NUCLEAR INNOVATION AND RESEARCH ADVISORY BOARD

The UK Civil Nuclear R&D Landscape Survey

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Executive Summary

This is the fourth review of the civil nuclear Research and Development (R&D) landscape, covering financial year 2022/2023 (April to March). It provides insight into key Government nuclear policy areas, funding sources of R&D, number of people employed in research activities and gives detail of the facilities where this is undertaken as well as providing detail on international collaboration activities.

The scope of this research is the civil nuclear sector in the UK. Whilst we have included some organisations from the nuclear defence sector or organisations that undertake cross-cutting research activities which are of general benefit to the nuclear sector within this review, we have purposely excluded any specific spending on defence R&D.

This research therefore covers nuclear fission and fusion only, with a stronger emphasis on nuclear fission, due to its size and the timescales involved in Government's energy security and net zero targets. We attempt to present both qualitative and quantitative data comparable with previous landscape reviews [1] to identify trends and to assess the impact interventions have had that have been trialled in the last couple of years.

It should be noted that the COVID-19 pandemic occurred between the third R&D landscape review and this one. Our research shows that all nuclear R&D programmes were impacted by this event, and many suffered serious delays or reductions to the scope of work undertaken because of working and travel restrictions. This inevitably has had a significant bearing on the sector.

Context of the Civil Nuclear R&D Landscape 2022/2023

The overarching sentiment from across UK Government and the nuclear R&D sector is that there is alignment on the need for secure, clean, and affordable energy for the long term, recognising that nuclear energy has a significant role to play in reaching that ambition. The nuclear sector has great potential to support decarbonisation of other industrial sectors, as well as provide economic benefit for the UK via exports to foreign markets. This sector keenly welcomed the Government's commitment to increasing the amount of nuclear electricity generating capacity in the UK as well as using nuclear heat as part of the wider ambition to attain net zero by 2050.

Key Findings

This landscape review was undertaken using a similar format to previous ones whereby any organisation, institution, company or body involved in nuclear R&D was invited to submit a response. A total of 48 respondents provided some level of input. This was slightly fewer than previous reviews, a result of changes to various companies' structures, the amalgamation of some organisations and the streamlining of R&D by others, as well as an absence of submissions from a small number of nuclear organisations that had previously provided input.

These changes in the organisational landscape and the fact some organisations provided only partial data sets, made it hard to make direct comparisons to the previous reviews. However, additional secondary research has been used to substantiate the data obtained and we have explained any assumptions or caveats throughout the report when we discuss implied data trends to previous years. Qualitative interviews were also undertaken for the first time in this edition by an independent research organisation to provide a deeper dive into some of the responses provided by organisations that are significant contributors to nuclear R&D.

The key findings from this landscape review are as follows:

Total R&D funding has increased (with the majority of funding being provided by Government):
Our key finding from this landscape review is that there has been a significant rise in total funding for nuclear R&D in the financial year 2022/2023 since the previous landscape study in 2018/2019. Funding has risen by 52% (after inflation) and stands at £577m (0.03% of UK GDP). Approximately £77m is from nuclear fusion activities (up from £54m in 2018/19) and £500m from nuclear fission (up from £140m in 2018/19). Over 1/5 of this annual spend is on Waste Management and Decommissioning activities associated with the NDA estate (£114m).

Annual spend is in-line with other economies with significant nuclear programmes, but from a very low UK baseline of R&D spend in recent decades and against the backdrop of a significant need to scale up R&D capacity to support new nuclear ambitions. 7% of total R&D funding is leveraged from a combination of private sector and international sources, the remaining balance originates from Government sources.

Significant R&D resourcing and staffing challenges in support of scaling-up wider sector capacity:
This landscape analysis indicates that the sector has increased its R&D capacity significantly over the last ten years. There are currently approximately 5400 full time equivalent (FTE) persons working on nuclear R&D in the UK. Work undertaken by the Nuclear Skills Strategy Group (NSSG) in 2022 to understand labour market requirements identified a significant challenge in resourcing new nuclear programmes whilst continuing to deliver existing programmes. In the context of a 24GWe target, the total nuclear sector (civil and defence) is projected to need an increase of between 80% and 120% in labour capacity on top of replacing workers that retire [2]. The R&D skills growth rate in 2022/23 does not meet the projected needs of an expanding nuclear sector.

UK researchers access a diverse array of facilities in order to conduct their research:
This landscape review revealed that during 2022/23 nuclear research was undertaken at over 50 international facilities and there was a heavy reliance on UK facilities accessed under the National Nuclear User Facility (NNUF) scheme [3]. As a result of the ambiguity on future financing of the NNUF facilities and the reliance on access arrangements to international facilities, a case is beginning to form for new UK research provisions and more certainty on UK access/long-term funding arrangements to existing facilities.

Nuclear R&D activities require a coordinated and clear strategy to meet net zero targets:
Given the Government's ambitions for net zero and for 24GWe (plus additional nuclear heat) of electricity supply to be provided by nuclear by 2050 [4], the sector would welcome greater clarity on and coordination of R&D activities. Whilst the UK currently remains open to all types of nuclear reactors to fill this energy capacity gap, respondents report that this means the sector is pointed in many directions at once, making strategic decisions on what R&D needs to be undertaken and by when very challenging.

Additionally, many responders report that the history of nuclear funding is characterised by periods of 'boom and bust'. Whilst respondents welcomed current levels of funding, they are concerned that the UK may be entering a period of increased fiscal discipline and political uncertainty which has historically led to reduced and short-term R&D budgets. Should this happen now, at a time where momentum is needed most, the ability to achieve any net zero decarbonisation targets will not be successful within the timescales proposed.

In summary, the respondents to this survey believe that the UK has world-leading nuclear R&D expertise and facilities that provide a solid foundation on which to build and advance the civil nuclear sector's capacity. Further funding in specific areas of research, coupled with development and access to wide-reaching research facilities will enable this. This will reduce the risk of future nuclear programmes not delivering on time whilst re-establishing the UK's reputation as a world-class nuclear R&D nation.

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Glossary

AFCP Advanced Fuel Cycle Programme
AGR Advanced Gas-cooled Reactors
AMR Advanced Modular Reactors
ANT Advanced Nuclear Technologies (UK term for SMRs and AMRs)
BEIS Department of Business, Energy and Industrial Strategy
BNFL British Nuclear Fuels Ltd
CEGB Central Electricity Generating Board
CDT Centre for Doctoral Training
DBT Department for Business and Trade
DESNZ Department for Energy Security and Net Zero
DSIT Department for Science, Innovation and Technology
EA Environment Agency
EPSRC Engineering and Physical Sciences Research Council
FNEF Future Nuclear Enabling Fund
FOAK First Of A Kind
FSA Food Standards Agency
FTE Full Time Equivalent
GBN Great British Nuclear
GDF Geological Disposal Facility
GDP Gross Domestic Product
GIF Generation IV International Forum
GW GigaWatt
GWe GigaWatt-electrical
GWth GigaWatt-thermal
HALEU High Assay Low Enriched Uranium
HMG Her/His Majesty's Government
HoC House of Commons
HoL House of Lords
HTGR High Temperature Gas-cooled Reactors
IEA International Energy Agency
JET Joint European Torus
KPI Key Performance Indicator
MoD Ministry of Defence
MWe MegaWatt-electrical
NAMRC Nuclear Advanced Manufacturing Research Centre
NDA Nuclear Decommissioning Authority
NEST Nuclear Energy Skills and Technology Framework
NIRAB Nuclear Innovation and Research Advisory Board
NIRO Nuclear Innovation and Research Office
NNL National Nuclear Laboratory
NNUF National Nuclear User Facility
NPL National Physical Laboratory
NSAN National Skills Academy for Nuclear
NSSG Nuclear Skills Strategy Group
NIP Nuclear Innovation Programme
NZIP Net Zero Innovation Programme
OECD Organisation for Economic Cooperation and Development
ONR Office for Nuclear Regulation
PWR Pressurised Water Reactor
R&D Research and Development
RD&D Research, Development and Demonstration
RD&I Research, Development and Innovation
STEM Science, Technology, Engineering and Mathematics
SME Subject Matter Expert
SMR Small Modular Reactor
UKAEA UK Atomic Energy Authority
UKHSA UK Health Security Agency

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1. Introduction

1.1 Background

Understanding the civil nuclear research and development (R&D) landscape is important, not only to Government, but to the wider energy sector. Nuclear R&D is a vital adjunct to the sector in order to:

- Provide key evidence to support through-life licensing and permitting of nuclear facilities
- Develop new technologies and innovations across the entire nuclear fuel cycle to improve energy outputs, efficiency, safety and reliability
- To support the translation of scientific, engineering and technical innovations into industrial applications
- Develop a pool of technical specialists and Subject Matter Experts (SMEs) to support future nuclear programmes
- Develop the teaching and academic framework to meet future nuclear workforce requirements

This report seeks to provide its readers with a comprehensive overview of the current landscape from organisations that fund and/or conduct civil nuclear R&D in the UK during the snapshot year of 2022/ 2023. It also looks to the future, identifying the challenges and opportunities facing the sector in coming years. The report touches on the policy landscape, funding sources, types of organisations and number of people doing civil nuclear R&D and the facilities needed as well as current areas of research interest.

The review seeks to follow on from previous civil nuclear R&D landscape reviews undertaken in 2013, 2017, and 2020 [1]. Where possible, data from this review has been compared to that from previous reports to assess trends and to understand further how the landscape is evolving. However, the nuclear landscape more broadly has changed significantly over the last couple of years and hence, in this review, we have taken the opportunity to undertake a deeper-dive into the opinions and thoughts of key respondents across industry, academia, regulators and national laboratories, to understand their current positions and to explore their thoughts on what the sector needs to do in order to realise the Government's net zero ambitions.

More information about the comparability of results between this and previous reviews can be found in the methodology section and in the Appendix.

1.2 Scope

The scope of this research is the civil nuclear energy sector in the UK, this includes legacy facilities, current operational nuclear power plants, future energy generation (fission and fusion), waste management and decommissioning. Whilst we have included some organisations in the nuclear defence sector within this review (as they have some civil nuclear spend), we have purposely excluded any specific spending on defence R&D.

This research therefore covers civil nuclear R&D only. The data for this research is a one-year snapshot for the financial year from April 2022 to March 2023.

1.3 Authors and Sponsors

NIRAB have commissioned this review, which has been compiled jointly by the Insights team at Madano Partnership, an independent market research company, and the Nuclear Innovation and Research Office (NIRO).

Sponsorship was provided by the Department for Energy Security and Net Zero (DESNZ).

1.4 Methodology

A three-stage process of data collection was undertaken to collect insights for this landscape review:

- Quantitative online survey which was open to any organisation regardless of type, size or location who identify themselves as conducting or funding nuclear R&D
- Qualitative in-depth interviews with key stakeholders across the nuclear sector to understand specific perspectives on R&D
- Secondary data collection, drawing on publicly available data and information to understand the nuclear R&D landscape in a broader context

The findings of this report are based on the combination of all three data collection methods; more detail on the survey questions asked and results obtained can be found in the Appendix. Table 1 below details the response totals across organisation type.

The pool of respondents, overall, by category and by sub-category, was smaller than that in 2020, where 76 respondents provided data. It should be noted, however, that some organisations that were recorded as separate entities in previous reports have now been recorded as a single submission (the Nuclear Decommissioning Authority (NDA) is an example of this, having previously provided data as six separate industry organisations, but now is collectively reported as a group). Beyond this, some organisations have since been acquired or merged, or have simply not undertaken any nuclear research during the snap-shot period and so did not provide a submission. A very small number of organisations that we believe have undertaken nuclear R&D have chosen not to respond. In addition, a small number of niche organisations have now withdrawn from the nuclear market. Beyond this, it is not possible to extract the same level of granularity as previous exercises have done, particularly the breakdown of funding against priority research areas, geographical split and spread of experience amongst staff as many organisations chose not to divulge this level of detail in this iteration.

To contextualise our primary findings and to provide a broader perspective, both in terms of UK domestic nuclear R&D and its context within a broader international setting, we conducted an extensive review of historic information on the civil nuclear industry and have presented this alongside our new data. As in previous iterations of this landscape review, information has been gathered using both a 'top-down' approach, in which we capture funding from Government departments and agencies and 'bottom up' where we capture funding from UK companies, universities, national laboratories and private investors.

Table 1. Total responses to the 2023 Civil Nuclear Landscape Survey by category

Category	Number of responses
Top-Down Funder/ National Laboratory	12
Industry Representative/Industrial Organisation	16
University/Academic/Research Institute	20
Total	**48**

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2. The Civil Nuclear Landscape

2.1 Wider Landscape

The last civil nuclear R&D landscape survey was published in March 2020 covering the year 2018 to 2019 [1]. Much has changed in the geopolitical landscape over the last three years.

