinned through further work by NIRAB, suggests in the region of £700 million over five years (2021–2026) should be considered to support demonstration towards commercialisation of two or three Advanced Nuclear Technologies. Table 7 provides an overview of a potential structure for a Government funded demonstration programme to support the development and demonstration of Advanced Nuclear Technologies towards commercialisation. These involve consideration of:

- ▶ Cost sharing on specific R&D funding to bring designs to readiness for demonstration and funding in support of licensing
- ▶ Incentivised payments as a demonstrator is successfully constructed, tested and operated to attract private investment
- ▶ Infrastructure funding to enable reactor concept developers to access test beds in the UK

NIRAB consider that any Government investment should be planned and designed to enable significant industry investment in the UK, for example, in the region of £2 billion or greater over the same five year period supporting the construction of demonstrators and the process towards commercialisation (noting again that the balance and focus of public and private funding will not be a 'one-size fits all' approach).

In a forward demonstration programme the choice of technology to pursue should be a commercial decision for private investors, where Government support is facilitative and dependent upon the development and deployment of technology led by the private sector. Participation should be open to a wide variety of reactor types and designs, subject to established protocols, and the ability of Government to provide the necessary policy framework and legislation (including Regulatory infrastructure). For example, Government should work with companies to establish appropriate arrangements for fuel cycle and ultimate safe, passive storage of waste product.

A number of start-ups around the world with different designs are attracting investment, alongside more established major organisations. Indeed, if multiple designs can attract investment in the initial design and engineering then an enabling framework should permit multiple designs - some will succeed, some will not. The Government role should be more stable, enabling a platform where prototyping can be done; this will involve providing infrastructure and buildings with associated 'fixed' costs.

The infrastructure and facilities for testing and prototyping Advanced Nuclear Technologies should be open to a wide variety of designs, but it is unrealistic to assume that more than two or three would progress to the demonstration phase in the UK. When a concept successfully moves towards commercialisation (FOAK) this would then open up an opportunity for another design to use the prototyping facility/ infrastructure in the UK. A successful framework has the potential to enable one or two projects to progress to licensing and implementation. Subsequent projects should need less support due to the operational experience and, for example, fuel and materials qualification.

It should be recognised that with innovation there is no single unbroken path through R&D, design, prototyping and deployment. The framework developed under the NIP needs to be cognisant of this and appropriately structured to evolve based on learning.

Table 7. Proposed elements of a Government funded Advanced Nuclear Technologies demonstration programme within the NIP (2021 – 2026)

NIP Area	Aim	Scope	Detail	Initial assessment of the potential magnitude of funding / £ million
Advanced Nuclear Technologies Demonstration Programme	Specific R&D funding to bring designs to readiness for demonstration	Cost sharing (e.g. 50:50) for design specific R&D to develop the maturity of the concept towards demonstration. Support access to UK capabilities and infrastructure developed under the broader NIP R&D programme.	Help to bring designs to maturity, progress through licensing and to develop supply chains. Different fuels, coolants and moderators and thus only some of the existing supply chain in the UK is relevant. Other supply challenges – pumps for sodium, lead and salt. And circulators for gas reactors. Funding to support up to 2 or 3 systems brought forward by developers through demonstration phases.	600
	Licensing	Continued support for the regulator	To develop capability to efficiently and effectively regulate advanced nuclear technologies.	
	Incentivised demonstrator construction support	Incentivised payments to reward performance and construction delivery. Government contribution should be a maximum of 30% of costs.	To incentivise construction and attract private investment. Private companies would be expected to cover the costs of engineering design work and construction. Incentivised payments as reactor successfully constructed, tested and operated to provide data in support of licensing. Payments not guaranteed, contingent on achievement of defined milestones. Funding to support one higher maturity concept through construction of a demonstration phase.	
Supporting infrastructure	Funding for infrastructure	Capabilities to support the demonstration of reactor concepts. To include non-active and access to reactor testing where possible.	A prototype or demonstration hub. A site and collection of capabilities to enable concepts to progress to and through engineering and performance demonstration phases in the UK. Reactor concept developers will require access to test beds for single effects feasibility testing, for example, scaled loops to enable the qualification of components. In addition they will also need access to 'in pile' testing to enable the qualification of components that need to be exposed to the actual environment they will see in the reactor core; this process is lengthy and the Government should assess where UK capabilities could enable and support testing.	100

The demonstration programme must complement the other elements of nuclear R&D under the NIP and also the wider enabling framework being put in place by Government for Advanced Nuclear Technologies. Taken together, these initiatives can help de-risk investment, build capacity in the UK supply chain, provide a stronger market pull, make UK companies more cost competitive and bring cross-cutting benefits to other sectors (such as modularisation, miniaturisation and economies of volume).

In addition to the current planned investment in the National Nuclear Users Facility (NNUF), up to around £100 million should be considered for nuclear infrastructure to support prototype and demonstration of reactor concepts – this should include consideration of siting.

5.4.4. Government and industry structures to deliver the Nuclear Innovation Programme

The scale of current NIP expenditure is expected to grow from a £10 million per year programme (in 2017 and 2018) to approximately £50–70 million per year programme between 2019 and 2021 (see Phase 3 in Table 3). Initial investment in the

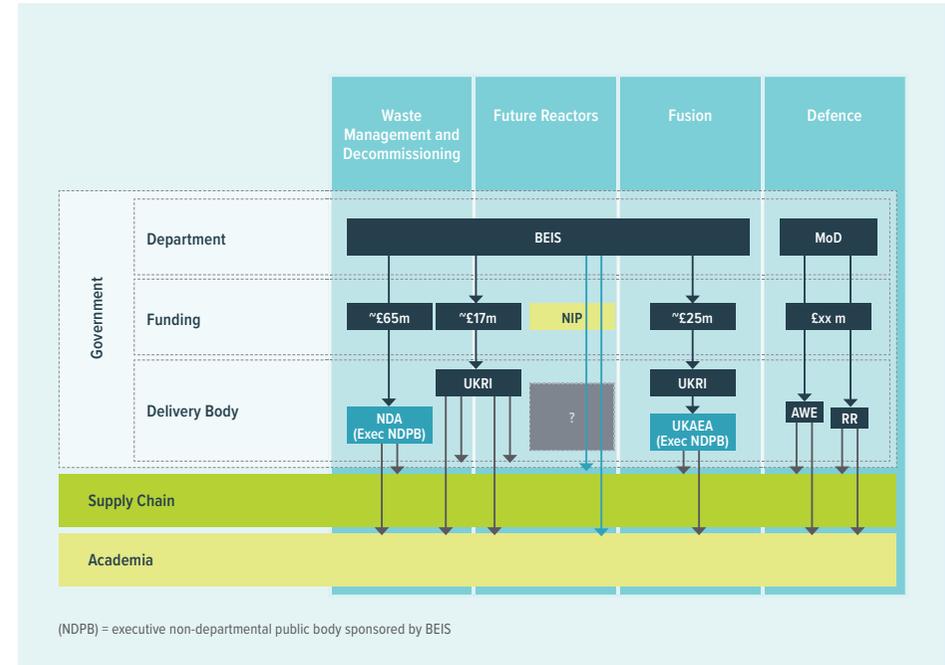
NIP and learning has shown, as discussed in section 5.1, that more resource and expertise will be required to manage and deliver a growing programme.

There is the need for an expert approach similar to that in place for all other publicly funded nuclear R&D (shown schematically in Figure 6), providing strategic oversight and challenge to ensure the programme is focussed on supporting delivery of investible commercial products to the market. Prior to the NIP and in the absence of investment this was not a gap. An expert delivery body should be complementary to and work closely with existing civil nuclear delivery bodies.

Recommendation 6

Government should ensure value for money by assigning a strategically focussed expert delivery body to actively manage and integrate public investment in civil nuclear innovation through a Nuclear Innovation Programme.

Figure 6. Schematic of approximate annual public funding for nuclear R&D and associated delivery bodies (approximate 2015/16 funding levels taken from The UK Civil Nuclear R&D Landscape Survey ⁽¹⁹⁾)



In addition to Government evolving to effectively deliver a forward programme, it should be recognised that the UK industry is not currently optimally structured to define, develop and deliver the investment in innovation programmes needed, to realise the long term vision. The UK has not delivered a sustained civil nuclear build programme in a generation. Organisations will need to evolve to deliver the size and scale of the development and deployment programme needed to deliver the ambitions

Work needs to be done to identify what industry needs to do, alongside Government, to ensure successful delivery of a roadmap for civil nuclear development. This needs to include an assessment of the structures and incentives required and an analysis of the key elements of the programme that must be delivered from the UK.

An analysis of the UK supply chain should be carried out to understand the gaps associated with particular technologies and deployment scenarios. This should be part of the wider business case for advanced nuclear technologies based on the market and a pipeline of opportunities. Speed is a priority as the UK is not on its own; other countries are moving more quickly. There is an opportunity for the UK but only if the UK moves fast enough.

5.4.5. Cutting edge skills development

An effective Nuclear Innovation Programme will drive the development of high-level skills and innovation that will be required to provide the UK with a competitive skills advantage, both for domestic development/deployment of advanced technologies and to position the UK as a partner of choice for international collaborative developments. Investment should, however, also look to address critical skills development approaches to enhance the innovation culture within the sector, build innovative technology skills

and grow technology commercialisation skills; all these will be required to improve productivity and to ensure the strategic ambitions around clean growth are achieved. The investment in skills through a Nuclear Innovation Programme should also align with the 'People' foundation of the Nuclear Sector Deal (NSD)^[6], including commitments to improve diversity across the sector in order to achieve 40 per cent female participation in nuclear (up from 22 per cent now) by 2030 and support the Nuclear Skills Strategy Group (NSSG) to deliver its Strategic Plan^[20].

6. Cost Reduction through Innovation

A key component of achieving the vision for the civil nuclear sector outlined at the start of this report will be making nuclear projects investible by increasing cost and schedule certainty; reducing costs; and introducing efficiencies across the full nuclear lifecycle. NIRAB is exploring how innovation in particular can enable this with the aim of identifying priority actions where Government support or intervention can stimulate and accelerate the pathway to reducing costs.

NIRAB has considered innovation in this context to be broader than technical; it encompasses all of the factors and processes that can lead to cost reduction and ultimately achieve market success. Examples are innovation in culture, financing, risk management, business models, contracting practices and regulation.

6.1. Building on the evidence base

There is a wealth of evidence contained within a number of recent studies related to this issue, both within and outside of the sector. The ETI Nuclear Cost Drivers Study^[10] analysed and broke down the costs of numerous historic global nuclear new build projects and identified key factors in cost and schedule overruns that have been symptomatic in projects in the West; the Expert Finance Working Group report A Market Framework for Small Nuclear^[12] explored in detail the risk profiles associated with small nuclear projects in an attempt to understand where Government intervention could stimulate private sector investment in future projects; the Big Technology Innovation^[21] initiative led by NNL in 2017/18 focussed on understanding how innovation could drive change across the sector and how learning from other sectors could be adopted; the MIT Future of Nuclear report^[11] examines the future role for nuclear in decarbonising electricity and how the cost of nuclear impacts this in different global regions, including quantitative modelling of nuclear in the UK electricity market.

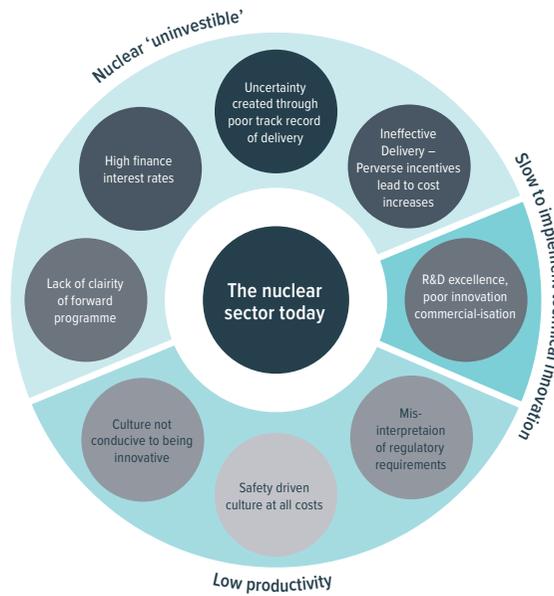
NIRAB has considered the findings of these reports, alongside numerous others, when considering where innovation can lead to a reduction in costs.

6.2. Current challenges and enablers to cost reduction

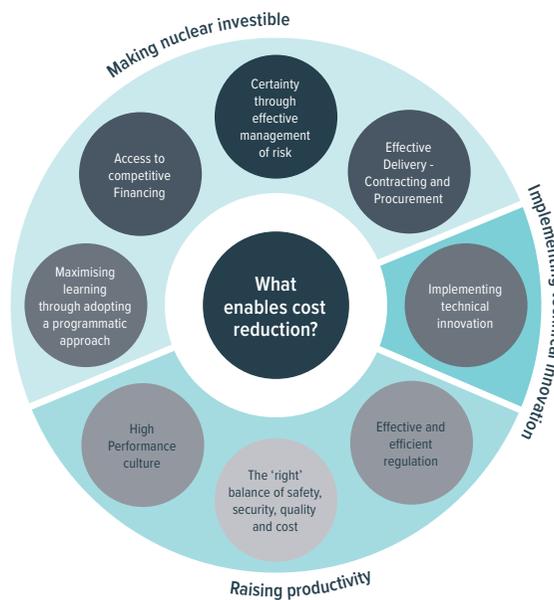
In order to identify and prioritise where innovation can lead to cost reduction it is important to understand current challenges faced by the civil nuclear sector today. Three key characteristics of the sector which need to be overcome for cost reduction to be achieved are shown in Figure 7, which in turn can be 'flipped' around to articulate what a successful high performing civil nuclear sector needs in place – the 'enablers'. These are explored further in the sections that follow.

