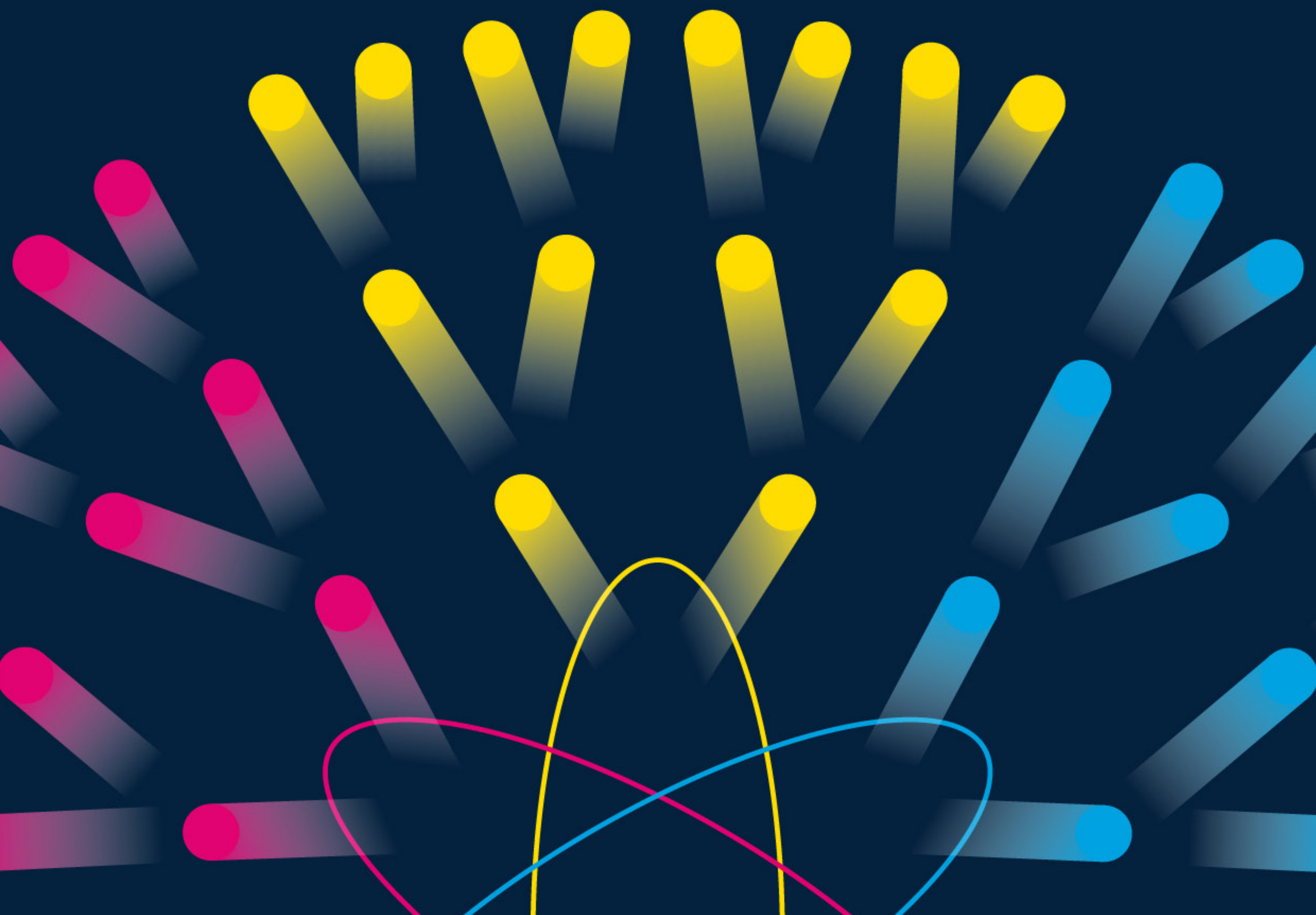
United Kingdom
National Nuclear
Laboratory

NuClear Science: Case Studies

2025–2026



UKNNL Science and Technology Agenda: Five years of progress and value

Quality

400 peer-reviewed **journal articles**

delivering world-leading **nuclear research** for the **global nuclear community**

Talent

Supporting **70** PhDs

Delivering cutting-edge nuclear research for the **global nuclear community**

Partnerships

launched new collaborating centres **2**

to work together to reach **net zero**

Impact

Published **29** **impact case studies**

At UKNNL, we apply science with purpose: tackling nationally important challenges, strengthening energy security and enabling a more sustainable nuclear sector.

As the UK's sovereign nuclear laboratory, we are a national asset in service to the UK nuclear sector. We sit at a unique intersection between government, industry and academia, and it is from this position that our scientists, engineers and technical experts help translate national ambitions into practical outcomes. We are the science to the sector's engineering. Where others build and operate, we provide the deep technical knowledge, the research capability, and the independent expertise that underpins confident decision making across the whole nuclear enterprise.

But UKNNL is more than a laboratory. We are a convenor, bringing senior leaders together to tackle shared challenges, and putting future talent front and centre as we build the workforce the sector needs. We are a collaborative partner, working openly with government and customers, measuring our success not by the science we produce but by the difference it makes.

These case studies reflect that mission in action. They showcase the impact delivered through five years of investment in UKNNL's Science and Technology Agenda, demonstrating how internally funded research is creating value for the sector, building critical capability, advancing knowledge and helping to address some of the most significant opportunities and challenges facing UK nuclear. From supporting the safe operation of the UK's nuclear power stations and advancing decommissioning programmes to developing next-generation fuels and providing world- class technical advice to government, each story represents UKNNL's science and technology being put to work on challenges that matter at a national level.

Behind every case study is a dedicated team of people applying deep expertise with real purpose. We hope these examples give you a sense of what UKNNL's science and technology community is capable of, and what we are building towards, together.

Dr Gareth Headdock
Chief Science and Technology Officer and Deputy CEO, UKNNL

Dr Paul Nevitt
Vice President Science and Technology, UKNNL

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1 | Strategic Research

Unlocking historical nuclear knowledge through artificial-intelligence-enabled searching

UKNNL holds around 100 million files dating back to the 1940s, and a new artificial intelligence (AI) enabled search platform now finds what teams need at least 10× faster than before, surfacing past research that is directly shaping cutting-edge programmes of the future.

Challenge

The UK's nuclear sector holds one of the world's largest and most complex technical archives. UKNNL alone stores around 100 million electronic files, some originating from as long ago as the 1940s.

Conventional search methods make it difficult and time-consuming to locate specific information, especially as many original researchers are no longer available to provide context.

This creates risks of duplicated work, programme delays and loss of valuable expertise. As the UK develops next-generation reactors and fuel-cycle technologies, rapid access to historical knowledge is critical.

Solution

To support the streamline searching of historical nuclear knowledge, a UKNNL team identified, tested and proved an AI-enabled natural language search platform and deployed this on its secure networks to index and interpret millions of scientific documents.

Deployment of the tool at this scale, with the support of the Office for Nuclear Regulation, represents the first of its kind both in the nuclear sector and internationally. It enables:

- search speeds at least 10× faster than manual methods
- more comprehensive and relevant search results
- discovery of previously overlooked or inaccessible content
- improved cross-sector collaboration
- enhanced information security through identification of legacy data

AI-enabled searching is now actively supporting research and development, programme design and technical decision-making across UKNNL and partner organisations.

Using knowledge to support growth: Developing the UK civil nuclear library

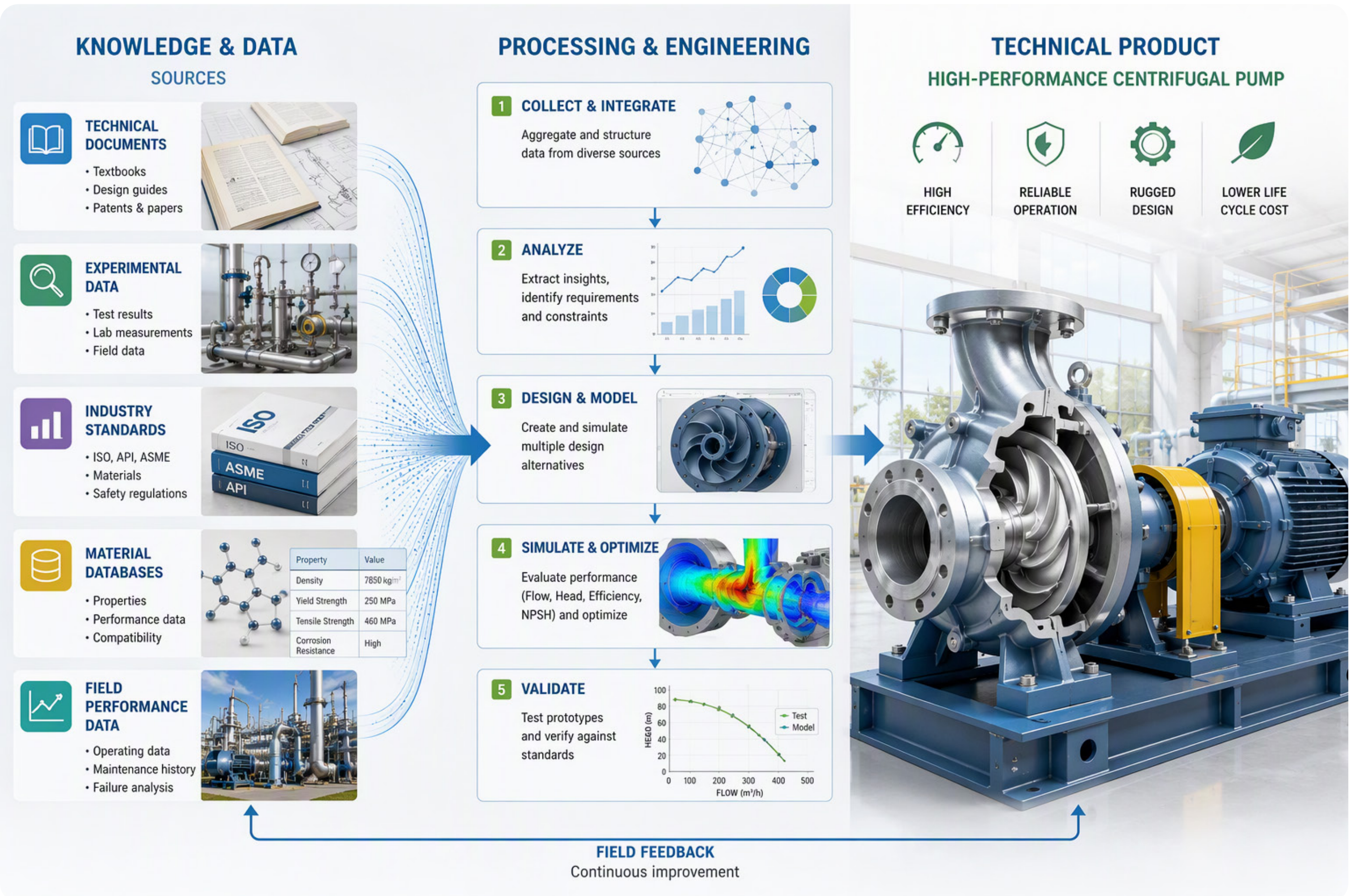
As part of UKNNL's commitment to unlocking the full value of its knowledge assets, the organisation has established a comprehensive Knowledge Asset Management Strategy. This strategy sets out how UKNNL will identify, protect and maximise the impact of its extensive historical and contemporary knowledge base.