Most notably:

COVID-19 pandemic

Whilst nuclear facilities remained open and operational during the COVID-19 pandemic, many organisations reported that non-essential R&D was paused. Undertaking R&D in the aftermath of the pandemic was also very challenging. Many research facilities took a great deal longer to get online after the lockdown periods and thus utilisation of UK facilities was for some time much lower than expected after restrictions had lifted. This was also, in part, compounded by the supply of scientific instruments and consumables that were manufactured in China being limited or not available. Consequently, some projects did not progress as far as they should have within the realms of the funding that was allocated to them, and some were extended in delivery time. In particular, the Nuclear Innovation Programme funding was delayed by over a year.

Geopolitical instability

The war in Ukraine, which started in 2022, has led to increased demand for energy security [5], as the UK tried to insulate itself from the economic shocks associated with instability through building a more self-reliant UK energy market [6]. In this context, increasing the capacity of the nuclear sector to provide increased nuclear power and to substantiate further life-extensions for some UK Advanced Gas-cooled Reactors (AGRs) is particularly salient. There has also been a focus on R&D for indigenous nuclear fuel manufacture, although the impact of this recent development is outside the time-period of this report. Further understanding of the impact of this nuclear fuel R&D will likely be captured in the next iteration of this review.

High inflation

The UK has faced a period of high inflation, including the cost of energy, in part linked to geopolitical instability and the COVID-19 pandemic [7]. This has a demand side impact, increasing the need for affordable energy. It also has a supply side impact, making investment decisions more challenging as the costs of staffing, infrastructure and materials increase. Ultimately, this period of high inflation means the Government also has had to make more challenging decisions on what its priorities are. This has also led to an increase in interest rates, therefore impacting the ability of private organisations to fund R&D.

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2.2 Policy

The 2009 Climate Act, which committed the UK to reducing its greenhouse gas emissions by 80% by 2050 compared to 1990 levels, formed the Committee on Climate Change and established UK carbon budgets. In June 2019 this was strengthened by committing the UK to bring all greenhouse gas emissions to net zero by 2050 [8].

2021 saw the UK publish its first fusion energy strategy, which set out a vision for UK fusion that focused not just on the UK's unique scientific and technical expertise but on commercialising that technology by developing a thriving UK fusion sector and collaborating internationally [9]. The objectives for the UK include demonstrating the commercial viability of fusion technology by building a prototype fusion power plant to deliver net energy via the Fusion Futures Programme (FFP).

In April 2022, the Government set out its British Energy Security Strategy, which outlined how Government would deliver "secure, clean and affordable British energy for the long term" [10]. It drew specific focus on the "energy trilemma": increasing sustainability (decarbonising energy), security (ensuring the security and reliability of energy supplies) and affordability (minimising the cost of energy to consumers) simultaneously [5]. The strategy set out a target of growing the capacity of the nuclear sector from 15% of the power consumed in Great Britain in 2021, to 25% (i.e. up to 24GWe electricity with additional heat outputs). This strategy also acknowledged that the UK had fallen behind other countries and that 'successive Governments have failed to make the necessary investments in British nuclear and committed to reversing this underinvestment. The energy security strategy also committed to the creation of Great British Nuclear [11].

A year later, in 2023 Government published The Net Zero Government Emissions: UK Roadmap, which provided interim targets for decarbonisation (50% by 2032, 75% by 2037) against a 2017 baseline and reinforced the overarching net zero by 2050 ambition against the context of devolution [12].

In the same year the Government also published Powering Up Britain: Energy Security Plan which committed to delivering a programme of new nuclear projects beyond Hinkley Point C and Sizewell C [13]. This included a commitment to 'a demonstration of an Advanced Modular Reactor (AMR) by the early 2030s'. It also re-committed to setting up Great British Nuclear (GBN) [11] and launching a competitive process to select the best Small Modular Reactor (SMR) technologies. The radioactive waste and decommissioning policy was also under review at this time to enable a risk informed approach to dealing with both legacy and future waste arisings.

In June 2023, the UK Parliamentary Science, Innovation and Technology Committee published a report on delivering nuclear power [14]. The key conclusion was that the UK needed a Nuclear Strategic Plan to turn high level aspirations into tangible steps to deliver on its ambition. The report highlighted several challenges in meeting the 2050 target.

These included:

An increased demand for electricity

The need to increase energy capacity is occurring at a time when the use of electricity is likely to rise as the UK electrifies different sectors (e.g. heating and transport) to reduce reliance on fossil fuels. Increasing the capacity of the nuclear sector from c. 15% to c. 25% of the UK's total energy requirements by 2050 therefore means not just growing its share of a fixed market, but actually growing its share of a substantially expanded market.

A need for new reactors

The UK currently has nine operational reactors at five sites, eight of which are currently expected to be shut down by 2028 unless further life extensions can be undertaken [15]. There is one twin GWe unit currently under construction (Hinkley Point C) which is projected to be operational between 2029 to 2031 [16], and a further commitment to build an additional twin GWe station at Sizewell C, which could be online before 2050 if planning/construction go to plan [17]. This means that UK nuclear capacity could fall from approximately 5.5GWe (2023 operational capacity) to 1.2GWe in 2028 (i.e. the output from Sizewell B).

However, if Hinkley Point C comes online in 2029-2031 this would then increase electricity generating power to about 4.4GWe and subsequently Sizewell C could bring the total generating capacity to 7.6GWe. To meet the 24GWe by 2050 targets, the nuclear sector therefore needs to triple its planned capacity increase. Figure 1, developed for this landscape review, shows a possible nuclear fission timeline out to 2050.

The question of generational change

The majority of current operational UK reactors are second generation, and no new reactors have come online since Sizewell B in 1995 [15]. Life extension of Sizewell B to 2055 is in planning, but this will only go some way to plugging the gap between generation capacity and deliverability of power into the UK grid. To increase its capacity for power generation, the UK can use established technology (GWe scale reactors like Hinkley Point C) or new technologies (SMRs or AMRs), or a mix of all types. The Government's commitment to a demonstration of an AMR by the early 2030s and the administration of a competitive process to select SMR technologies suggest that new capacity may well be generated by a mix of both Generation III and IV reactors. The decision to bring these technologies into use within a relatively short time frame comes coupled with the need to invest significantly in nuclear R&D and to have sufficient subject matter expert knowledge on each technology type to underpin design, delivery and operation.

The capacity of nuclear reactors operating from 2020 to 2050 (including both high-certainty future reactors planned as well as future ambitions) is summarised in Figure 1.

This information has been gathered from numerous sources and includes the following assumptions:

- All AGR's will cease operation by 2028 as is currently planned (we acknowledge that discussions are on-going with regard to further lifetime extensions, but this is unconfirmed and even if successful will only "buy" a few more years of operability)
- Sizewell B PWR will be granted a 20-year life extension from the current end date of 2035 to 2055
- Hinkey Point C, comprising two EPR reactors, each 1.63GWe, is currently in construction with the first reactor scheduled to come online in 2029 and the second in 2031
- Sizewell C, also a twin unit EPR, has recently been granted consent to proceed. At present it is assumed that the earliest date when it could become operational is 2034
- The first six SMR units come online incrementally from 2030, each contributing a maximum of 470 MWe to the grid with an operational lifespan of 60 years, totalling 2.8GWe from SMR's in 2050
- The first AMR delivers output from mid-2030's as a demonstration. We have assumed that its output will be used for purposes other than electricity generation but want to acknowledge that it could generate up to 400 MWth
- A third GWe-size station comes online in 2047 providing 3GWe to the grid (shown in the chart with intermittent shading)
- 100% availability is assumed for all units for all types of reactor
- The STEP Fusion reactor, currently planned for the late 2040's, has been omitted from Figure 1 due to the current uncertainty in its programme

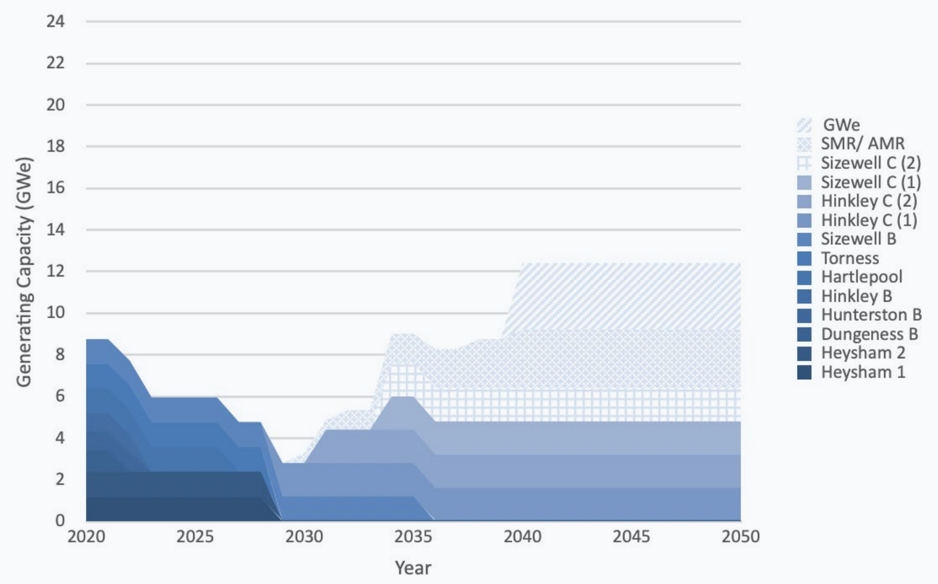
The UK Parliamentary Science, Innovation and Technology Committee's Delivering Nuclear Power report [14] identifies the need to close the gap between our current capacity and Government targets.

It acknowledges that Great British Nuclear (GBN) is administering a competitive process to select the best (SMR) technologies, but a more detailed plan is needed to understand how this gap will be closed by other technologies, i.e.,

- what mix of SMR, AMR and GWe scale reactors is anticipated within the 24GWe capacity?
- what is the route map to delivering this by the target date (2050)?

Figure 1.
UK Nuclear Fission Generation Capacity from 2020 to 2050

(note, all data from 2023 onwards is based on current project estimations).



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2.3 Stakeholder Perspectives

Stakeholders across industry, academia, national laboratories, and other Government organisations who participated in this review welcome the recognition that nuclear is important in meeting the net zero by 2050 ambition. Furthermore, many respondents are very optimistic and enthusiastic about the fact that a renaissance could put the UK back in a more prominent position in nuclear power generation R&D on the global scale. However, respondents expressed their concern that this renaissance will only be possible if the key stakeholders of the sector, including Government, its key organisations and National Laboratories, Academia and Industry align on a plan for how the sector can meet the 2050 target. Respondents expect to be consulted and work with Government to define how to achieve the 24GWe (plus heat) ambition.

Those taking part in this landscape review feel that Government is best placed to lead this conversation, and many want to see a detailed strategic plan for how the nuclear power gap should be closed, including details on what additional technologies and infrastructure will be utilised to enable the clean energy agenda to be successful on the timescales declared.

Many respondents describe the UK's approach to nuclear R&D as 'stop-start'. This is not a recent observation; similar sentiments have been voiced over several decades and in all previous NIRAB landscape reports. But it echoes the "Delivering Nuclear Power" report [13] which describes Britain's nuclear energy policy as being 'characterised by intermittency'. This 'stop-start' approach within the nuclear sector involves periods of extensive activity followed by a dropping off point and is seen as a key constraint to civil nuclear R&D achieving its objectives.

Without a clear, detailed long-term plan for nuclear R&D, some are concerned that the sector will be unable to invest in the people and facilities needed to achieve the 24GWe by 2050 goal. Others went as far as to say that the energy crisis faced today could have been avoided if nuclear programmes had been sustained over the last 30 years.

A lack of a clear, long-term R&D delivery plan is seen as a particular challenge in the context of the UK's fragmented nuclear sector. Some respondents compare the UK's current sector to how it was organised in previous decades, or how other countries organise theirs (in both cases with more state ownership or control or influence) and feel a decentralised approach is harder to pull in a single direction.

They praise the innovation of the researchers working within UK's nuclear sector, but feel that innovation can be scattered across a lot of organisations that each have a different focus and are all too often driven by commercial drivers rather than what is best for the overarching sector.

To pull a fragmented nuclear R&D sector in a common direction, four outcomes have been identified as beneficial from this landscape review:

A common focus
Outlining a clear route map to the delivery of 24GWe by 2050, defining the mix of GWe, SMR, AMR and micro-reactor technologies, and confirming targets for both electricity and heat.

Identifying and defining through-life R&D challenges
That need to be solved to enable investors to access and deliver new nuclear programmes in the UK and clearly defining how they will be addressed.

Consistency
Having a clear, long-term commitment to a single vision, with the strategic direction and funding being provided over longer durations without large time gaps to allow programmes to be delivered at pace and in the most time and cost-effective manner.

Pro-innovation regulation and permitting
UK regulatory bodies continue to develop approaches that help enable innovation by the UK nuclear industry, including considerations associated with streamlining licensing and approval processes.

Views from Responders

'Our funding is so intermittent it's hard to plan for the long-term. What we need is blocks of 5-10years of R&D funding sustained continuously over a 20+ year period.'