Figure 7. Changing the characteristics of the civil nuclear sector

Today



Future



6.2.1. Making Nuclear Investible

The challenge

Increasing cost and schedule certainty reduces the financial risk of projects in the nuclear industry: a repeated failure to do this on many large infrastructure projects in the UK has reinforced the perception of investors that the nuclear sector is high risk. This track record has resulted in an aversion to investing in new projects, and where there is investment this comes with a high 'nuclear premium' attached - interest during construction is a significant contributor to the cost of major nuclear infrastructure projects. In order to secure a more competitive finance rate and attract private sector equity investment the major risks to delivering civil nuclear projects on schedule and within budget need to be managed – certainty is key to attracting investment. The potential for the combined effect of reducing overnight costs through effective risk management and the cost of capital can deliver a significant reduction in the cost of new nuclear. Both Government and industry have a role to play in mitigating certain risks, creating more certainty on budget and schedule,

and exploring innovative financing models to secure future project investment.

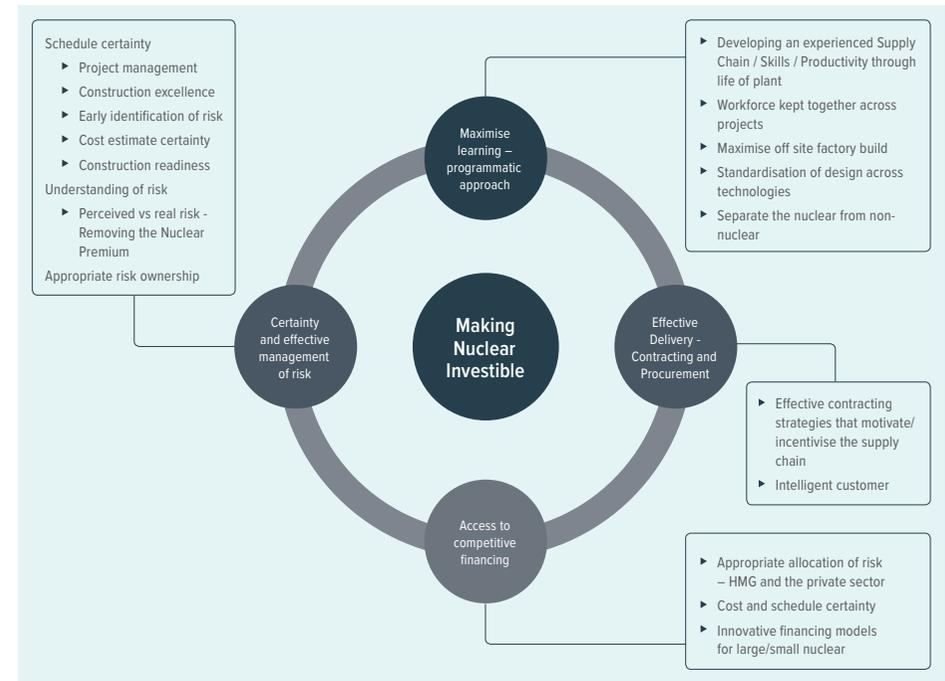
The UK nuclear sector does not have clarity of a forward programme for new build or decommissioning projects^[22] that will allow for the development of a consistent supply chain that is able to learn over successive projects and deliver cost savings that can only be brought about with such experience.

The sector needs to move towards a contracting and procurement strategy that incentivises innovation, cost reduction (e.g. through better scope definition and quality assurance; incentives that drive on-time and on-budget outcomes) and accelerating projects, driven by an intelligent customer who works in genuine collaboration with its suppliers. If successful, this counterbalances incentives to pursue avoidable claims.

The enablers:

Figure 8 shows the enabling principles that NIRAB considers are fundamental to making civil nuclear projects investible.

Figure 8. Enablers to making nuclear investible



22. The Nuclear Sector Deal recommends a 'joint review of the decommissioning pipeline' to address this.

6.2.2. Raising productivity

The Challenge

Productivity in the UK nuclear industry, and in particular in site construction^[22], is thought to be low compared to other sectors in the UK and overseas, as has been found in a number of recent studies^[10,21]. There is a culture which is quite rightly driven by ensuring safety and quality is paramount, which has resulted in a sector with an excellent safety track record, but in order to achieve excellence and cost containment in construction there must also be motivation and incentives for the workforce related to innovation, i.e. to achieve the same level of safety and quality at lower cost.

This is in essence the principle of ALARP (as low as reasonably practicable) however it is the view of NIRAB that this is often misinterpreted, resulting in a tendency to apply nuclear safety standards across whole plant rather than separating at a component level what needs to be at the highest quality

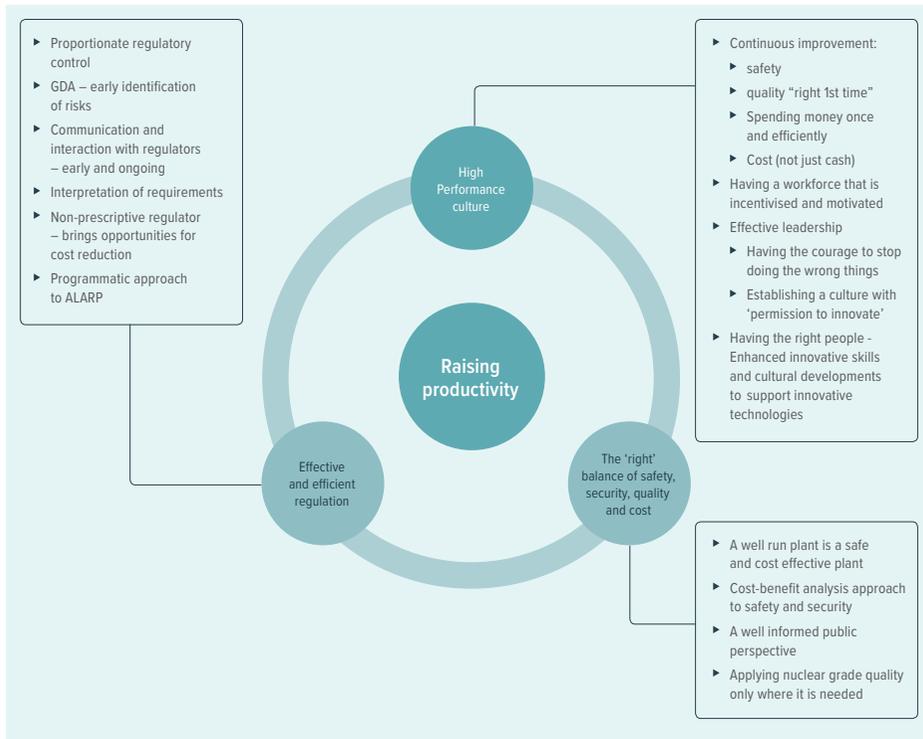
standard and what does not – the ‘nuclear premium’ effect may be needlessly being applied in some cases and deserves to be properly investigated.

The UK has a non-prescriptive regulatory regime and a principle of enabling regulation which allows for flexibility of approach to developing safety cases, presenting opportunities for innovation. For cost-effective delivery to meet safety and environmental regulatory requirements in the UK (for either new UK developed concepts or international designs being brought to the UK), it is essential that a risk based approach is adopted with full engagement of organisations with experience of the UK regulatory regime to make the most of where international developments on the harmonisation of codes and standards can be used to accelerate and de-risk investment programmes.

The Enablers:

Figure 9 shows enabling principles that are key to raising productivity in the nuclear sector.

Figure 9. Enablers to raising productivity



6.2.3. Implementing technical innovation

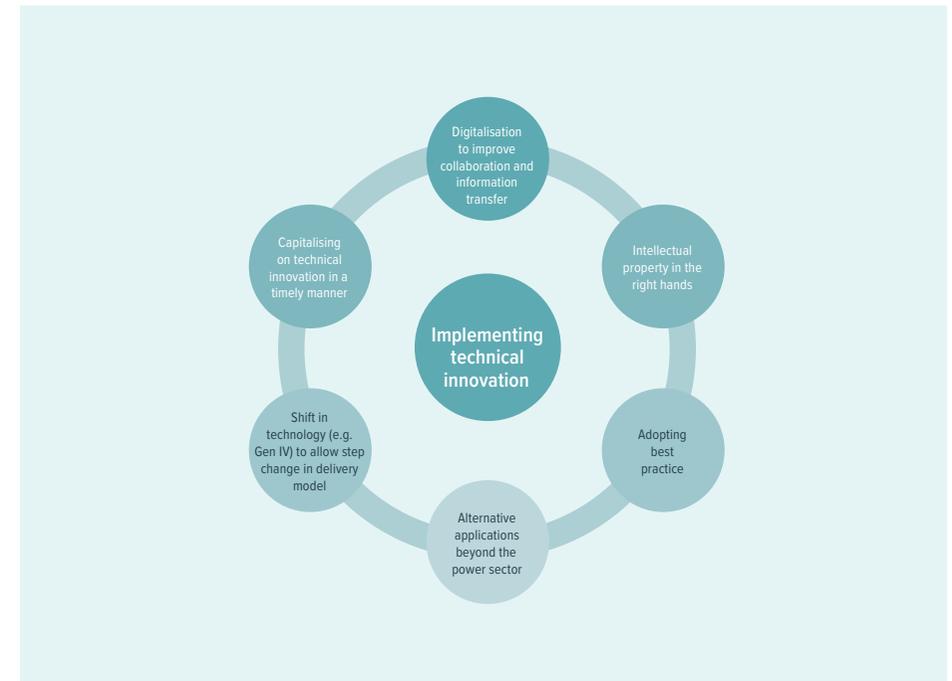
The Challenge

The UK has excellence within its research and innovation base, but the nuclear sector lags behind other sectors in introducing innovation into practice. There are numerous technical innovations that could lead to a step change in cost, for example in new nuclear energy systems. However bringing innovation to market in a timely fashion is critical – if innovation is not capitalised on its benefit diminishes.

The Enablers:

Figure 10 shows enabling principles which can lead to the successful and timely implementation of technical innovations.

Figure 10. Enablers to implementing technical innovation



6.3. Key learning and looking forward

Adhering to the enabling principles outlined above can achieve the aims of making nuclear investible, raising productivity and commercialising new technologies, and ultimately delivering costs and programme risk reduction. The following key messages build on those principles:

- ▶ **The urgency of addressing cost and programme risk must be recognised and acted upon.** The cost challenge facing the sector is having an increasing impact – UK new build projects have recently experienced difficulties in securing investors due to high risk to cost and schedule certainty. There is an urgency for the sector to address this if a future energy system which contains nuclear is to be realised.

- ▶ **Cost reduction is synonymous with programme risk reduction** - creating certainty around schedule and cost is necessary to stimulate investment in future projects.
- ▶ **There is huge potential for cost reduction in nuclear projects, and this can be achieved across the full lifecycle** - the single largest component of a large nuclear project cost is in the construction phase and in particular the interest during construction. However there are significant cost reduction opportunities through the full lifecycle of nuclear plant which should be identified and addressed.
- ▶ Taking a **programmatic approach** is fundamental to maximising learning and raising productivity. The UK nuclear sector would benefit from clarity of a forward programme for new build and decommissioning projects in order to develop supply chain capability; enable learning over successive projects; and deliver cost savings as demonstrated in successful low cost nuclear new build programmes elsewhere in the world.
- ▶ **Innovation is broader than purely technical innovation** – cultural, regulatory, delivery, contracting, financing, risk and safety innovation are equally as vital as technical innovation and can result in productivity gains and cost reduction realisation over a shorter timeframe. Technical innovation presents opportunities to effect a step change in costs in the longer term.
- ▶ Developing an **evaluation framework** from the outset to benchmark and measure cost reduction over time will be critical in understanding impact.
- ▶ There needs to be a **product/market focus** for developing new nuclear technologies which have an identified and valuable role in a future energy system, align with what customers want and what the investment community require of an investible product/project.
- ▶ **Working with and learning from other sectors.** There is a wealth of evidence to show where cost reduction has successfully been achieved in other sectors or in the nuclear sector elsewhere in the world, characterised by high productivity. The nuclear sector should work with these and other sectors facing similar challenges to nuclear, notably construction, as it develops its cost reduction strategy through the Nuclear Sector Deal.

Industry has committed in the Nuclear Sector Deal to reducing the cost of new nuclear projects by 30% and of achieving savings of 20% in the decommissioning sector by 2030. These targets are considered by NIRAB to be eminently achievable, and **efforts should focus on raising productivity** which can deliver efficiencies and cost savings on that timescale. Government can facilitate this through adhering to the enabling cost reduction principles outlined in this section.

Recommendation 7

New build 30% cost reduction by 2030 – Government support for new build should be contingent on the application of cost and risk reduction best practice, with full transparency on how industry intends to deliver these strategies and where innovation will increase productivity and result in cost savings.

Recommendation 8

Decommissioning cost savings of 20% by 2030 – Government should ensure that the waste management and decommissioning sector baseline cost estimates from which the cost reduction targets are to be measured are transparent and publicly available, and that the sectors strategy of how targets are to be met is understood and articulated such that it can work with industry to deliver the requisite cost savings through targeted innovation and productivity increases.

NIRAB recognises and welcomes that Government is actively exploring real and perceived risks across all aspects of nuclear projects, and how innovative finance models may be applied in an effort to make civil nuclear projects investible. NIRAB considers this to be a critical activity in allowing new nuclear projects to come to fruition.

Recommendation 9

Government should identify the role it needs to play in de-risking civil nuclear projects, including innovative finance models, such that they are investible to the private sector.

7. International collaboration

International collaboration will be instrumental in ensuring that the UK achieves its ambitions for clean growth and facilitating the pivotal role of nuclear within this.