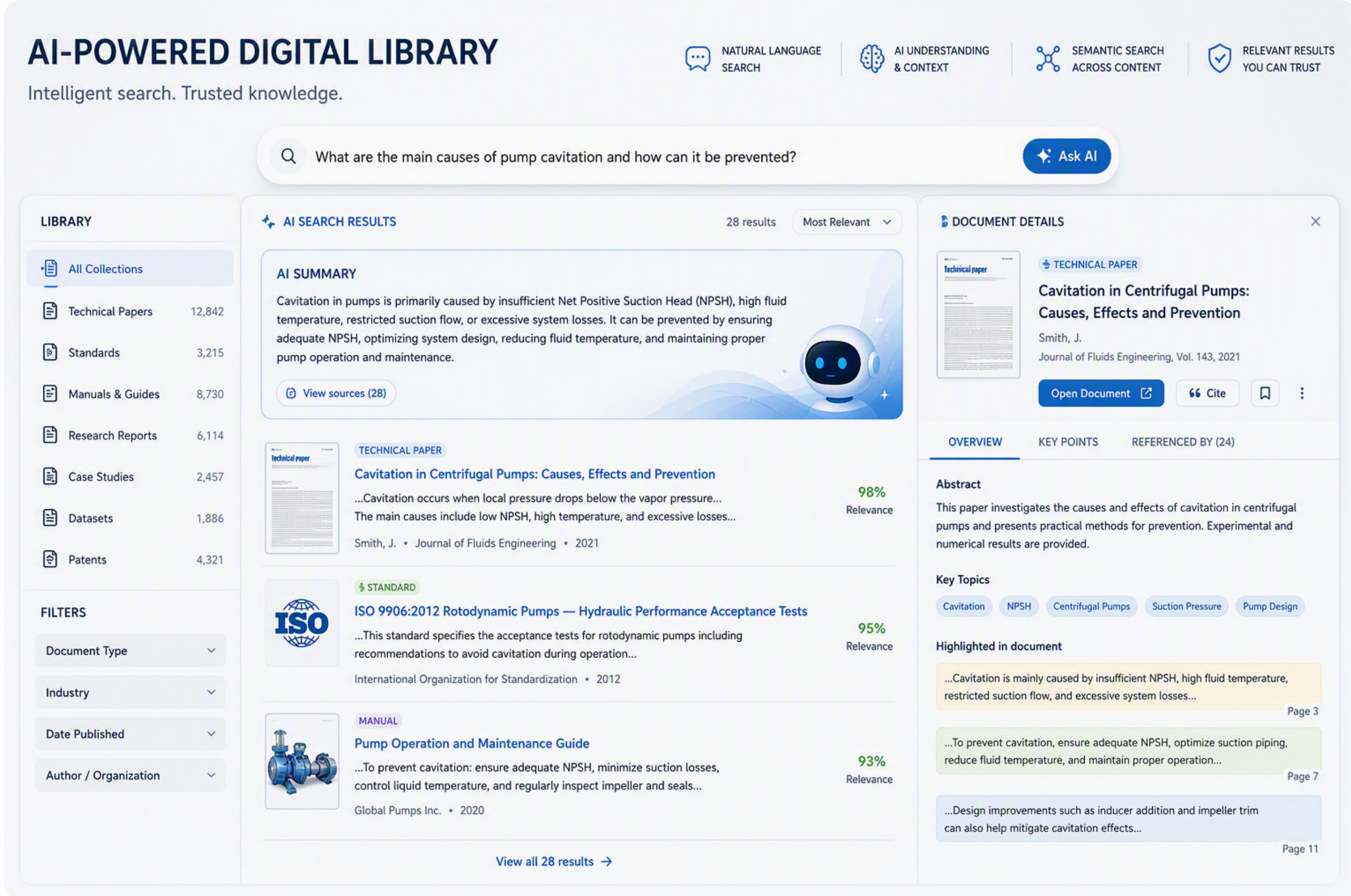
Working closely with industry-leading experts, and supported by advanced AI-enabled search tools, UKNNL is developing structured libraries of information that can be shared with partners to accelerate the deployment of advanced nuclear technologies.

We have already assembled a curated catalogue of more than 50 topic areas, spanning the entire nuclear fuel cycle. This provides a clear framework for communicating, accessing and exploiting knowledge assets across the sector and forms an essential building block for the emerging UK civil nuclear library.

> “AI-enabled searching has transformed our ability to understand and exploit our wealth of knowledge assets.”

Luke O'Brien
Fellow, UKNNL





Thermodynamic modelling support: Streamlining research into next-generation fuels

Crucial work is under way at UKNNL's Preston Laboratory to convert high-assay low-enriched uranium (HALEU) from its gaseous form into chemically stable compounds that can be used to make fuel for the next generation of advanced nuclear reactors.

Using the AI search engine, the team uncovered a kinetic study conducted in 1962 that was not publicly available elsewhere.

This document confirmed the predicted product and provided insights which directly shaped the design and statistical analysis of upcoming experiments, strengthening confidence in the approach. Without using the AI search engine, reproducing the equivalent data in the paper would have required months, or even years, of additional work to progress the project.

The use of AI on the HALEU project shows just how these tools can support the efficiency and effectiveness of the teams working to build a nuclear future.

> “The discovery of this paper through the use of AI searches has been extremely useful to validate and support the use of thermodynamic modelling for this project. It gave our team a real confidence boost in our results and methods to look at novel systems moving forward.”

Sophie Cooper
Chemical Modeller, UKNNL

Digital technology in action: Capturing knowledge about advanced modular reactors

To support cross-sector collaboration in the development of advanced modular reactors (AMR), it is essential to be able to leverage the UK's AMR knowledge base.

Funded by the UK Department for Energy Security and Net Zero (DESNZ) and delivered by UKNNL alongside Arup, AMR Knowledge Capture Programme digitised and indexed this knowledge to improve its accessibility.

More than 7,000 paper documents were scanned, indexed and integrated into a searchable SharePoint platform using AI-generated metadata and natural language processing.

This work prevents the loss of critical historical knowledge and supports faster, more cost-effective AMR development.

DESNZ confirmed that the project laid a strong foundation for improving accessibility of historical nuclear information, helping to position the UK as a leader in next-generation nuclear technology development.

> “ AI-driven search is transforming how nuclear knowledge is accessed and used. Through the UK's AMR Knowledge Capture project, we have shown how complex legacy information can be analysed and made accessible beyond conventional methods, unlocking new insights, reducing rework and accelerating cost-effective innovation across the sector. It also enhances collaboration by enabling knowledge to be more readily shared and applied. ”

Department for Energy Security & Net Zero

What the future holds

UKNNL is continuing to expand and refine its knowledge assets, working towards the development of a comprehensive UK civil nuclear library.

AI-enabled search will play a central and increasing role in helping to improve technical decision-making and reduce duplication of effort.

It will also be invaluable in supporting national programmes and training the future nuclear workforce, all of which can only serve to strengthen the UK's position in advanced nuclear technologies.

UKNNL has developed a **Knowledge Asset Management Strategy** to identify, protect and maximise the value of its knowledge assets.

By combining domain expertise with **AI-enabled search**, UKNNL is creating libraries of information that can be used with partners to **accelerate advanced nuclear technology deployment**.

A catalogue of **50+ topic areas**, covering the full nuclear fuel cycle, supports ongoing communication and the effective use of **UKNNL's knowledge base**.

100 million **files**

all areas of nuclear fuel cycle

8 decades of **knowledge**

50+ topic areas

2 | Strategic Research

Nuclear data at work: Tackling current and future challenges

Behind every reactor, every safety decision and every expected radiation dose lies something many people have never heard of: nuclear data.

UKNNL is one of a small number of organisations globally with the expertise to build and maintain nuclear data libraries, and our work is shaping internationally recognised standards used across the world.

Challenge

Behind the delivery of every new nuclear reactor to power the UK's clean energy future lies a complex set of calculations.

These calculations are carried out using specialised computational modelling that simulates all aspects of the new system to ensure controlled working and that it meets rigorous safety standards.

At the root of these calculations stand the nuclear data, a set of information built mostly on experimental evidence, which provide the reaction probabilities to the modelling codes.

Building this knowledge into libraries of nuclear data that can be accessed worldwide is a process which takes decades, and these libraries need to be regularly revisited and updated if the future of the UK's nuclear sector is to be assured.

Simulating how nuclear fuel changes during reactor operation, calculating the thickness of the shielding needed to protect workers from radiation and assessing whether nuclear materials are being kept safely below the threshold in normal and unexpected operation modes are just a few of the critical tasks that depend entirely on accurate nuclear data.

Solution

UKNNL is a key player in the international nuclear data community. We ensure that the UK influences how nuclear data libraries develop and has the expertise to use them confidently. This is an ongoing process, as libraries are regularly being updated with new knowledge. Being a strong partner in the nuclear data community means we can steer priorities and have some control over what is inside the libraries and how these data are compiled.

We are an active member of the Joint Evaluated Fission and Fusion (JEFF) collaboration, working alongside partners from across Europe to produce the latest nuclear data libraries. UKNNL scientists focus on fission product yields, the data describing what materials emerge when nuclear fuel splits apart, because this information is crucial for reactor operations and spent fuel management.

Beyond JEFF, UKNNL participates in the Working Party on International Nuclear Data Evaluation Co-operation (WPEC), in close co-operation with the International Atomic Energy Agency (IAEA) connecting British expertise with programmes worldwide. This global network ensures that UKNNL scientists understand not just how to use nuclear data but also how these are produced, checked and validated.

> "The IAEA Nuclear Data Section works with Member States and partner institutions worldwide to build the accessible, trusted nuclear data resources that researchers and decision-makers rely on. Our collaboration with UKNNL is one valuable example of that work, contributing to a nuclear data ecosystem that underpins scientific discovery and innovation across reactor systems, fusion and medical applications."

Professor Tzanka Kokalova Wheldon
Director, Division of Physical and Chemical Sciences, IAEA

The laboratory has also developed specialist tools that take advantage of nuclear data libraries to support the nuclear industry.

FISPIN,[1] a depletion and isotopic inventory code used in the UK nuclear industry since the 1970s, which has continued to be improved and developed over the years, calculates how material composition changes during and after irradiation.

This has been essential for supporting operations at Sellafield and across the wider fuel cycle. Meanwhile, the newly developed Computational Assessment of Radionuclide Production (CARP) helps optimise medical radioisotope production by calculating the best conditions for specific nuclear reactions.

“Nuclear physicists from AWE and UKNNL interact regularly in the field of nuclear data, where UKNNL’s expertise is widely recognised. In recent years, these interactions have focused heavily on the sharing of knowledge and best practice within the field, including addressing capability gaps – such as in data evaluation – within the larger UK community. These exchanges will play an important role in strengthening the foundations of the UK nuclear sector during a key period of renewal.”

Professor James Benstead
Theoretical Scientist,
AWE

Nuclear data in action: Powering developments in nuclear medicine

Hospitals increasingly rely on radioactive isotopes for diagnosing and treating diseases, particularly cancers. Traditionally, these isotopes were produced in nuclear reactors, but many of these facilities are ageing and expensive to replace.

New production methods, including particle accelerators, offer alternatives, but they require fine-tuning by scientists to calculate which nuclear reactions, which energy ranges and which intensities will most efficiently produce the desired medical isotopes while minimising unwanted byproducts.

At UKNNL, we are currently co-leading a pioneering project with Medicines Discovery Catapult that uses an isotope called lead-212 to perform targeted alpha therapies. This is a new type of radiopharmaceutical treatment that can effectively target and destroy cancer cells with minimal damage to healthy tissue.

The work is supported by nuclear-data-based calculations to accurately predict the outcome of the nuclear reactions involved in the radioisotope production and the composition of the target. This helps in making the best choices when tuning the instruments and feeding the information needed to the chemistry specialists.

[1] Spent nuclear fuel inventory code suite developed by UKNNL. It calculates the changes in the numbers of atoms of the nuclides of various species – heavy isotopes or actinides, fission products, and structural or activation materials – as a sample of material is subjected to periods of irradiation and cooling. It is a ‘point’ code: the whole sample is subject to the same irradiation conditions.

A case of priorities: Demystifying graphite irradiation

Advanced reactor development is a perfect example of the need for constant improvements in nuclear data. This development illustrates the importance of ensuring that we prioritise the data most likely to support the novel technologies needed for the UK’s energy transition.

Advanced reactor designs differ significantly from those of their predecessors, with different fuel types, moderators, structural materials, coolants, cladding and operating conditions, all of which results in additional nuclear data needs.

For example, high-temperature gas reactors (HTGR) operate at higher temperatures than current operating reactors, so there needs to be nuclear data available for this temperature range and for the materials used.

Specifically, the performance of the graphite, which makes up most of the materials in the core and is a large component of the coated particle fuel, has been noted to perform slightly differently in experiments compared with simulations.

Improved nuclear data based on new reactor-grade graphite measurements for HTGR operations are required to improve safety, reliability and economic viability. Owing to the competitive nature of advanced reactor designs, it is important for the UK to have a voice in nuclear data communities, to push these measurements up the UK and international priority lists.

The interactions with the reactor core with part-per-billion (ppb) levels of corrosion products that are gradually released from circuit pipes is, at first glance, a subtle phenomenon.

However, owing to the extremely high mass transport in a pressurised water reactor, this effect can dominate the production of operational radiological wastes and worker doses for commercial power plants. Mitigations are being developed by the industry to optimise their effectiveness and to support their application to new classes of material.

As well as experimental investigations, another key area is the numerical modelling of this effect on fuel deposit chemistry at microscopic scales. Enabling a link between experimental studies and simulation is a priority of the programme.

“The OECD Nuclear Energy Agency greatly values the deep technical expertise that UKNNL brings to international nuclear data development.

“Recent UKNNL contributions include the provision of fission-yield data for the Joint Evaluated Fission and Fusion (JEFF-4.0) library, significantly enhancing the accuracy and consistency of fission-product inventory predictions across reactor applications, alongside the development of application-specific nuclear data libraries that underpin the development and safety assessment of nuclear systems.