Academic

'You look at the spread of different technologies that we're considering at the moment, it's quite extraordinary. There's a pent-up want to innovate and a pent-up want to try new technologies. I just think we are limited in achieving these things by the lack of a real strategy and associated delivery plan at the moment.'

Academic

'If you want to do all of those things. Fusion, AMRs, SMRs, new builds we need a strategy that everyone's behind and then people can make business decisions on staffing and capabilities and whether to invest in a multi-million-pound facilities with a certain return on investment.'

Industry

In summary:
There is a lack of clarity on the reactor technology mix and the areas where R&D programmes are needed to support Fusion, GWe, SMR and AMR technologies. A more structured process, with support from UK regulators should be undertaken to determine the priority of R&D activities needed to support the 24GWe ambition. A clear strategy should be set out for nuclear heat and connectivity to any energy storage/ transport systems. NIRAB could be empowered to provide or at least give strategic direction to this R&D strategy to deliver Government policy ambitions.

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3. Funding

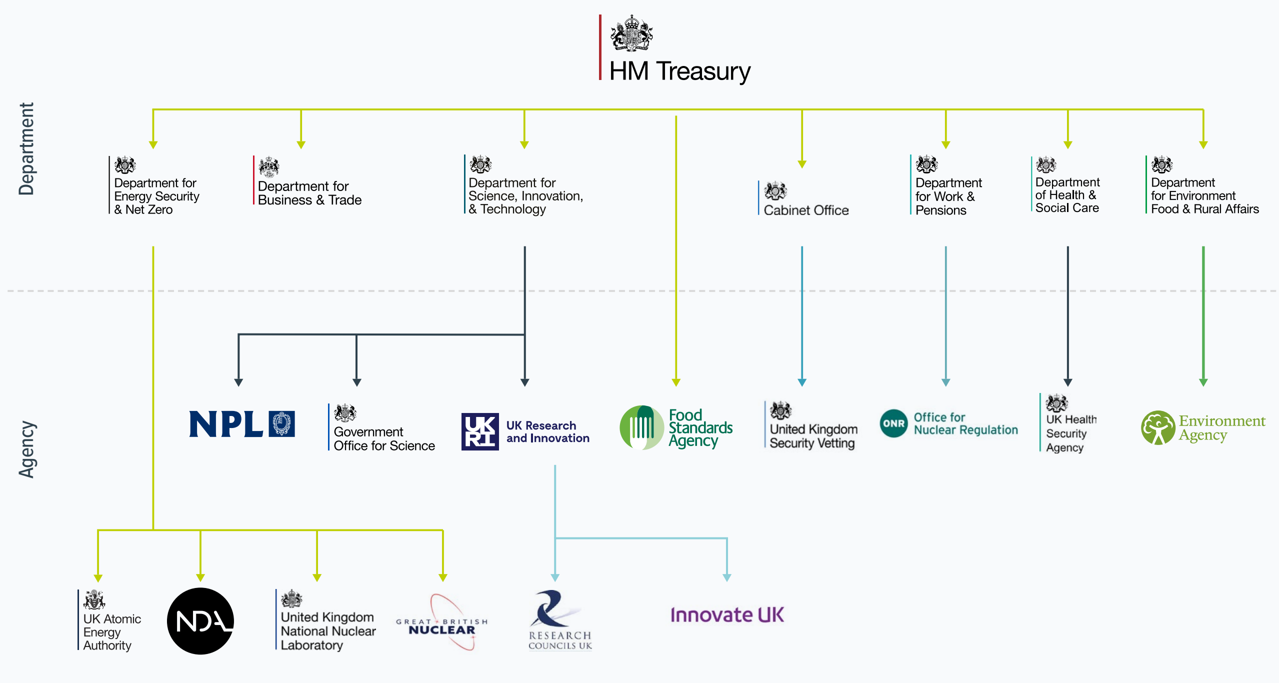
In the civil nuclear sector, R&D is undertaken by privately owned organisations, universities and national laboratories (which are Government owned). A small amount of work is undertaken or commissioned by arms-length bodies such as UK Health Security Agency, the Food Standards Agency etc. Funding for research originates from several sources.

Funding can come directly from one of these types of organisations, from the respective Government department (DESNZ, DBT, DSIT etc.) or be accessed through grants or via research councils, which are governed by UK Research and Innovation. Additionally, some research funding, directly related to the regulation of nuclear activities, is provided via the two main nuclear regulatory bodies, the Environment Agency (EA) and the Office for Nuclear Regulation (ONR). Whilst each regulator has a Government sponsor department, depending on the particular piece of research, funding is not necessarily provided by that department and may originate from different sources e.g. charges applied directly to licence holders. The Ministry of Defence (MoD) also provides funding for nuclear R&D but is excluded herein.

Lastly, some research funding comes from EU programmes and international research bodies, such as Euratom. Whilst there are a relatively small number of funding streams, the flow-down of money into the sector is complex and as such it is common for research programmes to be funded by multiple mechanisms and delivered collaboratively by multiple types of organisations working in partnership together. There are also numerous other R&D areas which benefit the nuclear sector, but which haven't been explicitly captured including robotics and Artificial Intelligence. To understand the current overarching nuclear ecosystem, it is important to highlight that this fiscal landscape can be further complicated by the fact some organisations have multiple roles and some are owned in-part or wholly by international organisations or overseas Governments.

In addition, there are some different funding arrangements for the devolved administrations. Figure 2 below shows a schematic of the main Government funding bodies/recipients of Government funding for nuclear R&D.

Figure 2. Summary of the major bodies for UK Nuclear R&D funding



During the financial year of interest (2022/23) there were several specific, large Government-funded multi-year programmes in flight, which provided top-down funding into the nuclear sector.

These included:

- Low Cost Nuclear Challenge (Phase 1 funding £18m November 2019 to June 2021, followed by Phase 2 funding of £210m (Government funding) plus £258m of private funding in June 2023 to end 2024) proposed by a consortium led by Rolls-Royce aimed to develop a SMR designed and manufactured in the UK, capable of producing cost-effective electricity.
- Net Zero Innovation Programme (NZIP) is a £1bn portfolio providing funding for low-carbon technologies and systems (running from 2021-2025). The Advanced Modular Reactor Research, Development and Demonstration Programme (AMR RD&D) Phase A is a £2.5m innovation programme funded from this portfolio. It aims to support the development and demonstration of High Temperature Gas-cooled Reactor (HTGR) technology in the UK by the early 2030's, in time for any potential commercial AMRs to support net zero by 2050.
- National Nuclear User Facility (NNUF) Phase 2 funding of £81m granted by EPSRC for 2019 to 2024 (including extension from COVID) as a one-off top up to incentivise development of both new nuclear facilities and to enable access by higher education establishments to nuclear facilities. This built on NNUF Phase 1 investment in 2014-2018 which developed facilities on five UK sites [3].
- As part of the £505m BEIS Energy Innovation Programme (EIP), funding was allocated to complete the Nuclear Innovation Programme (2016-2022). This included the Advanced Fuel Cycle Programme (AFCP) to connect experts across the nuclear supply chain to ensure that nuclear fuel cycle skills, technology and economy continues to advance. Coordinated by the National Nuclear Laboratory, £10m of funding was awarded to universities and organisations involved in R&D for advanced fuel programmes.
- The Nuclear Fuel Fund, a £75m fund confirmed in the net zero strategy to preserve UK capability in the front end of the nuclear fuel cycle, opened for bids in 2022.
- Funds for waste management and decommissioning activities are administered by the Nuclear Decommissioning Authority (NDA). In 2022/23 the NDA had net funding of £2700m of which approximately £120m was spent on R&D.
- The Fusion Futures Programme (FFP) represents up to £650m of new investment between 2021-2027 to support cutting-edge research programmes and facilities. This is in addition to the £826m of Government funding already invested in UK fusion technology to date.

The data collected as part of this landscape survey suggests that the total funding for nuclear R&D in the UK for 2022/2023 was around £570m[1]. This includes the flow-down of funding from the aforementioned programmes as well as private R&D investment.

The total R&D funding amount of £570m represents an increase of around 72% compared to 2018/2019 (52% increase once adjusted for inflation) where £331m was spent on nuclear R&D, and that in turn was substantially up on the 2019 figure of £66m.

An after-inflation increase in R&D spend of 52% is significant, because increased domestic inflation levels usually result in a reduction of domestic R&D investment. An increase in R&D funding during both a period of high inflation and whilst in competition with other challenges across Government, Academia, and Industry for funding post-COVID and post-BREXIT is therefore particularly significant.

R&D in the UK for 2022/2023 was around **£570m**

[1] It should be noted that whilst this landscape review is only concerned with civil nuclear R&D, some projects are indistinguishable as to whether they benefit the civil fission, fusion or defence sectors (and in reality many projects will benefit all three sectors to some extent) and hence we have omitted research that is obviously out-of-scope but have included some projects that have cross-sectoral benefits.

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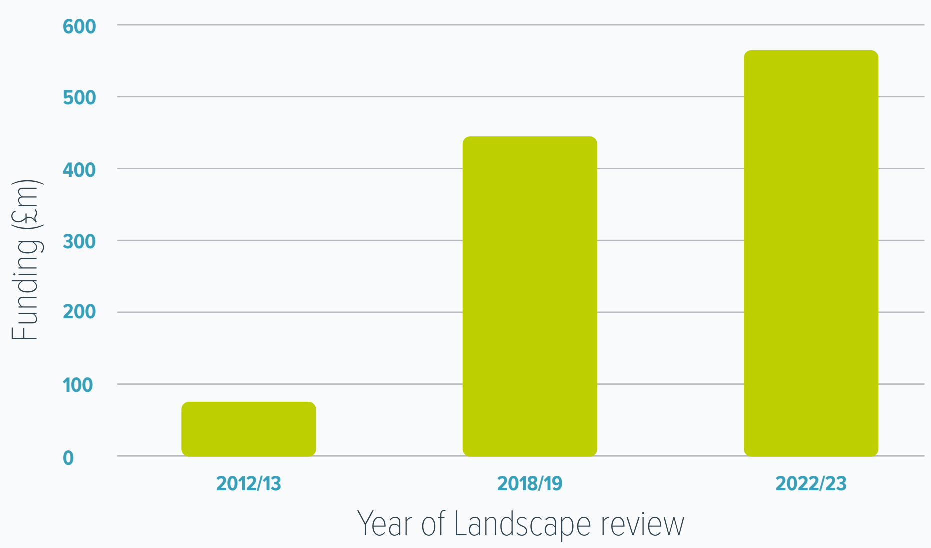
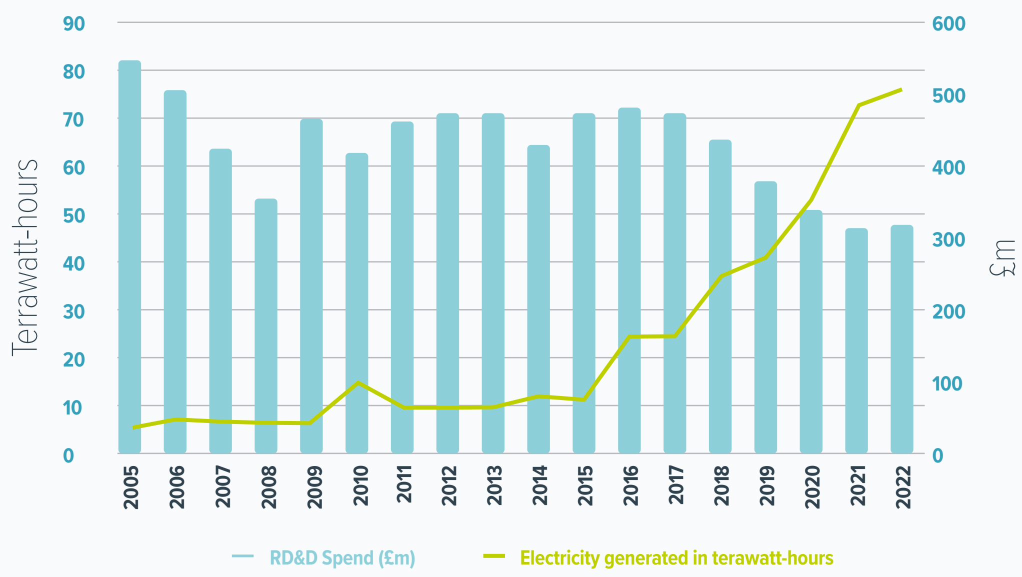
Figure 3. Total reported civil nuclear fission R&D expenditure over the course of the R&D landscape reviews *(data from previous landscape surveys adjusted for inflation to 2022 levels)*



The Organisation for Economic Cooperation and Development International Energy Agency (OECD IEA) provides data for each country's Government spend on R&D as a function of nuclear electricity generated [18]. The data for the UK has been reproduced in Figure 4. This shows the gradual increase in nuclear R&D spend from the mid-2000's, but also the decreasing amount of nuclear power generation in the UK, a result of closure of the Magnox reactors and the declining AGR fleet.

