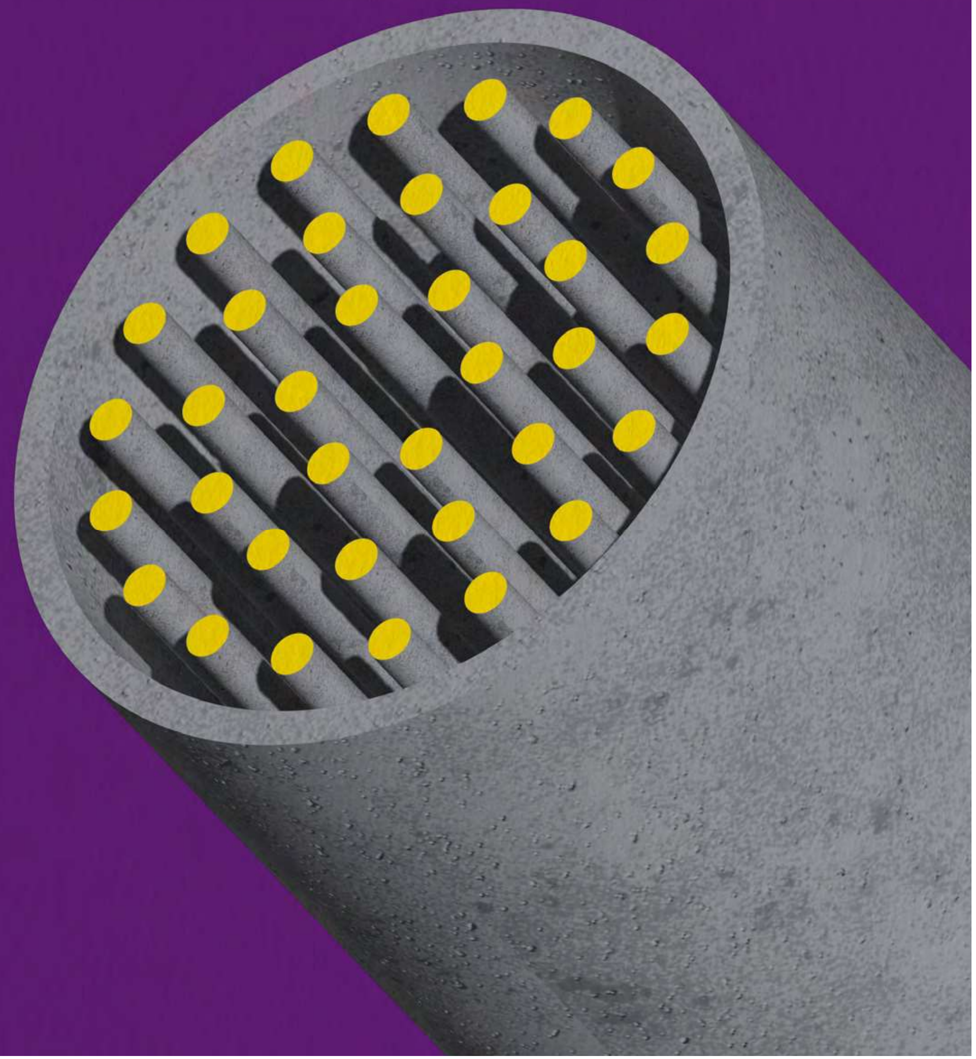
01 | Core science

Enabling **safe and efficient** operation of existing and future nuclear reactors.



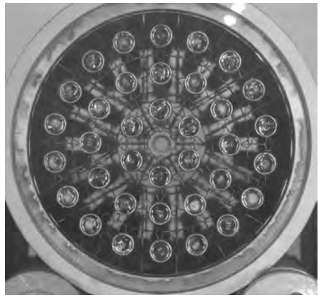
Irradiated Fuel Characterisation (IFC) is critical to the safe operation of our current fleet of nuclear reactors in the UK and a generation of new types of reactor set to begin feeding power into the grid in the 2030s.

