United Kingdom
National Nuclear
Laboratory

NuClear Science: Case Studies

2024–2025

Part of the S&T Agenda

UKNNL Purpose and Mission

What do we do? **Our purpose**

Nuclear science to benefit society

What do we do? **Our mission**

Enable and deliver nuclear outcomes for government	**Support growth of the UK nuclear sector**

How do we do it?

Be a custodian of national capabilities and infrastructure critical for national and energy security	Deliver practical nuclear research and enable decommissioning programmes
Become government's lead civil technical and strategic advisor for nuclear fuels and nuclear materials	Provide expertise and facilities to be a platform for the private sector to accelerate the deployment of technology to market
Carry out research to continue securing the safe operation of nuclear plants domestically and internationally	Champion and nurture advanced nuclear skills

UKNNL Science & Technology Agenda Value Framework

Quality
Delivering world-leading nuclear science and technology aligned to the needs of the UK

Talent
Fostering and supporting diverse and innovative talent

Nuclear Science to Benefit Society

Partnerships
Developing partnerships based on long-term sustainable value

Impact
Developing sustainable (environmental, economic and social) impact for UKNNL and the wider sector

Science and technology is, and always has been, the beating heart of UKNNL.

The Department for Energy Security and Net Zero recently published its review of the UK's National Nuclear Laboratory which outlined our mission: to enable and deliver nuclear outcomes for government, and to support growth of the UK nuclear sector. In this series of Case Studies, we've highlighted how our Science and Technology Agenda is at the forefront of delivering this critical mission.

We continue to be committed to world leading science and technology with our partners and stakeholders to deliver on this mission, through our Science and Technology Agenda.

It is through this agenda we invest in scientific research and unleash innovation, building capability for the UK. This investment is a key part of our work as a national laboratory; it enables us to serve our customers, our partners and our nation better, and play our part in positioning the UK as a global leader in nuclear technology.

Our Science and Technology Agenda is defined by three key pillars – Core Science, Innovation and Strategic Research – all of which are underpinned by Collaboration. In each case study we describe the value generated against our Science and Technology Value Framework: Quality, Talent, Partnerships and Impact and have selected examples which showcase the breadth of work undertaken over the last 12 months.

It's exciting to share these case studies and the value we are delivering in partnership with a range of national and international stakeholders from across academia, industry and government.

Dr Gareth Headdock
UKNNL Chief Science and Technology Officer (CSTO)

Dr Paul Nevitt
UKNNL Vice President Science and Technology

Throughout its history, UKNNL has been a cornerstone in our pursuit of energy security, national security and innovation.

Its contributions have not only supported the safe operation of our nuclear reactors but have also been instrumental in pushing the boundaries of nuclear research and development. The Department for Energy Security and Net Zero published its review of the UK's National Nuclear Laboratory, marking a pivotal moment for the laboratory, sector and, indeed, the nation's scientific and technological trajectory.

UKNNL has been at the forefront of numerous groundbreaking projects. From pioneering advanced nuclear fuel technologies to tackling complex challenges in nuclear waste management and decommissioning, the laboratory has consistently delivered world-class research and practical solutions. The Laboratory's expertise is unmatched with many UKNNL experts recognised as global leaders. This wealth of knowledge and experience is one of our greatest assets and a critical factor in our continued success.

In order to deliver the government's missions of energy security, economic stability, and climate goals, nuclear energy must play a more prominent role. Nuclear power is essential for powering Britain's clean energy future, contributing to the goal of a clean power system by 2030 and accelerating the transition to net zero across the wider economy.

The nuclear sector is evolving to meet these missions.

One of the key highlights of the review is the emphasis on science and technology. The review acknowledges the world-leading scientific capability of UKNNL and recognises the need to sustain and enhance this excellence. It praises UKNNL's role as the UK incubator for nuclear skills, which is essential as we move forward with our nuclear ambitions. By fostering a culture of continuous improvement and innovation, we will ensure that UKNNL remains at the forefront of nuclear research globally.

The review also underscores the importance of practical nuclear research and the development of advanced nuclear skills. As we continue to explore novel nuclear applications, the insights and expertise generated by UKNNL's research will be crucial in regenerating the sector.

UKNNL's role is vital to drive advancements in nuclear energy, support national security and contribute to the global scientific community. Let us seize this moment to reaffirm our commitment to excellence and to the future of nuclear research and innovation.

Professor Paul Monks
Chief Scientific Adviser for the
Department for Energy Security and Net Zero

Contents

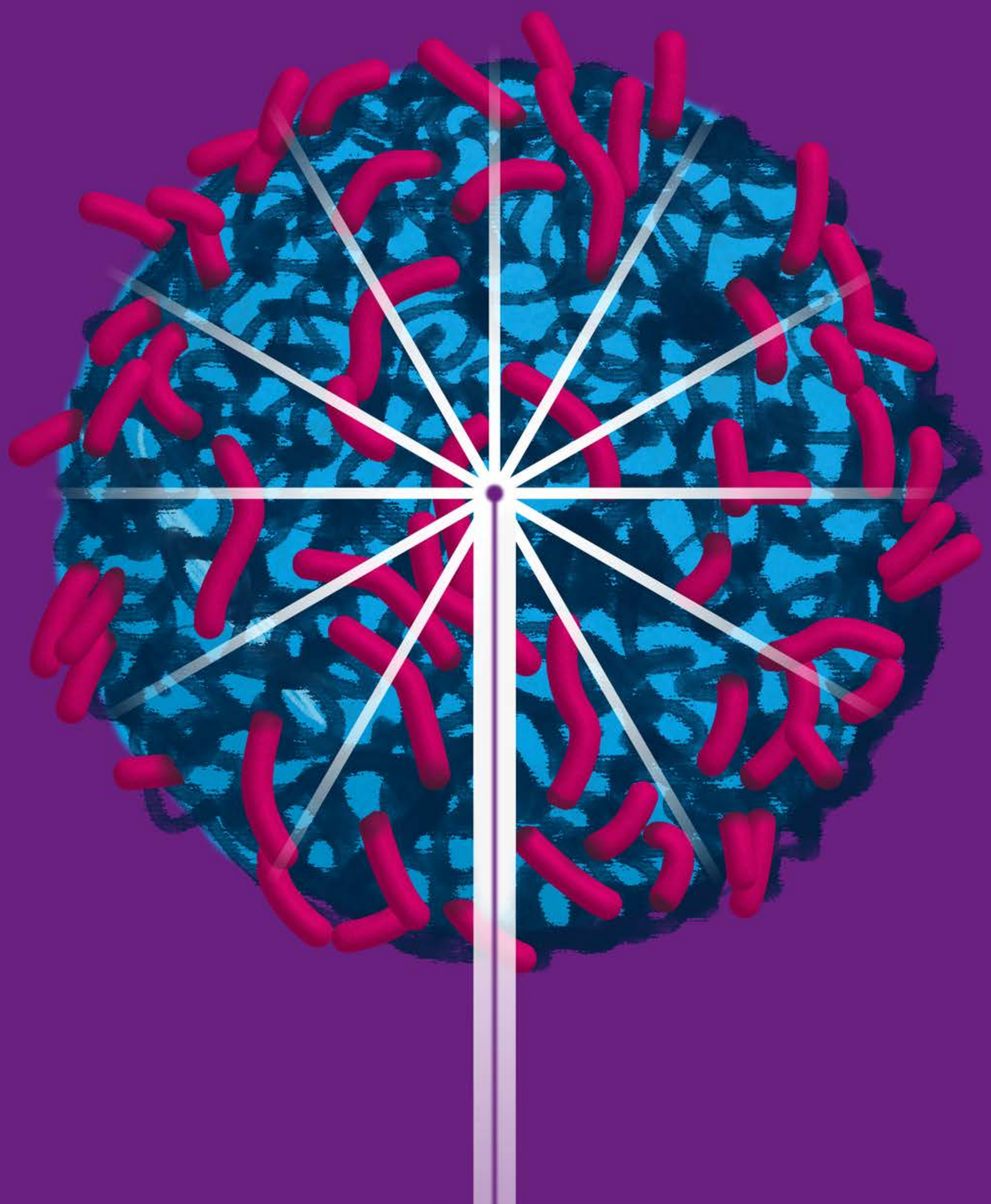
Core Science

Strategic Research

Innovation

1 | Core Science

Securing supply – an innovative production route for medical radioactive isotopes



Research by UKNNL's nuclear chemists has created an opportunity to secure a sustainable supply of sought-after medical radionuclides – instrumental in the diagnosis and future treatment of some of the most serious diseases. These innovative techniques, which extract medical radionuclides from stored nuclear material, could lead to a UK-based supply chain that could meet demand for several hundred years.

The nuclear industry currently stores material containing a wealth of radioactive isotopes that can be extracted for various purposes.

UKNNL is leveraging its skills and expertise in chemical separations, by pairing it with medical expertise at other research institutions to develop a new, secure supply of these valuable assets.

The UK needs a secure supply of radionuclides and UKNNL's research is supporting its development using byproducts from the production of nuclear power.

The need for a home-grown supply of medical radionuclides

The current supply of medical isotopes to the NHS has limited capacity and predominantly relies on importing the radionuclides from abroad. A reliable supply of these isotopes is essential to ensuring medical treatments can be administered rapidly, but building an irradiation facility to create them would take until the 2030s. UKNNL is developing the capability to supply a range of isotopes from existing materials created as by-products from the nuclear fuel cycle. This is a promising production route and supports sustainability through reusing materials.

Radioactive isotopes (radionuclides) are required for a variety of vital medical procedures. One of the most common uses of medical isotopes in the UK is for diagnosing disease by positron emission tomography (PET) scans that provide a detailed 3D image inside the body. PET scans are used for diseases impacting the brain and heart, and to understand the spread of confirmed cases of cancer. Advances in radiopharmaceutical science have identified specific radionuclides that are currently being used in clinical trials around the world to treat cancer, using targeted beta or alpha therapy.

“Precision radiopharmaceuticals present a huge opportunity for the UK to lead the world again in medicinal radiochemistry. Creating these new targeted treatments from stored nuclear waste could transform patient outcomes and give the UK back its domestic radiochemical capacity to serve its patients. To do this, we must invest in the infrastructure necessary to produce the materials and run patient trials.

“Combining MDC’s specialised radiochemistry and drug discovery expertise with UKNNL’s nuclear prowess, this project will accelerate important research to secure a sustainable supply of radionuclides for medicines. Doing so will unlock the development of game-changing treatments for cancer and improve patient lives.”

Professor Chris Molloy
CEO of Medicines Discovery Catapult

UKNNL’s work can develop a secure supply of medical isotopes suitable for a variety of cancer treatments that are being developed by medical research organisations. Not only is the laboratory investing in a route to extract medical isotopes, but it’s also installing a new laboratory which will be used by visiting researchers to develop the targeting molecules. This will help accelerate research into targeted cancer therapy and provide an environment for researchers to hone their skills. UKNNL is working with Medicines Discovery Catapult (MDC) to develop a supply of a specific radionuclide, lead-212, which looks promising for targeted alpha therapy.

NuClear Science in depth: Innovation to create new sources of supply

A range of different by-products from nuclear operations could be used to create a secure supply of medical radionuclides.