“Through UKNNL’s long-standing involvement in the JEFF library and the Working Party on International Nuclear Data Evaluation Co-operation (WPEC), UK experts provide high-value scientific contributions that strengthen the robustness and relevance of nuclear data for all NEA members and the wider international community.”

Dr Tatiana Ivanova
Head of Division of Nuclear Science and Education at the Nuclear Energy Agency (NEA)

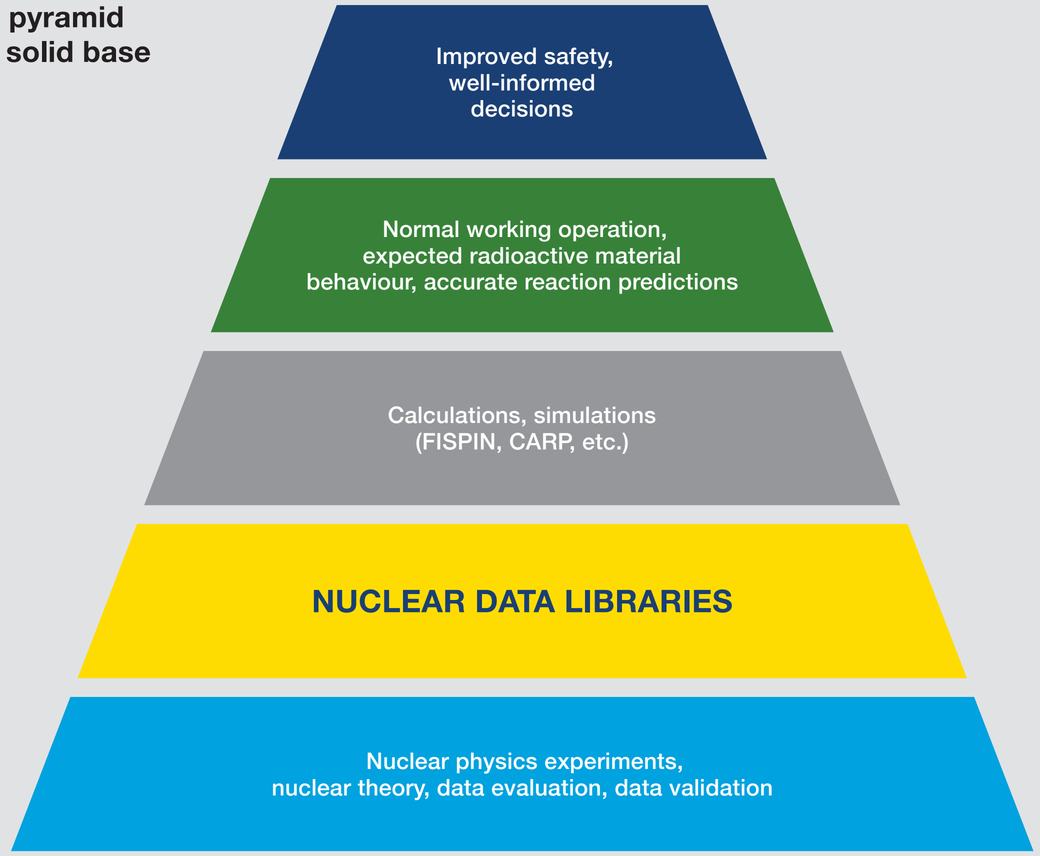
What the future holds

Nuclear data might remain invisible to most people, but its already strong relevance will only grow as the UK pursues its clean energy ambitions. Advanced reactors will push calculations into new fields not previously explored.

Decommissioning programmes will require precise predictions for materials never previously characterised. Medical applications will demand ever-more-targeted isotopes and more convenient production paths.

UKNNL's investment in nuclear data capability through international collaboration, tool development and training the next generation ensures that the UK will have the solid foundation and the tools needed to meet both today's and tomorrow's challenges.

A sound pyramid needs a solid base



3 | Core Science

Safety first for the future of clean energy

UKNNL's safety experts are leading nationally and internationally to develop smarter, more proportionate approaches that protect people and shape the standards for the nuclear industry.

Challenge

Safety has always been a key focus for the nuclear industry. It underpins all our active operations to make sure we can achieve our aims without affecting the safety of our colleagues and the public.

Without strong safety performance, trust is undermined – and this affects both our ability to keep existing nuclear operations running reliably and the potential for sustainability and growth in the sector.

New reactors and fuel technologies will only receive investment and regulatory approval if the nuclear industry can be demonstrated to be safe. Fundamentally, we view safety as the foundation on which the nuclear sector's support for the UK's sustainable energy goals must be built.

However, if implemented poorly, safety can be a barrier to getting things done. We have a legal and moral responsibility to conduct operations safely, but this must be done in a proportionate and fit-for-purpose manner to help us enable a clean energy future.

The recent Strategic Review by the UK Government's Department for Energy Security and Net Zero (DESNZ) alluded to this, noting that "UKNNL must reliably implement programmes effectively and efficiently".

Similarly, the Nuclear Regulatory Review 2025 (the Fingleton Report) found "three fundamental regulatory drivers of high cost and delay in the nuclear sector: risk aversion, priority for process over outcome, and the lack of incentives aligned with the public interest", all of which can be related back to the challenge of ensuring safety while maintaining efficiency and innovation.

Solution

To enable us to tackle this challenge head-on as recognised leaders in nuclear safety, the UKNNL Nuclear Safety Core Science Theme vision is to be:

An internationally recognised capability that leads on fit-for-purpose nuclear safety approaches and solutions.

Three core pillars in delivering this vision are: our leadership in national and international forums, UKNNL subject-matter experts (SME) tackling technical challenges and nurturing the development of the next generation of nuclear safety experts.

National and international leadership

As the UK's national laboratory, we are uniquely placed to play a leading role in nuclear safety, bringing together key stakeholders from safety disciplines worldwide.

This enables the UK to maintain authority in criticality safety, radiation shielding, and radiologic and chemotoxic safety, as the sector adopts novel fuel types and advanced reactor designs.

We collaborate with expert groups worldwide, driving the development of standards and guidance which help set the Relevant Good Practice. RGP refers to methods, standards, or approaches that are widely accepted across the industry as being effective in delivering particular safety, security, or safeguards outcomes, and which the regulator expects us to consider in showing our operations are safe.

This guidance therefore has a top-down influence across all nuclear safety assessments.

Senior Criticality Safety Consultant Lauren Flint is the UK Technical Lead on criticality safety ISO standards development.

She is a recognised member of the ISO/TC 85/SC 5 subcommittee, focused on nuclear installations, processes and technologies, which also allows her to assume the role of Head of UK Delegation representing the British Standards Institute as the national standard body.

This role is a prestigious appointment that involves Lauren acting as a key liaison with UK industry via the UK Working Party on Criticality (WPC) and collaborating with a wide range of international experts.

Deborah Hill, Head of Fellows and Senior Fellow for Criticality, has collaborated with American Nuclear Society (ANS) nuclear safety experts for many years, regularly hosting sessions at ANS conferences. She is currently secretary to the ANS-8 Standards Committee, which produces guidance that shapes regulatory expectations in the US and informs Relevant Good Practice for the UK regulator.

As far back as 2017, the WPC stressed the importance of securing UK input into standards and Relevant Good Practice at an early stage. The WPC cautioned that failing to engage early could lead to overly conservative or prescriptive safety case requirements, which could in turn have an impact on the viability of operations.

UKNNL's active involvement in this project directly supports our work in shaping emerging standards and ensures the needs of the UK nuclear industry are represented.

Nuclear Safety Theme Collaborations

Radiation Physics and Shielding Capability Manager Anton Murfin is the UKNNL member of the UK Shielding Forum and was, until recently, its chair.

The Shielding Forum is the premier UK working group on radiation shielding, and sets best practice across industry.

Anton led the technical work that identified that the British Standard on shielding from gamma radiation (BS4094 1:1966) requires significant updates, and he is currently leading collaboration across the Shielding Forum to address this.

In addition to collaborating in working groups, the UKNNL nuclear safety team continues to spearhead further initiatives for the benefit of the worldwide safety community. It is leading the establishment of an international version of the criticality safety Learning from Experience database, used to record, share and analyse information relating to nuclear criticality safety, the UK version of which UKNNL was instrumental in setting up.

Deborah Hill was awarded the prestigious position of American Nuclear Society Fellow in May 2024, in recognition of her outstanding technical and professional accomplishments in Criticality Safety and her work with the society.

In the past five years, the UKNNL Nuclear Safety Core Science Theme has produced:

4 journal articles

2 ISO standards with UKNNL co-ordinating the UK contribution

1 ANS standard with UKNNL leading

9 conference papers with UKNNL lead authors

“Simply put, the UK criticality safety community (including the UK WPC) would be struggling without the outstanding and highly respected role that UKNNL contributes. It demonstrates exemplary technical leadership in initiatives that are important to the WPC members and wider industry, including the Sensitivity/Uncertainty subgroup, ISO standards and the Criticality Learning from Experience database. UKNNL's commitment to professional development is equally impressive, leading and contributing to recent WPC continued professional development (CPD) workshops on ALARP (as low as reasonably practicable) and safety assessment methods while also spearheading the internationally recognised CPD webinar series. In addition to its technical leadership, UKNNL has been key in developing the next generation of professionals, through support and guidance to the Early Careers Criticality Safety Network and the activities it is delivering. Through this combination of expertise, leadership and dedication, UKNNL not only strengthens collaboration and promotes good practice but also ensures the UK criticality safety community remains at the forefront of safety, knowledge and technical excellence by sharing valuable insights from their networks and encouraging the next generation to be developed.”

Liam Payne
Safety Case Lead in Criticality Safety, Dose and Shielding and WPC Chair, Nuclear Waste Services

Technical expertise

When technical challenges arise in the production of nuclear safety assessments, one option is to apply conservative assumptions, increasing the margin of safety to compensate for any uncertainty.

However, this can lead to more onerous safety cases, thereby restricting operations. Instead, these challenges can be tackled with national and international collaborations.

UKNNL is currently leading a UK WPC subgroup on code validation using novel techniques, and collaborating with Lawrence Livermore National Laboratory (LLNL) on a world-first low-temperature criticality safety benchmark experiment.

“UKNNL is a vital contributor to the USDOE Nuclear Criticality Safety Program. The high-priority low-temperature critical benchmark experiment being advanced in partnership with LLNL and Los Alamos National Laboratory (LANL) is fundamentally important in addressing transportation challenges, and UKNNL's technical expertise has been instrumental in overcoming the demanding cooling requirements associated with this equipment, ensuring progress on an issue of strategic international significance. However, their contribution extends far beyond this work. Through active support of the international Criticality Learning from Experience database under your leadership, UKNNL is fostering stronger global collaboration and facilitating access to a powerful shared learning resource for the international criticality safety community, helping to further strengthen criticality safety worldwide.”

Dr Angela Chambers
Nuclear Criticality Safety Program (NCSP) Manager,
US Department of Energy

Criticality code validation

New technologies and novel fuel types, such as coated particle fuel (CPF) and high-assay low-enriched uranium (HALEU), must undergo rigorous assessment to ensure that they meet the required safety standards.

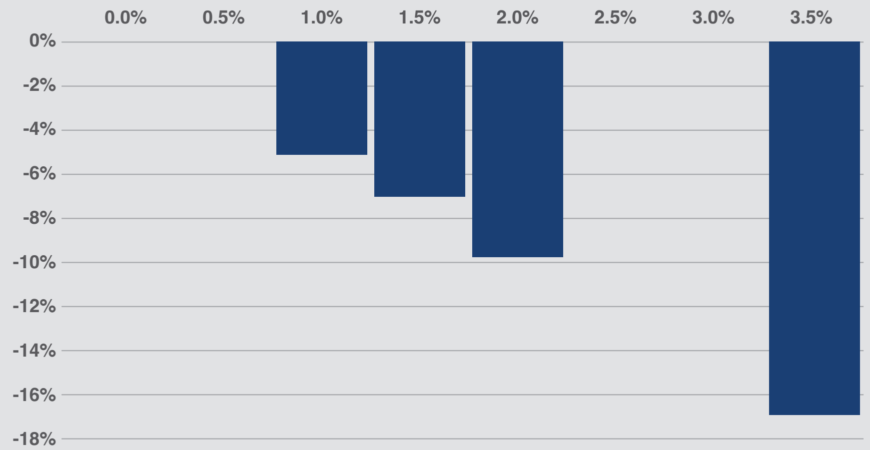
Simulation and modelling of these new systems require valid criticality safety codes and nuclear data, which are used to assess the safety of nuclear systems. It is important that we ensure these safety codes provide an accurate representation of real nuclear systems in action.

Any uncertainty about the safety codes or data used for testing may increase safety margins, which can adversely affect the viability of a new future technology. The graph (right) shows the effect of any additional safety margin on typical HALEU parameters.