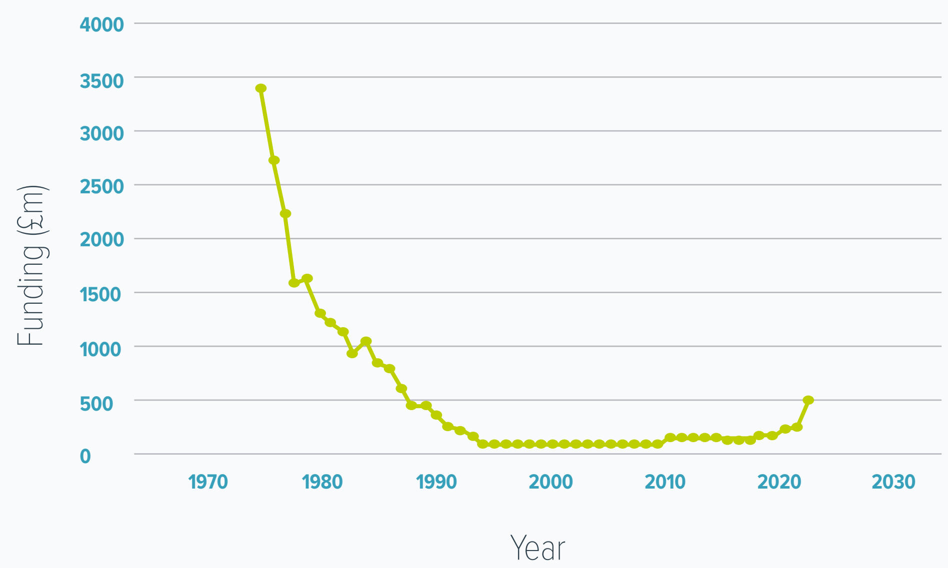
Figure 4. UK total Government spend on RD&D and nuclear electricity generated



Whilst the increase in funding for nuclear R&D reported over the last three landscape reviews is encouraging, it is also worth noting that it is occurring from a very low base line of R&D spend from the 1990's/early 2000's when funding was at an all-time low. The figure should also be put into context against the backdrop of a significant need to scale up capacity in the nuclear sector in many areas, but particularly in support of new reactor systems, an advanced fuel cycle, and disposal of new, novel waste streams in support of the development of Gen IV reactor systems, whilst also maintaining R&D into operational facilities, waste management and decommissioning.

Looking at historic data on R&D spend (Figure 5) we can see that this most recent uptick in funding is still very low compared to spending in the 1970's and 1980's. Throughout this time there were significant programmes of work in support of operating Gen II reactors, including experimental reactor programmes, reprocessing spent MOX fuel, fuel enrichment/production etc. and, to put this period into context, during this time the nuclear fleet generated approximately 25% of the UK's electricity needs, compared to today where 6.5GWe nuclear capacity provides 15% of the UK's electricity demand.

Figure 5. Total reported nuclear fission R&D spend over time (inflation corrected to 2022)



(Note historic data from 1975-2010 was sourced from archives. Details of projects included in this spend were not provided. No significant R&D was reported between 1995 and 2010, other than activities associated with waste management and decommissioning, which we believe to be underestimated during this period.)

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Looking at OECD figures from the IEA on energy technology RD&D statistics [18], we can see the UK's investment in nuclear R&D compared to other countries in Figure 6.

Figure 6. Total Government nuclear R&D spend in millions of US$ (2022 prices and exchange rates) by country

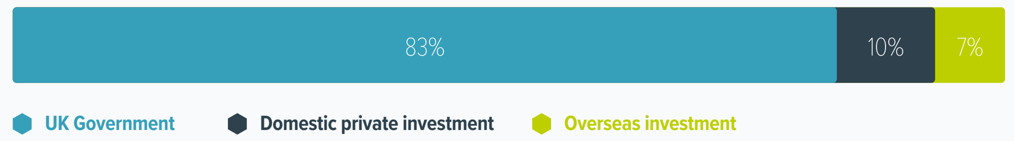
In **2022/23** UK spend on nuclear R&D was **0.03%** of GDP

In the first two decades of the millennium, UK nuclear R&D spending lagged behind comparable OECD countries. For example, in 2013 when the first landscape review was undertaken the United Kingdom ranked 9th in nuclear R&D spending in the OECD, behind Canada, Korea, Italy, Belgium, Germany, France, the United States and Japan (Figure 5). In 2022, the UK moved up five places, ranking fourth behind Japan, France, and the United States. But, by comparison, the UK ranks third by spend per GWh on nuclear R&D, behind the United States and Japan but ahead of France.

It is important to place the UK's civil nuclear research and development spending within a broader context. In 2022/23 the UK spent 0.03% of its GDP on nuclear R&D, compared to France which committed $962m to civil nuclear research and development, a similar GDP proportion to the UK (0.035%) [19]. In contrast, the US's expenditure on civil nuclear R&D in 2022 was the much larger sum of $1.78bn dollars, however this only represented 0.007% of the US's total GDP ($25.4tr) in that same year [20]. However, both the USA and France have maintained R&D spending at relatively steady levels over the past 50 years in stark contrast to the UK's intermittent funding pattern. So, whilst the UK's spending on R&D in 2022/23 is in line with other economies that have significant nuclear programmes, research funding is a leading indicator and therefore it takes a long time to feed through to delivering innovations and impacts. In addition, the inefficiencies associated with start-stop funding will have limited the impact of UK investments.

Looking at the ability for the UK Government to attract private investment into R&D we can see that during the snapshot year the vast majority of funding for nuclear R&D came from the UK Government. Only 10% of funding spent on nuclear R&D in 2022/23 came from private domestic investment and a further 7% from overseas (Figure 7). This equates to every £1 of Government investment being matched by 17p of industry funding.

Figure 7. UK spending in nuclear R&D by funding source for 2022



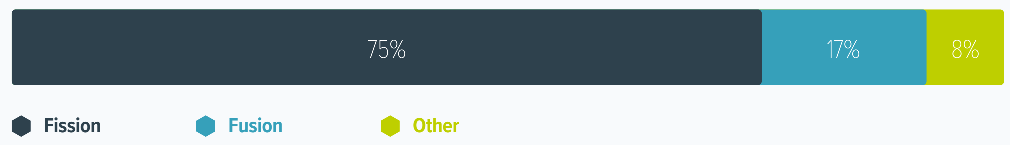
Looking further at the breakdown of R&D spend, we can see that UK Government spending on nuclear R&D has grown significantly in the last ten years. However, domestic investment has remained static since 2013. In 2018/2019, private, domestic spending was approximately £56m. In 2021/2022 it had only grown by 3% to £58m and today is £97m.

Our data shows that there has been a significant fall in the amount of overseas funding received by the UK R&D sector in recent times. In 2018/19, the UK received approximately £81m in funding from other countries. In 2021/22, this had fallen to around £41m. However, the majority of this discrepancy can be attributed to a reduction in funding for the EU JET fusion programme (which in 2018/19 accounted for £49m), the eligibility of the UK to receive European funding post BREXIT and the restrictions placed on the UK to access funding from the EU's Horizon programme.

Government investment in fusion has increased over the last three landscape surveys but remains significantly smaller than the fission sector - a reflection of its technical immaturity. In 2010 fusion funding was in the order of £33m, this increased to £48m in 2018/19 and in 2022/23 was approximately £77m.

The majority of the UK's recorded spending on nuclear R&D is therefore focused on nuclear fission. Approximately three in every four recorded pounds (75%) the UK spends on nuclear R&D is on nuclear fission, this accounts for around £331m – around the entire budget of the nuclear R&D sector in the last landscape review. Funding for nuclear fusion accounts for approximately 17% of recorded UK nuclear R&D spending. Our analysis for investment in nuclear fission and fusion does not account for all spending, as some organisations did not provide breakdowns of their research activities. We also were not provided data by all organisations who received fusion funding.

Figure 8. UK spending in nuclear R&D split by fusion and fission for 2022/23



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Given the history of funding intermittency, and the 'stop-start' approach to delivering projects, stakeholders who took part in this review are concerned that the UK is currently at the top end of a funding cycle that will slow down. Some are reassured by the Government's commitments to new nuclear endeavours that funding will continue. However, others feel that given the inflationary environment and need for funding in other priority areas it is foreseeable that nuclear R&D funding will suffer.

Some participants reported that the lack of consistency of funding and long-term planning means that publicly provided money is not being spent efficiently. This is both because money spent on skills and facilities is lost when people leave the sector, or facilities remain under-utilised (or risk being shut down) due to gaps in funding cycles as there is no continuity in programme funding. This challenge is exacerbated in the context of a decentralised sector in which private interests compete for contracts alongside universities and the National Laboratories and where there are often breaks between large multi-year research programmes.

In the context of historic data on the amount of money needed to underpin new technologies it seems implausible for the UK to have an advanced nuclear programme utilising new fuel and new reactor technologies with the existing amount of Government provided R&D funding. Quite simply, the amount of funding for nuclear R&D will need to increase if the sector is to contribute to meeting Government's net zero objectives.

This is particularly salient in the context of building AMR and SMR reactors and the need to:

- develop new fuel cycles
- have confidence in material performance in new reactors
- develop new supply chains
- deploy nuclear power in novel ways and settings
- operate new reactor systems for longer time-periods than have been licensed historically

A decrease in Government R&D funding will inevitably lead to a slow-down in the progression of new AMR technologies, loss of skills within the sector, a lack of investment in new infrastructure, and ultimately, the possibility that the 24GWe target is not met.

In summary:
Previous nuclear success has been possible through the large amounts of funding provided in the 1970's/ 80's which underpinned the AGR fleet. With the absence of continuity of funding over time momentum has been lost. We are now seeing some gains from the funding of programmes, which must continue if we are to meet the targets set by Government.

In particular, the sector will be looking at the progress of the next Phase of the AMR RD&D programme with interest as well as a new Nuclear Innovation Programme to:

a) provide cross-parliament funding for longer term projects that Advanced Reactor Technologies require
b) to provide funding for more generic, technology neutral R&D projects which benefit the wider sector's needs

Views from Responders

'We've come a long way in the last few years. 2016 was the first time there was a significant kind of spending review allocation to nuclear although there wasn't necessarily continuity of programmes.'

National Lab or Top Down Funder

'There's reason for optimism. If you go back 20 or so years, there was effectively no nuclear research programme within EPSRC. In 2001, there was one grant. It is only subsequent to that where there's been a significant upward trend.'

National Lab or Top Down Funder

'Government does not have a lot of money post pandemic and Ukraine war, and therefore funding is going to be tight. R&D is always something that, in general, you can stop in the short term with little consequence, but in the long term, it can have big impacts on strategic objectives. So, we've got to make a very strong case to keep the funding coming.'

National Lab or Top Down Funder

'The future is really uncertain at the moment. We're on really shaky ground and we're about to lose a lot of the things that we've built up over the last 5-10 years. If the money comes again in 2-3 years time it would be a case of starting from scratch again.'

Academic

4. Skills and Staffing

In total, our civil nuclear R&D landscape review in financial year 2022/23 accounts for approximately:

5405 Full-time employees

2384 Working on **fusion R&D**

3021 Working on **fission R&D**

These research staff are part of a broader nuclear workforce totalling 45,000 that are employed in the civil UK nuclear sector in 2022/23 according to the Nuclear Industry Association's Annual Jobs Map Survey 2023 [21].

This is 1686 R&D FTE's greater than the number recorded in the 2018/2019 review. When a comparative analysis of the organisations taking part between landscape reviews is conducted (Table 2), we can see changes in staffing levels over time. The increase in total FTE's in the sector in this snap-shot year is dominated by recruitment activities in industry and the national laboratories. Within the respondents from UK universities, we actually see a decrease in academic researchers since the last review was undertaken. The decrease in academic staff will inevitably have an impact upon the delivery of academic research programmes in the future as well as the ability of the university sector to supply sufficient numbers of early career researchers to the sector.

Looking at the longer-term staffing trends over the 10-year period since the first landscape review was undertaken, we can see that the sector has doubled in capacity. However, these figures must be caveated by the fact not all organisations contributed to each survey and there has been varying attrition rates between organisations over this time period, hence a direct year-on-year comparison should be viewed with some caution.