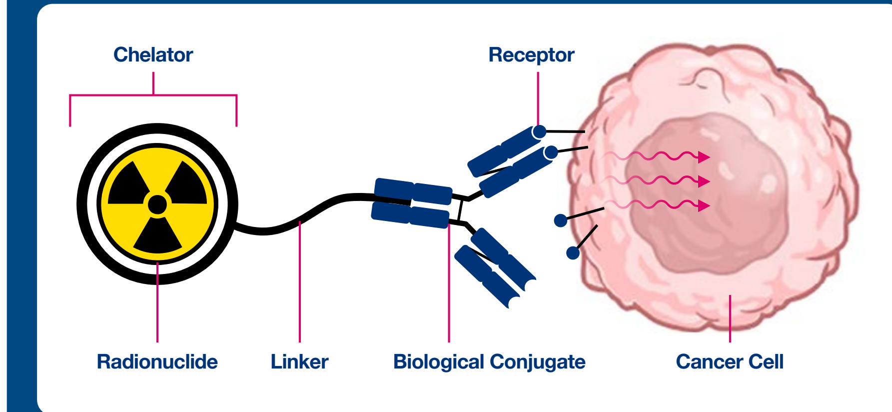
One promising by-product is reprocessed uranium, which is a stored and monitored asset in the UK. As the uranium undergoes natural radioactive decay, many different chemical elements are produced which can be separated and utilised.

To extract the useful radionuclides, a multi-step process dissolves the uranium before extracting thorium-228 (Th) in a set-up known as a thorium cow. The thorium decays naturally over several years, allowing the useful radionuclides – radium-224 which decays to lead-212 – to be extracted periodically.

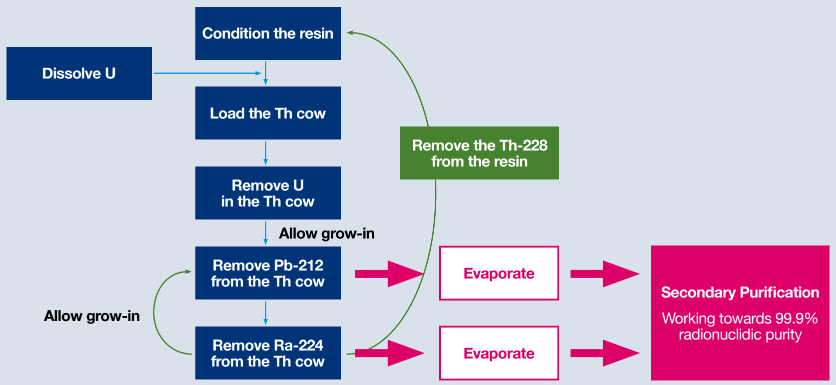
Having demonstrated the success of the thorium cow, UKNNL is now focusing on achieving the purity required for the next stage.

Fuel cycle operations provide a source of medical isotopes

Source	Radionuclide	Products
Reprocessed uranium from the thermal oxide reprocessing plant (THORP) plant at Sellafield, which has historically reprocessed some types of used fuel.	These contain uranium-232 which isn’t present in natural uranium.	It undergoes several nuclear reactions to produce radium-224 and lead-212 which are used in targeted alpha therapy.
One-off residues from the UK’s uranium refinery.	These contain protactinium-231 and actinium-227	Radium-223 and thorium-227 which are used in targeted alpha therapy.
Used clinoptilolite from the Site Ion Exchange Effluent Plant at Sellafield.	This contains a significant amount of strontium-90.	Yttrium-90 which is used in targeted beta therapy.



Targeted alpha therapy can directly treat cancer cells, minimising adverse effects of cancer treatments. This typically employs a ‘construct’: a molecule made up of four distinct parts. The radionuclide is held by a chemical known as a chelator. A chemical linker binds this to a biomolecule (the biological conjugate) which is designed to attach to specific receptors on the surface of the cancer cells. The alpha radiation given off by the radionuclides has a very short range so travels far enough to affect the nearby cancer cells while limiting the radiation dose to healthy cells. Alpha radiation is most likely to do a lot of damage to the DNA of the cancer cell, causing both strands of the double helix to break. Targeted beta therapy uses the same constructs and the beta radiation produced from the radionuclide is suitable for larger cancers that would not be completely penetrated by alpha radiation.



The steps involved in extracting useful medical isotopes from thorium-228

The uranium is dissolved in nitric acid then passed through a solid medium. Certain charged particles (ions) in the solid are exchanged for ions in the liquid. The chemistry is tuned so that only certain ions are exchanged, removing many of the radionuclides that aren’t useful. In our process, uranium isotopes are removed. The remaining liquid holds thorium-228, which also undergoes radioactive decay, leading to useful radionuclides being generated.

UKNNL has developed partnerships with Queen Mary University of London and King's College London to progress the research to this point.

The project is supporting seven PhDs which are looking at more effective ways of identifying useful radionuclides produced from the multiple decay products of uranium, as well as how other by-products of nuclear power plants can be used.

By supporting these PhD researchers, the project is helping to develop the next generation of subject matter experts (SME) and equipping them with specific skills in data mining, chemical separations and more.

In addition, UKNNL is involved in the 'Strengthening the European chain of supply for next generation medical radionuclides' (SECURE) programme, alongside 17 universities and research institutions across Europe.

The focus of this programme is on promising developments in the design of irradiation targets, and production routes for existing and new isotopes in nuclear therapy and diagnostics.

Industrial fellowship supports research to recover useful radionuclides

UKNNL's Samantha Ree is working on techniques to separate the useful radionuclides and has been awarded an industrial fellowship from the Royal Commission for the Exhibition of 1851 to support her PhD research. Samantha's research involves data mining several databases to shortlist potential medical isotopes and she is now assessing multiple industrial sources for their suitability to supply these isotopes.

In addition, UKNNL's Rachel Roberts is undertaking a UKNNL-funded PhD with the University of Manchester on 'Extraction and purification of alpha emitting radionuclides from legacy sources for use in targeted alpha therapy (TAT) of cancers'.

Production of medical radionuclides from nuclear material involves milking a thorium cow.

What the future holds

Research so far has worked with small amounts (around 2 MBq) of thorium-228 which has helped to establish the extraction techniques. The project will soon scale up to 10 MBq which will produce enough radium-224 and lead-212 to conduct in-depth development of the constructs. To support this, UKNNL is investing in a new laboratory where the constructs will be tested by visiting researchers.

Creating a construct requires in-depth knowledge of the chemistry. Optimising the chemical reaction involves considering many variables such as reaction time, temperature, and concentrations of the individual components.

Analysis helps with the optimisation which involves multiple iterations where each variable is thoroughly tested. The new laboratory at UKNNL's Preston site will employ well-known analytical techniques to determine whether a construct is ready for the next stage of trials.

Researchers will be able to test their constructs in our laboratory to find the optimal production regime. In the long term, the knowledge and techniques developed by UKNNL will lead to development of a central production hub to supply the NHS with medical radionuclides from a UK supply chain that could last for centuries.

> "This new initiative is immensely exciting, offering a huge boost to the future of molecular radiotherapy treatment and personalised medicine in the UK. Barts Cancer Institute and Radionuclides for Health UK welcome the leadership that UKNNL is showing on this issue. It is an important step in re-establishing a UK supply of medical radionuclides, securing the future of urgently needed research into new and more effective cancer treatments and making them available to UK patients."

Professor Jane Sosabowski
Barts Cancer Institute
Queen Mary University of London

Radionuclide achievements summary

for the financial year 2024–2025

QUALITY

2 papers published

1 paper submitted

TALENT

7 Supporting **7** PhD projects across **4** university partners

UKNNL mid-career and postdoctoral researchers are attending conferences, training courses and undertaking secondments to King's College London and Queen Mary University of London.

PARTNERSHIPS

3 collaborators

- Queen Mary University of London
- King's College London
- Medicines Discovery Catapult

£1.1m from the UK Government Medical Radionuclide Innovation Programme, supported by

+ **£1m** from government investment into our critical national research and development (R&D) infrastructure

£2.1m total

IMPACT

Finding a purpose for many tonnes of reprocessed uranium, which is currently seen as zero-value as it doesn't have a defined use, could lead to a secure UK-based supply for many of our radiotherapy needs.

Current PhD projects

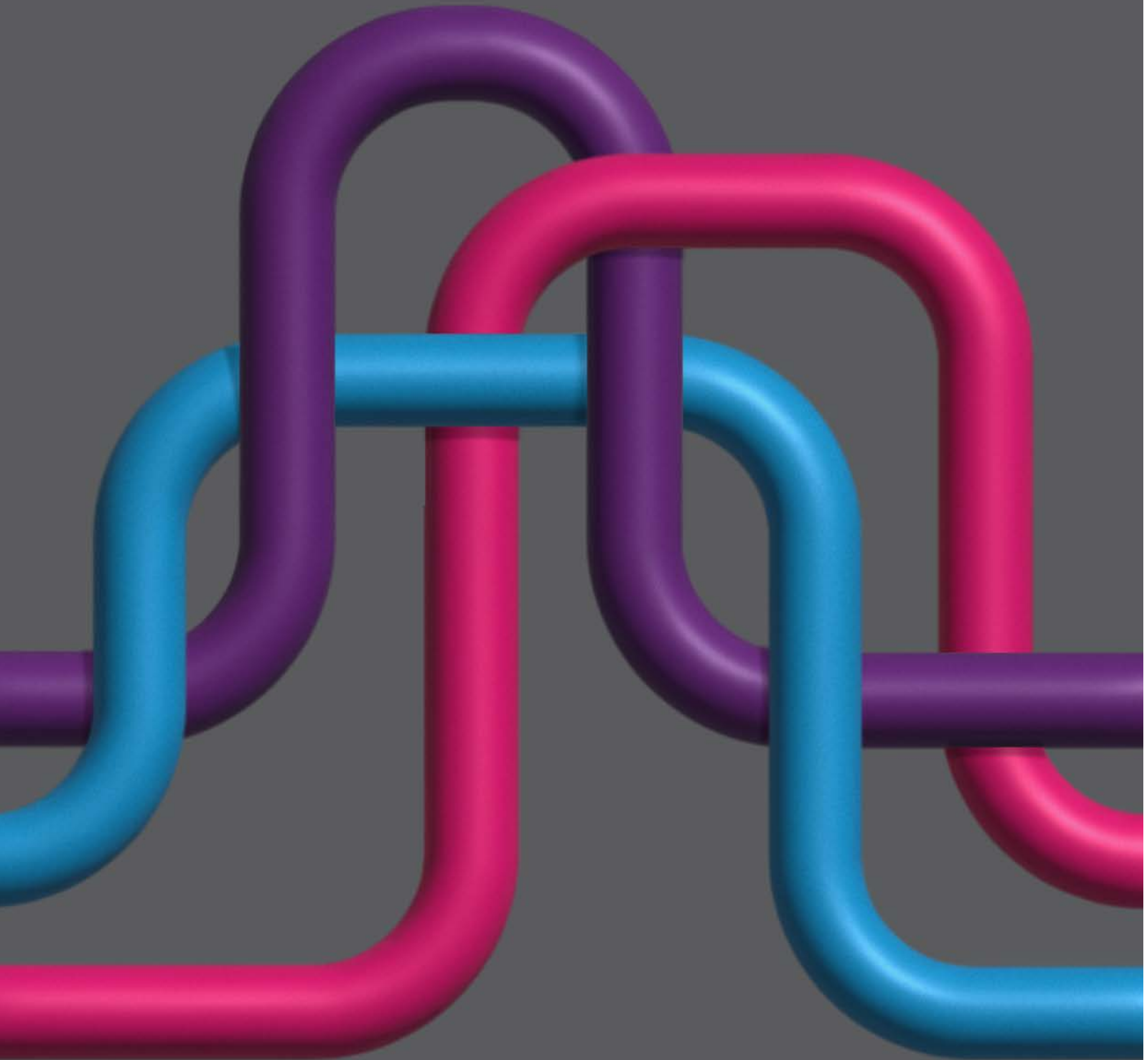
University	Project title	Start date	End date
University of Birmingham	Study of advanced accelerator based production of medical isotopes	01/10/2023	31/03/2027
King's College London	New chelators for diagnostic and therapeutic pairs of radioactive metal isotopes	01/10/2022	30/09/2026
Bangor University	Tailoring the neutron flux in a research reactor to optimise the production of novel medical radionuclides	01/05/2023	31/05/2026
King's College London	Inorganic nanoparticles for radiolabelling with ^{223}Ra / ^{212}Pb, for multimodal imaging and therapy in cancer	01/04/2023	30/09/2026
The University of Manchester	Separation techniques for the recovery of radionuclides suitable for cancer therapy from extant nuclear materials	01/04/2023	30/09/2031
The University of Manchester	Extraction and purification of alpha emitting radionuclides from legacy sources for use in targeted alpha therapy (TAT) of cancers	01/04/2024	30/03/2031
The University of Manchester	Flexible peptide decorated polyamino-carboxylate ligands for selective extraction of radiotherapeutic metals for targeted alpha cancer therapy	01/09/2025	31/08/2029