There are few nuclear safety code validation experts in the UK, and new tools that automate the validation process frequently suggest a larger safety margin than necessary for real-life systems, potentially delaying new systems. We need to strike a delicate balance to deliver systems of the future both safely and efficiently.

The UKNNL nuclear safety team leads a WPC subgroup that aims to develop a consensus approach to the use of sensitivity and uncertainty (S/U) tools and techniques in the validation of criticality codes and data.

Relative reduction in safe mass with increasing additional safety margin



Additional safety margin	Critical mass (kgU)	Relative reduction
0.0%	5.11	0%
1.0%	4.85	-5%
1.5%	4.73	-7%

Safety margin	Diameter (cm)	Area (cm²)	Relative reduction
0.0%	17.8	247.4	0%
1.0%	17.4	237.8	-4%
1.5%	17.3	235.1	-5%

Modern tools and techniques that serve to (at least partially) automate the validation process are attractive and give the impression of a step forwards for the industry, but we need to understand their real-world impact and any potential shortfalls before fully embedding them. The subgroup has already done much to open up honest conversation and knowledge sharing on this topic. This has helped to overcome a traditional reluctance to engage due to potential commercial impacts and low suitably qualified and experienced person (SQEP) comfort levels. The subgroup will produce a Good Practice Guide, and provide industry education, to shape how the UK nuclear industry embeds S/U tools and techniques.

Low-temperature critical benchmark experiment

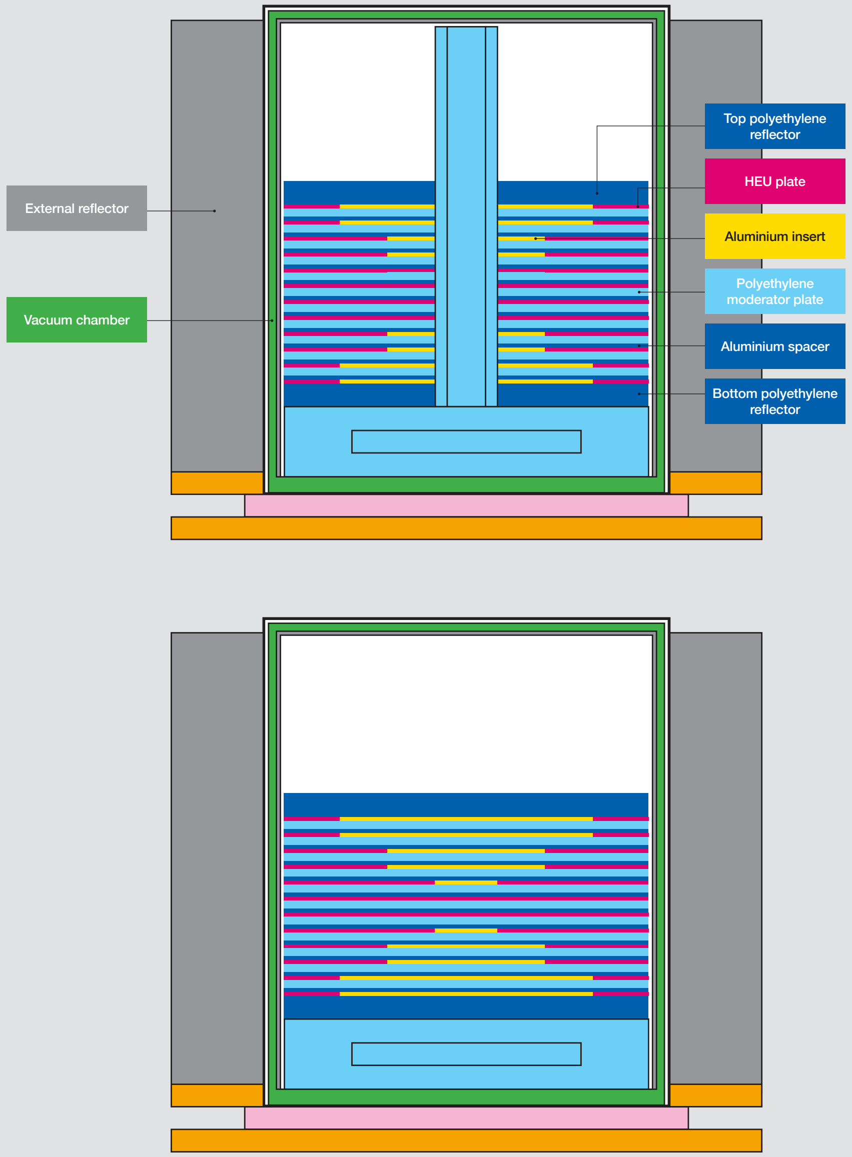
Under the Nuclear Safety Core Science Theme, UKNNL is supporting Lawrence Livermore National Laboratory on a multi-year project to design and run a world-first low-temperature critical experiment to take place at -40°C.

This will support the validation of transport assessments, required by international regulation to demonstrate safety down to subzero temperatures.

The validation of codes and nuclear data at this temperature range could pave the way for a reduction in safety margins, which in turn could allow more material to be loaded into a package or consignment and so reduce transport costs.

Following the experiment in 2026, its results will be published in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook, a programme sponsored by the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA), making the work available for use in future validation applications.

Schematic of the Low-Temperature Thermal Epithermal eXperiments (LT-TEX), showing configurations with and without a central spindle to improve cooling of the stack



Skills development

SMEs issue guidance from the highest levels of national and international working groups, and this sets strategic direction for nuclear safety.

But only by developing the next generation of safety assessors can we ensure this guidance is put into practice effectively. Inexperienced assessors may be more likely to adopt a cautious and conservative assessment approach, so training to a high industry standard is vital for ensuring safety cases remain fit for purpose.

Through our Nuclear Safety Core Science Theme, we are always looking for ways to support the development of early-career safety assessors, both internally and on behalf of the wider industry.

In 2023, UKNNL led a WPC workshop on Approaches to ALARP, which was attended by about 70 early career safety assessors, with contributions from other UK companies and the Office for Nuclear Regulation (ONR). The workshop focused on ensuring assessments are fit for purpose and not overly pessimistic, while providing suitable safety margins. In 2024, we supported another workshop on Safety Assessment Methodologies, which provided multiple training sessions.

UKNNL has supported the establishment of early careers networks for both the WPC and the Safety Case Forum, providing opportunities for early-career safety assessors to network and gain wider experience, and to amplify their voices within the industry.

What the future holds

Through its consistent call for a more practical, outcomes-focused and proportionate approach to nuclear delivery, the Fingleton Report encourages pragmatism as the industry evolves and novel fuels and applications continue to come thick and fast.

UKNNL will ensure that nuclear safety approaches keep up with the pace of innovation in the sector, by leading the national and international debate, taking up specific technical challenges when they arise and – perhaps most importantly – ensuring the next generation of assessors have the tools and experience needed to ensure nuclear safety remains an enabler of, rather than a barrier to, the industry of the future.

Milly Jarvis-Stiggants, Dose and Shielding Consultant, is a good example of this continuous professional development.

Milly attended the ANSWERS Software Service Seminar, an annual three-day nuclear industry event focused on radiation shielding, reactor physics and nuclear criticality, on behalf of UKNNL.

There, she presented a shielding validation study assessing a code's ability to model neutron transport through concrete. The experiment used dosimeters within a concrete block to record neutrons in a heavy water reactor.

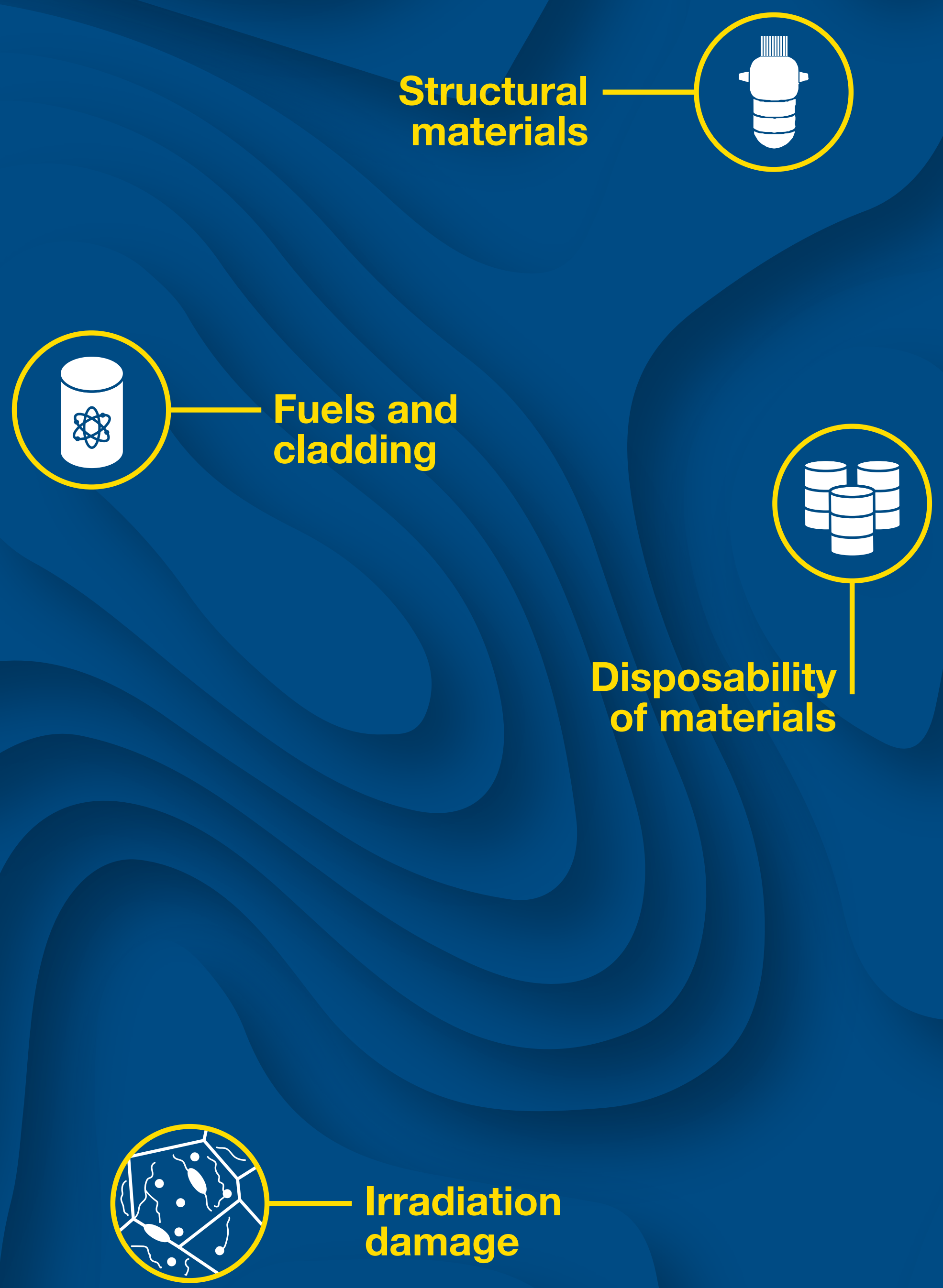
Milly's experiment was recreated with the shielding code MCBEND, developing an innovative approach in the face of limited experimental information.

Further validation work is now being proposed, thanks to Milly's insight.

Milly Jarvis-Stiggants
Dose and Shielding Consultant, UKNNL

4 | Core Science

Mapping the future of fission materials



Every nuclear reactor depends on materials that must survive extreme heat, radiation and corrosion for decades. UKNNL, working with the Henry Royce Institute and over 100 experts from across government, industry and academia, has developed the UK Fission Materials Roadmap to determine the right path for research and investment.

Challenge

Every reactor contains metals, alloys and other materials that must withstand extreme conditions for decades. They face intense heat, corrosive environments and constant bombardment from radiation.

Over time, this can impact the performance of the materials and ultimately limit the operational lifetime of components and, in some cases, the reactor itself.

We must understand how these materials behave throughout their life, so we can predict how they will perform and thus safely extend the life of existing reactors and confidently build new ones.

The UK currently faces some critical decisions around fission materials. Many of the materials used in older reactors are approaching or beyond their original design lifetimes.

The newer reactor designs being developed today, such as HTGRs, require materials that push the boundaries of current understanding. The research needed to qualify these materials and demonstrate their safety can take many years, so decisions and investments are needed now to build future reactors.

On top of this, the UK lacks some of the essential tools and infrastructure to carry out this work. There is no domestic materials test reactor (MTR), a specialised facility used to expose materials to radiation so their behaviour can be studied.

Access to international facilities is limited. Existing archives of irradiated materials, which are irreplaceable for research, are at risk of being lost. And, across the whole sector, there are not enough trained specialists to do the work.