Table 2. Nuclear R&D personnel (full time equivalent) in the UK

	2011/12	2015/16	2018/19	2022/23
Industry	397	534	944	1536
National Laboratory	1260	1317	1538	2907
University	1000	1344	1237	962
Total	**2657**	**3195**	**3719**	**5405**

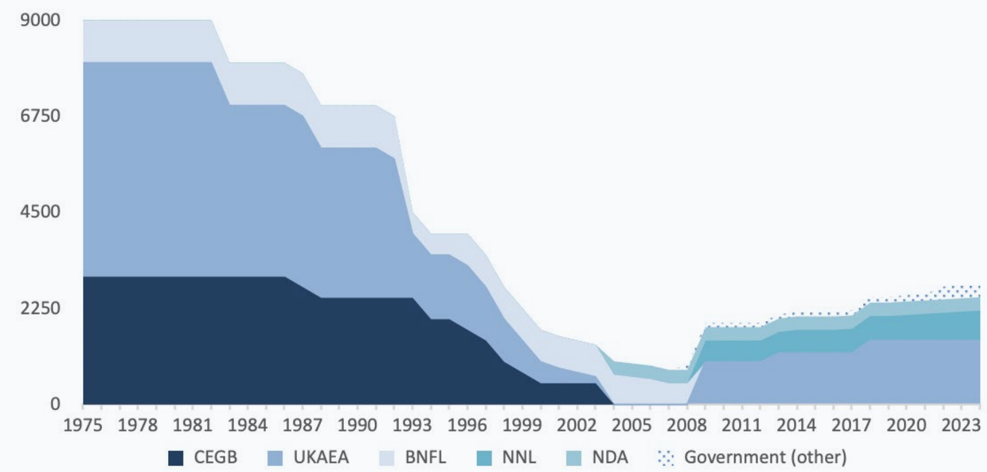
Comparing these figures to the funding data, where we report a 52% increase in funding (after adjusting for inflation) we conclude that the total (R&D staffing) capacity in the nuclear sector has not increased at the same rate as funding has and is in fact lagging behind. Assuming that respondents have not underestimated their R&D research staff numbers, the reasons for this difference may indicate higher spend on nuclear facility/ equipment investment e.g. as part of NNUF or expenditure on other non-staff costs.

The level of staffing, skills and expertise within the nuclear sector is frequently raised as a key challenge to meeting the sector's growth targets. Looking back at Government employment figures in the late 1970's/early 1980's, it is estimated 8,000 people were employed on nuclear R&D programmes in the UK (Figure 8), the predominant employers being British Nuclear Fuels Ltd (BNFL), the United Kingdom Energy Authority (UKAEA) and the Central Electricity Generating Board (CEGB).

From the 1990's to 2000's the sector was privatised and the funding for nuclear research significantly reduced such that the amount of people employed to undertake nuclear R&D declined to an all-time low of around 1,000 full-time-equivalents. The majority of these were employed on projects to support the enduring AGR/PWR operations and waste management and decommissioning activities. Since the mid-2000's when the NDA and the National Nuclear Laboratory were formed and UKAEA's focus turned to fusion, the number of Government employed R&D specialists has steadily increased[2].

Figure 9. Government employed nuclear research staff (full time equivalent) from 1975 to present

(note the period from 2000-2010 there were many changes in R&D organisations and data from this period is incomplete.)



[2] Whilst the supply chain has grown to over 200 companies in the last 10 years, very few of these organisations directly employ staff to undertake R&D, and many do not classify their core activity as R&D work, so the figures in this landscape review may under-estimate the number of R&D staff employed by industry.

Our data shows that over 962 people are employed in the nuclear academic sector in 2022/23, within which there are 334 PhD students.

59 in fusion

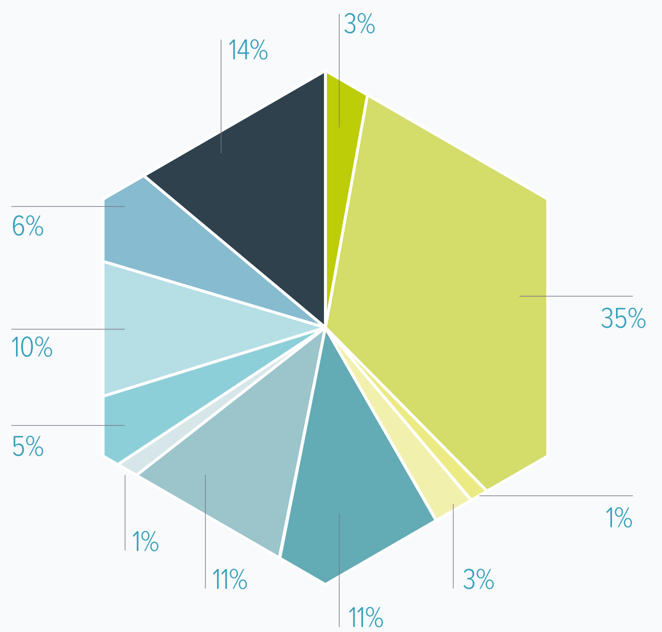
271 working on nuclear fission related topics

4 in medical isotope production

This is approximately half the number of nuclear PhD students recorded in 2015/16. There are 140 post-doctoral researchers, 33 researchers with less than 5 years of experience, 92 with between 5-15 years experience and 97 who have over 15 years of experience who are deemed to be Subject Matter Experts.

Figure 10 below shows the discipline breakdown of all researchers involved in nuclear academic research in the UK against their broad research areas. Unsurprisingly the largest area is research associated with cross-cutting activities, which include diverse topics, for example advanced computational methods, digitalisation and modelling, neutronics, nuclear data, safety, security, safeguards, social studies, public engagement, regulatory, economic assessments etc.

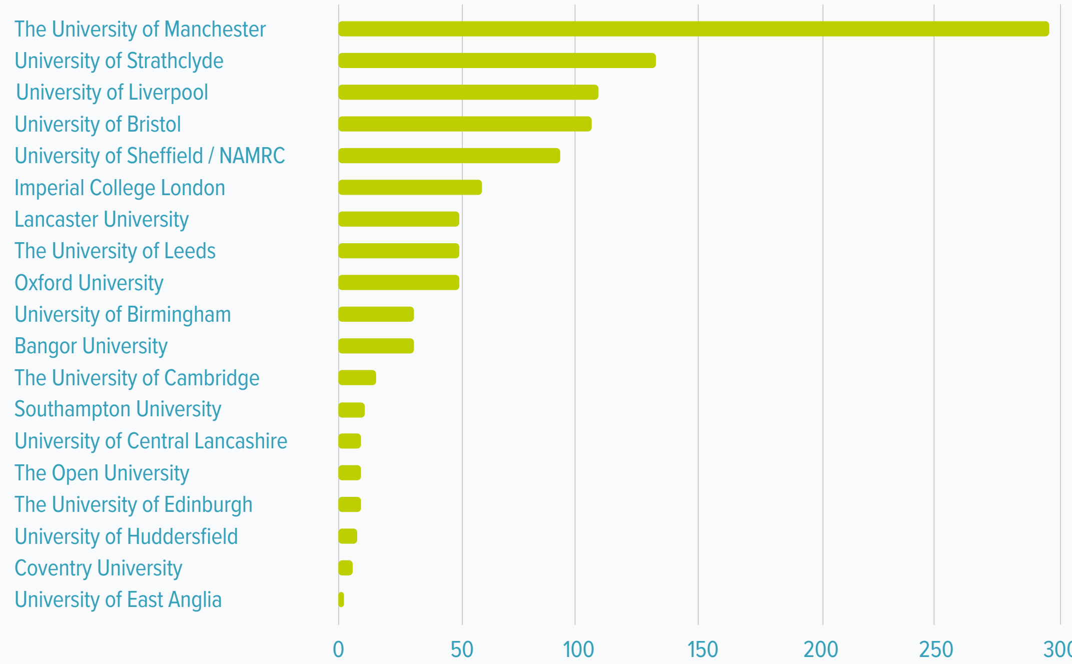
Figure 10. Breakdown by discipline area of the total number of FTE's involved in academic nuclear R&D in 2022/23



Many participants in this review acknowledge that the UK has exceptional researcher capability with deep subject matter expertise across the nuclear fuel cycle. They also recognise the organisations and funding routes that facilitate the building of this expertise as vital to the future of the nuclear sector. This includes world-leading universities, post-graduate and post-doctoral sponsorships and the integrated collaboration between academia and industry that enables cutting edge research to be turned into practical applications.

Comparing the distribution of academic research staff between this study and previous years we can see a slight shift in the distribution of expertise across core academic centres of nuclear research[3]. Whilst The University of Manchester has always dominated the landscape as a centre with both a high number of nuclear academics and significant research capability, a number of other universities have also grown their nuclear academic standing. In 2018/19 the top three Universities for nuclear research were Manchester, Sheffield and Imperial. In this review the top three are Manchester, Strathclyde and Liverpool, with Bristol closely following. This change in university standing is also confirmed by other measures of impact such as the number of journal publications that each institution publishes per annum and their leverage/ gearing.

Figure 11. Total number of researchers (FTE) undertaking nuclear R&D at UK universities
(figures include academics, post-docs and PhD students)



From an industry and national laboratory perspective the breakdown of skills across discipline areas is quite different to academia, as shown in Figure 12. Fission research accounts for 58% of the industrial/ national laboratory R&D workforce, with the largest number of researchers working on the existing nuclear fleet's reactor systems (and then waste management/decommissioning and cross-cutting technologies). 42% of the total R&D workforce are engaged in activities to support nuclear fusion, which is a modest increase from 2018/19, largely due to an increase in recruitment by UKAEA. Responders to this survey identified 685 Subject Matter Experts, with over 15 years of experience, within the total R&D community.

[3] A small number of universities that had provided data in the previous reviews did not contribute to this review and therefore have been omitted. However, two of these universities did receive grant funding to undertake nuclear R&D within the snap-shot time period and anecdotally we know they have significant R&D capability.

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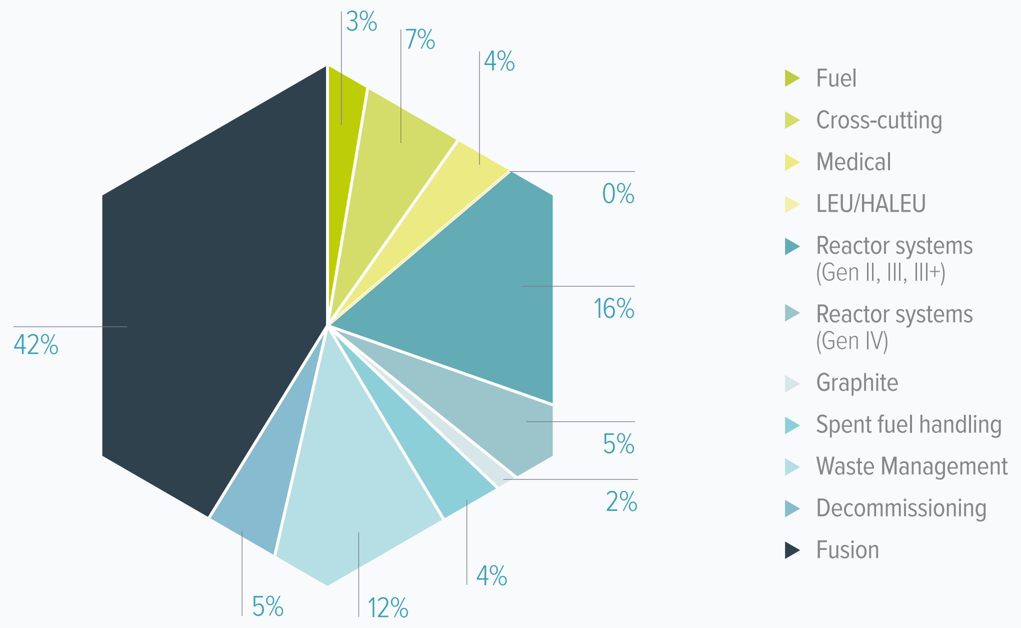
Figure 12.Breakdown by discipline area of the total number of FTE's involved in industry and national laboratory R&D in 2020/23



Within our focus groups, stakeholders described the system that turns students and early career researchers into UK future nuclear subject matter experts as:

> "a complex and interconnected eco-system that requires the careful development of specialist skills and expertise"

They stressed that the skills and expertise are developed over long time periods, frequently decades, with expert entrants to the sector often completing a 3 or 4 year doctoral qualification after a bachelor's and/or master's degree.

They emphasised the extent to which the post-graduate market is currently becoming less attractive, noting that students are more likely to go directly into industry having completed an apprenticeship or a university degree (than continue in post-graduate education) as the stipend for PhDs is now significantly lower than the starting salaries for apprentices[4].

Indeed, many academic institutions reported a much smaller number of applicants to study a nuclear PhD in 2022 compared to 10-20 years ago. They link this to an increasingly competitive market landscape, historic under-investment in the sector, as well as the pay/stipend levels for PhD students not being comparable to graduate salaries, even taking into account that stipends are tax-free.

More generally, many stakeholders across both academia and industry have concerns about how appealing the nuclear sector is to prospective employees. Many are aware of wider challenges in attracting people into STEM careers, and then into the nuclear sector when there is competition from other sectors including other forms of renewable energy and at a time when there are substantial nuclear programmes in many other countries (USA, China, for example) which are progressing at pace.

Looking at the qualitative responses to the landscape review, the top concern after funding was the level of staffing capacity within the nuclear R&D sector.

Points related to this include:

Generational change

COVID 19 and changes to pensions have been suggested as stimuli for people to retire early, and there is a consensus that a whole new generation of researchers is needed to replace those that are close to retirement age, but that the rate of Early Careers recruitment cannot be matched by sufficient knowledge transfer and mentoring programmes.