Publications

Year	Publication title	UKNNL Authors	Journal/Conference	Vol	Pages	Type
2025	Minimising the impact of stable ^{208}Pb on recovery of ^{212}Pb from a generator	Roberts, R. Carthy, T. Young, J. Awogboro, T. Greenwood, H. Sosabowski, J. Heath, S. Livens, F.	EJNMMI Radiopharmacy and Chemistry	10	49	Article - published
2024	Selection of radionuclide(s) for targeted alpha therapy based on their nuclear decay properties	Ree, S. Greenwood, H. Young, J. Roberts, R. Livens, F. Heath, S. Sosabowski, J.	Nuclear Medicine Communications	45	465-473	Article - published
2025	Selection of radionuclide(s) for targeted beta therapy based on their nuclear decay properties	Ree, S. Greenwood, H. Young, J. Maray, L. Roberts, R. Livens, F. Heath, S. Sosabowski, J.	Nuclear Medicine Communications	n/a	n/a	Article - submitted
2025	Production of medical radionuclides through accelerator-driven neutron irradiation	Capponi, L. Awogboro, T et al.	n/a	n/a	n/a	Article – in preparation
2025	Validation of a new irradiated target isotopic composition evolution modelling tool using EU SECURE data	Mayhem, D. Awogboro, T. Mills, R. Maroti, B. Lepore, L.	Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms	n/a	n/a	Article – in preparation
2025	Challenges in novel target development and post irradiation processing for non-reactor routes	Maray, L. Andrews, C et al.	n/a	n/a	n/a	Article – in preparation
2025	Medical radionuclide production in nuclear reactors – Sensitivity analysis to nuclear data	Duque, G. Capponi, L. et al.	n/a	n/a	n/a	Article – in preparation

2 | Core Science

Developing flexible reactor coolant testing facilities to support future reactors



Through a partnership with the University of Bristol, UKNNL is working to test and develop materials and chemistry improvements for both the current and next generation of nuclear reactors. This innovative work means that as new reactor technologies move into detailed design phases, the conditions experienced by materials used in coolant circuits can be optimised, maximising the lifespan of each plant.

The research also has implications internationally as nuclear power continues to be a cornerstone of the global response to the push for net zero.

As the nation embarks on a mission to develop clean, reliable sources of domestic energy, reactor technology will continue to evolve to meet the expected increased demand for both power and heat.

These emerging technologies require extensive research and development. In response, UKNNL has created an advanced testing facility for reactor coolant systems, repurposing existing infrastructure through a partnership with the University of Bristol.

The importance of understanding coolant circuits

Coolant circuits remove heat from the reactor core, where nuclear fission occurs, and transfer the heat as steam to generators to create electricity. Typically, two circuits are used in series to ensure radioactive materials are safely contained.

There is a profusion of different technologies, including many primary coolant types. In some cases, operating experience is limited, often requiring material performance to be inferred from historical test reactor programmes which operated under different conditions or shorter timeframes than required for a nuclear power plant. Designing a modern plant often requires additional data and simulation to predict and validate performance under actual plant conditions.

Additionally, the nuclear sector has a mission to learn from other high integrity and highly regulated industries to adopt innovative technologies to reduce costs and timescales. This is notoriously difficult in such an environment where nuclear safety is an overriding priority. The ability to carry out initial testing of unproven technologies in a lower risk environment which replicates important reactor parameters is a key enabler for successful technology transfer.

By building a testing facility now, UKNNL is supporting future reactor deployment. It also enables its scientists to research technology that will appeal to an international community, while developing necessary skills here in the UK.

NuClear Science in depth: Advanced coolant chemistries for today and tomorrow

The effect of dissolved zinc in primary coolant water on circuit surfaces has been recognised and exploited for several decades, although the mechanisms are not fully understood.

Steels and nickel-based structural alloys, which – aside from the fuel clad – constitute most of the coolant-facing surface area of a pressurised water reactor (PWR) or boiling water reactor (BWR), tend to oxidise very slowly in high-temperature water. However, even at very low rates, corrosion products released at part-per-billion (ppb) levels can interact with the reactor core and lead to increased production of radioactivity which increases waste and dose to the workforce.

In extreme cases, this interaction can lead to build up of thick crud which can affect fuel integrity and core neutronics, causing nuclear safety issues which would result in reactor output being reduced.

Where zinc is present in the coolant (also at very low levels), this is taken up into the alloy oxides and modifies their structure to become denser, more adherent and more protective. In turn, this reduces the corrosion product release rate, effectively ‘turning off’ the main reaction driving this source term.

This effect was originally identified unexpectedly, owing to inadvertent presence of zinc in the primary circuit, and was developed as a mitigation for both corrosion product release and stress corrosion cracking, which can initiate in some alloys in areas of high stress.

To realise the full benefits of zinc chemistry, research work undertaken with the UKNNL’s Bristol facility has examined the interactions of zinc at tens of ppb concentrations on very specific materials.

Samples of steam generator tubes specific to power stations, sampled from the fabrication process prior to installation, were exposed to quantify the differences in uptake and oxide characteristics arising from subtle differences in the fabrication route, but which could prove important in long-term operational performance.

The effect of zinc on advanced materials has also been studied by the Reactor Chemistry and Corrosion team as part of the first zinc exposures of a reduced activation ferritic martensitic steel developed for fusion applications, with similar testing underway of refractory high-entropy alloys.

The work showed that this advanced steel alloy interacted with zinc in a similar way to more conventional materials, paving the way for this chemistry to be applied in PWR-like fusion water coolant circuits of the future.

Securing the effective operation of the UK’s gigawatt nuclear plants

Globally, water is the most widely used nuclear reactor coolant, including the gigawatt-scale PWR in operation at the Sizewell B power plant, and the UK’s most progressed new build project, Hinkley Point C. Water cooling will also be the basis for near-term small modular reactors in the UK.

Teams from the University of Bristol are using UKNNL’s facilities to research the implications of water-cooled nuclear reactors. Hinkley Point C is expected to operate for the next 60 years, so researchers from the University of Bristol are using the UKNNL testing facility to understand the fundamental aspects of very slow corrosion processes. They are using samples from the components that comprise plant in new power stations. These are exposed to high-temperature, high-pressure water in test loops formed of thick-wall pressure vessels integrated with temperature, chemistry and pressure control and measurement devices, to allow a range of conditions to be applied and maintained over weeks and months while coolant is recirculated. Although extensive development has been undertaken internationally to understand the performance of structural materials, the new designs will operate for longer and are expected to perform to a range of new regulatory standards.

“Our partnership with UKNNL on reactor chemistry and corrosion has been a great multiplier of research success. The University of Bristol and UKNNL (as well as EDF) have together developed a capability in chemistry testing for water-cooled reactors (PWR and SMR) and advanced reactors using novel coolants.

“Through small pilot research programmes, we have built the testing and characterisation capability into a nationally important capability, with a number of PhD students and postdoctoral researchers funded on this topic, publications in respected materials and corrosion journals and presentations at international conferences.

“Our work together has enabled collaborations with international partners, and the outputs of our research work have direct impact into EDF’s research and development programme for current and future reactors, informing their safety cases for lifetime extension and new reactor construction, as well as supporting the development of coolant circuits for fusion reactors.

“Our close collaboration with the UKNNL Reactor Chemistry and Corrosion team allows us to be agile to developments in the field, and develop new capability quickly to establish our track record to meet the challenges of future nuclear energy.”

Professor Tomas Martin
University of Bristol

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

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

Coolant testing facilities enable the next generation of reactor technology

UKNNL is working in partnership with the Japan Atomic Energy Agency on the design of a HTGR, which uses helium gas as a coolant. Commissioning a HTGR demonstrator will require underpinning research to understand how high-temperature helium will interact with reactor components.

UKNNL has commissioned a helium loop testing facility at full commercial HTGR temperatures and pressures to support the research needed to understand the processes involved. The facility was built by reusing components from the former Berkeley Technology Centre, close to Bristol, UK. Equipment was originally used in rigs which underpinned lifetime extension of the Magnox nuclear power station at Wylfa, on Anglesey, UK. Wylfa is widely considered the forerunner of a generation of advanced gas-cooled reactors which have formed the backbone of the UK's nuclear generation for decades.

In collaboration with the University of Bristol and EDF Energy, the UKNNL team have completed technology-neutral tests with reference materials representing different reactor components. The results enable understanding of how impurities in the coolant could interact at the microscopic scale and change material properties over many years or decades.

Other organisations are accelerating advanced reactor designs based on a variety of coolants – including lead and salt. It is necessary to evaluate how the differences between coolant options translate into corrosion and coolant chemistry when circulated at high temperatures and pressures around and through the fuel assemblies.

Molten salt reactors are also in development around the world and require coolant testing facilities to increase their readiness to market. Each technology has different requirements but can benefit from expertise in high-temperature testing and characterisation. As the UK's national laboratory, UKNNL is developing a range of facilities to test the chemistry and corrosion of these mixtures, using highly specialised apparatus. This ensures the UK has fully up-to-date knowledge and capabilities for the range of technologies that could contribute to a clean energy future.

NuClear Science in depth: Enabling innovation in component development

A major barrier to the deployment of innovative technologies in the nuclear sector is the difficulty in testing early-stage components in the highly unusual and sometimes adverse conditions of a reactor core and primary circuit. This is particularly true for fluids which have very specialised handling considerations such as helium, molten lead and molten salts. By providing apparatus where early-stage components can be tested before they are ready for on-plant deployment, we can significantly reduce development time and lower technical risks. Examples of this have included the demonstration of high-temperature ultrasound transducers in molten lead, which allowed the first three-dimensional imaging in this coolant. Seal material testing is another significant consideration for high-temperature systems and has been addressed through developing assemblies where material performance can be established under a high differential pressure, as well as representative temperature conditions. A wireless digital implementation is currently underway with the aim to underpin eventual use of resilient communication protocols for plant sensing and control.

Impact – learning from the past to underpin the future

Work at the testing facility builds on decades of experience gained by operators across the nuclear industry. It will provide the information to predict plant operational lifetimes or support plant life extension.

Our partnership with the University of Bristol not only supports world-class science but also provides a valuable skills pipeline. This leverages other tasks within the Reactor Chemistry and Corrosion theme, including an "excellence in reactor chemistry" initiative which has included compilation of multimedia training resources from lifetime experts particularly in light water reactor primary chemistry and steam/water secondary circuits. This complements the experience available from running exposure tests at the coolant facility.