“A deeper understanding of how materials respond to nuclear environments is essential to improve the reliability, longevity and performance of the UK’s existing and expanding fleet of nuclear powerplants. The UK Fission Materials Roadmap is an important exercise to identify priority areas for future investment into nuclear materials to ensure the UK continues to support the science, innovation, infrastructure and skills essential for securing the UK’s clean energy future. It has been a pleasure to collaborate with UKNNL in the delivery of such a comprehensive roadmap, and we are excited for our continued partnership to maximise its impact and benefits.”

HENRY ROYCE INSTITUTE

Solution

The UK Fission Materials Roadmap, which UKNNL developed in partnership with the Henry Royce Institute (see box), focuses on four major technical areas:

- the **structural materials** that make up the reactor itself, which have a direct impact on the safety, efficiency and operational life of the facility because they enable reactor components to withstand the corrosive, high-temperature and intensely radioactive conditions present
- the **fuels and cladding used in the reactor core**, which have implications for reactor efficiency, safety and performance as well as being the first layer of protection against the release of radioactivity into the environment
- the **safe disposal of materials after use**, which is essential for long-term environmental protection and safeguarding of human health, thus ensuring nuclear power remains a safe and sustainable power source
- **understanding the long-term effects of radiation damage** on all of these materials, which is essential for maintaining the safety and assessing the performance of both current and future nuclear facilities

Crucially, the roadmap also identifies six key enabling activities:

- A National Materials Archive should be established within the next five years to preserve irreplaceable samples of irradiated and non-irradiated materials before they are lost. These samples are essential for research and cannot be replaced once gone.
- The UK needs guaranteed access to an MTR. In the short term, this means securing access to international facilities. A decision on whether to build a UK MTR should be made within the next two years.
- Long-term funding, covering at least five years at a time, must be secured to support sustained research programmes. Short-term funding cycles make it impossible to plan and deliver the kind of slow, careful science that nuclear materials research requires.
- Digital tools, including AI, advanced modelling and computer simulation, should be used alongside physical testing to speed up the qualification of new materials and reduce costs.
- The regulatory framework needs to be updated so that it can accommodate new qualification methods, including predictive modelling and novel testing techniques, without unnecessary delay.
- Finally, skills must be built at every level, from school leavers and apprentices through to postgraduate researchers and technical leaders. We need people to make delivery of the roadmap possible.

UKNNL is co-ordinating this effort and working with partners across the sector to turn the roadmap into action. The goal is a UK nuclear sector that is genuinely world leading in materials science and ready to power Britain's clean energy future.

This kind of partnership is central to our work. As the government's lead civil laboratory for nuclear fission, UKNNL's strength lies not just in its own scientific expertise but in its ability to connect government, academia and industry around shared national goals. The roadmap project is a clear example of that convening power in action and demonstrates how UKNNL is stepping into its role as the government's lead civil technical and strategic adviser on nuclear fuels and materials.

Deep dive sessions

21 workshops completed

190 contributions

87 different individuals

34 different institutions

Partnership in action

UKNNL partnered with the Henry Royce Institute, the UK's national institute for advanced materials research, to lead the development of the UK Fission Materials Roadmap. Together, we brought some of the brightest minds in the country around the same table.

The partnership hosted a series of collaborative workshops, including a major two-day in-person event at the Royce Hub Building in Manchester. Across the programme, a large number of experts took part, representing universities, industry, national laboratories, government and regulators. Between them, they made 190 individual contributions, covering the full range of materials challenges facing the UK nuclear sector.

The response from participants was overwhelmingly positive. One contributor said they wanted to "transfer these workshops into [their] own institution", while others praised the use of collaborative tools to draw in voices from right across the sector.

What the future holds

From the steels that hold reactors together to the fuels that power them, and the safe long-term treatment and disposal of waste, the roadmap will set out what is needed for the future of the UK nuclear sector and, crucially, when decisions must be made.

Convening experts to discuss the challenges and opportunities ahead and using collective knowledge to make key recommendations will provide crucial direction for the sector to proceed with confidence to use nuclear power to deliver clean energy.

The UK Fission Materials Roadmap has the potential to deliver significant and lasting benefits for the country. By bringing together government, industry, universities and national laboratories around a shared plan, it creates a coherent approach to research and investment, ensuring that effort and funding are directed where they are needed most.

This joined-up approach opens the door to innovative new technologies that can reduce costs, shorten timescales, improve sustainability and cut down on the waste produced by nuclear programmes.

With the Fingleton Report's recommendations on regulatory reform, the new materials and processes identified in the roadmap should be approved and accepted more quickly, meaning that the reactors and facilities the UK needs can be built and brought into operation faster than before.

Crucially, the roadmap acts as a framework that makes it easier to identify where collaboration is possible, whether between different parts of the UK sector or with international partners, thereby helping to share expertise, spread costs and accelerate progress.

Taken together, delivering the roadmap means the UK will be better placed to build the clean, secure energy future it needs, with a nuclear sector that is more efficient, more innovative and more competitive on the world stage.

UKNNL materials research in action

Structural materials

Graphite is the core structural material and the life-limiting factor in UK gas-cooled reactors, so the UK has unique experience and expertise in nuclear graphite.

The majority of Magnox and advanced gas-cooled reactors have exceeded their design lifetime.

UKNNL has supported the licensees to achieve lifetime extension through a number of activities: responsive post-irradiation examination to confirm model predictions, devising experimental programmes and developing new techniques, and research and development to support mechanistic understanding, as well as safety case support and structural integrity assessments.

Graphite is also the structural material in several fourth-generation (GEN-IV) designs. With its mission of science to benefit society, UKNNL has worked on transferring part of the UK experience to support the development of HTGRs internationally.

Specifically, UKNNL has been leading the ASTM Task Group on Non-metallic Component Degradation and Failure Monitoring, with participants from Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), the United States Nuclear Regulatory Commission (USNRC), X-energy, Kairos Power and FLiBe Energy.

This activity has led to the publication of the first ASME Code Case on Reliability and Integrity Management for graphite components in HTGRs.

Furthermore, under the CPF programme, UKNNL has developed the capability for the production, characterisation and qualification of matrix graphite.

Matrix graphite is the material where the coated particles are embedded to form pebbles and compacts for HTGRs. The UK has produced a matrix graphite compact for the first time in 50 years.

Further development, characterisation and learning will ensure UKNNL can support future fuel manufacturing, licensees and regulators.

Fuels and cladding

UKNNL has reached a significant milestone in re-establishing the UK's sovereign fuel capability, with the delivery to its Preston Laboratory of specialist coating equipment designed and built by Archer Technicoat Ltd (ATL) – marking the first time in a generation that the UK will produce coated particle fuel at pilot scale.

Coated particle fuel uses uranium kernels roughly the size of a poppy seed, each coated with four protective layers that allow it to withstand extreme temperatures while keeping radioactivity safely contained – making it, in the words of the US Department of Energy, "the most robust fuel on earth".

This fuel type, which relies on HALEU, is designed for next-generation high-temperature reactors and is central to the AMR designs that will be essential to the UK's clean energy future.

With graphite compacting equipment also being installed alongside the coater, UKNNL now has an end-to-end processing capability for this novel fuel, directly supporting the ambition for a world-leading UK fission materials capability set out in the roadmap.

UKNNL materials research in action

Disposability

Cement has been the nuclear industry's go-to material for managing low and intermediate level waste for decades, but the supply of traditional cement ingredients is becoming increasingly uncertain.

Since the 1980s, the industry has relied on blended cements that combine Portland Cement with by-products from coal-fired power stations and steel production – but with the closure of the UK's remaining coal-fired stations and changes to the steel industry, these materials are harder to come by. At the same time, the wider cement industry is under pressure to reduce its significant carbon footprint.

UKNNL is working with NDA operational companies, including Sellafield, to evaluate a new generation of lower-carbon and alternative cements that could meet the nuclear sector's needs over the coming century and beyond.

A key part of this multi-year programme is testing how these cements behave under radiation – including whether they generate gases such as hydrogen and oxygen that could pose safety challenges. The work combines direct laboratory assessment by UKNNL scientists with PhD research at universities across the UK, generating both fundamental scientific understanding and practical data to support regulatory approval.

Crucially, the findings will be relevant not just to the management of the UK's existing nuclear legacy wastes but also to the new generation of reactors being built and developed, including Hinkley Point C, Sizewell C and the Rolls-Royce small modular reactor programme.

Irradiation damage

The steels used in nuclear reactors undergo irradiation during service, gradually causing embrittlement and potentially limiting the operational lifetime of reactors.

Accurately predicting this damage is essential for extending reactor lifetimes and maintaining safety. Current methods rely on empirical, or mechanistically informed semi-empirical, models fitted to real data obtained from samples irradiated in reactors.

Recent UKNNL research[1] developed and tested advanced machine learning (ML) models using large international datasets to predict irradiation damage in pressure vessel steels.

It showed that ML can predict embrittlement more accurately than current industry standard methods and can capture the complex interactions between material composition and operating conditions.

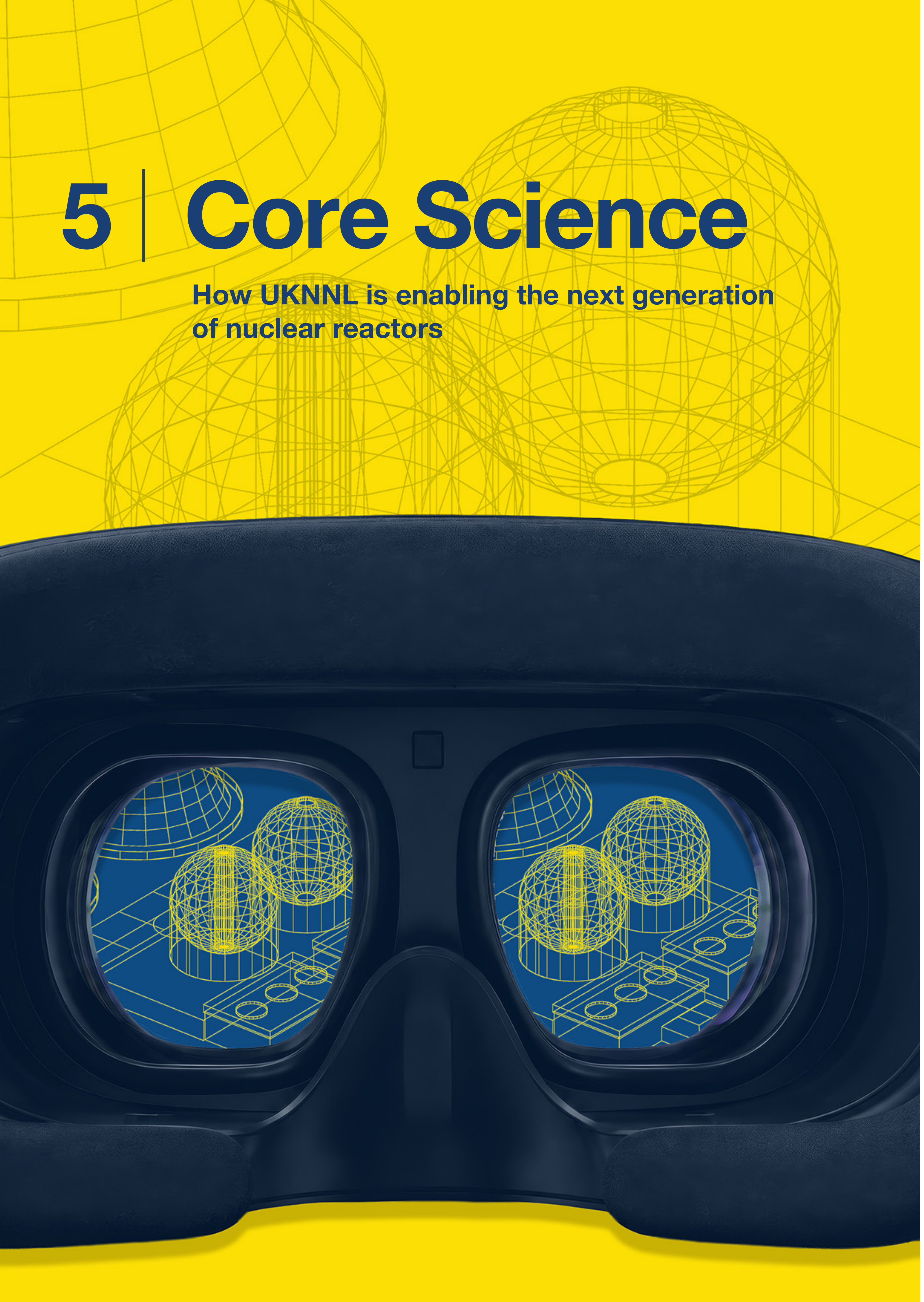
Our work assessed how user-choice of parameters impacted the results, and we provided recommendations for best-practice development of ML models.