7.1. International Landscape

Current bi-lateral focus areas for nuclear R&D collaboration:

- ▶ USA – US/UK action plan covering six areas of fission research was signed at a ceremony in Washington DC on the 13th September 2018 by the UK and US Governments.
- ▶ France – A UK-France summit meeting was held in January 2018 in London covering Industrial, R&D and Skills Development collaborations in nuclear and work continues to deliver these joint programmes
- ▶ Canada – In 2018 a joint meeting with the Canadian National Laboratory to discuss areas of mutual interest in areas of nuclear fission research
- ▶ Japan – many agencies and research and industrial organisations in the UK continue to support Japan in dealing with their waste management and decommissioning challenges post Fukushima
- ▶ Poland – UK Government facilitated discussions on High Temperature Gas Reactor research have been held with Poland to assist with their ambitious plans to develop nuclear technology to meet Clean Growth strategies

Multi-lateral cooperation:

- ▶ IAEA – the UK fully engages as a ‘top table nuclear nation role’ at the agency and significant effort has been and is being made to improve the coordination of this effort by the many UK agencies through technical working groups and the UK safeguards support programme
- ▶ OECD NEA – the UK is forging a leading role within the NEA and a workshop has been held to better coordinate UK involvement. The NIRO Executive Director was elected as Vice Chair of the NEA Steering Group in 2018

- ▶ Generation IV International Forum (GIF) - in January 2019 the UK joined as an active member of GIF. UK experts will begin to fill key positions in the GIF framework over the coming months
- ▶ Euratom – within the Euratom Fission and Fusion Research and Training Community the UK continues to engage and shape the agenda in line with UK priorities for research and international engagement. The NIRO Executive Director has been appointed to the role of UK Fission representative on the Euratom Science and Technical Committee. The UK continues to engage with European nuclear technology platforms for Fission, Geological Disposal, Radiation Protection, and Fusion.

7.2. A research and innovation international strategy

Work is ongoing within NIRAB to consider and articulate the most appropriate international strategy to support the delivery of the near and long term objectives for the nuclear sector which public investment in research and innovation is required to underpin. When considering an international collaboration strategy the following principles and drivers need to be considered:

Principles of an international strategy:

- ▶ International collaboration should support and deliver the near and long term nuclear objectives of the nuclear sector and government policy (e.g. NDA Strategy, Nuclear Sector Deal etc.)
- ▶ International collaboration should address mutually beneficial outcomes or opportunities which require a partnership approach and/or deliver added value.
- ▶ Partnerships - outcomes and opportunities should be prioritised against measurable criteria.
- ▶ There should be sufficient agility and flexibility in the approach to respond to opportunistic or political developments where there is a compelling rationale to do so.
- ▶ Due regard must be given to UK non-proliferation objectives in developing international collaborations.

End goals and drivers for international collaboration:

- ▶ R&D to drive clean growth through exports and inward investment
- ▶ R&D to reduce cost of new build and fuel cycle
- ▶ R&D to reduce cost, hazard and timescale of decommissioning and disposal
- ▶ Access to transnational infrastructure to support R&D with nuclear materials
- ▶ Maintaining the required human capital and mobility.
- ▶ Matters of strategic national importance: diplomacy, security, safeguards and robust supply chains across the sector

There are currently three distinct drivers for international collaboration on nuclear power and decommissioning:

- ▶ Working with other countries allows the UK to develop / maintain diplomatic relations and awareness of international developments in nuclear
- ▶ Working with other countries to maximise trade and export opportunities for the UK nuclear industry
- ▶ Working on shared programmes or collaborating with international organisations helps share resources, including access to specialist facilities (both overseas and in the UK), enables the UK to participate in - and lead - on international nuclear policy developments and supports maintenance of UK subject matter expertise at an international level.

In addition, international collaboration is the only credible route by which the UK can play a significant role in the commercialisation of Advanced Modular Reactors; maximising trade and industry opportunities, including opening up international markets.

The three primary sets of drivers for international collaboration (Political, Trade, and Research and Development) are illustrated in Figure 11. Whilst there are clear and specific reasons supporting the activities of each area, there is a clear and urgent need for a UK collective stakeholder coordination and response process. The uncoordinated effort of the individual three stakeholders appears to be making little progress in advancing UK international ambitions. The UK needs to coordinate the overall international engagement plan taking account of the priorities of each stakeholder group and Government within a virtuous triangle of coordination and interaction these drivers often pull in different directions, therefore work needs to be done to develop an effective international collaboration strategy to maximise the value of all these interactions.

BREXIT and BREXATOM will change the dynamic for research and innovation collaboration with Europe (though some bilateral collaborations with EU countries are unlikely to be directly affected). Although the impact is expected to be small it will be important to ensure that the mechanisms are in place to ensure that this is the case and disruption to ongoing programmes involving UK participants is minimised.

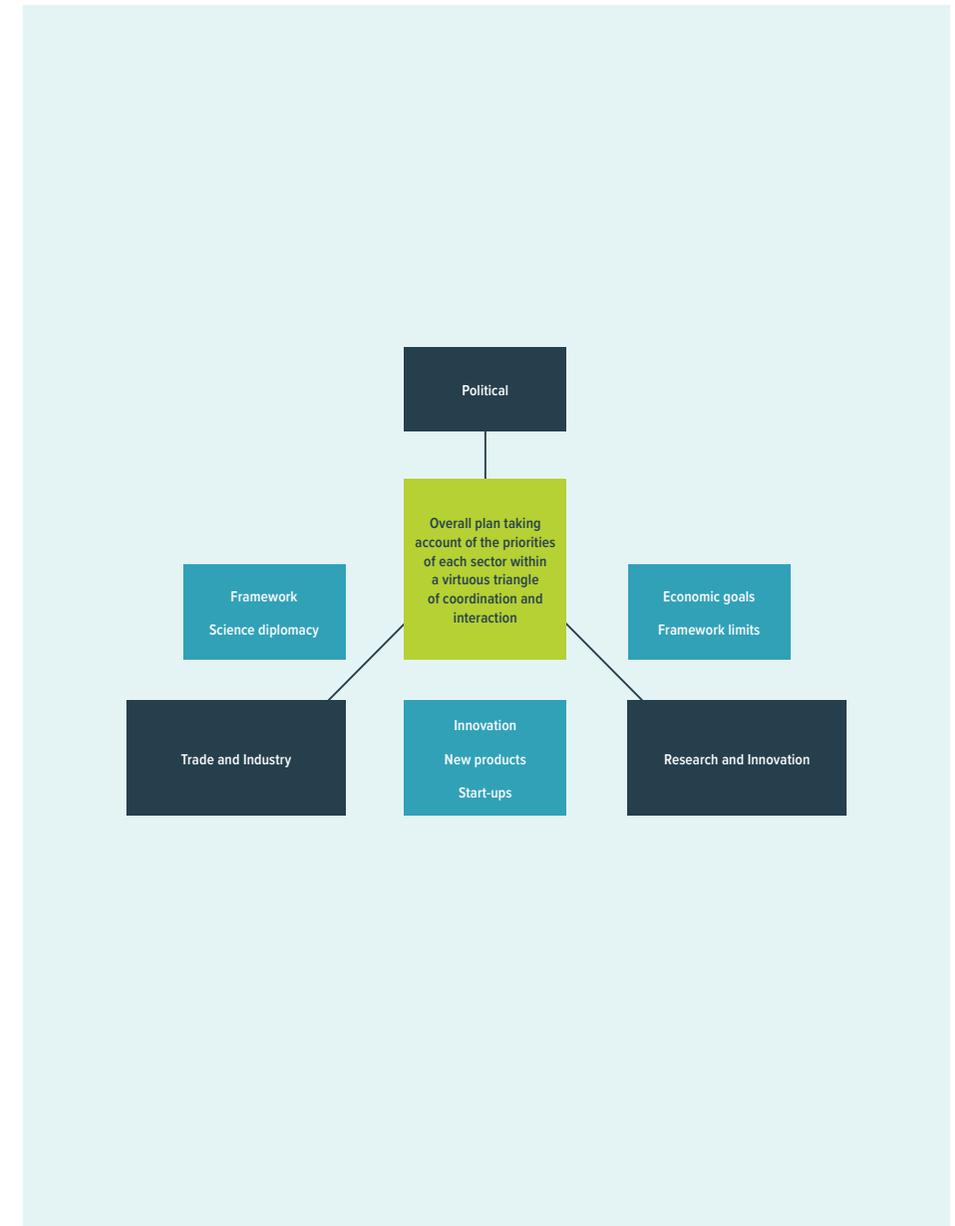
Recommendation 10

Government should establish an effective international collaboration strategy which balances goals relating to diplomatic relations, trade ambitions and research and development programmes.

Recommendation 11

Government should review the impact of BREXIT and BREXATOM on UK nuclear research and innovation programmes once the new arrangements are clear.

Figure 11. The drivers for international collaboration



8. Future priorities for NIRAB

8.1. Future role of nuclear energy in the low carbon economy

One of the priorities for the 2019/20 financial year will be to identify the role that nuclear energy can play in meeting the demand for cost effective clean energy in the UK. In doing so NIRAB acknowledges that there are a range of possible clean energy futures and that nuclear energy must be cost competitive with the other clean energy technologies that comprise the whole system. Renewables (wind and solar), thermal generation (Gas, oil, coal and biomass) with Carbon Capture, Usage and Storage and nuclear are expected to work together in a single energy system.

NIRAB will seek to evaluate the impact of a range of variables on the extent to which nuclear could contribute to clean energy needs. These will include:

- ▶ Quantifying the impact of achieving varying degrees of cost reduction on the take-up of nuclear energy – either in the form of large reactors, SMRs or AMRs
- ▶ Identifying the system characteristics required for nuclear to make a significant contribution to energy needs other than electricity (including low temperature heat, high temperature heat and hydrogen)
- ▶ The potential impact on economic growth, jobs and exports

NIRAB plans to make best use of well-established modelling tools such as the Energy Systems Modelling Environment (ESME) to inform its analyses. ESME is currently operated by the Energy Systems Catapult.

The outcome of this analysis will further inform our research and innovation recommendations.

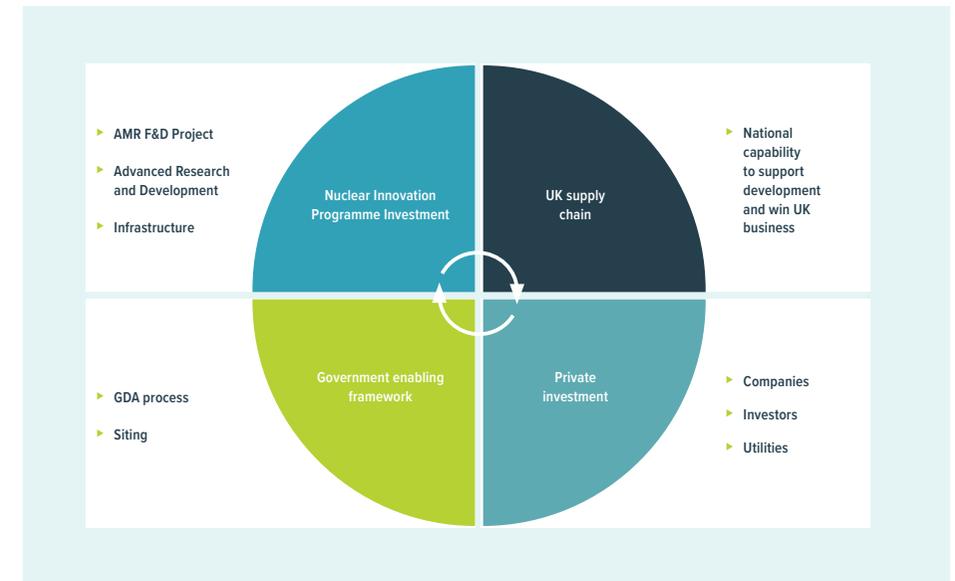
As many UK and global climate targets relate to 2050 as the reference point, this analysis will be focussed on identifying the role of nuclear in an energy system within that timeframe. It is worth noting that NIRAB believe energy needs and opportunities beyond this, and indeed into the next century, should also be considered to understand what action can be taken both now and in the future that will create a longer lasting positive impact.

8.2. BEIS Nuclear Innovation Programme

Figure 12 attempts to show schematically how the investment in the NIP will be one part of the civil nuclear investment 'jigsaw' that facilitates success and delivers commercial products to the clean energy market in a timely fashion. It is worth restating that the balance and focus of public and private funding will not be a 'one-size fits all' approach and will depend on a number of factors. Focus and urgency is imperative to enable a cost competitive build programme in the UK with substantial Clean Growth benefits for the UK. UK investment (Government and industry) in civil nuclear is critical to prevent a managed decline in capability and to capture significant opportunities for the UK supply chain to be a first mover in new markets for SMR and AMR technologies.

Over the coming year NIRAB will focus on providing detailed recommendations to Government around the structure of a programme and the infrastructure required to achieve the ambitions. NIRAB will work with a broad range of stakeholders to clearly define and underpin the scope and scale of public, and private, investment required. This will build upon the initial assessment and recommendations outlined in this document. It is, however, worth recognising that NIRAB is an advisory board and as such the basis of the recommended amounts is not underpinned by a detailed cost/benefit assessment. The amounts are indicative as a judged minimum for meaningful progress to be made, but further financial justification and economic assessment will need to be undertaken within Government to develop any business case for public investment.

Figure 12. The UK civil nuclear innovation investment 'jigsaw'



8.3. Opportunities for cost reduction

NIRAB will continue to investigate the opportunities for cost reduction through innovation; developing the enablers of making nuclear investible, raising productivity and implementing technical innovations into firm recommendations.

8.4. International and industrial collaboration

International Collaboration

NIRAB will develop recommendations for the most appropriate international strategy to support the delivery of the near and long term objectives for the nuclear sector which public investment in research and innovation is required to underpin.

Industrial Collaboration

Industrial consultation is currently on-going. NIRAB is in the process of gathering views from a range of industrial organisations (especially from representatives of Small and Medium-sized Enterprises) to identify areas of publicly funded research and innovation which would be valuable to industry and that industry would anticipate taking forward to commercialisation.

Views are also being sought regarding:

- ▶ Aspects of awareness and engagement of the current Nuclear Innovation Programme
- ▶ The extent to which UK Government funded nuclear research and innovation contributes to meeting UK Government objectives set out in the Nuclear Industrial Strategy
- ▶ Industries objectives for engaging in UK Government funded nuclear research and innovation
- ▶ Existence of new commercial opportunities to target as a result of engagement in UK Government funded nuclear research and innovation
- ▶ The point at which and on what basis organisations would consider investing in projects which would access UK Government funded nuclear research and innovation
- ▶ What infrastructure would be required to support the UK Government funded nuclear research and innovation
- ▶ The main barriers to engaging in UK Government funded nuclear research and innovation.