The University of Bristol offers one of the UK's few postgraduate master's courses on nuclear science and engineering. It has an enviable record of student entry into the nuclear industry, including PhDs. In fact, UKNNL has recruited some of the students who used the testing facility in their studies.

The testing facility is a valuable resource for both UKNNL and researchers from universities across the UK. It provides a rapid response to emerging research challenges and facilitates knowledge transfer to a new generation of scientists. UKNNL's testing facility provides easy access for researchers and has typically hosted the research work of up to four PhD and post-doctoral researchers concurrently. Partnerships both now and in the future will enable innovations that will further strengthen the sector and attract new talent.

Developing advanced testing regimes to support innovation

Coolant systems are also required for fusion reactors, with high-temperature water being one of the frontrunner coolants, where the fusion industry will benefit from the decades of operational experience gained from water-cooled fission reactors.

UKNNL is working alongside the UK Atomic Energy Authority (UKAEA), responsible for developing the UK's fusion technology. Fusion programmes are using a range of complementary water testing loops under national and international programmes (e.g. EUROfusion) to develop a suitable water chemistry to build confidence in the durability and performance of the facing structural alloys.

UKNNL built a bespoke module to enable testing, applying very high magnetic fields to simulate the plasma confinement systems in a tokamak. It has provided the first data on high magnetic field influence on advanced reduced activation steel in a representative cooling circuit environment.

UKNNL has also worked on various test methodologies for accelerating material development, such as the use of in situ miniaturised stress/strain rigs and surrogate ion irradiated materials in high temperatures.

The team is also working with another University of Bristol-led international partnership to develop a unique high-temperature atomic force microscope.

Having these facilities means that UKNNL can engage with a range of research initiatives, including the collaborative European EUROfusion programme and the UK Government's Advanced Modular Reactor Research and Development programme, supporting the deployment of these reactors to contribute to net zero goals.

The joint coolant testing facility at University of Bristol, showing the cells containing high-temperature, high-pressure water and helium apparatus, heater controllers and monitoring instrumentation.

Part of the high-temperature, high-pressure water test loop showing the hydrogen injection system, conductivity monitoring and heater controllers.

Core Science achievements summary

for the financial year 2024–2025

QUALITY

9 publications

TALENT

5 PhDs supported

2 across 2 university partners

PARTNERSHIPS

Participation in international programmes

€5m THEMIS (Nuclear Energy Agency of the Organisation for Economic Co-operation and Development programme: €5m, 12 countries – finished in 2024)

UNENE network of Canadian universities, industry, government and international institutions dedicated to excellence in nuclear science and technology.

Working with Universities: Bristol, Manchester, Guelph, Coventry and Birmingham.

IMPACT

1 Facilities developed by the theme currently in use **supporting UK PWR and HTGR programmes**

2 Novel work demonstrating the impact of **zinc addition and magnetic fields** on an advanced alloy in **high-temperature water**

3 Contribution to technical basis for **fusion circuit water coolant chemistry**

PhDs supported by UKNNL

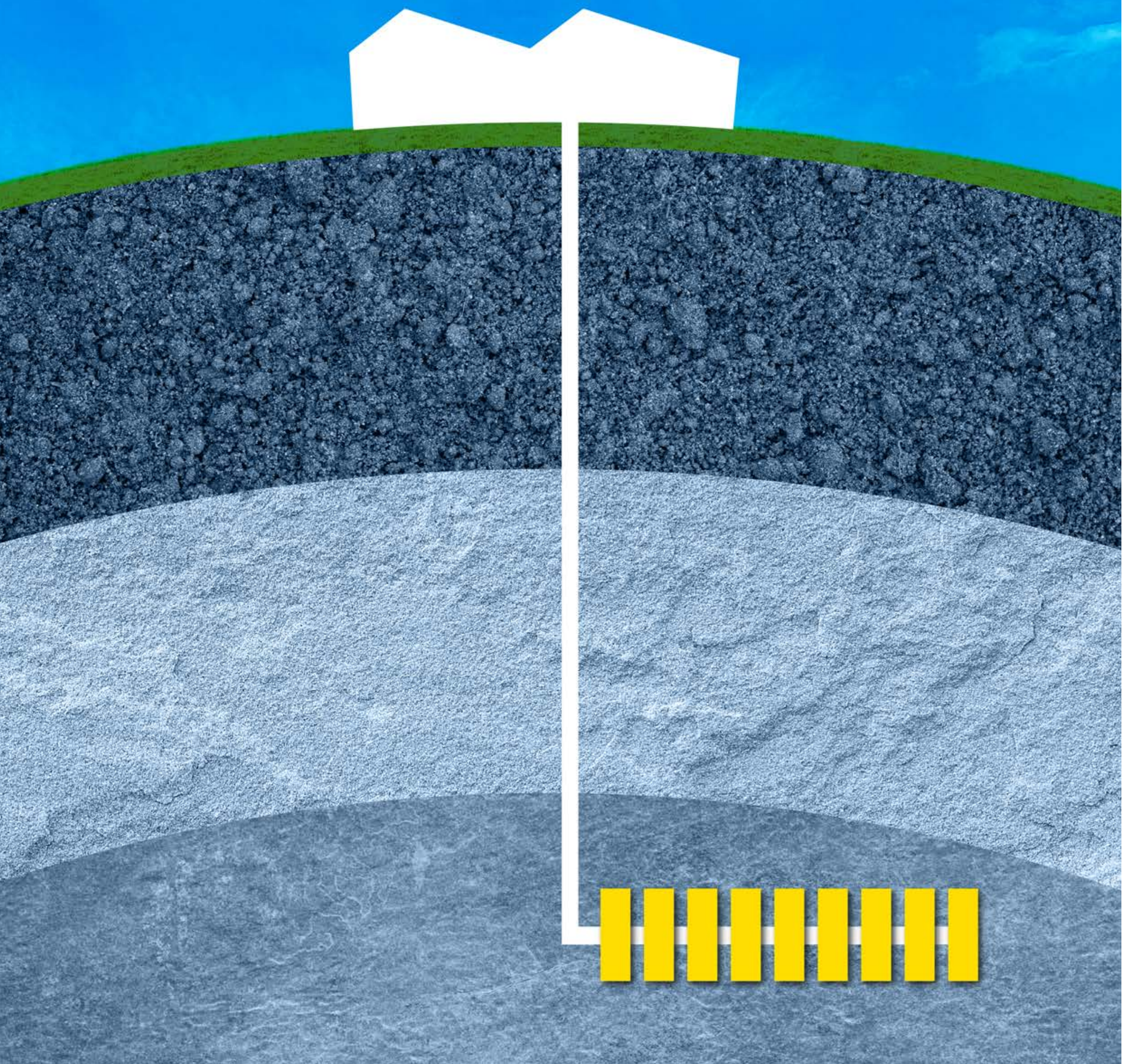
University	Project title	Start date	End date	Other partner
University of Bristol	Corrosion behaviour of fission and fusion relevant alloys in high temperature lead based coolants	01/10/2021	30/09/2025	UKAEA
The University of Manchester	Utilising X-ray tomography techniques to measure oxide solubility in high-temperature, high-pressure environments	01/10/2018	31/10/2024	
The University of Manchester	Printed graphene based sensors for real-time and wireless monitoring of nuclear waste storage	30/09/2021	01/08/2025	NDA
University of Bristol	Effect of cold work and Zn water chemistry upon the corrosion behaviour of Alloy 690 under simulated pressurised water reactor primary water conditions	01/10/2020	30/09/2024	EDF R&D UK
University of Bristol	The effect of zinc addition on structural alloy oxides under PWR primary conditions	01/07/2025	31/07/2029	EDF R&D UK

Publications

Year	Publication title	UKNNL Authors	Journal/Conference	Vol	Pages	Type
2025	Under the microscope: Reduced activation ferritic martensitic steel Eurofer-97 following ion-irradiation and high-temperature high-pressure water exposure	Clark, R. Kumar, D. Hawes, J. Burrows, R.	Journal of Nuclear Materials	605	155527	Article
2025	An in-situ corrosion small punch test for developing stress corrosion cracking in stainless steel	Clark, R.	Experimental Mechanics	65	893	Article
2024	Microstructural analysis of ex-service neutron irradiated stainless steel nuclear fuel cladding by high-speed AFM	Burrows, R. Hambley, D.	Journal of Nuclear Materials	600	155265	Article
2024	The transient thermal ageing of Eurofer 97 by mitigated plasma disruptions	Kumar, D.	Materials and Design	244	113207	Article
2024	First ionization constant of phosphoric acid and of acetic acid in H_2O and D_2O from T = 373 K to 573 K at p = 11.5 and 20 MPa by AC conductivity methods	Arcis, H.	Journal of Solution Chemistry	53	91	Article
2024	Demonstration of an ultrasonic imaging system for molten lead	Hawes, J. Knapp, J. Burrows R. Montague, R. Walters, S.	Nuclear Engineering and Technology	56	1460	Article
2024	Revised Parameters for the IAPWS Formulation for the Ionization Constant of Water Over a Wide Range of Temperatures and Densities, Including Near-Critical Conditions	Arcis, H. Dickinson, S. Lee, C.	Journal of Physical and Chemical Reference Data	53	023103	Article
2024	Achieving wetting in molten lead for ultrasonic applications	Hawes, J. Knapp, J. Burrows R. Montague, R. Walters, S.	Nuclear Engineering and Technology	56	437	Article
2024	Reactivity of quasi-free electrons toward N3− and its impact on H_2 formation mechanism in water radiolysis	Sims, H.	Physical Chemistry Chemical Physics	26	11604	Article

3 | Core Science

Radioactive waste disposal



Safe and secure long-term disposal of the UK's nuclear waste is a national priority. Research by UKNNL's teams is providing insight to support the location and design of future radioactive waste disposal deep underground. At the same time, these projects are nurturing nuclear skills in the future workforce and scientific community through collaborations with universities across the UK and by funding research projects aligned to this critical national mission.

Two major projects are underway. The UK Research and Innovation GeoSafe project is investigating the geology of potential locations for a geological disposal facility (GDF). The National Nuclear User Facility project is assessing low-carbon cement formulations for waste encapsulation – critical to containing and storing nuclear waste.

This case study gives more detail about both projects and the concept of a geological disposal facility, linked to the UK's nuclear power generation heritage.

Leveraging expertise and building UK capability to support national priorities

It is a critical national mission to develop an understanding of how and where nuclear waste can be disposed in the long term. The current plan is for it to be permanently disposed of in a GDF to ensure that the waste is isolated and passively contained away from human intrusion.

As the UK Government's lead civil nuclear fission laboratory with a wealth of experience across the nuclear fuel cycle and world-class facilities, UKNNL launched a disposal research theme in recognition of this nationally significant infrastructure project.

Aligned to UKNNL's recent strategic review, the disposal theme will help play a fundamental role in accelerating the UK to net zero, by delivering cutting-edge innovation and demonstrating new nuclear technologies.

The process of siting, designing and constructing a GDF is one of the UK's largest environmental protection programmes.

In support of the GDF mission led by Nuclear Waste Services (NWS), UKNNL's research will focus on the interaction between waste forms, engineered barrier systems and potential host rock environments.

Research teams collaborate across UKNNL to investigate a range of radioactive waste management and disposal topics. They also collaborate with universities, the supply chain and other critical public sector research establishments, such as the British Geological Survey.