The results also demonstrated that prediction quality depends strongly on the data used and that models can become unreliable when applied beyond known conditions – an area where further study is required.

[1] C Cunningham, G Papanikos, (2026) 'Using machine learning to predict reactor pressure vessel embrittlement: Human factors and best practice' Journal of Nuclear Materials, 623, 156416.

5 | Core Science

How UKNNL is enabling the next generation of nuclear reactors



As the UK looks to a new generation of advanced reactors, UKNNL is developing the specialist modelling and simulation tools that allow engineers to test how these new designs will behave under every conceivable condition, contributing to major European programmes and shaping international standards in the process.

Challenge

There is a national need for next-generation nuclear reactors, to help the UK to achieve its net zero goals, safeguard energy security and ensure that the UK remains a world leader in the nuclear sector.

Much of the UK's existing nuclear reactors are expected to retire by 2030, and innovative replacements will be required.

These new reactor types, such as AMRs and Small Modular Reactors, will be an essential complement to renewable energy sources and will help to enable a future energy system that is sustainable, secure, efficient, and technologically advanced.

For new reactors to be built, safety cases, and licensing and design codes, need to demonstrate that they can operate safely, effectively and efficiently.

We typically approach this challenge through detailed modelling and simulation activities, which are used to underpin the performance of the reactor system and wider facility.

The modelling and simulation outputs are supported by experimental data to ensure that we understand how the reactor will behave under all conditions.

Solution

To support the future needs of government, regulators and vendors, arising from the deployment of new reactor systems in the UK, UKNNL is working to ensure it is independently capable in all areas of reactor technology.

This includes reactor chemistry, materials degradation and structural integrity, safety and security, environmental management and decommissioning, spent fuel management, graphite core performance, and modelling and simulation.

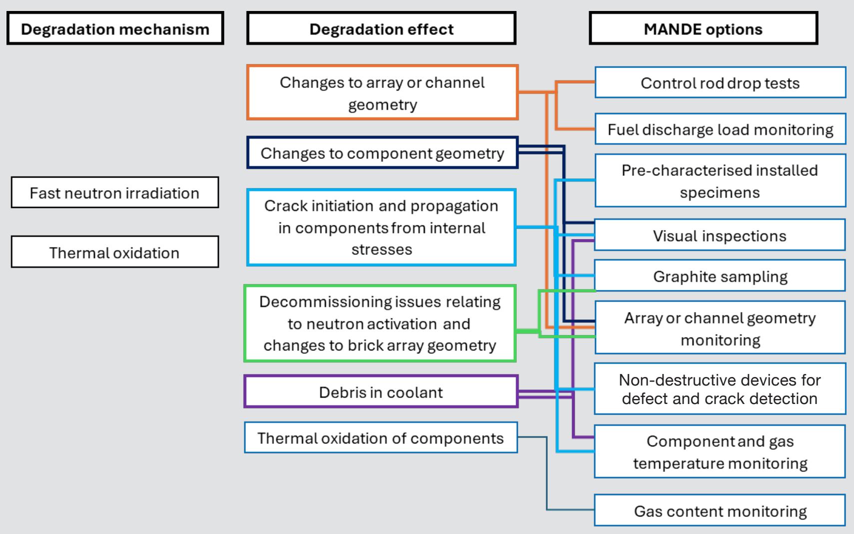
In this case study, we focus on UKNNL expertise in graphite core performance, and modelling and simulation, as both technology areas underpin the safety, design validation and long-term operability of new reactor systems.

Graphite technology

Graphite technology is crucial for accurately evaluating the behaviour of reactor cores during accident scenarios, such as air ingress, where oxidation and structural degradation of graphite can significantly influence heat transfer, fission product release and overall core integrity.

In an air ingress scenario, where atmospheric oxygen enters the reactor core following a depressurisation incident, it is essential to get a full picture of gas coolant temperatures and gas flow paths to properly understand the extent of oxidation in the core support structures, as well as in the fuel. Thermal oxidation in graphite exponentially decreases the structural integrity of the affected parts of the components.

Basis of ASME Code Case N-954: Degradation effects and monitoring and non-destructive examination (MANDE) options



UKNNL completed a study investigating the penetration depth of oxidation at high temperatures for different graphite grades, using fluorescence microscopy.

This work has the potential to support future design and structural integrity assessments under the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.

In addition to contributions to the ASME design code, UKNNL has led the development of ASME Nuclear Code Case N-954 on the reliability and integrity management of non-metallic component components.

As the UK is the only nation that has been operating graphite-moderated gas-cooled reactors for decades, UKNNL has been supporting the development of associated international codes and standards through GEMINI 4.0 and through the NEA activity on Regulatory Frameworks and Technical Approaches for Qualification and Through-Life Performance of Materials in Advanced Reactors.

Modelling and simulation overview

The application of modelling and simulation tools involves creating computer-based models of parts of a virtual nuclear reactor, and testing how it behaves under a range of conditions.

As the UK looks to a new generation of more advanced reactors to help reach the nation's net zero goals, we need cutting-edge tools and expertise to model how these new designs will perform.

The technical challenge is to improve the quality of predictions, through our research and development activities.

In many cases, there is crossover between different areas used to provide a full understanding of the reactor system.

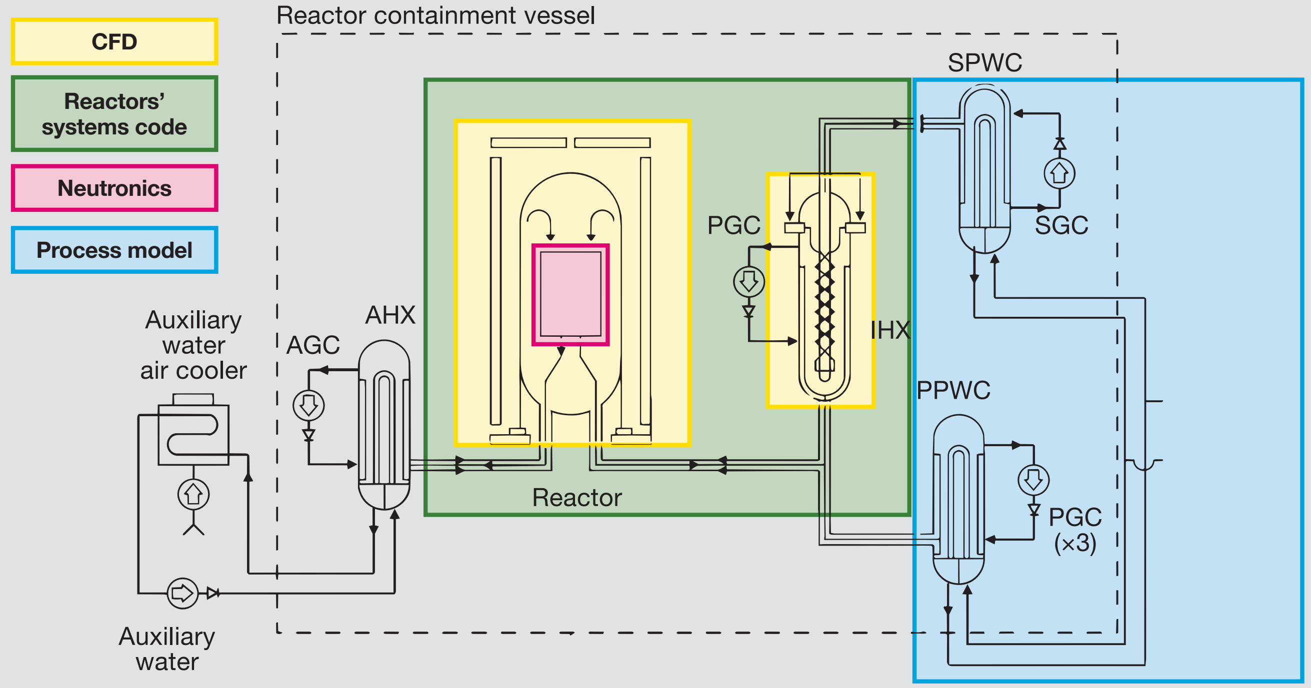
For example, knowledge about materials, such as graphite, will intersect with expertise relating to nuclear physics and thermal hydraulics, helping us to understand the effect of nuclear fission and temperature on the structure.

Reactor chemistry simulations give important insight into the behaviour of metals in the primary circuits of reactors.

Recently, the UK government has been focusing on AMRs, and particularly HTGRs, a design that uses helium gas instead of water to transfer heat and can run at much higher temperatures than traditional reactors.

To meet this need, UKNNL is developing the specialist computer modelling tools and scientific expertise required to support this reactor technology and help ensure the UK has the knowledge it needs to design, assess and safely operate the next generation of nuclear reactors.

Schematic showing the specific focus of modelling and simulation activities and how they fit together in a reactor analysis.



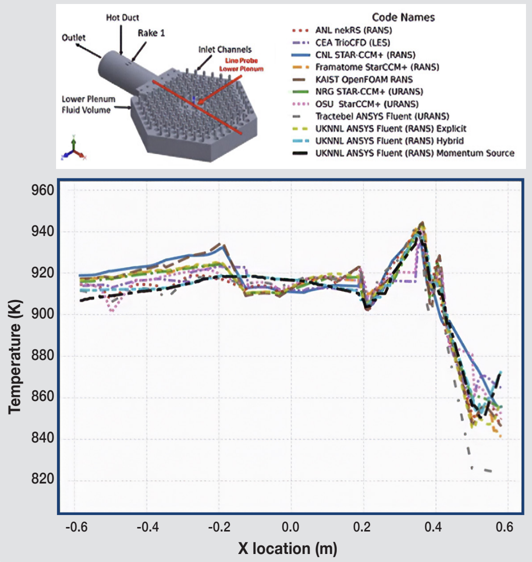
HTGR lower plenum mixing

When the hot helium coolant from an HTGR reaches the bottom of the reactor core in the lower plenum at temperatures of up to 950°C, the temperature distribution can be non-uniform.

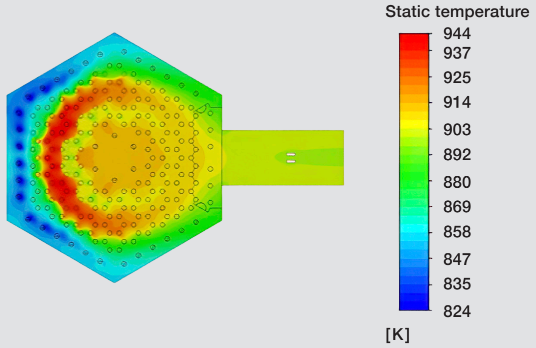
These temperatures can affect downstream metallic structural components. Fatigue can be induced in them during cyclic operations. The integrity of these metallic components is a key part of the safety case, to ensure that no radioactive material is released from the primary circuit.

In addition, at these high temperatures, impurities in the coolant can react with graphite, which can affect the structural integrity of the core support structure and the core itself.

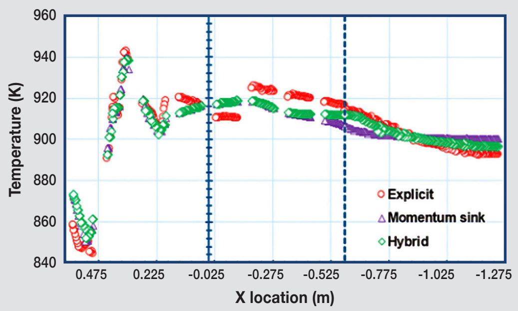
To better understand these conditions in HTGRs, UKNNL has been developing modelling methodology for predicting temperature non-uniformity at the base of reactor cores in two applications: OECD/NEA International Benchmark on HTGR Lower Plenum Mixing and GEMINI 4.0 Thermal Hydraulics.



Predicted gas temperature profiles from Working Party on Scientific Issues and Uncertainty Analysis of Reactor Systems (WPRS) benchmark contributors across the lower plenum



A horizontal plane through the lower plenum showing UKNNL temperature predictions for the WPRS HTGR benchmark



Sensitivity of the UKNNL predicted lower plenum temperature profiles as a function of modelling methodology (including the momentum sink approach) for the WPRS HTGR Benchmark

OECD/NEA WPRS benchmarks

On the international stage, over the past three years, UKNNL has been an active contributor to the benchmark exercises co-ordinated by the OECD/NEA Working Party on Scientific Issues and Uncertainty Analysis of Reactor Systems (WPRS) to determine how well various modelling approaches compare against others.