Meeting future needs

Given under-investment in nuclear R&D capacity over the last 20 years, there may be challenges in meeting demands for skills, particularly in the context of the need to increase capacity in areas where subject matter expertise is required or in areas where a change in policy may require maintaining skills in core areas (e.g. fuel reprocessing).

Recognising that there was a significant decline in research staff over time and very little recruitment/development of early career specialists twenty years ago, the R&D sector has a bimodal age profile within the current workforce. The recent up-tick in early career researchers should help to change the age profile, but this is likely to take many years and there is a concern that, as the current generation of SMEs retire, there will be insufficient mid-career specialists to take over.

Supply-side challenges in academia

Reductions in sponsorship for nuclear PhDs and the reduction of funding for nuclear Centres for Doctoral Training (CDTs) mean that the pipeline of nuclear researchers that can enter the sector in the future will be more limited. Changes to the student loan programmes and stipends for PhD students also make the higher education sector beyond first degree more challenging.

Demand-side challenges in academia

Challenges in encouraging students to enter STEM subjects which could lead to a nuclear research career, plus competition from subjects like artificial intelligence and nuclear fusion may present further risks to nuclear fission academic recruitment.

Many stakeholders are concerned that in the coming years, a significant number of people in the nuclear R&D sector, as well as the wider sector, will retire, leading to a loss of expert knowledge and key technical skills.

The Nuclear Workforce Assessment 2023 [2] provides a comprehensive forecast of skills supply and demand across the nuclear sector. It found that the nuclear workforce is predominantly male, and 10% of the current workforce is aged over 60. The 2021 assessment found that 'even in the absence of a civil new build programme, a substantial replacement demand exists, partially driven by an aging workforce' [22]. This sentiment is echoed by a number of stakeholders spoken to as part of this review, who also recognise the challenge of increasing nuclear capacity in the coming years.

The Nuclear Workforce Assessment [2] modelled three scenarios for increasing nuclear power output, in order to explore the capacity needed in the sector. To meet the staffing demands related to increasing nuclear capacity, the report found that it will need between around 150,000 and 180,000 skilled persons within the nuclear energy and defence sectors by 2043 for a 24GWe scenario.

[4] The PhD stipend in 2022/23 was £17,668 and is tax-free. The average UK STEM apprentice salary in the same year was £19,740 per year and the average graduate starting salary in the same year was £25,911 (in the nuclear sector the graduate salary average was £28,000).

This means increasing capacity across the broader sector between

80% and 120%, over and above replacing those that retire.

The same report predicted that **40,000** new jobs will be created by 2030, doubling the sector's current rate of recruitment.

On PhDs, there is a strong argument for the need to quadruple the number of specialist science and engineering PhDs to ensure that we have sufficient SME's in the UK defence and civil nuclear sector.

The report highlights that securing the supply of these high-level skills will play a major role in enabling technical delivery of our nuclear programmes and ensuring that the UK remains a world leader in nuclear capability.

Increasing the capacity of the nuclear R&D sector is seen as a particular challenge in the context of questions over funding for CDTs, and the level of funding for academia in coming years. CDTs provide comprehensive training for doctoral students and their alignment to industry helps to provide an entry route into the sector directly aligned to known skills shortage.

During the snapshot year there were two nuclear fission CDTs: Growing Skills for Reliable Economic Energy from Nuclear (GREEN) and Nuclear Energy Futures, both with intakes from 2019-2023, supporting a total of 124 students.

Of those CDT students that graduated in 2022/23 over

70% gained employment in the nuclear sector of which 52% entered an industrial organisation and 45% stayed in academia

However, going forwards it is highly likely there will only be one nuclear fission CDT administered through the Engineering and Physical Sciences Research Council (EPSRC). Removing/ reducing funding for nuclear CDTs in the context of increasing demand for capability in the sector will have a significant impact on nuclear capacity.

The nuclear skills challenge is not unique to the UK, with many other nuclear nations facing similar. To address such issues, the Nuclear Energy Agency (NEA) developed the Nuclear Education, Skills and Technology (NEST) Framework in 2019 to help fill important gaps in nuclear skills capacity building, knowledge transfer and technical innovation in an international context. Implemented through projects in specific topics relevant to the nuclear sector, it offers young nuclear professionals, NEST Fellows, a chance to develop skills and acquire practical experience under the supervision of mentors at leading organisations. It benefits NEA member countries (that join NEST through a specific mechanism for which the UK is not currently a member), by establishing links and networks between universities and industries, research organisations and regulators. These interrelationships, in turn, aim to strengthen university education programmes. Academic institutions play an important role by nurturing the next generation of nuclear leaders and professionals, thus developing the talent pipeline necessary for the sustainability of the nuclear sector.

Nevertheless, the NEA has had little direct engagement with academic institutions that are responsible for developing the next generation of nuclear science and technology experts. To address these gaps, the NEA established, in January 2021, the Global Forum on Nuclear Education, Science, Technology and Policy, an inclusive network of experts from academia who are well-suited through their expertise and knowledge to provide solutions to the complex and emerging issues and challenges that affect the nuclear energy sector, particularly with regard to human resources development.

Responders to this survey, provided a number of suggestions as to how the UK could increase resource capacity.

These include:

- Enabling more experienced workers who are approaching retirement to engage with knowledge management/ succession planning activities. Many feel that the sector needs a specific approach to knowledge management and succession planning, recognising the importance of passing on first-hand experience and expertise to younger researchers
- Enabling new routes for specialists to enter the nuclear industry. Given the length of time the standard academic PhD route takes, there is appetite among some to grow alternative pipelines to the standard academic PhD. These included apprenticeships and training experienced hires in similar sectors on nuclear subject matter
- Providing "salary top-up" to PhD stipends. Given there is a discrepancy between PhD "take-home" pay and graduate salary, top-up funding should be provided to PhD students for the duration of their research to ensure they aren't disadvantaged by continuing their education and to support the increased cost of living

Many respondents to the landscape review want industry and academia to work more closely together. Whilst it is widely acknowledged that there are good links between industry and academia, many believe that it is possible and necessary to do more to provide a greater number of skilled people to consider a career in nuclear.

This is the case both to increase the number of people entering the nuclear sector and to help ensure that those that entered the sector have the skills needed for the future. Many welcome the opportunity for academic teaching to be supported by industry and wish for students at all levels to have a greater awareness of the opportunities the nuclear sector offers.

Often, questions of how to increase capacity in the nuclear R&D sector link back to the wider perceived need for a long-term strategy. This is the case both in terms of the need for funding to support a consistent approach to developing skills, but also in terms of understanding which skills will be needed in the development of new energy systems.

Stakeholders point out that, in the absence of an understanding of which type of reactor will be used to meet the 24GWe target, it is challenging to understand what skills will be needed in the coming years and exactly how many people will be needed in each broad discipline area.

Views from Responders

'Retirement is an issue, twenty years ago the nuclear industry was in decline and had a recruitment pause, so we're becoming increasingly short of mid-career scientists and engineers.'

National Lab or Top Down Funder

'[We have] an ageing demographic close to retirement who are experts in particular subject matters that need replenishing. There's a lot of talk but no significant industry driver to replenish those SME's at present.'

National Lab or Top Down Funder

'National objectives are to increase [human] capacity and then in the last 12 month period, we reduce the number of nuclear related CDTs. Exactly at the same time that everyone is screaming, 'there's a skills crisis' - so there's a disconnect that needs to be addressed.'

National Lab or Top Down Funder

'We did try to trailblaze a level 8 apprentice programme, to balance the education profile and increase the qualification routes available. The theory being if we can attract candidates when they are 15-16 years old, train them through a normal apprentice route, make them experts in one particular area in the nuclear industry and award them their doctoral qualification upon completion then we would increase higher-level skills capacity. But Government refused on principle to this idea and categorically refused to fund even a pilot. Its unfair to say industry hasn't tried to be creative in recruitment and training, it has. It has just been met with many, many hurdles.'

Industry

'There's an issue with the university sector becoming too small, with insufficient numbers of academics to train early career researchers. It's a negative spiral. There's fewer academics teaching fewer courses, so there's fewer students, so there's fewer academics teaching fewer courses and so on... our pipeline just gets smaller and smaller and smaller.'

Academic

'Industry needs to put more effort into coming into universities and saying, 'these are the problems we're working on'. Universities also need to put more effort in by having some sort of liaison officers who can interact with industry and encourage them to come in and give presentations.'

Academic

'We don't want to lose people to banking and other industries. Nuclear Scientists and Engineers need to get paid the same as other high-skilled job roles. You look at the starting salaries in legal, finance and other highly regulated professions and compare to the salaries scientists and engineers achieve and you think, 'what would I do? Do I really want to pursues a science career?'

Academic

'One of the things we may have to face is how do we keep the retiring workforce engaged part time? We've got to train lots of people, we can't have the people that we've got left doing the doing and doing the training. We need to be creative, we need some flexibility in our workforce.'

National Lab or Top Down Funder

'So, when a student wants to get a job at the end of [a PhD], some years there's over 50 jobs across the nuclear sector, some years there's like twenty or none that year because the sector is in a hiring freeze. We need a strategy there for jobs, post-education to make sure that skills pipeline unclogs.'

Academic

In summary:

The UK has world-class universities, academic and industry researchers who have pioneered the progression of knowledge and understanding in many areas of nuclear science. However, the number of current researchers in the UK is not enough to sustain the amount of research needed to underpin future nuclear ambitions. Reductions in funding and attractiveness of the sector are all barriers to recruiting new early career researchers into the sector. Providing more and different opportunities to access a STEM research career will be key to ensuring the workforce is sufficiently staffed going forwards.

5. Facilities

The UK has a number of world leading research facilities and laboratories for nuclear R&D. These include (but are not limited to) the Advanced Manufacturing Research Centre (AMRC)[5], Dalton Nuclear Institute, the National Nuclear Laboratory's facilities (at Windscale, Sellafield and Springfields), Harwell Campus facilities as well as the facilities operated by universities that are included in the National Nuclear User Facilities (NNUF) catalogue [3] and those operated by private sector organisations such as Jacobs.

NNUF nuclear R&D facilities

In 2019, the UK Government awarded £80m to be managed by EPSRC to create national facilities, accessible by UK Higher Education Institutions and National Lab based researchers alike. This programme was called the National Nuclear User Facilities (NNUF).

Reviews of the UK nuclear Research and Development (R&D) Landscape in 2011, 2013, and 2017 had identified the need for growing a pool of UK researchers to access cutting edge equipment to study radioactive samples and that the need would be best met though a coordinated programme. The purpose of NNUF was to pool plans, resources, and identification of research needs, and to provide access across the nuclear sector and academia. NNUF was needed as both academic organisations and National Labs struggled to invest in new equipment with high operational and maintenance costs, limiting the ambition of nuclear materials research.

This resulted in an underinvestment in research using radioactive materials and a reduced number of individuals who were trained and competent to undertake nuclear R&D activities. Organisations came together to form groups to propose facilities, tools, and project hubs, and continue to work together to develop experimental and analytical projects through this funding route.

£80m of new equipment allowing cutting edge research and development has been installed. These facilities support staff, provide training within active facilities and enable nuclear research covering the following areas:

- Underpinning science
- Nuclear Fuel
- Advanced Modular Reactors
- Life Extension
- Materials Degradation
- Fusion
- Radioisotopes
- Environmental
- Small Modular Reactors
- Robotics in harsh environments
- Legacy disposal / waste
- Irradiation of Materials

30 Facilities are involved in the NNUF network across universities, the UK Atomic Energy Authority, the National Nuclear Laboratory and Diamond Light Source

7.5 Million was made available to qualifying researchers to train or be shown how to use the facilities developed during NNUF 2 as they came online

12 Universities house a NNUF facility or equipment

30 Individual projects received investment from the 2019 funding (NNUF 2) round which concluded in March 2024

160 'Scopus' publications have acknowledged support from NNUF, which have been cited 932 times

88 Participants from 35 different organisations have been involved in the project over its lifetime

[5] Since this document was finalised the future of NAMRC looks uncertain.

This review found that during 2022/23 UK researchers accessed more than 75 facilities in the UK and 50 facilities internationally, including research, reactors, accelerators, and disposal facilities

The UK also continues to invest in key facilities
For example, RAICo1, a new robotics hub developed by the UKAEA, NDA and the University of Manchester; The Dalton Cumbrian Facility, which is now incorporated within the NNUF and provides experimental infrastructure and expertise in radiation science, The Henry Royce Institute; a UK national centre for research and innovation in advanced materials, and Jacobs High Temperature Facility, located in Warrington, which is also now part of NNUF.

In early 2023, Jacobs was awarded funding by the UKAEA's Fusion Industry Programme to develop a Liquid Lithium Testing facility, which has some linkages to the fission sector. In addition to domestic facilities, the UK also has access to international facilities.