A key output of the disposal theme is bolstering future skills within the UK to aid in developing capacity and capability within the UK where there will likely be increased future demand because of the long-term requirements of the UK GDF programme.

To achieve this, the disposal theme is working with the Nuclear Decommissioning Authority (NDA), NWS and the Department for Energy Security and Net Zero to nurture early career development. The programme will foster new skills through impactful science and engineering aligned to delivering national priorities.

NuClear Science in depth: Future-proofing disposal

We can expect significant environmental and societal change over the lifetime of a GDF. The UK landmass may experience renewed glacial periods or even new civilisations after GDF closure and therefore it must be able to withstand such changes. To achieve this, a GDF is comprised of several natural and engineered barriers which provide defence in depth; this is known as the multi-barrier concept.

Waste which has been mixed with cement (grouted) or turned into glass (vitrified) is packaged in a metal container. This is placed underground, surrounded by a buffer of breathable materials which allow potential gas to escape to avoid overpressure (e.g. from the corrosion of steel or radiolysis of water). The underground disposal location needs to be a natural low-permeability rock, known as a host rock, with little to no groundwater movement to isolate the wasteforms and remove the potential for naturally occurring radionuclide transport pathways.

There's plenty of evidence about the long-term efficacy of the types of materials that may be used in a UK geological disposal facility. The pristine preservation of ancient glass and ceramics uncovered by archaeologists, and oil and gas trapped in rock for tens of millions of years show us what is possible. Understanding these processes gives confidence on how engineered and natural systems could operate in unison to isolate waste for hundreds of thousands of years.

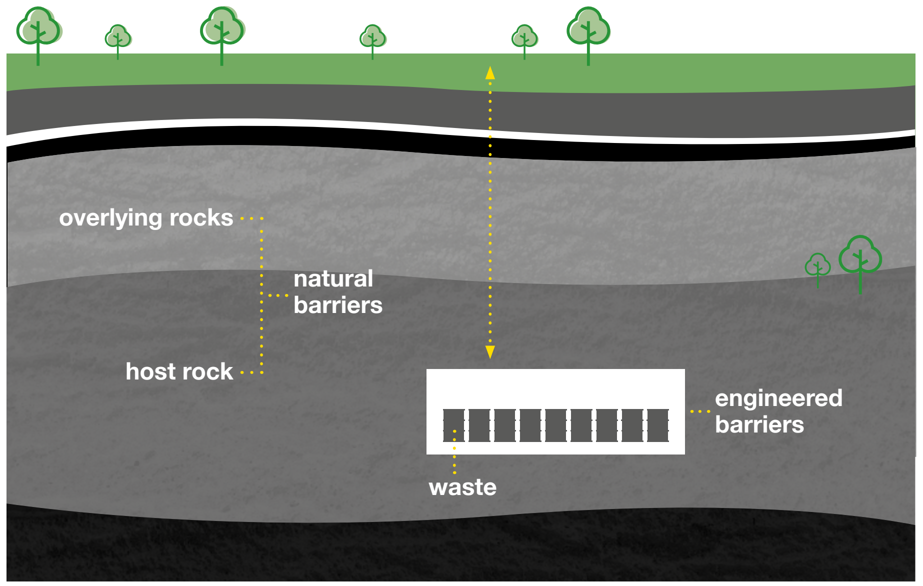
To be successful, it's critical that all aspects of the multi-barrier concept work together. For example, if groundwaters are salty then the appropriate materials for the GDF design must be selected to withstand this kind of harsh environment.

Pioneering Nuclear means managing legacy waste

As a pioneer of nuclear technology, the UK has been producing and managing radioactive waste on an industrial scale since the 1940s. Currently, the UK's most hazardous radioactive waste is stored in ageing nuclear fuel storage ponds and waste silos which were not designed to store waste indefinitely.

How the UK Government, led by the NDA, chooses to manage and dispose of this inventory has sparked debate within scientific, political and societal spheres. Key challenges include safety, environmental impact, security (including nuclear proliferation), cost, deliverability and a shortage of both technical and non-technical critical skills.

Aligned to international best practice, the UK Government's plan is to immobilise and dispose higher activity radioactive waste without further human intervention (known as passive containment). It will be contained in a GDF between 200 metres and 1000 metres deep underground for hundreds of thousands of years.



Geological disposal facility (GDF)
Source: NWS - Science File - The multi-barrier approach

Geosphere characterisation and evolution: GeoSafe project

UKNNL is currently participating in research projects to aid in characterising two end-member UK mudstone units that may act as future host rocks for a UK GDF.

The Jurassic Ancholme Group mudstones, found in the deep geology off the coast of Lincolnshire, are relatively well understood and similar to potential European GDF host-rocks like those in France, Switzerland and Belgium. By contrast, the Triassic Mercia Mudstone Group, found in the deep geology off the coast of west Cumbria, is more complex as it also contains a wider range of potential rock types, such as mudstones along with rocks formed by the evaporation of saline solutions, known as evaporitic rocks.

Importantly, both potential host rocks have a history as caprocks to multiple oil and gas fields, meaning we know they have the capacity, under the right conditions, to hold back fluid for hundreds of millions of years – longer than required for a GDF.

However, more robust understanding is required to ensure the potential GDF host rocks are feasible. As part of the GeoSafe consortium led by Imperial College London, UKNNL will undertake fundamental research that will advance NWS's understanding of the potential effects of a GDF on potential host rock environments.

Research outputs will be integrated to help inform the siting process and design of the GDF.

Specifically, UKNNL's teams are conducting research related to subsurface characterisation and coupled-process reactive transport modelling to better understand how contaminants may move through the host rock and engineered barrier environments over GDF timescales.

In addition, as part of our commitment to champion and nurture advanced nuclear skills, and as custodian of national capabilities, UKNNL is also investing in several PhD projects that will further bolster the GeoSafe team.

> “Working with UKNNL during my PhD project is incredibly beneficial for both my personal and professional development. My UKNNL supervisors have vast knowledge and experience with characterising and modelling properties of key rock units in the UK, which helps guide my project into very interesting research avenues and their support and guidance is invaluable to me.”

Holly Mills
PhD student (UKNNL-funded)
the University of Manchester

The research in detail

In the geological containment part of the GeoSafe project, UKNNL is carrying out novel research, as well as funding additional PhD research at the University of Liverpool and The University of Manchester, to better understand how small to large-scale (sub-mm to several km) variability in the Mercia Mudstone Group may impact its ability to isolate fluid and contaminants. Research includes studying rock outcrops across the UK, studying legacy boreholes, and building geological models as inputs to reactive transport models.

The contaminant pathways part of the GeoSafe project will see UKNNL leverage its world-class radiochemistry and geochemistry expertise (built up in partnership with the Environmental Radiochemistry research theme under our Core Science programme), to build a mechanistic understanding of how radionuclides and non-radioactive contaminants may migrate within lower strength sedimentary rocks (LSSR) over hundreds of thousands of years.

UKNNL is working alongside Heriot-Watt University to investigate the interactions between chemical reactions, fluid flow and mass transport phenomena like advection, diffusion and dispersion in the mathematical modelling part of the GeoSafe project. The ambition of this work programme is to improve our understanding of how these complex interactions influence the behaviour of the fluids and solutes.

> “Collaborating with UKNNL on waste disposal has been an immensely rewarding experience, broadening my perspective on research areas and challenges and helping with my career development. Throughout the projects we have worked on together, I've gained valuable insights into many waste management techniques and a comprehensive understanding of the complex issues faced by the nuclear industry, along with the critical scientific questions we aim to resolve. I am grateful that my expertise can contribute to advancing solutions in the nuclear sector, and I look forward to a continued partnership that fosters further growth and discovery.”

Dr Lin Ma
Senior Lecturer
the University of Manchester

Future of encapsulants and engineered barrier systems: NNUF project

The UK nuclear industry, until recently, has relied on bespoke carbon-intensive cements for some waste forms. The industry is evolving rapidly to use lower carbon variants, both to encapsulate waste and as part of the GDF.

Hypersaline groundwater conditions may also be present within the Mercia Mudstone Group, creating a chemically aggressive environment for cement-based materials.

In partnership with The University of Manchester and Lancaster University, UKNNL is working on two projects funded by the National Nuclear User Facility (NNUF):

- Encapsulation of uranium metal in traditional and lower-carbon cement formulations: these experiments will investigate the corrosion of uranium metal, using advanced three-dimensional imaging to look at the interaction between the uranium and different low-carbon cements over time.
- The effect of different groundwaters to understand the interaction with different cements: low-carbon and traditional cement forms will be exposed to three groundwater compositions (high salinity, high sulphate and high carbonate). This will assess the viability of low-carbon cements and advance knowledge of how different cements work as encapsulants as part of the wider engineered barrier system.

Impact

UKNNL is building an independent body of practical nuclear research that will help NWS's decision-making about which location(s) are suitable for GDF and the design of the facilities.

The results of this research will help ensure potential host rocks can provide a safe, secure and permanent home for the UK's most hazardous nuclear waste, and low-carbon technologies can be used when viable to reduce the sector's carbon footprint.

The collaborations and commitment from this work will grow the next generation of technical experts through investing in people in their early careers, as well as at undergraduate and postgraduate level. This will ensure today's decisions can be safely and securely implemented by future experts.

> "The UKNNL Disposal Core Science Theme team contribute to a range of NWS projects across several topic areas. These include PhD programmes aimed at developing geological understanding of materials across a range of scales, and other projects aimed at developing tools and techniques to understand groundwater geo-chemistry processes. This work has contributed to Nuclear Waste Services' knowledge base on material properties relevant to a UK Geological Disposal Facility."
>
> **Andy Wiseall**
> Senior Geological Operations Manager
> Nuclear Waste Services

Disposal science achievements summary

for the financial year 2024–2025

QUALITY

4 journal publications

1 journal publications under-review

Award: 1st Place
UKNNL received 1st place for best poster presentation at the UK Project on Nuclear Issues at the Royal United Services Institute on the case for a GDF in the UK

TALENT

MSc completed 1

PhDs completed 2

PhDs in-flight 4

PARTNERSHIPS

£5m — Co-investigator on a £5m UK Research and Innovation project entitled "Derisking geological disposal in lower strengths sedimentary rocks," in collaboration with several UK universities and the British Geological Survey (BGS).

€4m — Co-investigator on a €4m EURAD-2 project, entitled "radionuclide mobility under perturbed conditions," in collaboration with 32 international groups from 13 countries.

£150k — Successful National Nuclear User's Facility (NNUF) large project application (£150k) entitled "Screening of Future Low Carbon Cement Powders for Nuclear Waste Disposal," in collaboration with The University of Manchester and Lancaster University laboratories.

£800k — Encapsulation Integrated Research Team (EIRT) £800k , A joint programme with researchers from UKNNL, Sellafield Ltd, TÜV SÜD and the University of Sheffield

Partnerships:
University of Aberdeen, The University of Manchester, University of Liverpool, Imperial College London, Heriot-Watt University, University of Leeds, University of Lancaster, BGS, GTK (Finland).

IMPACT

The Disposal CST is building an independent body of practical nuclear research that will help NWS's decision-making with regards to the safe, cost-effective, and secure disposal of the UK's most hazardous radioactive waste.