NIRAB plan to analyse the results of the survey and use these to inform its recommendations to Government.

Appendix 1.

NIRAB Terms of Reference

Nuclear Innovation and Research Advisory Board Terms of Reference and Ways of Working

This Appendix sets out the terms of reference and ways of working for the nuclear research and innovation advisory framework comprising a combination of the Nuclear Innovation and Research Advisory Board (NIRAB) and the Nuclear Innovation and Research Office (NIRO).

Context

NIRAB was originally convened in January 2014 and provided advice on nuclear research and innovation to Government for a period of 3 years until it was disbanded in December 2016. Throughout this time NIRO acted as expert secretariat to NIRAB to convene meetings, gather and analyse data and draft reports.

Government found the advice valuable, along with other inputs, to inform the decision to invest in an ambitious Nuclear Innovation Programme and revitalise the nuclear research landscape in the UK. Government wishes to retain access to independent expert advice as the Nuclear Innovation Programme evolves and has tasked NIRO with convening a reconstituted and restructured NIRAB able to draw on a wide range of expertise.

Terms of Reference

NIRAB'S Role

To work in partnership with NIRO to advise Ministers, Government Departments and Agencies on issues related to nuclear research and innovation in the UK. In particular to:

- ▶ Monitor the delivery and impact of the BEIS Nuclear Innovation Programme and recommend any amendments that may be necessary in the light of outputs from the programme and developments in the nuclear landscape.
- ▶ Advise where innovation could drive down costs across the whole nuclear cycle
- ▶ Identify opportunities for greater collaboration with industry and international partners

- ▶ To support the development of recommendations for new research and innovation programmes required to underpin priority policies including energy policy and industrial policy
- ▶ To oversee a regular review of the nuclear research and innovation landscape which may include facilities, capability, portfolio and capacity in the UK
- ▶ To foster greater cooperation and coordination across the whole of the UK's nuclear research and innovation capability, portfolio and capacity

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 meetings of the Nuclear Industry Council to discuss R&D issues.

Membership of NIRAB

NIRAB will need to be able to draw on a wide range of expertise to be able to offer informed advice on the range of issues that may need to be addressed in the coming years. NIRAB will therefore comprise a pool of up to 40 members with attendance at meetings being determined by the expertise needed to address specific issues on the agenda.

Members will be invited to join NIRAB, for an initial period of two years with membership to be reviewed periodically beyond this point. With the exception of the Chair, appointments will be unfunded, other than the reimbursement of reasonable travel and subsistence costs.

Membership will encompass a wide range of subject expertise, and Members will be individuals with the credibility and position to best represent their fields. Members will be appointed as individuals and be expected to represent the interests of their field rather than their employer.

Observers and Supporting Staff

Meetings may include Observers such as Government and Departmental Chief Scientific Advisors, officials and representatives of public funding organisations including Research Councils, NDA and Innovate UK, as appropriate.

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

Ways of Working

Meetings

It is anticipated that NIRAB meetings will take place up to four times per year, with attendance at each meeting dependent on the subjects to be covered at the meeting; not all Members will therefore be called upon for every meeting. 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, with participation not limited to NIRAB members.

Relationship to NIRO

NIRO is a full-time team and will comprise a part of the advisory framework. NIRO will:

- ▶ Provide secretariat support for NIRAB meetings and any sub-groups that may be convened
- ▶ Provide the analytical capacity required to provide advice to officials
- ▶ Draft annual reports and other reports, as required, for review by NIRAB
- ▶ Carry out gap analysis in order to inform advice to Government on R&D programme priorities
- ▶ Facilitate coordination of nuclear innovation and R&D activity and communications within and between Government and industry
- ▶ Support Government's production of the business cases required to underpin nuclear research and innovation programmes

Appendix 2.

NIRAB Member Profiles



Mike Tynan, Chair,
Independent

Mike Tynan has a career spanning 5 decades in the civil nuclear industry, and has held senior leadership positions in site operations, manufacturing, nuclear services, and research and development. Mike began his career at Calder Hall nuclear power station in 1975 and spent much of his early and mid career at the Sellafield nuclear complex, where he gained broad experience in services, operations, waste management, and decommissioning. Appointed Managing Director for Springfields Fuels Ltd in 2006, Mike went on to lead Westinghouse UK as CEO, moving to The University of Sheffield in 2013 as CEO for the Nuclear AMRC. He has worked at numerous UK and international nuclear facilities and has been at the forefront of changes in the UK civil nuclear industry over the last 20 years, including the formation of Site License Companies for the NDA, and nuclear new build projects for the Westinghouse AP1000 reactor. An accountant by profession, Mike has an MBA (Lancaster), and was Visiting Professor in Nuclear Manufacturing at The University of Sheffield until his retirement in 2017. He has served on numerous Boards and committees, and was a founder Board member of both the National Skills Academy for Nuclear (NSAN) and the Lancashire Enterprise Partnership (LEP), and is a member of the UK Nuclear Industry Council.



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

Tim Abram has held the Westinghouse Chair in Nuclear Fuel Technology (and more recently in Nuclear Engineering) at the University of Manchester since 2008. Prior to this he gained over 20 years research experience in nuclear fuels and advanced reactors technology in the UK (at BNFL and the National Nuclear Laboratory) and in the USA (at Westinghouse). He has experience in the design, performance and safety analysis of all major fuel and reactor types, and in the development of computer codes for the analysis of fuel performance. He has participated in over 15 EU Framework projects in nuclear fuel and reactor technology, and is the UK's representative on the IAEA TWG on Fast Reactors. He was co-author of the Fuels and Materials section of the first Gen-IV Roadmap, and was the Euratom representative and Chair of the VHTR Fuel and Fuel Cycle Board. Prior to joining the University, Prof. Abram was the Senior Research Fellow for Fuels and Reactor Systems at NNL, where he retains the position of Senior Visiting Fellow. He has been an External Examiner for the Royal Navy's nuclear engineering programmes, and for the University of Cambridge MPhil in Nuclear Engineering. He has served as an advisor to UK Government, and was a member of NIRAB from 2014-16. Prof. Abram is the Director of the Rolls-Royce University Technology Centre for Nuclear Science and Engineering, and leads the new Manchester Nuclear Fuel Centre of Excellence: a collaboration between the University and

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NNL that undertakes research into U, Th, and Pu-bearing nuclear fuel materials. Since 2009, Prof. Abram has led the development of the U-Battery: a 10 Mwt micro-reactor based on a prismatic HTR design, which is currently being developed by a consortium led by Urenco. His research group has also contributed to the development of the Stable Salt Reactor: a molten salt reactor design being developed by Moltex Energy.



David Boath, Vice President and Chief Engineer,
Wood

As Vice President and Chief Engineer of Wood Nuclear (formerly Amec Foster Wheeler), David is functionally responsible for Wood's Nuclear project operations including technologies, standards, systems, processes and assurance. He is also a Governing Board member of the Sustainable Nuclear Energy Technology Platform, a stakeholder advisory body to the European Commission on nuclear research priorities in support of the EC's Strategic Energy Technology Plan. This encompasses 3 supporting pillars (NUGENIA, ESNII and NC2I) aimed at: maintaining the safety and competitiveness of today's technologies; developing a new generation of more sustainable reactor technologies; and developing new applications for nuclear power. David is a member of the Office for Nuclear Regulation's Independent Advisory Panel and the National Skills Academy for Nuclear Advisory Board. With a passion for sustaining the future skills required by the industry, he is on the Engineering Construction Industry Training Board's Council and chairs their Nuclear Forum. He is also a member of the Nuclear Skills Strategy Group.

wood.



Stuart Broadley, Chief Executive,
Energy Industries Council

Stuart joined the Energy Industries Council (EIC) as Chief Executive in 2016. EIC is a leading not-for-profit trade association with 600+ members, focused on oil & gas, power, nuclear and renewable markets, that helps UK supply chain companies to grow their business at home and around the world. In his capacity as EIC CEO, Stuart has unique insight into policies, trends, innovations and technologies across all energy sectors in the UK and globally. Prior to the EIC, Stuart held global energy leadership roles across a 25-year career in oil & gas, power and renewables, with Wood, Servion, Hoerbiger and Rolls-Royce, focused on gas turbines, wind turbines, compressors and material handling.

EIC



CAMMELL LAIRD

Johnathan Brown, Managing Director, Cammell Laird Energy

Jonathan joined Cammell Laird in July 2016 to lead the Energy team, providing engineering consultancy, component manufacture, module assembly and a logistics service capability across the Energy Sector. Prior to joining Cammell Laird, Jonathan has worked for various companies including Rolls Royce, Serco, AWE and BNFL and undertaken roles in different sectors including nuclear, marine and rail sectors. Jonathan is a Chartered Chemical Engineer, a Fellow of both the Institute of Chemical Engineers and the Institute of Directors and a member of the Innovation Board of the Liverpool LEP.



EDF ENERGY

Maggie Brown, Innovation Manager, EDF Energy

Maggie Brown is currently working for EDF Energy on the Hinkley Point C (HPC) project where she is responsible for developing and delivering a first of kind innovation programme in a nuclear new build environment. Prior to her role on HPC, Maggie was an Innovation Manager for Crossrail's award winning innovation programme where she was responsible for delivering innovation projects as well as driving the development of the i3P (Infrastructure Industry Innovation Platform), the industry's first collaborative innovation delivery programme. She currently chairs the Innovation Leadership Group (ILG) for the i3P. Her experience is backed by an Msc in Political Sociology from the LSE where she learned about public policy and organisational politics. Her project management roles span across multiple sectors in the public, non-profit, and private spheres.



KBR
We Deliver

Paul Brown, Senior Advisor, KBR

Paul was appointed Senior Advisor, Nuclear for KBR in 2014 supporting their Programme and Project Management Services team. His early experience in the nuclear sector was as a Project Engineer during construction of Heysham and Torness Power Stations when he also completed a research MPhil into joining of critical components within the AGR pressure containment plant. He was also responsible for project engineering of packages within construction of what were then known as Thorpe and Pond 5 at Windscale. After a number of international operations executive roles in the public and private sectors he became CEO of the Radioisotopes Division of AEA Technology (GSA) in 2003, commercialising and rationalising radioisotope R&D and production in the UK, Germany, USA and China. This included being Chair of a highly successful JV between China Isotope Corporation a division of CNNC and AEA based in Shenzhen China. Up until 2012 he worked for 4 years as interim COO at ONR and has a good understanding of how UK nuclear regulation is delivered. His core strengths are advising on how best to drive change in operations and project delivery to improve economics, cost reduction, increase efficiency and reduce time to market. Paul is a Chartered Engineer and Fellow of the Institute of Mechanical Engineers and is a member of the Joint Audit Committee for Surrey Police.



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Professor Grace Burke, Director of the Materials Performance Centre, University of Manchester

Prof. M. Grace Burke is the Director of the Materials Performance Centre at the University of Manchester, where she leads investigations of materials' behaviour in nuclear power systems. Prior to joining the University, she acquired extensive experience in this field during a 30 year career in the US nuclear industry with research positions at the Westinghouse Science and Technology Center, and the Bettis Atomic Power Laboratory in Pittsburgh, where she was the Consultant Scientist for Materials Technology. Including prior research experience at a corporate steel industry laboratory she has over 35 years of expertise in steels, the materials of construction of nuclear power plants, and irradiation damage, SCC, and hydrogen embrittlement of structural alloys. She is particularly known for her application of advanced microscopy/microanalysis techniques to nuclear materials research. Grace is a recognized expert in numerous international nuclear science and technology organisations including NUGENIA, ICG-EAC, and IGRDM. Grace is a Fellow of ASM International, the Institute of Materials, Minerals and Mining (UK), the Microscopy Society of America, and the Royal Microscopical Society.



IDM
integrated decision management

Professor Gregg Butler, Director, Integrated Decision Management Ltd

Professor Gregg Butler read Metallurgy at University College Swansea, and completed a PhD on uranium alloys. Gregg worked for British Nuclear Fuels plc in R&D, planning, commercial, plant and general management posts, in fuel cycle areas from fuel manufacture and centrifuge enrichment, to reprocessing, waste treatment and disposal. Gregg was Deputy Chief Executive from 1993-1996, a Director of UK Nirex (1990-1994), and MD of Pangea Resources Australia Pty Ltd (1998/99). He was a member of the Radioactive Waste Management Advisory Committee (1994-2004) and is currently a member of Committee on Radioactive Waste Management (2012-date).

Gregg now co-Directs Integrated Decision Management Ltd and is Head of Strategic Assessment for the Dalton Nuclear Institute of the University of Manchester. He has published extensively on a broad range of nuclear topics.



**UK Atomic
Energy
Authority**

Professor Ian Chapman, CEO, UK Atomic Energy Authority

Ian Chapman is CEO of the UK Atomic Energy Authority and Head of the Culham Centre for Fusion Energy. He has held a number of international roles in fusion, including Chair of ITER international working groups. He has published over 110 journal papers, one of which was shortlisted for the Nuclear Fusion Award in 2013, and given 30 invited lead-author presentations at international conferences. He received the European Physical Society Early Career Prize in 2014, the Institute of Physics Paterson Medal in 2013, the IUPAP Plasma Physics Young Scientist Prize in 2012 and the Cavendish Medal for Best early-career UK physicist in 2011. He was made a Fellow of the Institute of Physics in 2013 and became a visiting Professor at Durham University in 2015.



Professor Mamdouh El-Shanawany, Chief Nuclear Advisor, Lloyd's Register

Professor Mamdouh El-Shanawany is an international expert on nuclear safety. For the last 40 years, he has provided leadership, design, research & development, analysis, management and critical safety assessment, applications of Statutory regulatory requirements and policy development for the nuclear industry in the UK, Canada and Internationally. He is a member of the IAEA team which was awarded the Nobel Prize for Peace in 2005.