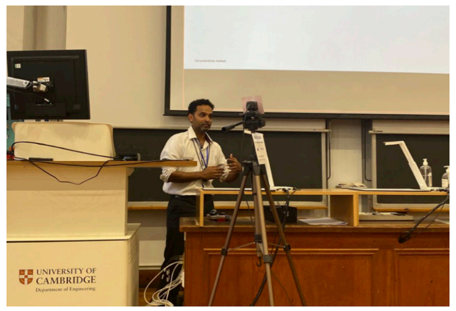
We presented an update on our work in Cambridge at the recent annual WPRS meeting. Regular participation in these benchmarking exercises reinforces UKNNL's global standing and scientific reputation, facilitates collaboration with international reactor thermal-hydraulics experts and enables access to high-resolution experimental datasets for model validation.

In one such benchmarking exercise, computational fluid dynamics (CFD) analysis of thermal-fluid mixing in the lower plenum region of a high-temperature test facility (HTTF) was performed using a novel momentum sink modelling approach.

The novelty of the approach adopted by UKNNL comes from the fact that the models retain fine-scale accuracy while enabling more of the reactor to be covered in a single analysis.

> “ The Nuclear Energy Agency Working Party on Scientific Issues and Uncertainty Analysis of Reactor Systems (WPRS) brings together experts from NEA member countries to advance modelling and simulation (M&S) for current and future reactor technologies through benchmarking and validation activities. Recent progress in new reactor development has led to stronger engagement by UKNNL, which has also helped promote WPRS activities across UK industry and academia, including through the strong UK participation in last year's WPRS benchmarks workshops at the University of Cambridge. Continued UK involvement in the WPRS remains important to ensure that its programme of work contributes to UK strategic priorities. The sustained participation of UKNNL delegates is therefore highly valued and expected to remain mutually beneficial. ”

Oliver Buss
Deputy Head,
Division of Nuclear Science and Education,
NEA



UKNNL thermal hydraulics team members Venkata Ravindra and Georgina Reece presenting at NEA WPRS annual benchmark workshops

GEMINI 4.0

UKNNL's knowledge in HTGR lower plenum simulations has provided key input to the Euratom GEMINI 4.0 reactor project, a European initiative focused on developing and deploying high-temperature reactors to build a low-carbon future for industry.

Our input to this project has included highlighting and reviewing options to circumvent any challenges that are present. The CFD study involved a successful collaboration with thermal hydraulics specialists at NRG PALLAS, the Netherlands.

“ For the European collaborative GEMINI 4.0 project, NRG PALLAS and UKNNL collaborated on an optimisation study for the core outlet region of a HTGR design. By bringing together the thermal hydraulic expertise and modelling capabilities on both sides of the North Sea, numerous optimisation options were studied, resulting in important feedback to the reactor designers. We really appreciated the collaborative attitude and deep thermal hydraulic knowledge of our UKNNL colleagues, without which we would never have achieved the goals of this project. ”

Ferry Roelofs
Account Manager,
NRG PALLAS

Development of reactor physics methods

Reactor physics is used to determine the neutron flux throughout the reactor system.

This, in turn, is used to determine the fuel-cycle length, the fluence (or accumulated radiation exposure) of key structural components and the power/temperature profile throughout the core.

These parameters are used by other codes, such as fuel performance, thermal hydraulics or structural integrity, to underpin their performance.

As part of UKNNL's support for the GEMINI 4.0 project, we were able to verify our reactor physics modelling method for the new reactor design.

Originally, this had been performed using NRG PALLAS's Serpent full core reactor physics model; UKNNL developed a method using Serpent for cross-section generation and CAPP (Core Analyzer for Pebble and Prism type VHTRs) as a core simulator.

The results showed good agreement between the two methods and that, in future phases of the programme, the new method would reduce the modelling and simulation time.

Energy applications

Energy applications represent how the energy of a reactor system could be used to support the UK's net zero transition. Traditionally, nuclear energy has been used almost exclusively for electricity generation, providing a low-carbon source of energy.

For future reactor systems, especially HTGRs, there is the opportunity to produce heat which can be used directly by industry or turned into synthetic fuels, such as hydrogen. Hydrogen can be burnt as a low-carbon energy source, or further refined into products such as sustainable aviation fuel (SAF), thereby further supporting the national energy transition.

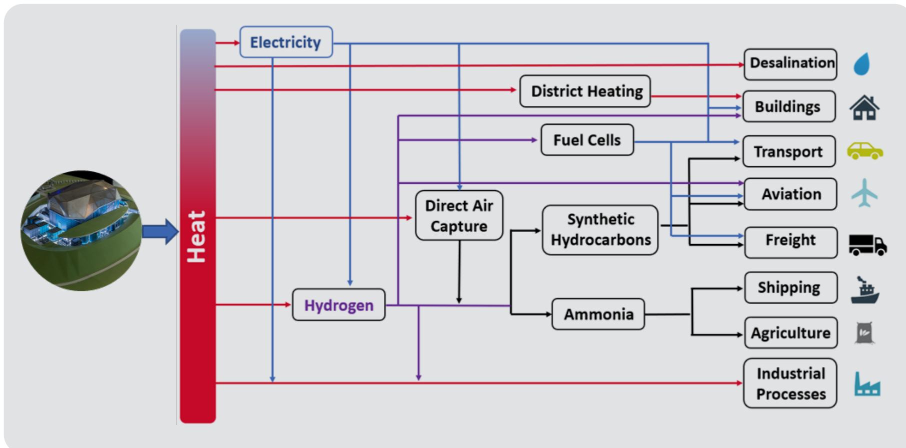
At UKNNL, we have leveraged our capabilities in chemical and process modelling to investigate the technical feasibility, efficiencies and costs of hydrogen production for a wide range of reactor types.

For HTGR, we have supported the GEMINI 4.0 project in developing flow sheets and technology assessments for hydrogen production methods using the copper–chloride cycle, the sulphur–iodine cycle and high-temperature steam electrolysis.

Our modelling methods enable us to understand key parameters, such as the hydrogen produced per unit of energy, which are reflected in the cost per kilogram of hydrogen and other aspects of the business model.

Hydrogen is a key low-carbon energy carrier that is needed to enable the UK's net zero ambition, particularly in sectors that are difficult to electrify, such as heavy industry.

Production therefore needs to scale massively over the next few years, and the feasibility of this is directly linked to the efficiency of the process.



What the future holds

We will continue to enhance UKNNL's understanding of the performance of nuclear reactor systems and their associated facilities, which is key to demonstrating their performance with regard to both safety and economics.

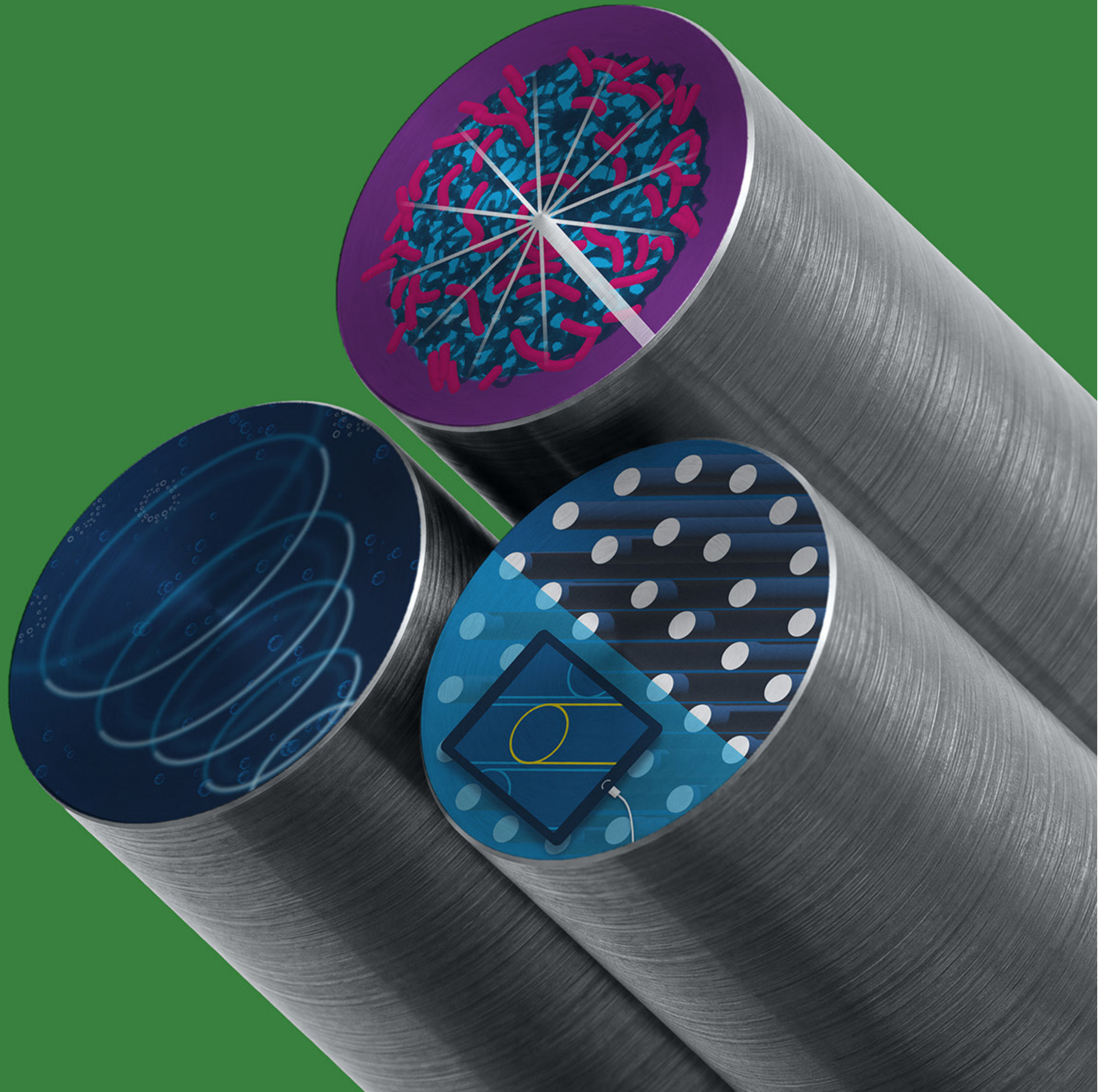
There is an opportunity to leverage the skills developed during our work so far in this area for subsequent UK and international reactor programmes, including Phase B of the UK's AMR programme and the EU GEMINI 4.0 programme.

Continuing to showcase our technical capabilities on the international stage will help build confidence in UK reactor designs and technologies, and ensure that UKNNL remains a world leader in advanced reactor technology. Our memberships of NEA expert groups give us a platform to shape methods, standards, best practice and research agendas, all of which add to the credibility needed for the UK's reactor programme to gain regulatory approval, investment and, potentially, international partners.

In addition, they provide direct access for our early-careers staff to both learn from and contribute to international programmes, thereby reinforcing UKNNL's ability to continue supporting the growth of the UK nuclear sector in the future.

6 | Innovation

Innovation across our Science and Technology Agenda



Innovation sits at the heart of UKNNL's mission. As the UK's national nuclear laboratory for fission, we are responsible for maintaining and advancing national nuclear capabilities and supporting industry to bring new technologies to market, a role strengthened by the 2024 Strategic Review.

Through a challenge-led approach, our bespoke innovation programme has developed technologies that address real operational challenges across the nuclear sector.

We have made, and continue to make, critical breakthroughs for the sector.

For this case study, we highlight projects which demonstrate the breadth and impact of UKNNL's work.

Together, they show how our Innovation team is not just solving today's technical challenges but also identifying, translating and applying new ideas in ways that create lasting value for the business, the sector and the wider world.