This review found that during 2022/23 UK researchers accessed more than 75 facilities in the UK and 50 facilities internationally, including research reactors, accelerators, and disposal facilities to undertake UK-funded research activities (more details can be found in the Appendix).

Within the respondents to this landscape survey there was disagreement about the current position of UK nuclear facilities. Some feel that the UK is in a good position, with the range of facilities available, particularly given size of the country. Others state that, if the sector is to improve its capacity through use of new technologies and innovation investment in new facilities, upgrades of existing facilities such as active handling capability is necessary.

Three factors contribute to the disagreement amongst participants of this review about the state of the UK's R&D nuclear facilities.

Decentralised approach means any investment must deliver value for money
Some stakeholders consider the state of UK facilities from the sole perspective of conducting R&D activities focused on new innovative technologies and say more facilities are needed for this purpose. However, others consider the wider need to ensure that any new facilities can be sustainably run (from a usage and financial perspective), and that therefore building new facilities also comes with risks. Individuals who share the latter viewpoint were more likely to be satisfied with the existing infrastructure, as they do not consider the risk of building facilities that may not be fully utilised to be worth the financial investment required.

Innovative sector but with no central focus means there is limited alignment on the facilities needed
When asked what type of facilities are needed in the UK, a broad range of facilities were mentioned (see Appendix for more detail). Whilst there was some consensus on a handful of facility types, it is likely that any reasonable infrastructure investment in facilities could not satisfy the requirements of the whole R&D community. Moreover, the responses were very much skewed to the individual's area of interest.

UK organisations can access international facilities
Linked to the previous point, the UK R&D research community access a large range of different facilities in Europe and North America as well as, less frequently, other countries in order to undertake their research (Figure 13). It is therefore unlikely that the UK could or would wish to replicate all the facilities currently being accessed internationally. However, there was repeated feedback that transporting radioactive samples overseas is problematic and that the research takes much longer and costs much more. Whilst there was not a strong agreement on the types of facilities researchers would like in the UK, there was unity across responders in the requirement for facilities to allow Early Career researchers to train and learn active skills. Many researchers described how the lack of a research or test reactor means that the opportunities to train and develop new entrants to the sector is limited. While the UK has had several of these kinds of facilities in the past, they have all now been decommissioned. Given the UK's need to increase its nuclear power capacity and staff training needs, the lack of this type of facility is seen as a real draw-back for the UK.

Continuing access to research facilities through the National Nuclear User Facility (NNUF), is also stressed as important. The NNUF is a Government-funded initiative that supports researchers to access nuclear facilities across the UK. It is funded by EPSRC and DESNZ, and has facilities for irradiation, high performance computing, materials testing and hot cells for handling and examining radioactive materials. When asked which facilities the nuclear community needed access to, respondents to this review repeatedly mentioned facilities accessible through NNUF. These included test facilities or rigs; places where specific conditions can be replicated for the purpose of experimentation.

These facilities are needed to test and qualify the materials, components, structures, and systems that are required for new reactors. However, concern was raised that NNUF was not funded beyond March 2024, so the UK may have facilities, but accessing them and maintaining them could become more challenging in the future.

Some stakeholders report that in the context of a decentralised sector, a strategic decision on the approach to developing wider nuclear infrastructure is needed. They feel that it is only once that decision has been made that the UK can invest in the R&D facilities needed and direct the research required. Otherwise, it is likely to be challenging to develop a business case to justify the level of investment needed.

Facilities, Equipment and Capabilities within the UK

Figure 13. Facilities, Equipment and Capabilities within the UK

Illustration of how the Facilities, Equipment and Capabilities are spread out across the UK demonstrating how nuclear fission R&D is being undertaken across the length and breadth of our shores.

Facility:

Active Nano Mapping Facility
University of Bristol
- Bristol

ADRIANA
Lancaster University/
University of Liverpool/ UKAEA CCFE
- Lancaster/ Liverpool/ Abingdon

BUFF
Bangor University
- Bangor

Centre for Radiochemistry Research
University of Manchester
- Manchester

Dalton Cumbrian Facility
University of Manchester
- West Cumbria

Diamond Active Materials Laboratory
Diamond Light Source
- Didcot

EXACT
University of Southampton
- Southampton

FaRMS
University of Bristol
- Bristol

HADES
University of Sheffield
- Sheffield

High Flux Accelerator-Driven Neutron Facility
University of Birmingham
- Birmingham

High Temperature Facility
Jacobs
- Warrington

Hot Robotics Facility, RACE
University of Manchester/ Bristol/NNL/UKAEA
- Bristol/ Manchester/ Workington/ Oxfordshire

Lancaster Accelerator Mass Spectrometer (LAMS-UK)
Lancaster University
- Lancaster

Materials Research Facility
UKAEA
- Culham

Molten Salts in Nuclear Technology Laboratory
University of Manchester
- West Cumbria

MULTIForm
University of Leeds
- Leeds

National Nuclear Laboratory
NNL
- West Cumbria/ Preston/ Workington

Nuclear Materials Atom Probe (NuMAP)
University of Oxford
- Oxford

PANAMA
University of Strathclyde
- Glasgow

PLEIADES
University of Sheffield
- Sheffield

Pyrochemical Research Laboratory
University of Edinburgh
- Edinburgh

RADER
University of Manchester
- Manchester

SIMFUEL and Alphas active material manufacturing and characterisation facility
University of Manchester
- Manchester

UTGARD Laboratory
Lancaster University
- Lancaster

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International facilities accessed by UK researchers

Canada
CNL Research Test Reactors
Waterloo University, Ontario Other

USA
ATR at Idaho National Lab Research Test Reactors
Oak Ridge National Laboratory Research Test Reactors
MIT Reactor Research Test Reactors
National Science User Facilities Material Testing Facilities
Pacific Northwest National Laboratory Material Testing Facilities
Brookhaven National Laboratory Material Testing Facilities
Sandia National Laboratories Material Testing Facilities
Los Alamos National Laboratory Material Testing Facilities
Oak Ridge National Laboratory Material Testing Facilities
Westinghouse Hot Cell Facility and Labs Material Testing Facilities
MIT laboratories for corrosion Qualification Facilities
Molecular Foundry - Lawrence Berkeley National Laboratory Qualification Facilities
Thermal Treatment VSL Test Facilities
University of Virginia thermal conductivity mapping Test Facilities
University of Michigan in-situ irradiation Test Facilities
National Institute of Standards and Technology (For development of Carbon-14 laser spectroscopy) Other
US National Laboratories (Princeton, Sandia, Los Alamos) Other
University of Illinois Other

Belgium
JRC Other

Czechia
LVR-15 (part of the FIDES European program) Research Test Reactors
CVR Czechia (supercritical-CO2 testing) Material Testing Facilities

Finland
Onkalo Material Testing Facilities
VTT Other
VTT (ICME modelling) Other

France
ILL Grenoble Research Test Reactors
Bure URL Material Testing Facilities
Melox Qualification Facilities
CEA Other
GANIL Grand Accélérateur National d'Ions Lourds Other
IRSN (Institute for Radiological Protection and Nuclear Safety) Other

Germany
University of Bayreuth (creep testing) Material Testing Facilities
DESY Other

Romania
Accelerator facilities at IFIN-HH Other

Slovenia
Jozef Stefan Institute Triga Reactor Research Test Reactors

Spain
CIEMAT Madrid (Small punch testing) Material Testing Facilities

Sweden
Aspo URL Material Testing Facilities
Studsvik Hot Cells Material Testing Facilities

Switzerland
Mont Terri Underground Research Laboratory (URL) Material Testing Facilities
Grimsel Test Site Material Testing Facilities
University of Bern Material Testing Facilities
PSI Other
CERN Other

Japan
Japan Atomic Energy Authority Facilities Material Testing Facilities
4D-STEM + analysis, J-PARC Diffraction proton accelerator Other

Australia
ANSTO Research Test Reactors
HIPing Facility at ANSTO Test Facilities
ANSTO Neutron irradiation Test Facilities
University of New South Wales Other

Views from Responders

'We don't have a [research] reactor and hence we don't have the ability to irradiate new materials. We've got a wonderful materials research community in the UK. But we have no ability to assess ourselves how they actually perform inside a reactor.'

Academic

'A research reactor is one of the big ticket items the UK so desperately needs.'

National Lab or Top Down Funder

'We have got lots of advanced material and engineering challenges facing the sector over the next few decades but there's just not a full suite of facilities that exist in the UK to carry out all the research needed. If you look to the French model, it's very different. France does everything in-house and its research programme is half a billion Euros.'

Industry

'The UK needs to be smarter in its approach to developing and using research facilities. The NNUF model was an excellent example of opening the doors to allow researchers from across institutions in to do important work. We need to continue and grow this model to maximise its cost-effectiveness.'

Academic

'We have put a lot of money into facilities in the last three to five years. The real question we have now is how are they going to be used? What's the research that's going to be done in them? What's the impact of that research? and how will the facilities be sustained in the future?'

National Lab or Top Down Funder

In summary:
NNUF funding has clearly had a significant positive impact on the R&D Landscape. Funding should be re-established/ re-confirmed to support higher education access to the NNUF facilities over longer time frames aligned to specific R&D programmes.

Whilst the UK has a large number of facilities where nuclear R&D is undertaken, many of these are now ageing and are not fit for advanced research.

UK researchers access a vast number of facilities overseas. Access arrangements to these facilities vary from country to country and in some cases, there are long wait times before researchers are granted access. In some cases, UK researchers would benefit from Government negotiating long- term access arrangements to ensure UK research programmes are not compromised.

The UK was a world leader in research and materials testing using small reactors. The UK has decommissioned all of its civil research and materials testing reactors. The survey revealed significant general interest in re-developing capability in both research, training and materials testing reactors in the UK, which would not only help the progression of scientific and engineering knowledge but would also act as a training facility to develop the next generation of scientists and engineers. Such developments would require strategic decision making and coordination so that the purpose and functionality of any such reactor was clearly defined.

6. Collaboration

Effective collaboration is essential to the success of the UK nuclear R&D sector. There is evidence gathered in this landscape review of extensive collaboration within the nuclear sector, as well as collaboration with Europe, America, and the rest of the world. In the UK, several platforms and organisations exist for the purpose of collaboration, for example:

National Nuclear User Facility (NNUF)
As previously mentioned, this is an initiative that allows researchers to access specific facilities in the UK to undertake nuclear R&D. Funding ended in March 2024, but is in the process of being negotiated further.

Centre for Doctoral Training (CDTs)
Funded through UKRI, CDTs are a platform through which industry and academia collaborate to produce post-graduate training programmes for the nuclear sector.

National Nuclear Laboratory (NNL)
Owned by UK Government Investments (UKGI), NNL's purpose is to support the UK to deliver environmentally and financially affordable solutions within four focus areas; Clean Energy, Environmental Restoration, Health and Nuclear Medicine and Non-Proliferation. Being owned by Government it is capable of convening UK R&D capability to deliver national missions, an example of which was the Advanced Fuel Cycle Programme (AFCP), which was part of the wider NIP programme mentioned earlier.

Advanced Manufacturing Research Centre (AMRC), Manufacturing Technology Centre (MTC) and Factory 2050
Part of the Catapult Network, these organisations are a collaboration of academic and industry partners. They are focused on research and development for advanced manufacturing technologies supporting new innovative technologies and modularisation of component parts.

UK Atomic Energy Authority (UKAEA)
An executive non-departmental public body, sponsored by DESNZ, UKAEA undertakes research into fusion and related technologies. UKAEA hosts the Joint European Torus (JET) programme, a Materials Research Facility (MRF) and Remote Applications in Challenging Environments (RACE) facilities and is embarking on designing a nuclear fusion power station - The Spherical Tokamak for Energy Production (STEP). There are many areas of overlap between fission and fusion, not just in people and skills but in technical areas such as helium, thermal hydraulics, high heat load/high neutron load materials, AI, robotics, decommissioning etc.

Nuclear Innovation Research Advisory Board (NIRAB)
NIRAB, continues to provide a forum to aid coordination across public and private sector research. NIRAB publishes its findings openly on its website www.nirab.org.uk.

Internationally since the last landscape review was undertaken the UK has forged stronger links with the Nuclear Energy Agency, coordinated through DESNZ and the Generation IV International Forum. There have also been a large number of new bilateral cooperation agreements between key nations.

Many in the sector who participated in this review feel that more collaboration is needed across the UK. This is particularly the case as some see the UK's sector as fragmented, with different organisations pursuing different objectives. Whilst it is acknowledged that there is collaboration, some call for a platform for broader partnerships across the sector, rather than collaboration focused on a specific issue or area is needed. There was unanimous support for better knowledge management, knowledge transfer between organisations and more awareness of historic nuclear R&D programmes, which many acknowledge as being key to accelerating research especially on topics such as coated particle fuel and high-temperature gas reactor experimentation.

There was a recurring theme amongst participants for there to be either a central repository/archive for historic data that is easily accessible or at least a single place to sign-post where and how researchers can access historic R&D outcomes.