Understanding how nuclear fuel behaves in a reactor is essential to ensuring that the operator can use the fuel safely and to maximum efficiency. Examination of irradiated fuel also gives us important insights into how spent fuel that leaves the reactor behaves under storage and how it can be securely disposed. Significantly, our work allows reactor operators and spent fuel stores to demonstrate compliance with reactor safety cases.

"Being aware of and able to predict the behaviour of spent fuels is vital to ensuring that irradiated fuel is stored and disposed of in ways that are effective and efficient. NNL's work in this area is particularly important at the moment as we look to deliver reliable and resilient options for managing spent fuels from Small Modular Reactors. Without our ongoing IFC work, it would not be possible to use nuclear fuel for energy generation in the UK and dispose of spent fuel in ways we know are safe and environmentally sustainable."

David Hambley
Fellow for
Spent Fuel at NNL

The majority of our IFC work takes place in a heavily shielded hot cell facility at NNL's Windscale Laboratory. Windscale is the UK's only facility capable of examining large quantities of irradiated fuel. The facility is run by a host of highly-skilled nuclear specialists, from scientists and technicians to engineers, fitters and electricians, with specialised techniques for handling and analysing highly radioactive irradiated fuel.



A complete element of AGR fuel. NNL conducts examination of these elements in station ponds and at Windscale to provide assurance that fuel is behaving as it should be.

Impact

Sharing science and maximising investment

Windscale receives fuel for examination from across the current fleet of reactors in the UK. Over the past decades, our scientists have been responsible for examining many thousands of nuclear fuel rods thus enabling safe generation of electricity in the UK.

Building on this legacy, work has begun this year to develop a library of irradiated fuels required for future research programmes. These fuel samples are to be linked to a database of records identifying each material, how it was manufactured and the irradiation conditions it has experienced.

Often our scientists at NNL, and our partners in industry and academia, are looking to conduct an experiment on a specific type of fuel, for example fuel that has experienced water ingress during irradiation or storage. Supported by this database, we will be able to identify useful material from within the library.

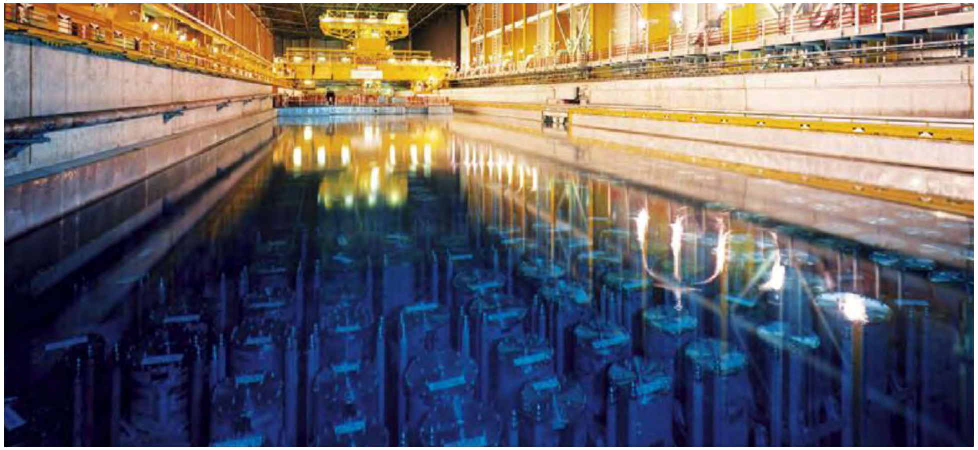
Not only does this ensure we are making best use of existing materials but, for our partners in particular, it drastically reduces their potential costs and permits work that otherwise would not be feasible. Without access to this resource, we would have to commission a programme specifically to produce fuel with the desired properties.