He is Chief Nuclear advisor to Lloyd's Register, and visiting Professor of Nuclear Safety, Centre for Nuclear Engineering, at the Imperial College, London University.

Professor El-Shanawany was the Head of the Safety Assessment Section at the IAEA, September 2004 to June 2012. The main responsibilities of the Safety Assessment Section are to strengthen Member States' capabilities (Regulatory Bodies, Designers and Operators) in effective safety assessment and safety enhancement of nuclear installations.

Professor El-Shanawany is an Independent Expert Evaluator for research project allocations, UK Engineering & Physics Science Research Council and Euratom Nuclear Research and Training, European Commission. He was also a member of Generation IV Technical Advisory Committee of the UK Government's Department of Trade and Industry.

Prior to joining the IAEA, he was employed by Her Majesty's Nuclear Installations Inspectorate, the UK Regulatory Body, where he was responsible for managing, assessing and formally agreeing and accepting the Licensees' arrangements and safety cases for faults studies and severe accidents analysis for the operating plants. In the early nineties he was a Senior Nuclear Safety Specialist, Directorate of Safety Analysis and Assessment, Atomic Energy Control Board, Canadian Government.



Professor Stephen Garwood, Imperial College London

Steve studied Mechanical Engineering at Imperial College, followed by a PhD in Applied Mechanics. He developed his early career at the Welding Institute where he became Head of Engineering in 1989 and subsequently Head of Structural Integrity. Steve joined Rolls-Royce in 1996 as Technical Director of Rolls-Royce and Associates, becoming Director of Engineering & Technology for Marine Power in 1998. He then took up various Corporate positions (Director of Technology, and Director of Materials) returning to the Marine business as Director, Engineering and Technology – Submarines in 2006. In 2013, Steve directed the research activities for the Nuclear Sector developing Rolls-Royce's Nuclear UTC's at Imperial College and Manchester. Following retirement from Rolls-Royce in 2013, Steve joined the Mechanical Engineering Department at Imperial College, London as Professor of Structural Integrity. He is also a Non Executive Director of the Transport Systems Catapult and FESI, and serves on a number of Nuclear Advisory Committees.



Kirsty Gogan, Co-Founder and Executive Director of Energy for Humanity (EFH)

Kirsty Gogan is co-founder and executive director of Energy for Humanity (EFH), a UK and Switzerland-based non-profit organisation with a global outlook focused on solving climate change and enabling universal access to modern energy services. Future leaders will need all tools at their disposal to solve global challenges including air pollution and energy security, whilst providing low cost, clean power to billions of people and improving life chances for women and children throughout the world. In pursuit of these goals, Energy for Humanity (EFH) strongly advocates for evidence-based, whole-system, and technology-inclusive solutions in pursuit of the best (meaning, fastest, most cost-effective, most feasible) outcomes for people and nature. Our work includes running projects in multiple countries, including oversight of a successful campaign to prevent premature closure of the Swiss nuclear fleet in 2016. EFH led a delegation of the world's most highly regarded climate scientists to Paris COP21 in order to make the case for nuclear to be recognised as a climate solution. EFH was subsequently shortlisted for the Business Green Leaders "Green NGO of the Year" Award in 2016. In 2017, at COP23, EFH published a new report on European Climate Leadership 2017 and presented a new study on Decarbonizing Cities with Advanced Nuclear. Ms. Gogan is also founding director of CleanTech Catalyst (a consultancy specialising in climate and energy), recently commissioned by the Energy Technologies Institute to lead the Nuclear Cost Drivers Study in partnership with Lucid Strategy (based in Cambridge, MA). Ms. Gogan is regularly invited as an expert speaker on science communication, nuclear competitiveness and innovation to high profile events around the world. She has more than 15 years' experience as a senior advisor industry, non-profits and Government, including at 10 Downing St, the Office of the Deputy Prime Minister, and the Department of Energy and Climate Change.



Professor Neil Hyatt, Head of Department of Materials Science, University of Sheffield

Neil is Professor of Radioactive Waste Management at the University of Sheffield, Head of Department of Materials Science, and lead for civil nuclear energy research at The University of Sheffield.

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, advanced accident tolerant nuclear fuel fuels and their recycle, and nuclear forensics and security. He has served as an IAEA technical expert, provided advice and guidance to radioactive waste management organisations in the UK and overseas, and was a member of the original NIRAB between 2014 and 2016.



Professor Hector Iacovides, Head of Thermo-Fluids Group, University of Manchester

Professor Hector Iacovides, DEng, FIMechE, FASME, is Head of the Thermo-Fluids group at the School of Mechanical Aerospace and Civil Engineering at the University of Manchester, and chair in Heat Transfer since 2004. He has expertise in experimental and computational thermal hydraulics and in CFD and turbulence modelling. He has over 200 publications and since the 1990s he has carried out nuclear thermal hydraulics research, initially for British Energy and later for EDF-Energy. He has been Principle of Co-Investigator in 40 research grants most of are related to nuclear thermal hydraulics through which he has developed a suite of specialist experimental facilities. He is the PI for UoM on a BEIS (through Frazer-Nash) research program and the Col on a Newton Fund program on Solar Power. He has been involved in the supervision of over 25 PhD students. Professor Iacovides is also currently the Co-Leader of the UK Special Interest Group in Nuclear Thermal Hydraulics which is supported by the UK Fluids Network.



Monica Jong, Head of Operations, Materials Research Facility, UK Atomic Energy Authority

Monica Jong is Head of Operations for the Materials Research Facility at the UK Atomic Energy Authority. She has a BSc in Engineering and Materials Science, along with 25 years of materials research experience with participation in lifetime extensions programs for GEN2 reactors, irradiation damage studies for GEN4 fission and fusion materials, and development of techniques to process, test and evaluate activated materials in hot cells and other shielded environments. Monica moved to UKAEA from the Netherlands in 2015 and is currently building up and expanding the facility to enable sub-sized and micro-sized samples to be evaluated using microstructural, mechanical and thermophysical techniques. She is working closely with other institutes and universities to realise goals, which are: efficient use of irradiated materials; comparison of standard techniques against new innovations in materials research; development of new standards and completing existing design codes with data from new developed standards and guidelines in databases.



Professor Malcolm Joyce, Lancaster University

Malcolm Joyce is Professor of Nuclear Engineering at Lancaster University in the UK. His research interests include applied radiation detection & measurement, decommissioning-related analytical methods and nuclear policy & environmental assay. He is author on > 140 refereed journal articles and specializes in digital mixed-field radiation assay with fast, organic liquid scintillation detectors. Malcolm has a BSc (Hons.) in physics, a PhD in gamma-ray spectroscopy and a DEng in digital fast neutron assay. He was a member of the UK Government's Nuclear Industry Research Advisory Board (NIRAB) and is co-chair of UK's National Nuclear Users' Facility. In 2014 his team was awarded the James Watt medal by the Institution of Civil Engineers for best paper in the journal Proc. ICE (Energy) for research on the depth profiling of radioactive contamination in concrete. He was Head of Engineering at Lancaster, 2008-2015, and is editor on three journals in the field. In 2016 he was awarded a Royal Society Wolfson Research Merit Award and in 2017 he authored a text book on nuclear energy: 'Nuclear Engineering: A Conceptual Introduction to Nuclear Power', published by Butterworth-Heinemann.



Professor Ralf Kaiser, University of Glasgow

Professor Ralf Kaiser is the founder and CEO of Lynkeos Technology Ltd. and Professor of Physics at the University of Glasgow. He studied physics at the University of Münster, Germany, and at Simon Fraser University, Vancouver, and worked as a postdoctoral fellow at the German national laboratory DESY before he joined the University of Glasgow in 2001. From 2010 to 2017 he served as Head of Physics at the International Atomic Energy Agency (IAEA), responsible for the IAEA programmes on nuclear fusion, accelerator applications and nuclear instrumentation. In this function he represented the IAEA on the Councils of the ITER and SESAME projects and was responsible for technical cooperation projects in more than 50 countries around the world. Prof Kaiser has more than 20 years of experience in detector development, algorithm and software development and project management. He is a certified PRINCE2 Practitioner and has completed the Financial Times Diploma for Non-Executive Directors. His publication list includes more than 150 publications and over 12,000 citations.



Miranda Kirschel, Ernst and Young

Miranda is part of the Energy Advisory team in EY's Advisory practice, where she leads the Nuclear Strategy and led the Small Modular Reactor (SMR) TechnoEconomic Assessment for the Department of Energy and Climate Change (DECC). Miranda previously led Business Development for major engineering consultancies operating in the nuclear sector. Miranda began her career at the Nuclear Industry Association, establishing the All-Party Parliamentary Group on Nuclear Energy. She founded and was President of Women in Nuclear UK, and is a Trustee on the Board of the Nuclear Institute. Miranda is a politics graduate with 16 years' experience in the nuclear sector.



Mike Lewis, formerly Head of Nuclear Technology, Horizon Nuclear Power. Director, Lewis Risk Consulting Ltd.

Mike is a chartered nuclear engineer with over 40 years' experience in the nuclear sector in the UK and internationally (Europe, Canada, Middle East). He brings knowledge and insight from positions in nuclear design, engineering, operations, and expert services, for established and new build nuclear facilities. Mike's principal technical expertise lies in the technology, safety and risk assessment, and licensing of nuclear power stations. In addition to leading a number of key projects in these areas, he provides advice to a number of corporate nuclear safety committees and management boards.

Mike was Head of Nuclear Technology at Horizon Nuclear Power until the project's suspension, and is Director of Lewis Risk Consulting Limited



 context

Phil Litherland, Context Information Security

Phil is a member of the Critical National Infrastructure team within Context Information Security, where his focus is to identify and provide requisite cyber security & information assurance advice, technical support and practical guidance to client organisations across CNI sectors, particularly civil nuclear.

He is an experienced senior level engineering & technology professional with a proven track record of safety & security risk management in both the IT & Industrial Control Systems/Operational Technology (ICS/OT) domains.

He has demonstrable capabilities in senior stakeholder management, leading organisational & cultural change, developing leading-managing multidisciplinary teams across geographical boundaries and also has broad commercial & technical experience on large projects.



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Professor Francis Livens, Interim Director Dalton Nuclear Institute, University of Manchester

Francis was appointed as Interim Director of the Dalton Nuclear Institute in 2016. He was the founding Director of the Centre for Radiochemistry Research, established in Manchester in 1999 and is currently additionally the Director of the EPSRC-funded Next Generation Nuclear Centre for Doctoral Training and a Professor of Radiochemistry. He has worked for over 30 years in environmental radioactivity and actinide chemistry, starting his career with the Natural Environment Research Council, where he was involved in the response to the Chernobyl accident. He has held a radiochemistry position at The University of Manchester since 1991. He has worked in many aspects of nuclear fuel cycle research; including effluent treatment, waste immobilisation and actinide chemistry. He has acted as an advisor to the nuclear industry both in the UK and overseas.



 UNIVERSITY OF OXFORD

Professor James Marrow, University of Oxford

Professor James Marrow is the James Martin Chair in Energy Materials. He is the chair of the OECD/NEA (Organisation for Economic Co-operation and Development/Nuclear Energy Agency) EGISM (Expert Group on Innovative Structural Materials), which has the objective of conducting joint and comparative international studies to support the development, selection and characterisation of innovative structural materials that can be implemented in advanced nuclear fuel cycles. He is the UKERC (EPSRC UK Energy Research Centre) representative in the European Energy Research Alliance (EERA) Joint Programme for Nuclear Materials (JPNM); this supports the European Technology Platform on Sustainable Nuclear Energy (SNETP), which defines the European vision on both the role of nuclear energy and R&D needs for nuclear fission technology. Prof. Marrow is an independent



 Westinghouse



 CATAPULT
Energy Systems

member of GTAC (Graphite Technical Advisory Committee) for the UK Office of Nuclear Regulation. Within the UK Research Council project Nuclear Universities Consortium for Learning, Engagement And Research: NUCLEAR (aka. "Nuclear Champion" project), he is part of the team that aims to facilitate effective and sustainable UK academic engagement in national and international nuclear research programmes, with a particular interest in Generation IV systems. In 2014 he was elected a Fellow of the European Structural Integrity Society (ESIS), and he is a member of Council for the UK Forum for Engineering Structural Integrity (FESI).

Bob McKenzie, Chief Technical Officer, Westinghouse Springfields

Bob McKenzie is the Chief Technical Officer at the Westinghouse Springfield site, Preston. Bob has 40 years' experience in the manufacture of high quality nuclear fuel, with specific responsibilities relating to fuel design, process development, component supply and Quality Assurance. Away from work Bob is a director of a C of E Multi Academy Trust. He is a Chartered Engineer and graduated in Production Engineering at Manchester in 1986.

Mike Middleton, Energy Systems Catapult

Mike Middleton joined the Energy Systems Catapult in Autumn 2017 on transfer from the Energy Technologies Institute where for 4 years he deepened the understanding of the potential role of nuclear technologies as part of the energy mix in delivering a UK transition to a low carbon economy. This involved designing and delivering a project portfolio procured through open competition and disseminating the knowledge gained through ETI insights. His diverse experience in nuclear operations, projects and services includes; waterfront submarine support; liquid and solid waste processing; construction projects; nuclear facility decommissioning; and new nuclear power. Mike graduated from UCL with a first class honours degree in Mechanical Engineering. With the Royal Corps of Naval Constructors he completed an M.Sc degree with distinction in Marine Mechanical Engineering from UCL and later an M.Sc degree with distinction in Nuclear Reactor Technology awarded by the University of Surrey. He is a Chartered Engineer and was elected Fellow of the Institution of Mechanical Engineers in July 2000. His previous appointments include Facilities Director at the Clyde Naval Base and Infrastructure Director at Sellafield.