Current PhD projects

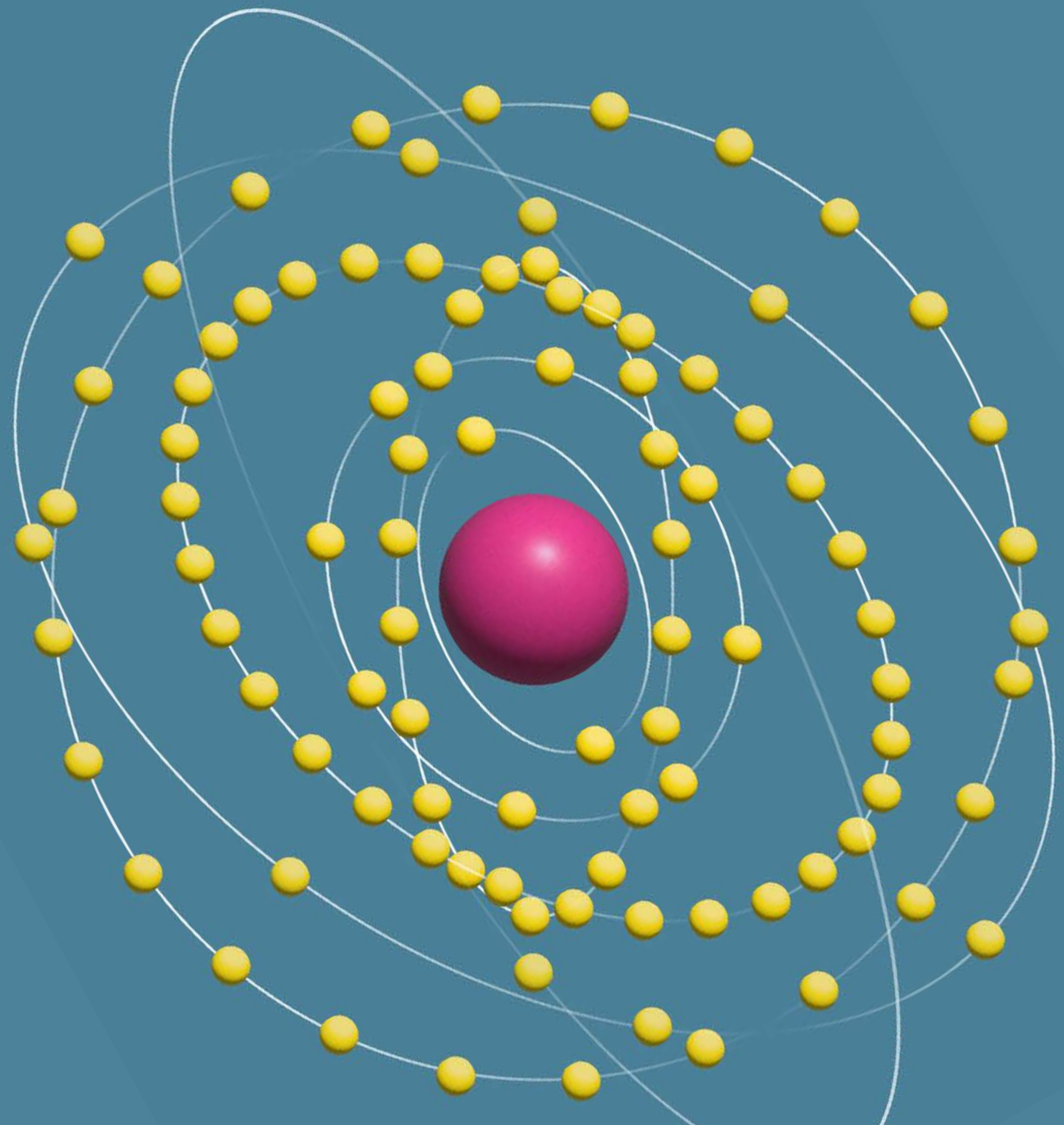
University	Project title	Start date	End date
University of Liverpool	Use of machine learning for the interpretation of modern and ancient marginal marine clastic sediments	01/09/2020	30/09/2024
University of Liverpool	Automated classification of estuarine sub-depositional environment using sediment texture	01/09/2020	30/12/2025
University of Liverpool	Depositional and diagenetic controls on fluid flow in fractures in a potential Geological Disposal Facility in the Mercia Mudstone Group, UK	01/10/2023	30/09/2027
University of Manchester	Upscaling fundamental controls on fluid migration in the Mercia Mudstone Group based on 3D multi-scale imaging and modelling	01/10/2023	30/09/2027
University of Sheffield	Understanding clays and filler loadings in Portland-limestone calcined clay cement (LC3) encapsulants to establish near and medium-term security of supply and capability	01/09/2024	30/09/2028
Liverpool John Moores University	Building resilience to coastal flooding resulting from climatic changes: the application to decommissioning NDA assets	01/09/2025	30/09/2029

Publications

Year	Publication title	UKNNL Authors	Journal/Conference	Vol	Pages	Type
2025	The ability to manage uncertainty for solid radioactive waste characterization in the UK nuclear industry	Hiller, P. Pyke, C. Lennon, C. Tuck, O. Painter, C.	Nuclear Engineering and Technology	57	103119	Review – published
2025	Mineralogical and textural variation in subsurface estuarine sediment: Implications for sandstone reservoir quality	Griffiths, J.	Journal of Sedimentary Geology	n/a	n/a	Article – submitted
2024	A detailed investigation into the legacy of glacial readvances and ice-dammed lakes around Sellafield, West Cumbria: Implications for 3D modelling, hydrogeology and ground engineering	Smith, N.	Proceedings of the Geologists' Association	135	695	Article – published
2024	Encapsulation of iodine-loaded adsorbents in blended Portland cement and geopolymer wasteforms	Turner, J.	Cement and Concrete Research	179	107480	Article – published
2025	Machine Learning for Reservoir Quality Prediction in Chlorite-Bearing Sandstone Reservoirs	Nichols, T. Worden, R. Houghton, J. Griffiths, J. Brostrom, C. Martinius, A.	MDPI	10.3390	n/a	Article – published

4 | Strategic Research

The science behind safely managing the UK's plutonium – and new uses, thanks to research



Plutonium (Pu) is one of the most scientifically interesting and amazing elements in the periodic table. It has properties like no other element and there is still much to understand after many years of research into this member of the actinides. With the UK having the world's largest inventory of separated civil Plutonium – a result of civil reprocessing of nuclear fuels – understanding the science and its behaviour is important.

UKNNL is collaborating to understand more about what happens to the properties of plutonium materials during extended storage, but also to spot opportunities to harness its unique capabilities, including a breakthrough leading to new capabilities to fuel spacecraft power and heating units.

UKNNL's expertise and world-leading facilities play a vital role in supporting national policy development and maintaining critical nuclear expertise in plutonium management. It is a UK government priority to ensure the safe and secure management of these plutonium materials while working towards immobilisation and disposal of the inventory to put this material beyond reach.

Collaborative research and long-running partnerships with Sellafield Ltd and the Nuclear Decommissioning Authority (NDA) support nationally important missions across plutonium science. This facilitates access to the UK's civil plutonium inventory and provides UKNNL with both funding and technical co-operation, enabling research impossible elsewhere in the UK.

Read on for more insight into the challenge of storing and managing the UK's plutonium inventory and a breakthrough which means this nuclear waste legacy has the potential to be a fuel of the future.

The plutonium challenge

Plutonium is an artificial element produced in nuclear reactors when uranium fuels are irradiated. It exists in a variety of different isotopes and attracts attention due to its high radiotoxicity and applications in nuclear weapons.

From the 1950s until 2022, the UK reprocessed used nuclear fuel for waste management, commercial and strategic reasons for organisations in the UK and overseas. During this reprocessing, plutonium was separated from uranium and other fission products.

The UK's civil plutonium inventory – the largest in the world – is stored at custom-built facilities that ensure its safety and security at Sellafield in Cumbria. These stores require careful stewardship before long-term government policy solutions for plutonium disposal are implemented.

Plutonium is stored in packages – specially designed containers which isolate the highly radioactive element to keep it safe. UKNNL's research to support Sellafield Ltd's stewardship of plutonium stores includes carrying out research to understand how the condition of the storage packages, the gas composition within, and the plutonium itself changes over time, alongside a programme of surveillance to verify the condition of packages.

Specialised research and characterisation of plutonium materials can only be carried out in secure facilities such as UKNNL's Central Laboratory. This work is vital to understanding how stored plutonium changes over time.

> "Future progress in Pu Sciences at UKNNL is dependent on new analytical and experimental techniques integrated with alpha gloveboxes. This is highlighted by the installation of a Thermogravimetric Analysis-Mass Spectrometer (TGA-MS) that will enable UKNNL to develop a better understanding of plutonium oxide (PuO_2) surface chemistry."
>
> **Chris Gregson**
> Postdoctoral research scientist in plutonium, UKNNL

Progress on plutonium

Since 2010, in collaboration with Sellafield Ltd, UKNNL has made significant progress with research into the unique challenges presented by plutonium. Research has improved understanding, contributing to world-leading science, which helps safeguard vital skills for the nuclear industry, particularly related to handling and storing of radioactive materials. This new understanding underpins the UK's plutonium management strategy, demonstrating it is robust, safe and scientifically sound.

UKNNL uses experimental studies of plutonium packages and powders together with computational modelling to build a picture of what's happening inside those in the inventory. Modelling and simulation help to understand the temperature changes, water vapour diffusion and the effects of radiation in different package types.

This modelling has been benchmarked against data from plutonium storage packages from the two plutonium reprocessing plants at the Sellafield site. This work is complemented by extensive UKNNL laboratory studies on plutonium and similar materials, alongside basic science studies at universities, to understand the interplay between radiation, porosity and the atmosphere inside the canisters.

The heritage of plutonium science research within UKNNL is the bedrock of the skills and capabilities required for the future mission of the NDA and Sellafield Ltd plutonium disposition programme. This programme is the cornerstone of UKNNL's plutonium research agenda, skills development and experimental base, but UKNNL's role as a national laboratory enables us to see synergies across a broader range of national programmes and government priorities in areas such as clean energy, defence, nuclear forensics and space power.

NuClear Science in depth

The UK's civil store of plutonium comes from different types of reactors and two reprocessing plants, so there are different mixes of plutonium isotopes, powder morphologies, can atmospheres and temperatures.

Plutonium is arguably the most bespoke and complex element in the periodic table. This, together with the unique storage environment and long timescales, means there are a lot of factors to consider. This is a challenging multi-dimensional scientific problem even before you consider the hazards of handling and studying plutonium materials.

As plutonium undergoes natural radioactive decay, it emits primarily alpha radiation while changing into other elements and isotopes. During storage, plutonium materials are subject to intense alpha radioactivity emissions and, in some cases, high temperatures from self-heating resulting from radioactive decay. This leads to physical and chemical changes, both in the plutonium powders and in the atmosphere above the plutonium. We must understand these changes to ensure the safe long-term storage of plutonium and to efficiently design new processes that will treat it in the future.

Separated plutonium is stored in packages as plutonium dioxide (PuO_2). Due to the original production and packaging processes, the powders have adsorbed trace amounts of moisture (water vapour) and other gases. These chemical species are affected by the radiation and temperatures they are exposed to during storage, undergoing myriad chemical reactions.

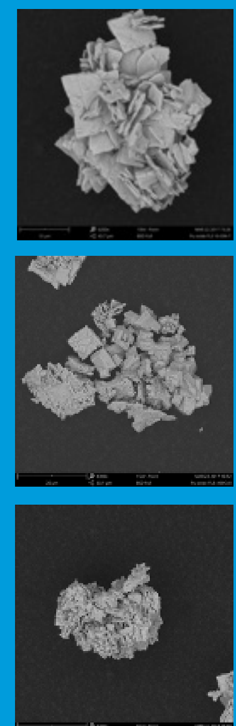
As well as helium gas generated naturally by the radioactive decay of plutonium, the risk of hydrogen gas generated from radiolysis of the moisture, potentially leading to a build-up of pressure inside the package, must be assessed. Research carried out at UKNNL has helped understand the mechanisms that affect helium and hydrogen production, explaining why packages are not pressurising from hydrogen and safe conditions are maintained.