In the year ahead, our scientists will be making use of material in the fuel library to perform studies on high burnup structure – a feature that develops in nuclear fuel as fission products accumulate. Examining high burnup structure is important because it can affect basic properties of the fuel, such as how the fuel might fragment if released from the fuel clad. Knowledge of these properties allows us to predict how the fuel will behave, and ensure we keep the fuel within a safe operating envelope. The work expands on investigations, published by our scientists in the last year, which combined examination of high burnup structure with computer modelling of fuel behaviour.

As part of this work, we will be:

Examining a segment of Uranium Oxide base fuel using the Focused Ion Beam (FIB) technique. This technique involves focusing a high energy beam of ions which allows us to remove small sections of material so that we can analyse the inside of the material rather than the surface alone. Supporting methods also permit analysis of the composition of the structure.

Identifying a section of fuel of a contrasting fuel type, from the library, for comparison with the Uranium Oxide sample.



Spent nuclear fuel is to be held in carefully controlled storage ponds for many decades, until final geological disposal. NNL's work secures our understanding of how fuel will behave in such conditions, underpinning the decisions on how to manage fuel.

Quality

Providing a world-leading understanding of fission gas mechanics

Nuclear fuel rods consist of ceramic pellets of uranium dioxide contained in a metal alloy rod that is filled with helium. When uranium fissions it splits into two atoms, a substantial proportion of which are the noble gases xenon and krypton. As a result of their insolubility, these gases may diffuse out of the pellet matrix and grow as a fraction of the original helium fill gas, causing the pressure of the fuel rod to rise. If this pressure were to become too high, it could lead to a failure of the fuel clad – the outer jacket of the rod – resulting in radioactive fission products being released into the coolant of the reactor.

Understanding fission gas behaviour plays a key role in assuring the safe operation of fuel in both normal and off-normal reactor conditions. As part of this area of work, we have published an overview of techniques for analysing fission gas in irradiated fuel rods. This includes recommendations on how best to extract fission gas from a fuel rod and measure the internal pressure of the rod, and how to analyse the composition of the sampled gas.

Fission gas analysis has been a field of interest at NNL for many years and is one in which we have built significant expertise. Through our knowledge of fission gas mechanics, we are able to help reactor operators make informed decisions on the conditions a certain fuel is experiencing. Our work has also supported the development of the ENIGMA fuel performance code which is used for modelling and predicting the behaviour of fuel in a reactor.

"Nuclear fuel and reactor designs continue to evolve, both to improve safety and to better serve the need for a low carbon economy. The work performed by NNL on irradiated fuel ensures that the UK continues to hold a sovereign capability for assuring the safe operation of these new fuel designs.

Our expertise and facilities to provide this capability have been developed over more than four decades and are strongly aligned to our nation's current fuel needs. Our work in IFC ensures we can develop these assets further to be ready for the next four decades and beyond."

Dr Matthew Barker
Fellow for Post Irradiation Examination at NNL

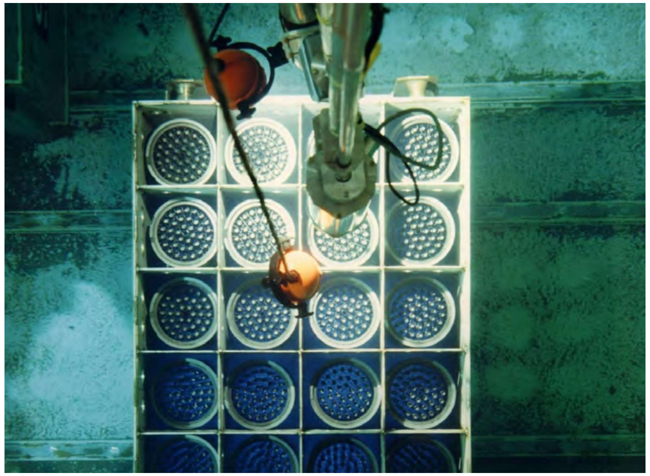
Talent

Developing the UK's next generation of materials scientists

IFC is a key area in which we engage with UK academia and our nation's next generation of materials scientists. Led by NNL Fellows Matthew Barker and David Hambley, our IFC research programme is made up of 12 scientists in the first few years of a career with us and a similar number of mid-career scientists.