John Molyneux, Director of Engineering and Technology, Rolls-Royce

John has been with Rolls-Royce for 32 years. During this time he has undertaken a variety of roles covering all aspects of the nuclear project life cycle, and a very broad range of disciplines embracing engineering, programme management and business leadership. John began his career in the Submarines business and transferred to the Civil Nuclear business of Rolls-Royce in 2007. He is currently the Director of Engineering and Technology for Civil Nuclear activities globally.



Chris Moore, Independent

Chris Moore is a self-employed Business Consultant specialising in Business Planning and Strategy Development across the nuclear and low carbon energy sector. Chris offers informed, insightful advice on all aspects of national and international business development to senior leaders who are accountable for business success. He is currently supporting a number of businesses in the nuclear sector, including the World Nuclear Transport Institute (WNTI) and the Nuclear Advanced Manufacturing Research Centre (NAMRC), in addition to acting as an Independent Expert Witness on a UK based Arbitration Panel associated with a commercial dispute for an Eastern European nuclear power plant. Chris is also working with the Energy Research Accelerator, a Midlands based consortium of six academic institutions, and the British Geological Survey, tasked with creating a world leading hub of energy talent delivering technologies capable of enabling the UK's transition to a low carbon economy. Chris is a well-respected professional with over 25 years of nuclear related experience, having recently undertaken roles as Strategy and Strategic Business Development Director for the National Nuclear Laboratory and Customer Project Director for Westinghouse UK. Both of these positions have contributed to the cultivation of a strong awareness of what is needed to develop international business relationships and Chris has developed an ability to work across cultural boundaries gained through engagement with customers and Government representatives in China, Japan, South Korea, UAE, USA and France. Chris is a Chartered Engineer, Fellow of the Institution of Engineering and Technology and member of the Nuclear Institute.



Dr Manus O'Donnell, Generic Design Assessment Officer, EDF Energy

Currently Manus is leading the Generic Design Assessment for the UK HPR1000 in a joint venture between China General Nuclear (CGN) and Électricité de France in the UK (EDF Energy). Prior to this he has held a number of senior positions within EDF Energy including; The Head of Development, Head of Technology, Innovation and Research and Development in support of nuclear operations in the UK. Manus has worked in the civil nuclear industry since 1996 on topics from safety-related research through to leadership of operationally-focused engineering teams and significant plant recovery projects. He is a graduate of Trinity College Dublin, with degrees in Mechanical & Manufacturing Engineering and Mathematics and holds a PhD for his research on materials' performance, conducted at the European Commission's Joint Research Centre in the Netherlands. He is a chartered engineer and a fellow of the Institution of Mechanical Engineers.



Dr Lee Peck, Head of Technical Assurance & Governance, Sellafield Ltd

Lee works for Sellafield Ltd as a senior manager in the Strategy and Technical Department. Lee is a chartered chemist with over 22 years' experience in the nuclear industry spanning a range of roles from: strategic planning and development; scientific research; and programme management including the development of business cases to secure sanction for major projects from HM Government. Lee's knowledge of nuclear research and development includes advanced spent fuel reprocessing, safe and secure storage of plutonium, nuclear waste treatment and decommissioning. He currently chairs the Sellafield Technical Committee which has oversight of a £100M portfolio of technical work.



Professor Andrew Randewich, Head of Physics, AWE

After completing a PhD in plasma physics, Andrew joined AWE in 1997 in the High Altitude Nuclear Effects Team where he developed a novel capability to model Nuclear Induced Van Allen Belts, worked on Electromagnetic Pulse phenomenology, and won the Discovery Award for Early Career Scientific Innovation. Andrew later worked on thermonuclear burn modelling in support of Inertial Confinement Fusion and as a Team Leader in the Computational Physics Group. Since then, Andrew managed the Physics Certification programme and later led the High Performance Computing Group. After acting as Head of Design Physics, Andrew was appointed Head of Plasma Physics in 2011. The Department's main role is using high power lasers to underwrite high energy density physics simulations. Andrew was Asset Manager for the ORION laser, one of the largest science capital investments in the UK and managed several other science facilities. Also in 2011, Andrew became Head of Profession for Physics and in 2013 moved to be AWE Chief Scientist in which role he assured AWE Science and Capability and led the company's Strategic External Outreach. He is now Head of Physics Function comprising 550 staff including AWE's Criticality and Design Safety groups. Andrew is deputy Chair of the AWE Nuclear Safety Committee, the Warhead Safety Committee and a co-opted member of the MoD Trident Safety Committee. Andrew was appointed as a visiting Professor at Imperial College, London in 2012, and is a Chartered Physicist, a Chartered Engineer and a Fellow of the Institute of Physics.



Dr Fiona Rayment OBE, Executive Director, NIRO

Fiona Rayment is the Executive Director of NIRO, a division of the UK National Nuclear Laboratory that is charged with providing strategic nuclear advice to Her Majesty's Government. She has more than 25 years of nuclear industry experience working primarily within operations and strategic planning roles across a number of different nuclear sites, both in the UK and internationally. Fiona is a chartered chemist and engineer with a PhD in chemistry from University of Strathclyde, Glasgow and is a fellow of the Royal Society of Chemistry and of the UK Nuclear Institute. She has an MBA from Manchester Business School. She recently received an OBE in the 2017 Queen's birthday honours for her services to Nuclear innovation and research.

Fiona's other roles across the sector include being on the board of the UK Nuclear Institute, and the American Nuclear Society. She is a member of the Office of Nuclear Regulation Independent Advisory Panel and Idaho National Laboratory's Nuclear Science and Technology Advisory Committee. Fiona is the chair of the UK's Nuclear Skills Strategy Group, the strategic body that oversees UK nuclear sector skills requirements, vice - chair of the Steering Committee of the Nuclear Energy Agency and a member of Euratom's Science and Technology Committee.



Professor Thomas Scott, Director of the Southwest Nuclear Hub, University of Bristol

Professor Thomas Scott is Director of the Southwest Nuclear Hub, the Bristol-Oxford Nuclear Research Centre (NRC) and the Interface Analysis Centre (IAC) at the University of Bristol. He holds a prestigious Royal Academy of Engineering professorial research fellowship part funded by the AWE and for the past 6 years has worked closely with the NNL and Sellafield Ltd as the academic lead for their Centre of Expertise for Uranium and Reactive Metals. In 2017 he was appointed as a Special Adviser to the House of Lords Science and Technology Committee assisting with the inquiry and arising report on civil nuclear technologies (Nuclear research and technology: Breaking the cycle of indecision).

His research is related to nuclear materials and the development and use of instruments to analyse and/or detect them for ensuring safety in the context of nuclear waste storage and disposal, reactor plant life extension, nuclear decommissioning, mining and surveying and nuclear accident response. He is an international expert in uranium corrosion and uranium hydride behaviour in nuclear waste storage and disposal environments with over 160 publications in leading international peer reviewed journals. Most recently he has become involved as a Co-Director for both EPSRC research hubs on Nuclear Robotics, using his experience of device development and deployment on nuclear sites to drive significant positive changes for the UK nuclear industries through the accelerate adoption of robotics and AI technologies.



Professor Andrew Sherry, Chief Scientist, National Nuclear Laboratory

Professor Andrew Sherry is the National Nuclear Laboratory's Chief Scientist. He leads the development and implementation of the Science and Technology strategy which is shaping the delivery of high impact research, technology and innovation; the development of technical skills and subject matter expertise; and the investment in NNL's facilities and equipment portfolio. He provides strategic advice to government, industry and national laboratories in the UK and overseas on aspects of nuclear science and innovation and on nuclear safety. He maintains a Research Chair at Manchester where he leads research on materials performance and structural integrity. He is a Fellow of the Royal Academy of Engineering, the Nuclear Institute, and the Institute of Materials, Minerals and Mining.



Dr Eugene Shwageraus, University of Cambridge

Dr Eugene Shwageraus is a Senior Lecturer and Course Director of Nuclear Energy MPhil in the Department of Engineering at the University of Cambridge. He is also a part of the University of Cambridge Nuclear Energy Centre which links and coordinates projects in areas related to nuclear technology, among them advanced reactor concepts as well as safety, waste management, nuclear policy and regulation. Previously, he was an Associate Professor and served as the Head of the Nuclear Engineering Department at Ben-Gurion University in Israel. He also spent two years as a Visiting Associate Professor in the Department of Nuclear Science and Engineering at MIT and holds a PhD degree from MIT as well. He has strong research ties with Energy Sciences and Technology Department at Brookhaven National Laboratory in the US and worked there as a Visiting Scientist on multiple occasions. In the course of his career, he was a PI and Co-PI on a number of research projects sponsored by government research organisations, power utilities and private companies. He participated in and was a contributing author to a high-profile interdisciplinary study on "The Future of the Nuclear Fuel Cycle" commissioned by the MIT Energy Initiative. He has long standing academic interests in the development of numerical methods for modelling advanced reactors.



Stephen Smith, CEO and Founder, Algometrics Ltd

Stephen Smith is CEO and founder of Algometrics Ltd. His background in investment banking involved the financing of infrastructure projects and complex cross-border deals for clients in Asia and Latin America. He also pioneered quantitative models for asset and derivative trading, establishing a hedge fund with a prominent securities firm in Singapore, and developed advanced systems for high frequency trading of financial instruments. Since 2003 Algometrics has built a universal laboratory facility in Cambridge for the research and development of viable technologies and techniques for use in advanced nuclear reactor designs and other high energy physics research. Stephen is also involved with his family-owned business, established in 1965, which is a leading manufacturer of instrumentation and equipment for the aerospace, defence, energy and nuclear sectors in the UK and globally. Stephen has a triple first class degree in electrical sciences from Cambridge University and a Masters with distinction, in solid state physics from Imperial College. He conducted further academic research in applied mathematics with applications in cryptanalysis and computer science. He is also a Chartered Financial Analyst ("CFA") and ASIP.



Professor Andrew Storer, CEO, Nuclear Advanced Manufacturing Research Centre

Andrew was appointed as Chief Executive Officer of the Nuclear AMRC in August 2017, after joining as Managing Director in 2015.

Andrew has 30 years' experience in the nuclear sector, from helping deliver large reactor components for Sizewell B at Northern Engineering Industries, to various manufacturing and engineering roles at Rolls-Royce. He was in charge of the UK submarine reactor component design group, before becoming the General Manager for through-life maintenance and support of the UK submarine reactor fleet. He then became Programme Director for Rolls-Royce's civil nuclear business, leading customer engagement and bids with new build developers.

He represents the Nuclear AMRC on the UK Nuclear Industry Council and is an active member of the NIA Delivery Group. He sits on various groups, committees and associations and leads a number of supply chain initiatives on behalf of UK industry and Government. He is a Visiting Professor of Nuclear Manufacturing and Capability Development at the University of Sheffield.



Ashley Townes, Project Development Director, Westinghouse

Ash is a hands-on business leader and nuclear project professional with 28 years' experience in the engineering and construction industry, mostly in the nuclear sector.

Currently employed by Westinghouse as a Project Development Director, operating out of the UK and reporting to Cranberry US head office, Ash is responsible for Project Development for a portfolio of AP1000 projects worldwide.

Ash has significant practical experience in management roles on large nuclear EPC and development projects; from feasibility, design, nuclear safety case, to construction and commissioning management.

Ash understands the UK nuclear regulatory environment, has a good balance of commercial delivery acumen and empathy with nuclear operators' drivers; a demonstrable track-record of achieving successful outcomes for all stakeholders.



urencO

Chris White, Director Government Affairs, URENCO Limited

Chris White is Director, Government Affairs, URENCO Limited, one of the leading Uranium Enrichment Companies, operating four facilities across Europe and the USA.

Located in the United Kingdom, Chris has responsibilities covering government affairs across the UK; his specific focus is leading on government engagement and outreach activities, to optimise the Group's standing and influence with external stakeholders, in support of the Group's strategic and commercial objectives.

Chris's previous experience includes serving as company secretary/head of legal at a utility company, and as an energy partner at two international law firms, based in the City of London. Chris holds a Master's Degree in International Business Law from the University of Manchester, and is qualified as a Solicitor in the United Kingdom.



TWI

Dr Paul Woollin, Research Director, TWI

Paul Woollin is Research Director at TWI, responsible for setting the technical direction of the £70m Research, Consultancy and Training business. His technical work at TWI concentrated on the performance of welded stainless steel and included many weld failure investigations and research and development programmes to find solutions to the underlying problems. Specific subjects have included avoiding cracking of duplex stainless steels under cathodic protection, weldability and stress corrosion cracking resistance of supermartensitic stainless steels and corrosion fatigue behaviour of carbon manganese steels and stainless steels. Paul is a fellow of the Royal Academy of Engineers, The Welding Institute and the Institute of Materials, Minerals and Mining.

Appendix 3. Nuclear Innovation and Research Office

The Nuclear Innovation and Research Office (NIRO) is a small full-time group of nuclear specialists working under contract to the Department for Business, Energy and Industrial Strategy. The role of NIRO is to provide independent technical and strategic advice and support to Government that will de-risk investment, inform policy and enable Government to achieve maximum value for money to the UK taxpayer. NIRO therefore comprises a part of the advisory framework. Its role in relation to NIRAB is described in the Terms of Reference set out in Appendix 1. In summary NIRO will:

- ▶ Provide secretariat support for NIRAB meetings and any sub-groups that may be convened
- ▶ Provide the analytical capacity required to provide advice to officials
- ▶ Draft annual reports and other reports, as required, for review by NIRAB
- ▶ Carry out gap analysis in order to inform advice to Government on R&D programme priorities
- ▶ Facilitate coordination of nuclear innovation and R&D activity and communications within and between Government and industry

The NIRO Executive Director sits on NIRAB. Much of the work of NIRAB is carried out through working groups. More information of the working groups that have operated over the period covered by this report is provided in Appendix 4. Members of the NIRO team support the Chairs of these working groups by taking the role of Vice-Chair. Where possible the Vice-Chairs attend meetings of other working groups to ensure that information is shared between the groups and a consistent approach is adopted.

Appendix 4.

NIRAB Working Groups

Most of the work required to shape the recommendations made by NIRAB has been carried out in a series of working groups which report their findings to the main Board for endorsement or amendment.