At the microscopic level, the powder is porous. The pores can have a diversity of sizes and connectivity which affect how gas and moisture interact with the surface of the powder. The effect of radioactive decay (which causes the plutonium powder to heat up) means that the plutonium, and the surrounding atmosphere in the package, is changing even as you measure it. Even the small variations in composition of the atmosphere or the powder can make a remarkable difference to what is produced by the chemical reactions that the radiation initiates. The interplay of all these factors must be understood.

Heat treatment process for legacy chloride-contaminated PuO_2

Sellafield Ltd is currently building a £1bn plant to repackage plutonium. The Package Surveillance programme is providing data on standard Thorp and Magnox derived PuO_2 powders and their packages that will help underpin the design of the plant. However, there is a small quantity of old PuO_2 contaminated with chlorine from degradation of the PVC bags that were used in the 1970s. This material also contains high levels of moisture and so must be stabilised before repacking into modern packages in Sellafield Product and Residue Store Retreatment Plant. Between 2012 and 2019, UKNNL worked with Sellafield Ltd to characterise samples of these materials, understand the chemistry that was occurring at the PuO_2 surface and develop a heat treatment process that could stabilise the powders. This work provided unique data on a very complex system, as well as a practical process for retreatment. It led to a series of publications in peer-reviewed journals, including ref. [1] below which described the heat treatment of samples and characterisation of the materials by scanning electron microscopy.

1.Kevin Webb, Robin Taylor*, Catherine Campbell, Michael Carrott, Colin Gregson, Jeff Hobbs, Francis Livens, Chris Maher, Robin Orr, Howard Sims, Helen Steele, Sophie Sutherland-Harper, Thermal processing of chloride contaminated plutonium dioxide, ACS Omega 4(7), 12524-12536 (2019).



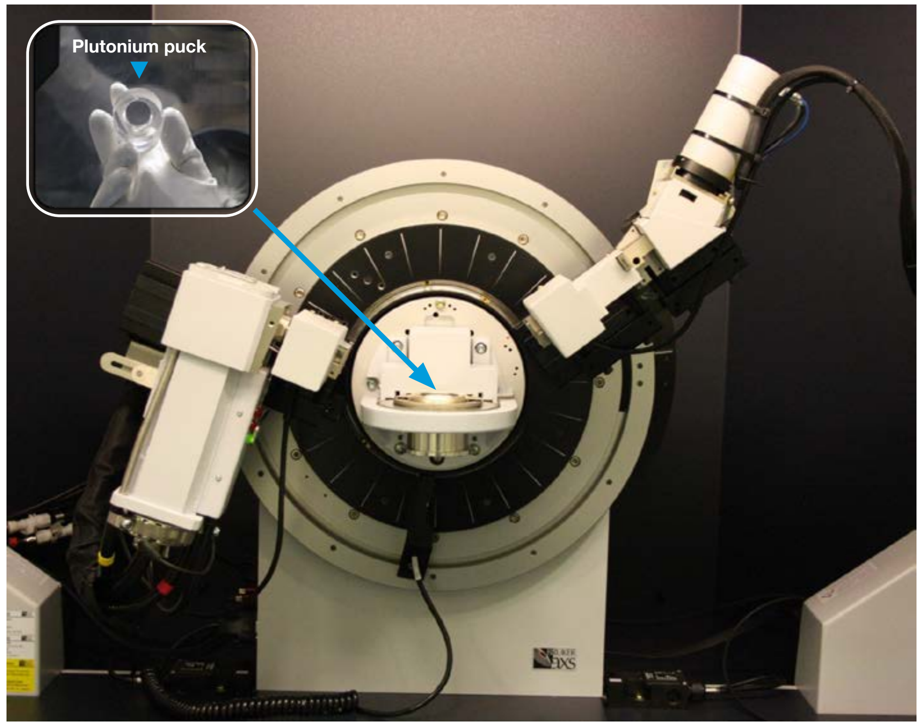
Scanning electron microscope (SEM) images of chloride-contaminated PuO_2. From top to bottom: as received; heat treated at 400°C; and heat treated at 950°C [adapted from ref. 1]

Using UKNNL's plutonium science base to support national programmes and find new uses for materials

A decade of research has led to a breakthrough and a new use for a by-product of plutonium's radioactive decay. UKNNL has developed a new separation process which can now recover americium-241 from plutonium oxide. The recovered americium can be used in spacecraft power and heating units, leaving the plutonium oxide cleaner than before.

The process has been proven at lab scale in UKNNL's PuMA Lab, and the UK Space Agency (which will become part of the Department for Science, Innovation and Technology in 2026) is now funding the commissioning of a new bespoke laboratory, PuMA2, to produce enough americium for use in the European Space Agency's missions in the 2030s.

Powder X-Ray Diffraction (XRD) capability in UKNNL Central Laboratory for analysing plutonium samples. The plutonium puck is removed from the glovebox.



" With its unique scientific and technical capabilities, UKNNL has a key role to play in supporting the Nuclear Decommissioning Authority, Sellafield Ltd and Nuclear Waste Services in delivering the government policy to immobilise plutonium and put it beyond reach. "

Danny Fox
Chief Strategist: Nuclear Fuel Cycle
Nuclear Decommissioning Authority

" The excellent work UKNNL does supporting the Sellafield Ltd Pu Science and Package Surveillance programmes is vital to the Special Nuclear Material (SNM) value stream delivering our mission. "

Dr Jeff W Hobbs
Head of Technical,
Special Nuclear Materials
Sellafield Ltd

The flagship package surveillance programme at UKNNL

At UKNNL, experimental studies underpinning plutonium storage comprise two basic approaches: small-scale laboratory science-driven experiments, and destructive analysis of plutonium packages from storage. This is part of the Sellafield Package Surveillance Programme, where packages are sent to UKNNL's Central Laboratory.

Commissioned in 2016, the High Alpha Facility in UKNNL's Central Laboratory is a world-leading resource for analysing the state of packages and plutonium materials they contain.

Through its work on plutonium, the facility is producing first-of-a-kind data, including on gas compositions, helium release rates, powder morphologies and package condition monitoring. These are transforming the knowledge base underpinning safe, long-term storage of plutonium oxide at Sellafield.

A unique aspect of this programme is the Plutonium Can Processing (PCP) glove box line in which plutonium cans are punctured to sample the gases contained within.The gases are extracted and then sent for analysis by gas chromatography.

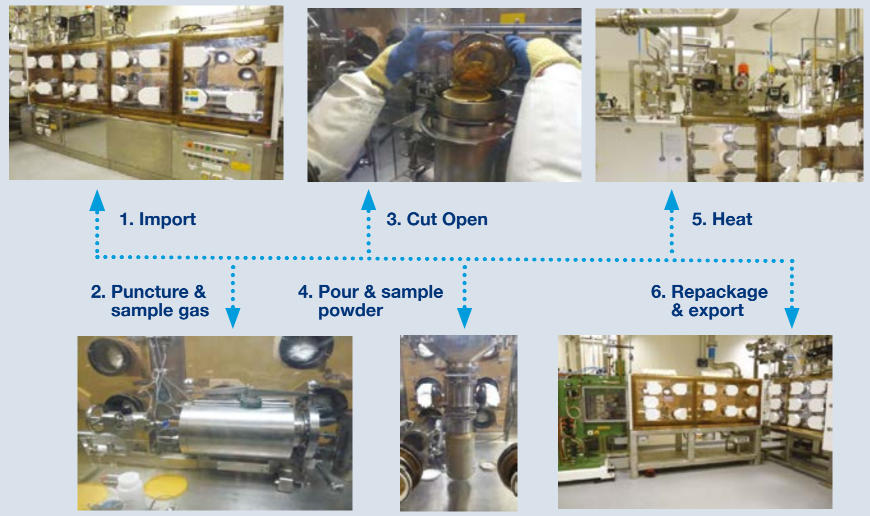
" As deputy technical lead for the Sellafield Package Surveillance Programme, I have had the opportunity to develop and run a major project which has been a hugely valuable experience both in terms of new techniques developed in the laboratory and skills gained across the whole team. For example, training early careers researchers in plutonium active operations which are vital for maintaining alpha skills in this area of work, ensuring we are continually building expertise and capacity for the future.

" Additionally, in collaboration with the NDA I have had the opportunity to set up a Community of Practice on MOX enabling experts from across the industry (including academia) to meet and discuss topics surrounding MOX, sharing knowledge and expertise in an environment that is not necessarily possible in our everyday jobs. Recent meetings have involved Orano sharing their experience on mixed oxide (MOX) fuels for the MELOX plant in France. "

Hannah May Colledge
Technology Manager (Pu Science)
Pu & Radioisotopes Team, UKNNL

Above: Plutonium dioxide (L) and mixed oxide pellets (R)

Below: Plutonium Can Processing facility in UKNNL Central Laboratory for opening plutonium packages from Sellafield



Publication, collaboration and skills

As well as UKNNL's wide range of plutonium programmes for customers, its skills base is enhanced by participation in the **Alpha Resilience Capability project (ARC)** which is a major investment in plutonium skills made by the UK Government.

UKNNL regularly shares its findings with the scientific community, with scientists at all levels of their career presenting at international conferences and publishing their results in peer-reviewed academic journals. Doing so ensures the UK remains at the forefront of research and actively demonstrates progress while gaining valuable insight from other research carried out in other nations.

One example is UKNNL's collaboration with Pacific Northwest National Laboratory in the US in 2024. Together the organisations co-edited a special issue of the **Frontiers in Nuclear Engineering journal** focused on "Plutonium Legacy Storage and Degradation"

As well as work for customers, UKNNL itself invests in plutonium science. Through this self-funded work, it aims to provide a stepping stone to boost new ideas and innovations for the industry while offering excellent development opportunities for earlier career researchers and technical leadership opportunities for the next generation of subject matter experts.

UKNNL's Science and Technology investment also supports collaborations with UK universities (PhD training and post-doctoral research in plutonium science) and internationally.

The Alpha Resilience Capability (ARC) project

The UK ARC Programme is a proactive collaboration, bringing together experts from the ARC partner organisations to identify synergies and opportunities to address challenges in our alpha areas. At UKNNL, we manage the ARC Technical workstream through six cross-industry Communities of Practice in:

- **Plutonium Properties**
- **Decommissioning & Decontamination**
- **Hydrogen & Radiolysis**
- **Polymers**
- **Analytical**
- **MOX**

Projects supported by ARC include:

- **Radiolytic hydrogen generation in heterogenous systems**
- **Guidance on safe and secure handling of actinides in academia**
- **Development of a method to examine plutonium powder samples by transmission electron microscopy (TEM)**

Frontiers in Nuclear Engineering

Between 2022 and 2024, six open access articles on the theme of "Plutonium Legacy Storage and Degradation" were published in a Research Topic (special issue) of the journal.

The topic was edited by Dr Edgar Buck of Pacific Northwest National Laboratory (PNNL) (USA) and Dr Robin Taylor (UKNNL) and UKNNL published two articles.

These summarised our theoretical knowledge of radiation chemical reactions on the PuO_2 surface and the results of a decade-long experimental programme measuring hydrogen generation from water radiolysis on PuO_2.

Additionally, Drs Buck and Taylor published an editorial to frame the key issues in plutonium storage covered by the topic.