A novel approach to decommissioning

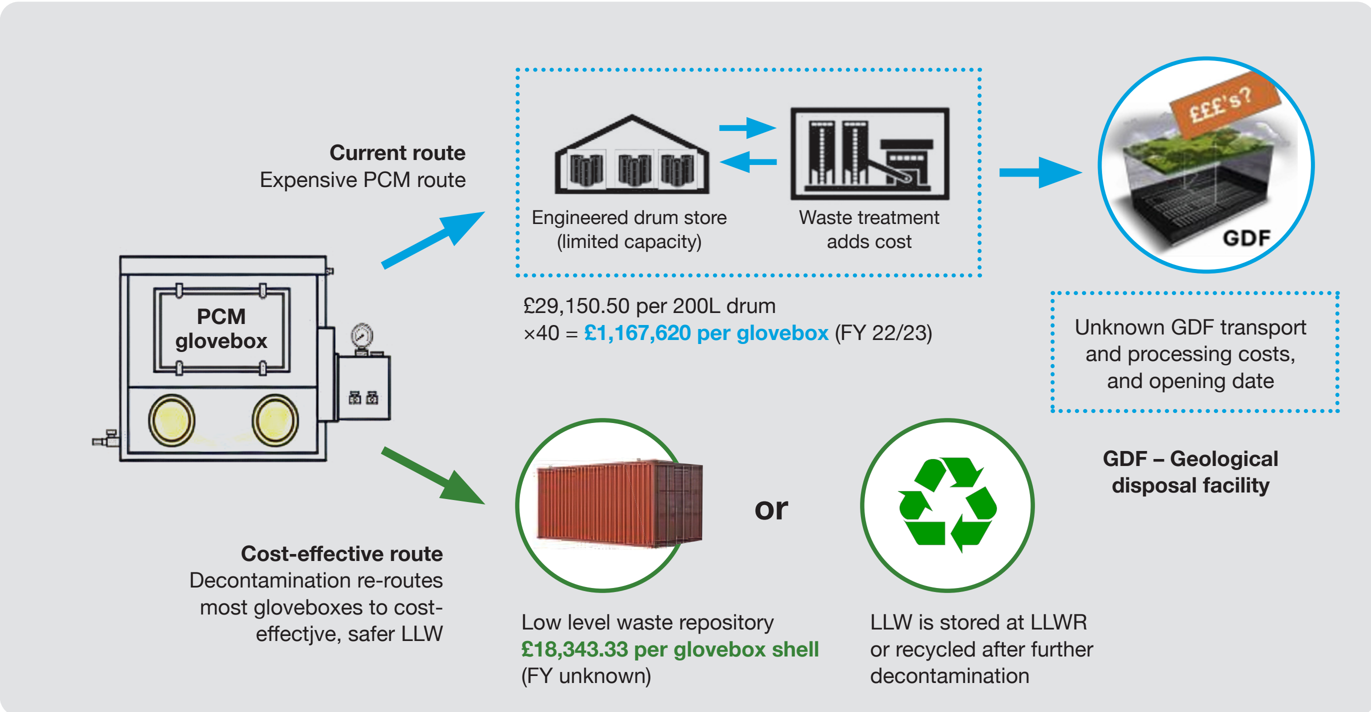
Challenge

Decontaminating nuclear waste is highly complex, particularly where grease, solvents, paints and radioactive residues adhere to pipework and equipment.

Irregular geometries, bends and restricted access make pipes especially difficult to clean, which means that conventional methods often fail.

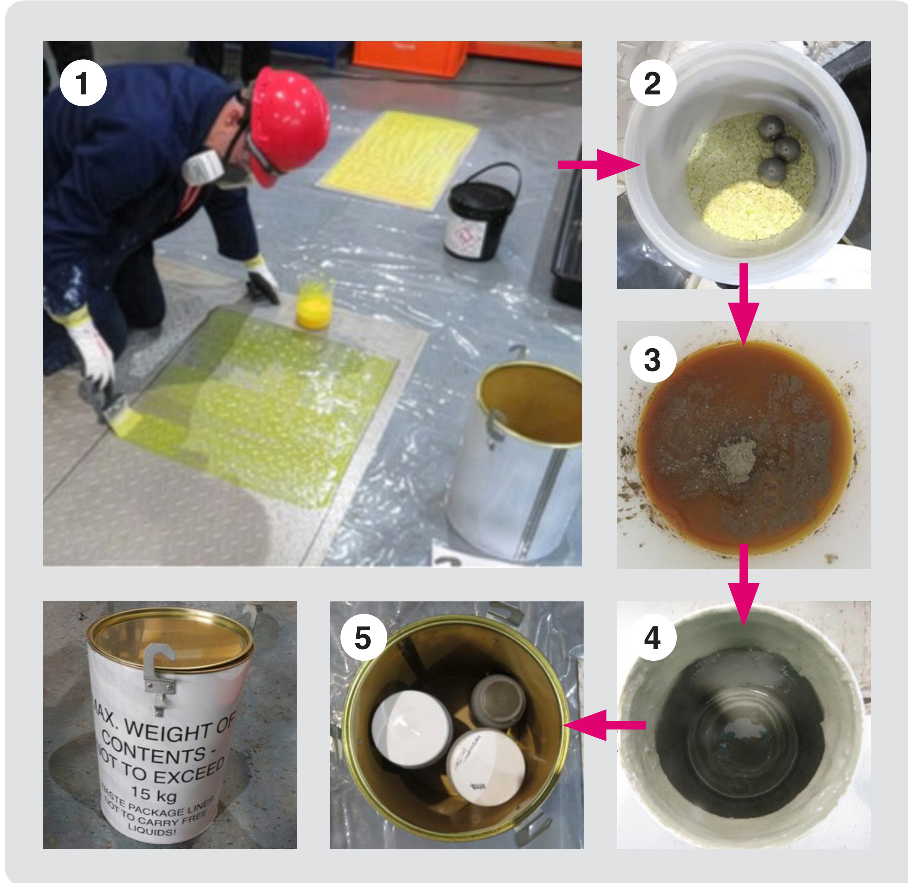
Although ultrasound technologies are proven in other industries (e.g. jewellery, medical devices, automotive), standard immersion bath systems cannot withstand the harsh chemical and radiological conditions, nor can they be deployed effectively in nuclear plant environments.

A more robust, targeted ultrasound solution was therefore required to make the technology viable for nuclear decontamination.



Potential financial savings when using electrochemically assisted surface decontamination (EASD) to decontaminate gloveboxes rather than defaulting to the pPlutonium contaminated material route.

EASD and Aspigel 100E training at Sellafield.
1. Sellafield operator applying the Aspigel 100E
2. Dried gel is collected and crushed
3. Spent gel is neutralised
4. Spent gel is encapsulated
5. All waste placed in MDGWS package



Solution

To address the challenges of decommissioning, UKNNL and partners have developed EASD – an innovative technique that uses an electric current to remove contaminated surface layers in situ.

The removed material can be captured in a liquid or gel, immobilised and safely managed through existing waste routes. The process leaves clean metal that can be reused or recycled, supporting faster and more environmentally responsible decommissioning.

At Sellafield, EASD has the potential to be particularly valuable as facilities enter post-operational clean-out (POCO).

It enables the effective decontamination of diverse metal components, including vessels, pipework, fume hoods and gloveboxes, and enables many items to be reclassified from costly intermediate-level waste (ILW) to low-level waste (LLW) which is much cheaper to process.

What the future holds

We have demonstrated EASD to have a major effect on contaminated gloveboxes.

Sellafield currently has more than 800 redundant units, 350 of which contain plutonium-contaminated material. Traditional ILW disposal costs around £1.2 million per glovebox, whereas EASD-enabled reclassification to LLW reduces this to around £28,000.

This represents potential savings of over £900 million, along with reduced storage pressures and improved waste management.

Operators at Sellafield have already been trained in the method, with further deployment planned.

We have also developed a waste conditioning method using a commercial decontamination gel, Aspigel 100E (from FEVDI/CEA, France), and delivered training on this alongside the EASD training at Sellafield.

Overall, EASD and related methods are powerful tools that can help to significantly accelerate UK decommissioning efforts while minimising environmental impact and reducing long-term liabilities.

Surface decontamination using ultrasound technology

Challenge

Decontaminating nuclear waste is highly complex, particularly where grease, solvents, paints and radioactive residues adhere to pipework and equipment.

Irregular geometries, bends and restricted access make pipes especially difficult to clean, which means that conventional methods often fail.

Although ultrasound technologies are proven in other industries (e.g. jewellery, medical devices, automotive), standard immersion bath systems cannot withstand the harsh chemical and radiological conditions, nor can they be deployed effectively in nuclear plant environments.

A more robust, targeted ultrasound solution was therefore required to make the technology viable for nuclear decontamination.

Solution

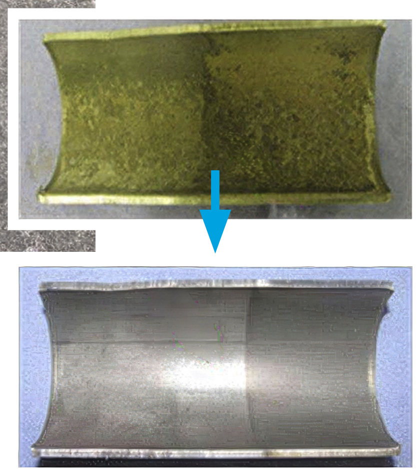
UKNNL's Innovation programme invested to develop a ruggedised ultrasound device that focuses cavitation energy directly onto contaminated surfaces, thereby enabling effective cleaning in confined and complex geometries.

Unlike immersion bath systems, the device can be precisely targeted and is engineered to withstand harsh chemical and radiological environments while remaining deployable in restricted plant settings.

We designed the system in collaboration with engineering colleagues and supply chain partners, and it was informed by operational experience at Sellafield and UKNNL sites.

Testing on both radioactive and heavily fouled non-radioactive pipework demonstrated strong performance across a range of contamination types, and the device is now chemically resistant and submersible in liquid.

This has enhanced the suitability of the technology for decontamination application in a range of settings.



What the future holds

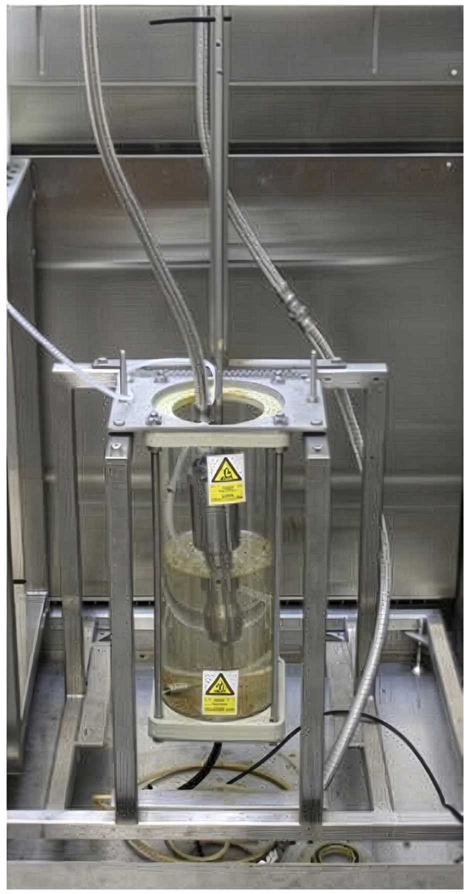
The ruggedised ultrasound device can decontaminate materials in minutes, rather than the days or weeks required by conventional methods, delivering major efficiency gains for waste management operations.

Beyond surface cleaning, it can break down solids to keep them pumpable, thus reducing blockage risks and improving the performance of decontamination agents.

It also enables some wastes to be reclassified and recycled, significantly lowering both cost and hazard across the nuclear estate, and has the potential to become part of a wider decommissioning toolkit.

The programme has helped develop skills for the future workforce through early career talent and opened up new research opportunities, including novel oxidation chemistry applications.

Through the UKNNL Innovation programme, the ruggedised ultrasound device has been externally recognised through an award from the Government Office for Technology Transfer, validating innovation expertise and potential in this space.



Turning nuclear expertise into cancer treatments

Challenge

Almost 3.5 million people in the UK are living with cancer, and many could benefit from new targeted alpha therapies – treatments that deliver powerful radioactive particles directly to cancer cells while sparing healthy tissue. These therapies depend on specific radionuclides, but the UK currently lacks a domestic supply and therefore relies on imports.

Although suitable materials exist within UK nuclear facilities, they are typically stored in ways that make extraction difficult without disrupting decommissioning operations.

Solution

To address these difficulties, UKNNL's Innovation team created REAPER (REcovery of Alpha Patient Enhancing Radionuclides), a modular system that extracts radionuclides from more accessible liquid locations, such as fuel storage ponds or process vessels. This approach reduces waste and radiation exposure and avoids the challenges of accessing solid waste stores.

Initial development included a 3D-printed prototype and the identification of an effective material for selectively capturing strontium-90 from radioactive cooling pond water at the Sellafield site. This strontium can then be processed in UKNNL's active laboratories, to extract yttrium-90, which the radiopharmaceutical sector can incorporate into revolutionary cancer treatment drugs.

What the future holds

The REAPER programme is enabling the UK to establish its own long-term supply chain for medical radionuclides, potentially lasting centuries, owing to the volume of available spent nuclear fuel. It is also developing specialist nuclear and medical expertise, supporting PhD researchers and strengthening partnerships with institutions such as Medicines Discovery Catapult, Queen Mary University of London and King's College London. Together, these efforts position the UK as a current and future leader in advanced cancer treatment development.

Summary

These examples show what can be achieved by applying scientific knowledge and investigation to problems across the nuclear sector.

From solving decommissioning challenges to repurposing our waste for positive purposes, such as improving human health, research programmes and collaborations like these continue to support UKNNL in achieving our purpose: nuclear science to benefit society.

Furthermore, such innovation programmes will continue to provide skills and experience for early-career researchers and contribute to the retention and development of our nuclear know-how.

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