Membership and leadership of working groups

All of the NIRAB working groups are made up of NIRAB members and are chaired by a NIRAB member. In each case a member of the NIRO team acts as vice-chair and takes responsibility for organising meetings, compiling information and drafting reports for consideration by the working group. All of the NIRAB members belong to at least one of the working groups.

During the first year of NIRAB's existence a series of 6 working groups have been operating. Each is addressing some aspect of the exam question posed by Government. The purpose and scope of each group is outlined below.

Working Group 1

Purpose

The purpose of Working Group 1 is to clearly articulate the near, medium and long term objectives for the nuclear sector which public investment in research and innovation is required to underpin.

Scope of work

The working group will draw on and, where necessary, interpret

- ▶ Existing Government policy statements (for example the Industrial Policy and the Clean Growth Strategy)
- ▶ Official documents which are anticipated to become policy
- ▶ The outputs from wide ranging consultations (for example the Big Tech workshops facilitated by NNL)

The working group will not:

- ▶ Seek to independently develop objectives which it believes Government or Industry should espouse
- ▶ Focus simply on short term objectives

Working Group 2

Purpose

The purpose of Facility Needs Working Group (WG2) is to clearly articulate the facility needs of the UK Nuclear Sector consistent with the future strategic direction and goals of the industry.

The objective is to propose an efficient and substantially sustainable suite of nuclear development facilities which align with the strategic objectives of the UK nuclear strategy / sector deal.

Scope of work

The scope of work of the group will follow clear phases of work:

- ▶ Review and update the UK Nuclear Facilities landscape map including active and non-active facilities:
- ▶ Identify the Capabilities needed to underpin the UKs future strategic nuclear power objectives:
- ▶ Compare and contrast the current suite of UK nuclear development facilities with the capabilities required to meet the strategic goals:
- ▶ Recommend how access to capabilities required to fill the capability gap can be achieved:
- ▶ Review nuclear research access arrangements and how any barriers could be overcome:
- ▶ Recommend actions for any excess capabilities:

The working group will draw on and, where necessary, interpret:

- ▶ The output of other Working Groups
- ▶ Existing Government policy statements (for example the Industrial Policy and the Clean Growth Strategy)
- ▶ Official documents which are anticipated to become policy
- ▶ The outputs from wide ranging consultations (for example the Big Tech workshops facilitated by NNL)

The working group will not:

- ▶ Review or include or make recommendations concerning facilities which are privately funded, but which are relevant to future nuclear innovation unless there is the potential of a loss of capability which is important to the strategic UK strategy.

Working Group 3

Purpose

The purpose of Working Group 3 is to assess the completeness and efficacy of the current BEIS Nuclear Innovation Programme, and advise on the structure and content of a post-2021 programme, in line with the near and long term objectives for the nuclear sector.

Scope of work

The Working Group will use the outputs of Working Group 1 as the near and long term objectives for the BEIS Nuclear Innovation Programme;

The Working Group will take into account (from the outputs of WG1):

- ▶ The objectives that the various elements of the programme set out to achieve
- ▶ How circumstances have changed since NIRAB made its original recommendations in a way that means the content of the programme needs to change

The Working Group will consider whether:

- ▶ The current six Nuclear Innovation Programme areas appropriately focussed to meet the objectives.
- ▶ The existing contracted components of the programme are delivering what they were expected to deliver.
- ▶ The programme structure and delivery mechanism is effective in delivering the targeted outcomes
- ▶ The prioritisation that was carried out to align the original NIRAB recommendations to the available budget is still appropriate

- ▶ There are any gaps or unnecessary elements in the programme.
- ▶ The current anticipated funding for the Nuclear Innovation Programme is appropriate to facilitate achieving the near and long term objectives.

and

- ▶ How the programme needs to evolve post-2021 to best achieve the objectives

The Working Group will not:

- ▶ Undertake a detailed technical peer review of the programme areas that have already been contracted.
- ▶ Develop new detailed programme content for any gaps identified in the current programme.
- ▶ Advise on the detailed content of any post-2021 programme recommendations.

Working Group 4

Purpose

The purpose of Working Group 4 is to clearly articulate the International Strategy to support the delivery of the near and long term objectives for the nuclear sector which public investment in research and innovation is required to underpin. The International fission research community offers the opportunity to access programmes, capability and facilities to deliver the programmes with leverage of the BEIS Energy Innovation Programme funding available.

Scope of work

The working group will review existing and future relevant International programmes and the opportunities these present and their alignment with:

- ▶ Existing Government policy statements (for example the Industrial Policy and the Clean Growth Strategy)
- ▶ Official documents which are anticipated to become policy

- ▶ The current Nuclear Innovation Programme
- ▶ The outputs from wide ranging consultations (for example the Big Tech workshops facilitated by NNL)

The working group will not:

- ▶ Seek to establish any relationships with International organisations

Working Group 5

Purpose

The purpose of the NIRAB cost reduction Working Group is to advise Government and industry on where research and innovation can reduce the cost of the Nuclear Lifecycle.

Much work has been done recently within the UK and globally related to cost-reduction and so the Working Group should consider and build on a range of recently published studies in these topic areas, in addition to the expertise of the group members, to provide tangible actions for Government and/or industry which aim to achieve set of short and long term recommendations.

Scope of work

The scope of the working group is to:

- ▶ Evaluate strategic initiatives that can be taken to reduce costs and determine in what areas, if any, Government could and should develop an enabling framework to drive this change.
- ▶ To develop recommendations for specific innovation areas/programmes for NIRAB to consider where:
 - ▶ Existing Government funding may be redirected within the current Spending Review period to better meet the cost reduction ambition set out in the Nuclear Sector Deal objectives – close communication with Working Group 3 will be necessary
 - ▶ New Government funding may be required as part of the next spending review period to better meet cost reduction objectives

Working Group 6

Purpose

The purpose of Working Group 6 is to clearly articulate the areas for research, development and innovation required by the UK nuclear industry if it is to meet the objectives set out by UK Government and identify the outcomes that the industrial sector would welcome.

Scope of work

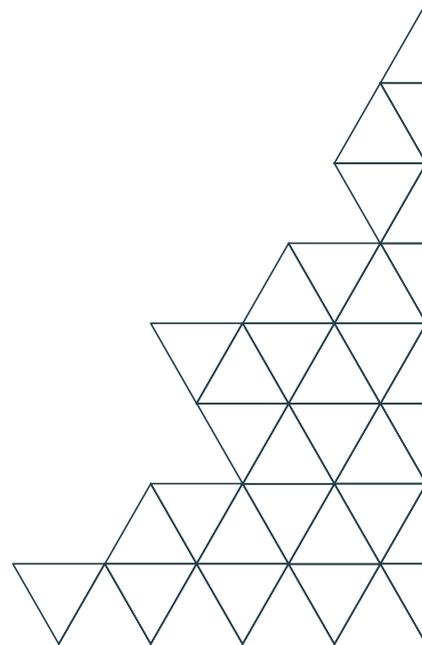
The working group will draw on the mid to long term objectives articulated by Government, as summarised by Working Group 1.

In addition the working group will

- ▶ Identify those areas of publicly funded research and innovation which would be particularly valuable to industry and that industry would anticipate taking forward to full commercialisation. This will include programmes which are already underway, programmes which are currently planned and identify any additional programmes which are not currently planned
- ▶ Review the current and planned scope of the Nuclear Innovation Programme (NIP) with a focus on research and innovation required by the UK nuclear industry, to progress through the low Technology Readiness Levels (TRLs) to the point where industry would invest in further development through to industrialisation.

The working group will not:

- ▶ Seek to recommend research, development and innovation for government support that could, should and would be otherwise undertaken by UK industry on the basis of reasonable business case for industrial investment, increasing capacity, demonstrating capability, and availability of investment funds.



Appendix 5.

Progress against NIRAB Recommendations from 2014 - 2016 Final Report (February 2017)

	Recommendation	Comments
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.	BEIS commissioned the first phase of a Nuclear Innovation Programme in 2017. Some subsequent contracts have been let and procurement of a second phase is under way in some areas. However there are aspects of the programme yet to be committed to.
2	Government should put in place arrangements to integrate and review the output of publicly funded civil nuclear research programmes.	Government officials are taking the lead in integrating and reviewing the outputs from all components of the BEIS Nuclear Innovation Programme with support from NIRO.
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.	No progress to report.
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.	Convening the current NIRAB has secured access to such independent expert advice.
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.	NIRO has been given the accountability of updating the Civil Nuclear Landscape at appropriate times, with NIRAB providing oversight. It is anticipated that an update will be published late in the 2019/20 financial year.
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.	Research expenditure in this area has been maintained over the last 2 years. There have been some increases in funding in areas such as robotics which are applicable to a number of sectors including nuclear.
7	Government should develop a plan to resume active membership of the Generation IV International Forum.	The UK was formally ratified as an active member of the Generation IV International Forum (GIF) on the 16th January 2019.
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.	Various activities have taken place related to UK's international research and innovation collaborations such as resuming active membership of GIF, the UK-US action plan. BEIS has asked NIRAB to provide further advice on where international research focus could be directed.
9	Government should assess the potential impact of the UK exiting the European Union on nuclear innovation and research activity and mitigate accordingly.	Formal arrangements for BREXIT and BREXATOM have yet to be finalised. However Government has taken action to minimise the impact by, for example, putting in place arrangements to underwrite the cost of UK participation in Horizon 2020 projects if the UK exits the EU under certain circumstances.
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.	Government published an Advanced Nuclear Technologies Policy Paper and the Generic Design Assessment (GDA) process for small and advanced modular reactors was opened for expressions of interest in December 2018. Government is also considering a proposal for an SMR from a UK Consortium led by Rolls-Royce that could lead to significant joint investment.

Appendix 6.

The BEIS Nuclear Innovation Programme

Research Theme		Apr 18	Apr 19	Apr 20	Apr 21
Advanced Fuels	Accident Tolerant Fuels	NNL			
	Coated Particle Fuels	NNL			
	Pu containing fast reactor fuels	NNL			
	Reactor physics	NNL	NNL		
	Nuclear Data	NNL			
Reactor Design	Thermal hydraulic model development	Frazer-Nash			
	Thermal hydraulic facility development	Frazer-Nash	UKAEA		
	Reactor safety and security	Frazer-Nash	Frazer-Nash		
	Virtual engineering	Wood			
	Modelling and simulation	Wood			
Spent fuel recycle	Development of proliferation resistant spent fuel recycle technology	NNL			
Materials and Manufacturing	Materials testing and development	Wood/Frazer-Nash /Sheffield University			
	Advanced component manufacturing	NAMRC			
	Large scale manufacturing / assembly	NAMRC			
	Pre fabrication module development	Cammell Laird			
	Codes and standards	Wood			
Nuclear facilities and strategic toolkit	Strategic assessments		NNL		
	Fast reactor knowledge capture		NNL		
	Regulatory engagement		NNL		
	Access to irradiation facilities		NNL		
Advanced Modular Reactors	Feasibility Study		Multiple		
	Design Development				

Figure A6-1 Overview of current NIP (with lead contractors identified)



Figure A6-2 Selection of the many organisations delivering the NIP



Case Study

Appendix 7.

Case Studies: The BEIS Nuclear Innovation Programme

Case Study: Advanced Manufacturing and Materials

Simple (single manufacturing platform environment) and Inform (intelligent fixtures for optimised and radical manufacture)

Lead Organisation:

Nuclear Advanced Manufacturing and Research Centre (NAMRC)

In Collaboration with:

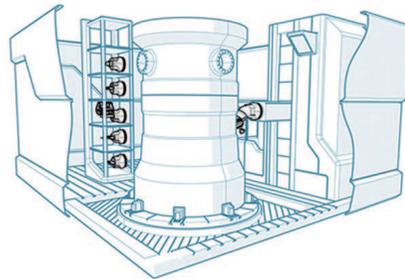
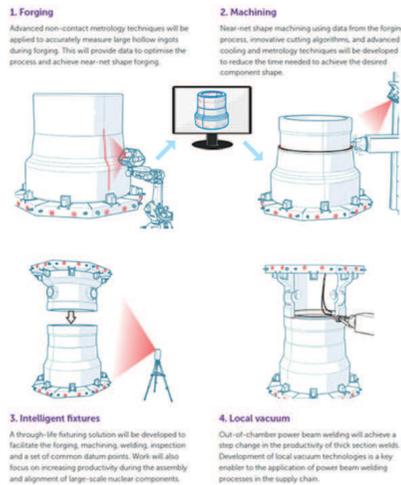
MetLase, Sheffield Forgemasters, Cambridge Vacuum Engineering, NPL, TWI, the Advanced Forming Research Centre (AFRC), the Advanced Manufacturing Research Centre (AMRC) with Boeing, University of Sheffield, and Peak NDT.

The Inform project (intelligent fixtures for optimised and radical manufacture) will develop an adaptive fixturing system to ease the movement of large parts around a factory, and ensure precision throughout forging, machining, welding, inspection and assembly. The Nuclear AMRC is leading the project with partners include fixturing specialist MetLase, Sheffield Forgemasters, Cambridge Vacuum Engineering, NPL and TWI. The project aims to cut cost and time for manufacturing large complex nuclear components on a series of dedicated platforms by at least 50 per cent.

Simple (single manufacturing platform environment), aims to integrate a range of manufacturing operations onto a single machining platform. The Nuclear AMRC lead a research consortium including two of its sister centres within the High Value Manufacturing Catapult, the Advanced Forming Research Centre and AMRC with Boeing, as well as the University of Sheffield physics department, TWI and Peak NDT. In the first phase, the partners will develop an integrated welding and monitoring system which combines a range of sensors and testing tools with an automated arc welding head. This will

allow automated in-process inspection of welds, improving quality and reducing the risk of weld failure leading to costly scrapping or rework.