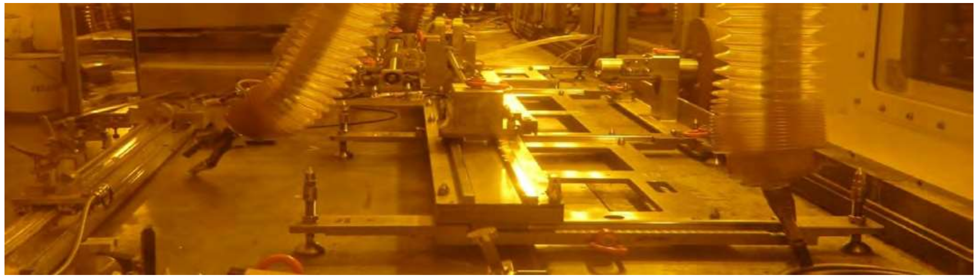
The team is closely linked to, and supports a broader capability of, over 100 scientists and technicians at NNL who are working on investigations of irradiated fuel for a range of customers and partners. These include EDF, Sellafield Ltd, the Nuclear Decommissioning Authority (NDA), Nuclear Waste Services (NWS) and Rolls-Royce.

The programme also enables PhD researchers to develop their nuclear skills through access to the irradiated fuels capabilities we uniquely offer.



Examination of fuel in a station pond demonstrating the range of techniques NNL can apply to examine irradiated fuel.

Examination of irradiated fuel takes place inside hot-cells consisting of concrete walls and lead-glass windows over a metre thick. Equipment is operated using remote manipulators and a great deal of skill.



Partnerships

Sharing best practice with partners in the UK and globally

NNL has a long and proud history of working with our partners in industry. These partnerships, including with EDF, Sellafield Ltd, the NDA, NWS and Rolls-Royce, have been instrumental in developing skills and capability within our laboratories at NNL.

IFC is a programme that benefits directly from the workstreams being pursued by our partners and customers and likewise significantly contributes to them.

Extending our expertise in IFC beyond the UK, NNL is working closely with the International Atomic Energy Agency on a variety of projects related to the management of spent fuel and the establishment of best practices.

In recent years, we have delivered a project with the IAEA to better understand how fuel behaves in reactor accidents. Using historical understanding and scientific data from events in Three Mile Island, Chernobyl and Fukushima, we chaired a collaborative research project to collate information on the three incidents, the technologies available for the retrieval and characterisation of the debris, and how to best characterise debris itself.

Off the back of this collaboration, our scientists are now working with international partners as part of a joint OECD-Nuclear Energy Agency project to help improve the characterisation of fuel debris at Fukushima specifically. This data can subsequently be used to enhance understanding of how the incident progressed to further strengthen reactor safety.

NNL has also been designated as the UK's first IAEA Collaborating Centre on the Advanced Fuel Cycle – the first of its kind anywhere in the world. The Centre is making an essential contribution to realising the vital role advanced nuclear technologies play in achieving net zero carbon emissions by 2050, whilst supporting the development of the next generation of global experts.

> "Maintaining understanding of the behaviour of the fuel during operation is of vital importance to the safe operation of EDF Energy's fleet of AGR reactors. Post-irradiation examination of AGR fuel is a key aspect of maintaining this understanding, and Windscale Laboratory is the only facility with this capability in the UK.
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> The capability and expertise held at the Windscale facility has been essential to support the operation of the UK's 14 AGR reactors throughout their history. Information obtained on the fuel condition has been crucial to underpin EDF Energy's reactor operations, as well as informing improvements to operational regimes to improve safety and reliability. The facility has also developed bespoke solutions to complex issues arising with the downstream management of irradiated fuel, and is the only facility in the UK with the capability to meet EDF Energy's needs in this area."
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> **Nick Wright**
> Fuel Engineer,
> EDF Energy