See https://www.frontiersin.org/research-topics/41491/plutonium-legacy-storage-and-degradation for further information.

Plutonium science achievements summary

for the financial year 2024–2025

QUALITY

Sharing with the global community our world-leading nuclear science research through publications in high-quality peer-reviewed and open access academic journals

including special issue of

Frontiers in Nuclear Engineering

TALENT

4 & **1**

supporting 4 PhDs

supporting 1 PDRA
Post-doctoral Research Associate

PARTNERSHIPS

NDA
Sellafield Ltd
AWE
Alpha Resilience Capability (ARC)
UK Academia
UK SPACE AGENCY
Pacific Northwest NATIONAL LABORATORY
INL Idaho National Laboratory
Los Alamos NATIONAL LABORATORY

1. Underpinning safe long-term storage of UK plutonium in partnership with Sellafield Ltd
2. Developed heat treatment process for Sellafield Product and Residue Store Retreatment Plant for legacy chloride-contaminated plutonium
3. Using our expertise and knowledge base to address other government priorities and national programmes in plutonium and actinide science
4. Growing resilience in technical alpha skills and developing the next generation of plutonium SMEs
5. Using and expanding our world-class facilities for plutonium research in UKNNL Central Laboratory
6. Leading-edge research on real-world plutonium materials published in peer-reviewed academic journals
7. Collaborating with UK academia and international organisations

IMPACT

Current PhD projects

University	Project title	Start date	End date	Other partner
Lancaster University	Ag electrochemistry/dissolution	01/10/2022	30/03/2027	
University of Glasgow	Using experimental actinide chemistry to solve technical challenges in spent fuel and nuclear material management within the NDA Group	01/10/2022	30/09/2026	NDA
Lancaster University	Interactions of extrinsic species with PuO_2 during storage	30/09/2021	01/10/2026	Sellafield Ltd
Lancaster University	Development of a mechanistic model for He release from PuO_2 powders	01/10/2024	30/10/2028	NDA
University of Sheffield	Ceramic wasteform and process development for plutonium disposition	30/09/2021	30/09/2025	NDA
Lancaster University	Disposal MOX for Immobilisation of the UK's Plutonium Inventory: A Study of the effect of Manufacturing Route on Its Microstructure and Subsequent Performance under Geological Disposal Conditions	01/10/2024	29/09/2028	NDA
University of Huddersfield	Evaluating the performance of plutonium immobilisation matrices under geological disposal conditions	23/01/2024	22/01/2027	NDA

Publications since 2023

Editorial: Plutonium Legacy Storage and Degradation
Frontiers in Nuclear Engineering
Edgar Buck*, Robin Taylor*
3:1447819 (2024), (doi: 10.3389/fnuen.2024.1447819).

Radiation chemical processes in the water layer on the surface of PuO_2
Frontiers in Nuclear Engineering
Howard E*. Sims, Robin M*. Orr
3 (2024), (doi: 10.3389/fnuen.2024.1294584).

Effects of relative humidity, surface area and production route on hydrogen yields from water on the surface of plutonium dioxide
Frontiers in Nuclear Engineering
Kevin Webb, Colin Gregson, Josh Holt, Bliss McLuckie, Robin Orr, Howard Sims, David Woodhead, Jeff Hobbs, Helen Steele, Fred Currell, Luke Jones, Simon Pimblott, Robin Taylor*
2:1127504 (2023), 1-17 (doi: 10.3389/fnuen.2023.1127504).

Name = UKNNL co-author
* = corresponding author

5 | Innovation

Faster, easier, costing less – how adapting ultrasound technology can help decontaminate nuclear waste

A significant breakthrough by the team at UKNNL means that materials previously classified as radioactive waste can now be decontaminated in minutes, not days, using existing standard equipment – the first time this process has been applied in a nuclear context.

Researchers at UKNNL are working on plant decommissioning challenges in nuclear waste where deposits may arise from several scenarios, such as grease, solvent or paint, or where solids need to be broken up to enable them to be moved, for example from the bottom of a tank. Using existing low-frequency ultrasound technology can decontaminate waste materials in minutes. The process creates hot energy spots which effectively decontaminate the material's surface.

Significant efficiencies in waste management – including cost savings – will become possible once this technology is fully developed. Cost savings would be realised through more efficient processing of wastes, faster decontamination times and reduced use of reagents compared with current methods.

This breakthrough was made by researchers working to adapt existing standard industrial equipment to withstand the challenging conditions inherent in nuclear environments, including exposure to strong acids, alkalis and radiation. Adapting existing technology and equipment is a strong innovation approach, saving time and money versus developing completely novel solutions.

UKNNL is now partnering with experts who manufacture industrial ultrasonic devices to deploy this technique in a nuclear setting.

Read on to find out about how ultrasound can facilitate decontamination, how UKNNL is developing technology and skills, and how it's collaborating with others to develop sustainable solutions.

What led us to ultrasound

Applying intense bursts of energy on a small scale, including microwaves, electricity and ultrasound, can speed up a chemical process and separate contaminants from materials. Initial testing of ultrasound in the laboratory showed promising results in removing surface deposits that cannot be removed by other methods.

The initial focus on deploying this technology is to support waste management and decommissioning, but this is a versatile technology with potential applications in multiple settings.

Developing alternative uses of ultrasound

Industrial and medical applications of ultrasound are widespread, such as in food and drink manufacturing, defect detection, and welding. Some, such as pregnancy scans and plastic welding, use very-high-frequency soundwaves. Heavy industrial cleaning ultrasound processes generally use lower frequencies.

Alongside partners, UKNNL carried out research to understand if it was possible to create a low-frequency ultrasound device suitable to be used in the specific environments found on nuclear sites. The chemical environment found in the nuclear sector can be harsh. Equipment can be exposed to concentrated acid or alkali and may involve full immersion in liquids. Standard low-frequency industrial ultrasound equipment is not resistant to these conditions.

Developing this technology has provided unique opportunities to foster advanced nuclear skills. UKNNL scientists have now applied it to decontaminate pipework from a nuclear facility currently undergoing decommissioning. Decontaminating pipework can be particularly challenging as it is difficult to access, expansive, irregular in shape, sometimes containing bends, and can have build-ups of deposits.

> “Ultrasonic treatment is a promising technology for decontaminating items and vessels. It has the potential to mobilise contamination which has become adhered to surfaces, it can remove blockages in pipework and it has the potential to improve the effectiveness of decontamination reagents.”

Sarah Bibby
Technical Manager,
Sellafield Ltd

Project impacts

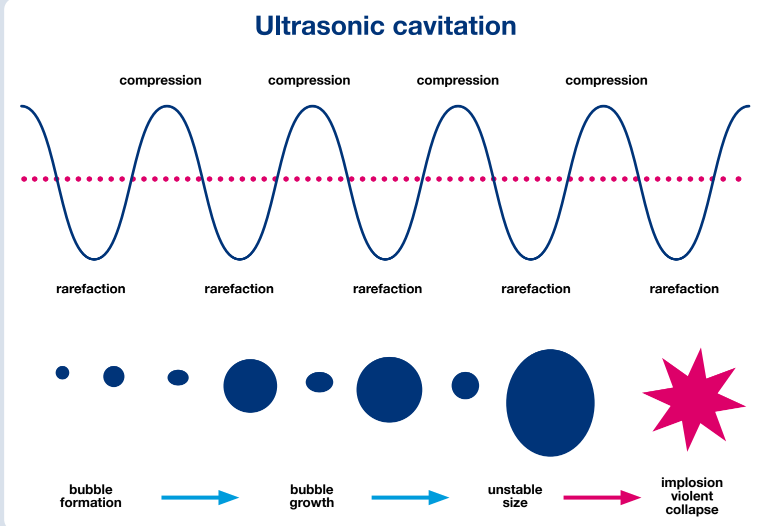
As the UK continues to harness the potential of clean energy from nuclear power, there will be a continued need to decontaminate the waste generated. This project creates a process that not only enables previously contaminated waste to be recycled through standard channels, but also reduces the time taken to decontaminate waste, achieving it in just minutes compared to the previous standard of one week.

As part of the project, two early career scientists have developed critical skills and gained practical experience in developing a new technology. This kind of experience is necessary to support the development of a skilled nuclear workforce, an imperative for the UK's sustainable future.

NuClear Science in depth

UKNNL is using a technique called ultrasonic cavitation. This applies ultrasound frequencies between 20 kHz and around 2 MHz to an object to produce tiny bubbles in liquid which rapidly collapse. This generates localised high pressures and temperatures up to several thousand degrees centigrade. These extreme conditions can accelerate chemical reactions and enhance decontamination.

This temperature change is short lived and localised, which means the enhanced chemistry is possible with just a slight increase in overall liquid temperature.



What's next?

Work to develop the technology so it can be used in operational nuclear settings is currently underway in our Preston Laboratory. UKNNL is building a partnership with an organisation with expertise in manufacturing ultrasonic devices to develop a version of our laboratory-scale equipment suitable to be used on a nuclear site.

Development of this ultrasonic device will also benefit from collaboration across teams within UKNNL. The decontamination team, who had the initial idea, will soon start work to further develop and prove the efficiency of this technology in a real industrial setting. They will work with operators in the active handling facility at our Windscale laboratory and at our residue processing and decontamination facilities at the Preston laboratory.

This novel decontamination method could become part of a wider decommissioning toolkit with the potential to reduce both costs and hazard. Critically, the breakthrough has shown waste can be reclassified and recycled through standard channels by removing deposits from surfaces.

> “I'm excited that we are working to develop this promising technology, it has a lot of potential to enhance the sustainability of a range of nuclear operations.”

Luke O'Brien
Fellow, UKNNL

> “ I’m pleased work with ultrasonics is continuing to be developed. Having had the opportunity to work on early iterations of the technology and observing the ease with which heavy contamination could be removed from piping which had been recovered from an active facility, it was clear this is a great tool for decontamination, one that can easily be used in conjunction with other techniques such as Electrochemically Assisted Surface Decontamination (EASD), removing contamination and producing a waste product that can be classified as very low level waste. ”

Peter Durham
Senior Research Technologist
Waste & Residues Processing
UKNNL

Nurturing Innovation

It’s imperative to be agile to solve some of the critical challenges of our generation. UKNNL’s approach to innovation harnesses the best ideas from both inside the organisation and across the world.

A structured approach enables swift identification of projects worthy of further investment or with potential to fail fast. Funding is available for colleagues with ideas which need pursuing. Teams work on a variety of projects with varying levels of resource allocated, depending on how well-defined the scope is. Timelines can vary from five-day innovation sprints to six-week periods of focused work.

The process also identifies when UKNNL can’t develop a solution alone, partnering with external organisations where needed to make the best progress, rapidly.

Open Nuclear is UKNNL’s innovation platform, which invites innovative thinkers globally to contribute to solving defined challenges and developing innovative technology. Open Nuclear is keen to work within a partnership model which brings in divergent thinking, shares expertise, and co-develops technologies for shared reward

Contact engagement@uknnl.com for more information.

Innovation achievements summary

for the financial year 2024–2025

QUALITY

safer, more efficient and cost-effective **environmental restoration**

Addressing an unmet need to decontaminate and reclassify items, enabling safer, more efficient and cost-effective environmental restoration to be achieved.

TALENT

2 early careers workers

gained experience in the development of the new technology

PARTNERSHIPS

Working collaboratively

Working collaboratively with a technology consultancy to develop a unique technology matching our respective expertise to deliver a solution

IMPACT

Recycling material, safer operations and **reduced use of natural resources**

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