In looking for an organisation to lead on developing collaboration across the sector, some responders turn to Government organisations such as the National Laboratories or more recently Great British Nuclear (GBN) to take the lead.

However, there was significant ambiguity from responders across organisation types in the role that both of these organisations have within the sector. The role of both organisations should be clearly defined. Some see the need for a more all-encompassing National Laboratory positioning between academia, industry and as part of Government as giving it a unique role in organising the collaboration activities of the sector. But there is wide-scale acknowledgement that it is not enabled to do such activities at the moment.

Similarly, there is ambiguity around the legal responsibilities and role of GBN in enabling new reactor designers, developers and operators to invest efforts in the UK nuclear market and whether it has the overarching responsibility to define the nuclear technology mix of the future, or whether its sole responsibility is administering the SMR competition.

There are also several international platforms through which the UK collaborates with countries across the world including, but not limited to:

International Atomic Energy Agency (IAEA)
The IAEA is an organisation within the United Nations family, which is the centre for cooperation in the nuclear field. It works to promote the safe, secure, and peaceful use of nuclear across the globe.

Nuclear Energy Agency (NEA)
NEA is part of the OECD and is an intergovernmental agency that promotes cross-country cooperation on safety, technology, science, environment and law. The Halden research project through NEA has been a major benefit to the UK over the years.

Generation IV International Forum (GIF)
The GIF is a cooperative international forum aimed at conducting the research needed for the creation of fourth generation nuclear systems. Its aim is to make IV Generation Reactors available by 2030. The UK is only a member of two out of six systems agreements for VHTR and SFR. Currently, organisations commit their time for free to this platform.

Bilateral Agreements
The UK is also part of a number of bilateral agreements. For example, in March 2023, the UK and France entered into an agreement to support greater energy security. This included the potential to support an increase in the UK's interconnection with France by two thirds.

European Organisation for Nuclear Research (CERN)
CERN is a world leading particle physics research facility. As a founding member, the UK continues to play a prominent role at CERN, with a significant amount of UK research conducted at the facility each year. There is a small but important cross-over in nuclear physics and nuclear engineering.

European Collaborations
Horizon Europe is the European Union's key funding programme for research and innovation, although nuclear R&D runs separately through Euratom. In September 2023, the UK re-joined Horizon through a bespoke new agreement with the EU, meaning that researchers can apply for grants and bid to take part in projects under the Horizon programme [23].

Some within the UK R&D sector say that access to Horizon funding continues to be a challenge. In the survey year the UK was still outside the Euratom programme, through which the majority of nuclear R&D funding flows [24].

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Views from Responders

> 'Funding and delivery are both fragmented, so part of the difficulty is having that holistic picture where there's adequate coordination.'
>
> National Lab or Top Down Funder

> 'There's a need to have coordination across all the different areas of the sector i.e. between new nuclear and nuclear decommissioning and there's not really a particularly great forum for that at the moment.'
>
> National Lab or Top Down Funder

> 'International collaboration is more challenging. You need a mechanism to enable that collaboration. So, whether it's EURATOM or some mechanism that's doing that collaboration. It's been more difficult because of the whole BREXIT situation.'
>
> National Lab or Top Down Funder

> 'The UK has such a wealth of historic knowledge which could be really valuable to future researchers. We need to ensure access to this knowledge is maintained and that people know where and how to access such information.'
>
> Industry

In summary:
The UK has a large number of nuclear R&D collaboration schemes and routes to enable collaboration. Many of these have been developed over long time-periods and have led to a wide-range of impactful outcomes. There are a number of international collaboration programmes which have dual benefit of not only sharing knowledge and understanding between countries but also in demonstrating the UK's commitment to delivering world-class R&D.

However, it appears that if we are to continue to develop a successful nuclear R&D sector, issues such as the lack of both a central historic data archive for nuclear programmes and leading organisation promoting cross-sector collaboration must be tackled. Thus, attention and thought needs to be given to what organisations within the sector have historic information, data and insight that would be valuable for future nuclear endeavours and how best this information should be managed.

The UK must also continue to monitor international collaboration platforms and assess the appetite for further involvement in such activities going forwards.

7. Conclusions

Since the Government outlined plans for an expansion of nuclear power, including the building of a major new power station at Sizewell C and investment in advanced nuclear fuel production, there has been renewed positivity about the future of the sector. This landscape review has picked up on some of the "mood music" across academia, industry and the funding organisations and, compared to previous surveys, has attempted to provide more context through focus groups and interviews.

It is clear that the sector is calling out for key decisions to be made by Government to give a firm demand signal that a nuclear renaissance is going to be delivered within the timescales publicised. Engagement with the future market to understand its perception of R&D needs is maturing, but the stakeholders involved in this review strongly believe that the future science and engineering challenges are surmountable if funding is unlocked early and that there is firm long-timescale commitment.

Some people within the R&D sector feel that too much is currently left to market forces, rather than being driven by Government. Many responders want to see more strategic direction from Government either coordinated through its National Laboratories (e.g. NNL, UKAEA, NPL etc.) or from another centralised body.

From this review we know that the nuclear R&D sector is seeking:

Strategy and coordination of R&D activities
The UK remains open to AMR, SMR, GWe scale reactors and other technologies to fill this capacity. Given the key role of Government funding in nuclear R&D, many would welcome greater clarity on which reactor types will be used to achieve 24GWe and where they will be sited as a clear programme will help drive private investment and regional economic growth.

Consistency of funding
Many are concerned that the UK is entering a period of increased fiscal discipline, which could lead to reduced R&D budgets and a loss of momentum in the sector at the time where momentum is needed most. They desire a long-term plan that takes the nuclear sector to 2050.

Scaling up capacity (staffing)
R&D investment is one of the ways that the industry builds technical capability to lead programmes and projects. In increasing capacity, this review identifies a number of challenges that need to be addressed. These challenges are mainly in the University sector and include the ongoing need to attracting young people into STEM subjects, and funding of nuclear Masters and PhDs. Respondents also point to the loss of expertise through retirement and lack of mechanisms to transfer knowledge from experienced researchers to Early Career staff. This is a key challenge in increasing capacity in the sector.

Less reliance on testing facilities overseas
Many believe the UK needs its own Research Reactor/ Test Reactor/ Isotope Production Reactor to alleviate pressure on overseas facilities. Some respondents describe the additional benefits having such facilities would have, for instance in training and developing staff and in demonstrating a particular proof of concept.

Long-term access arrangements for NNUF
Respondents to this review said that re-funding the National Nuclear User Facility (NNUF) access scheme is important in allowing researchers to access the facilities the UK has, to advance knowledge and understanding and to maximise the benefits from funding the equipment and facilities to date.

Post-Irradiation Examination (PIE) facilities
A strategy to provide post-irradiation examination facilities in the medium to long-term is vital for underpinning future reactor and new fuel types.

Collaboration
There are currently a number of collaborations between universities, industries and national laboratories in flight, both within the UK and overseas and there would be a benefit in strengthening some of these further to leverage the full economic value of funding available.

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9. Appendices

9.1 Detailed Methodology

Overview

A mixed-methods approach was applied to ensure a multi-dimensional and robust survey of the civil nuclear R&D sector. The research methodology was a three-step process, incorporating an online, quantitative survey which was distributed through email with in-depth qualitative interviews. Beyond this, extensive desk research was carried out to add broader context to the narrative which individual respondents may not provide, while also validating the top-level findings of this research. The triangulation of methods has helped the robustness of this study while also helping to overcome some of its limitations.

Quantitative Online Survey

The first phase of the research was a structured online survey, designed to collect quantifiable data from a wide array of respondents. This was so as to enable the study to gather a broad and representative picture of the civil nuclear sector – both in terms of numerical funding and staffing levels but also attitudes and beliefs with regards to the UK's civil nuclear sector.

The survey was hosted on a 3rd party platform and distributed to prospective respondent organisations through email. These organisations for contact were drawn from previous surveys and from new organisations carrying out R&D in the civil nuclear space.

The survey sought detail on R&D funding activities across a series of research themes in FY 22/23 (the template for which was provided as a downloadable Excel table for respondents to submit along with their online survey), staffing and researcher figures, as well as experience and geographical split of these tallied individuals.

Attitudinal questions were also asked around the UK's research capabilities (in terms of resources, expertise, R&D facilities which can be readily accessed and collaboration).

Beyond this, respondents were provided open text boxes to expand upon their stated attitudes towards aspects of the UK's R&D capabilities (with regards to strategic issues facing the UK's civil nuclear R&D landscape for example).

Qualitative Interviews

To delve deeper into the complexities of the sector, we conducted qualitative interviews with a select group of survey respondents. These interviews allowed us to explore complex issues in a nuanced and detailed manner. The narrative data gathered from these conversations provided rich insights into individual experiences and perceptions, adding depth to the numerical data gathered from the survey.

Desk Research

To contextualise our primary findings and to provide a broader historical perspective, both in terms of UK domestic nuclear R&D and its context within a broader international setting, we conducted an extensive review of existing literature and data on the civil nuclear space. This included, for example, exploring the OECD and IEA figures on civil nuclear research and development.

9.2 UK Facilities Necessary for Future R&D Ambitions

During this survey a number of different types of research facilities and equipment were mentioned as needed by the research community in order to serve future R&D needs. We have attempted to group similar types of facilities and equipment together to provide a consolidated list. We recognise that many of these facilities listed are very large, complicated infrastructure builds and hence wish to clarify that NIRAB is not saying that all are needed in order to progress an advance nuclear programme.

Rather we recognise the strategic importance of the UK research community having access to such facilities in the future.

Materials Research/ Test Reactor:

- Materials test reactor
- Post-Irradiation Examination Facility
- Modern post-irradiation examination facility

Qualification/ Test Facilities:

- Thermal Hydraulics Facilities
- Open access thermal hydraulics facilities
- Next Generation Pulsed Power Machines
- A range of radiation exposure platforms for radiation protection research
- Access to a flexible high-flux thermal neutron source and access to high luminosity gamma sources
- Fusion spectrum neutrons at high flux
- Irradiation testing capabilities
- Post-Irradiation Examination (PIE) Facilities

Handling and Storage Facilities:

- Refurbished/new active handling laboratories
- Nuclear radioactive materials storage/handling/testing capabilities

Accelerators:

- High energy ion and electron accelerators

Computational Facilities:

- Investment in supercomputers or high-power computational facilities

Decommissioning Facilities:

- Open access nuclear decommissioning facilities

High-Temperature Testing Facility:

- High temperature helium (as a primary circuit coolant) testing facility

9.3 International Facilities Accessed by Participants

During the course of the year, under review, UK researchers accessed the following international facilities in order to conduct their work.

Research Test Reactors:

- LVR-15 (part of the FIDES European program) (Czech Republic)
- ILL Grenoble (France)
- Jozef Stefan Institute Triga Reactor (Slovenia)
- ATR at Idaho National Lab (USA)
- CNL (Canada)
- Oak Ridge National Laboratory (USA)
- MIT Reactor (USA)
- ANSTO (Australia)

Material Testing Facilities:

- Mont Terri Underground Research Laboratory (URL) (Switzerland)
- Grimsel Test Site (Switzerland)
- Bure URL (France)
- Aspo URL (Sweden)
- University of Bern (Switzerland)
- Onkalo (Finland)
- Studsvik Hot Cells (Sweden)
- University of Bayreuth (creep testing)
- CIEMAT Madrid (Small punch testing)
- CVR Czechia (supercritical-CO2 testing)
- NSUF
- Pacific Northwest National Laboratory (US)
- Brookhaven National Laboratory (US)
- Sandia National Laboratories (USA)
- Los Alamos National Laboratory (USA)
- Oak Ridge National Laboratory (USA)
- Japan Atomic Energy Authority Facilities (Japan)
- Westinghouse Hot Cell Facility and Labs (USA)

Qualification Facilities:

- Melox (France)
- MIT laboratories for corrosion (USA)
- Molecular Foundry - Lawrence Berkeley National Laboratory (USA)

Test Facilities:

- Thermal Treatment VSL (USA)
- HIPing Facility at ANSTO Australia
- University of Virginia thermal conductivity mapping (USA)
- University of Michigan in-situ irradiation (USA)
- ANSTO Neutron irradiation (Australia)

Other Facilities:

- PSI (Switzerland)
- VTT (Finland)
- CEA (France)
- JRC (Belgium)
- DESY (Germany)
- GANIL (Grand Accélérateur National d'Ions Lourds, France)
- Accelerator facilities at IFIN-HH (Romania)
- CERN (Switzerland)
- National Institute of Standards and Technology (For development of Carbon-14 laser spectroscopy) (NIST, USA)
- Waterloo University, Ontario (Canada)
- US National Laboratories: Princeton; Sandia; Los Alamos
- University of Illinois (USA)
- University of New South Wales (USA)
- 4D-STEM + analysis, J-PARC Diffraction proton accelerator (Japan)
- VTT Finland (ICME modelling) (Finland)
- IRSN (Institute for Radiological Protection and Nuclear Safety, France)

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