<http://namrc.co.uk/centre/inform-simple/>



Case Study

Case Study: Advanced Manufacturing and Materials

Project Force

Lead Organisation:

Frazer Nash Consultancy

In Collaboration with:

University of Bristol, Nuclear Advanced Manufacturing Research Centre (NAMRC), Cammell Laird and VEQTER

BENEFITS – Confidence in the ability of novel techniques to bring down the cost of nuclear builds

This work helps to reduce an important blocker for the wide-scale use of power beam welding techniques in the nuclear industry.

The adoption of power beam welding by the nuclear industry could significantly cut manufacturing costs, particularly with the move to modularisation where systems are assembled within a factory environment.

A greater understanding of the effects of power beam welding techniques could also reduce through-life costs, as welds are generally the regions within components that require the most onerous inspection and assessment regimes, potentially limiting the life of a component, and ultimately the reactor.

THE CHALLENGE – The ability to justify the safety of welds to nuclear regulators

Welding metallic components is a core technology across all nuclear reactor designs. There are a range of welding techniques and each results in complex microstructures in the vicinity of the weld. Understanding the effect of welding parameters on material properties and residual stresses is of paramount importance for structural integrity in the design and operation of nuclear plant.

Electron beam (EB) and laser beam (LB) welding techniques have great potential for future nuclear reactors. Benefits over contemporary techniques include: faster process time, smaller heat affected zone, and potentially favourable welding residual

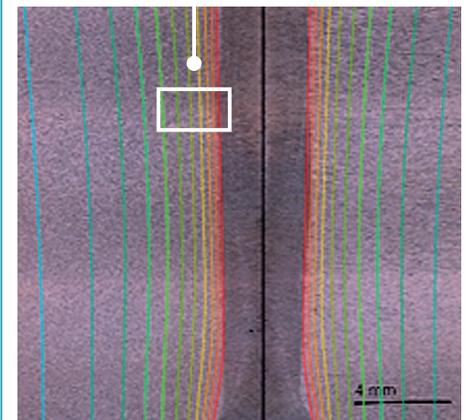
stresses. A greater understanding of power beam techniques is required for their wide-scale adoption, which includes developing validated modelling approaches that allow complex materials effects to be predicted and optimised.

SOLUTION – Bringing together existing skills to provide validation of novel techniques

The work programme focusses on three key areas:

- ▶ The detailed characterisation of EB and LB welds, and the development of a modelling approach to predict the weld residual stresses accurately and efficiently.
- ▶ Prediction of the fracture behaviour of power beam welds in the presence of residual stresses and the effects of component thickness and ageing.
- ▶ The development of a framework for how variations in material properties and residual stresses can be accounted for in structural integrity assessments.

The work is focussed on 316L stainless steel and considers typical component geometries such as plates and cylinders. The validated modelling approaches being developed will be implemented in industry standard codes to maximise applicability to the nuclear new build.





Case Study

Case Study: Spent Fuel Recycle and Waste Management programme

Secondment to Idaho National Laboratory

Lead Organisation:

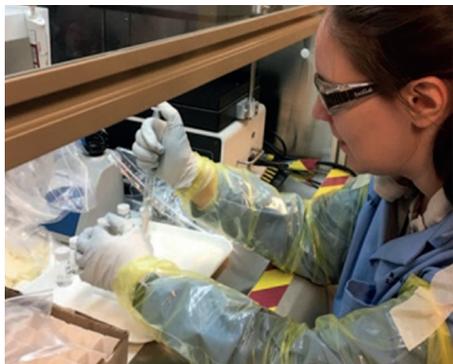
National Nuclear Laboratory (NNL)

In Collaboration with:

Lancaster University, University of Leeds, University of Manchester

CHALLENGE

In developing future advanced aqueous recycling processes the challenge from radiation will be greater due to the higher burn ups and possibly mixed oxide and even fast reactor fuels that will need to be reprocessed. This leads to increased solvent radiolysis and degradation that must be managed by the process. There is, therefore, a strong need to undertake basic and applied studies of radiation chemistry on process solutions



and solvents to quantify these effects. The UK has an excellent radiation science facility at the University of Manchester's Dalton Cumbria Facility but at present this facility cannot use uranium or other active solutions in its irradiation facilities and expertise in radiolytic degradation chemistry is limited.

SOLUTION (research undertaken)

The solution was to arrange a secondment for the University of Manchester post-doctoral researcher (Kathryn George), who is funded by the recycle programme, to the Idaho National Laboratory (INL). INL has world leading facilities and expertise in radiation chemistry of the aqueous and organic phase solutions that are used in fuel reprocessing and minor actinide partitioning flowsheets. The irradiation facilities at INL are capable of handling active solutions, such as containing uranium. A 3 month secondment was arranged with INL with the cost to the project only being travel and subsistence funds and provision of consumables and materials. INL covered facility costs and one of their key experts (Dr Dean Peterman) supervised Kathryn's work. Kathryn studied the effects of gamma radiation on PUREX solutions containing zirconium, ruthenium, iodine and uranium. Some of her samples are being sent back to Manchester for further characterisation.

BENEFIT

The secondment was a perfect way of starting this work in the current project, obtaining some early results and building expertise that can be transferred back to the UK. It has motivated the project team to try and introduce uranium-active solutions into the DCF facility as part of the next phase of the recycle programme which would be a significant step forward in the development of the UK radiation science capability. Obviously, this requires some modifications to safety procedures and approval from the University. It has provided a valuable training and development experience for the post-doctoral researcher involved. The secondment has also helped promote a specific technical link between INL and the NIP recycle programme that hopefully will grow in the future, especially now the UK-US memorandum has been signed.



Case Study

Case Study: Spent Fuel Recycle and Waste Management programme

"Sim-Plant"

Lead Organisation:

National Nuclear Laboratory (NNL)

In Collaboration with:

Lancaster University, University of Leeds, University of Manchester

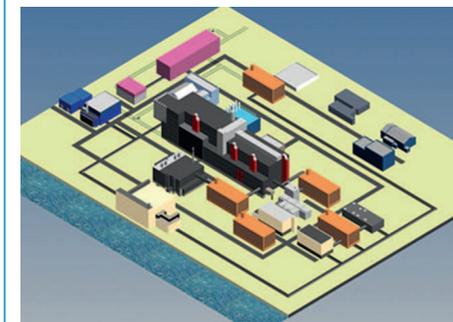
CHALLENGE

The NIP is investing substantial funds into nuclear energy R&D with the aims of developing technologies that can deliver low carbon energy and are more cost effective, more proliferation resistant, more publicly acceptable and generate less wastes than past nuclear systems. The Strategic Toolkit programme is developing fuel cycle models, such as ORION, that can analyse the range of future scenarios for UK nuclear energy and fuel cycles. However, these are large scale fuel cycle models that do not necessarily demonstrate the impact of the R&D being done in the different parts of national programme, i.e. reactors, fuels and recycle. The results from fuel cycle modelling, also, obviously, depend on the input data for the various parts of the fuel cycle and the assumptions made. There is a potential gap between the detailed chemistry and engineering R&D and the fuel cycle modelling related to how we can quantify and communicate the impact of the R&D on the advanced reprocessing plant and, more broadly, the recycling site. That is, addressing the question of whether the advances made in the process chemistry and engineering actually will lead to less waste, smaller plant footprint/volume, lower capital costs and greater proliferation resistance than current reprocessing as practiced at Sellafield and La Hague, for instance. As well as, addressing the reverse question of how do we identify which parts of the plant/site should R&D focus on in order to have substantial impacts on costs, wastes, size etc.

SOLUTION (research undertaken)

A concept has been devised for a new modelling and simulation tool termed "Sim-Plant" – taking inspiration from the computer game Simcity". The intention is for a platform in which the user

can generate a scaled 3D representation of a reprocessing site through the selection and manipulation of input variables such as fuel type, burnup, cooling time and reprocessing flowsheet. The software will utilise built-in modelling flowsheets to produce mass balances, enabling the tracking of material throughout the system. The tool should also enable estimates of size (footprint, volume) and, from these data, costs can be inferred. The inter-connections between reprocessing plant, waste plant(s), stores and co-located fuel fabrication can be visualised and efficiencies identified. Preliminary discussions have been held with the Strategic Toolkit programme on how Sim-Plant can be linked to ORION fuel cycle models, thus improving the fidelity of and data input for ORION. Initially, in this phase of the programme, the focus has been on developing the basic structure of Sim-Plant and applying it to calculations of waste streams from the Advanced PUREX process compared to Thorp reprocessing. The work is also leveraged through the GENIORS (EURATOM Horizon 2020) project where the "EURO-GANEX" process is being analysed by Sim-Plant.



BENEFIT

Sim-Plant will ultimately provide a means of quantifying and visualizing the impacts of advanced recycle R&D on the reprocessing plant and broader recycling site. It will aim to cover the factors of interest to policy makers (costs, wastes, nuclear materials flows etc.) in an easily understandable way. It should bridge the gap between R&D and fuel cycle models such as ORION and also be usable in the reverse mode of identifying which parts of the plant/site should be the focus of R&D to maximise the impacts on costs, wastes, etc., thus accelerating and increasing the impact of the NIP funded R&D.



Case Study

Case Study: Advanced Manufacturing and Materials

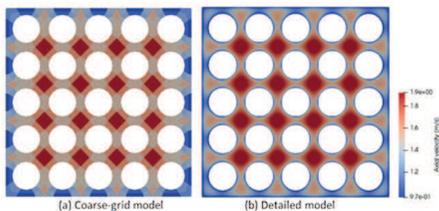
Nuclear Thermal Hydraulics Modelling

Lead Organisation:

Frazer Nash Consultancy

In Collaboration with:

Westinghouse, EDF Energy, Science and Technology Facilities Council, University of Manchester, University of Sheffield



(a) Coarse-grid model

(b) Detailed model

THE CHALLENGE

Thermal hydraulics is key to the overall system integration and design of reactor plants and it is important to build this capability now to position the UK to take advantage of nuclear new build, SMR deployment and Gen-IV reactor development. Pre-existing nuclear thermal hydraulics modelling capability in the UK is strong, but requires further planning, development and integration to ensure this capability is central to the design and qualification of nuclear thermal hydraulics in the future.

SOLUTION (research undertaken)

The modelling project is ongoing with the technical approach summarised as:

- ▶ A critical review of the state-of-the-art in thermal hydraulic prediction capability.
- ▶ Review of user requirements for modelling capability. This highlighted the need for:
 - ▶ Quantification of uncertainty in Computational Fluid Dynamics to increase 'trust' in advanced thermal hydraulic models;
 - ▶ High quality validation data to support model development and reactor design activities;
 - ▶ Innovative combination of modelling tools and techniques for quicker and more complete physical analysis;
 - ▶ Improvements in the understanding and simulation of four thermal hydraulic phenomena: natural convection, 2-phase flow, single phase turbulent mixing, and fluid flow driven component fatigue.
- ▶ A specification for an innovative thermal hydraulics modelling capability.

BENEFIT

The key outcome of the project is the focus on the specifics of what modelling capability is needed by the end users/ developers, thus providing the most effective targeting for investment in development work. As this originates in requirements set by the developers of future nuclear power, this opens up the paths to the commercial exploitation of the UK's high-value added nuclear thermal hydraulics capability.



Case Study

Case Study: Advanced Fuels

Advanced Fuels – Accident Tolerant Fuels (ATF), Coated Particle Fuels (CPF), Fast Reactor Fuels and Reactor Physics

Lead Organisation:

National Nuclear Laboratory (NNL)

In Collaboration with:

University of Bristol, University of Manchester, Imperial College London, Manchester Metropolitan University, Wood, Nuclear Advanced Manufacturing Research Centre (NAMRC), University of Leicester, University of Liverpool, UKAEA, University of Surrey, University of York, National Physical Laboratory



CHALLENGE

Development of a strong nuclear fuels R&D base that attracts international investment, supports retention of the UK's fuel manufacturing capability and underpins subsequent delivery of nuclear fuels to the domestic and international markets. This includes the development of expertise and infrastructure needed to advance manufacturing routes either via new technical approaches or improvements to existing processes.

PROGRAMME OBJECTIVES

Development of new fabrication routes to produce high density accident tolerant fuel (ATF).

Manufacture and testing of Cr-coated Zr alloys as a near term ATF cladding concept.

Demonstration of fabrication and joining of SiC composites as a long term ATF cladding concept.

Development of reactor physics models to support future fuel & reactor requirements..



BENEFIT

Development of new manufacturing methods, subject matter experts and associated supply chain companies to enable the UK to develop a world leading capability and be at the forefront of the international nuclear industry, and to exploit the associated commercial benefits.

International collaborations in accident tolerant fuel (ATF) development, fast reactor fuels and nuclear data development programmes – establishing the UK as a key contributor

Industry co-investment in research programmes and subsequent industrial deployment.



Glossary

AMR	Advanced Modular Reactor
AMR F&D Project	Advanced Modular Reactor Feasibility and Development Project
ANT	Advanced Nuclear Technology
BEIS	Department for Business, Energy and Industrial Strategy
BNFL	British Nuclear Fuels Ltd
CCC	Committee on Climate Change
CNL	Canadian Nuclear Laboratories
EFWG	Expert Finance Working Group
EPR	European Pressurised Water Reactor
FOAK	First of a Kind
GDA	Generic Design Assessment
GIF	Generation IV International Forum
HMG	Her Majesty's Government
HTGR	High Temperature Gas Reactor
IP	Intellectual Property
NDA	Nuclear Decommissioning Authority
NIP	Nuclear Innovation Programme
NIRAB	Nuclear Innovation and Research Advisory Board
NIRO	Nuclear Innovation and Research Office
NSD	Nuclear Sector Deal
NOAK	Nth of a Kind
NWDRF	Nuclear Waste and Decommissioning Research Forum
ONR	Office for Nuclear Regulation
R&D	Research and Development
SFR	Sodium Faster Reactor
SMR	Small Modular Reactor
SLA	Site Licence Application
STEP	Spherical Tokamak for Energy Production
TEA	Techno Economic Assessment
UKAEA	United Kingdom Atomic Energy Authority
UKRI	UK Research and Innovation
UN	United Nations
VHTR	Very High Temperature Reactor





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

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