Nuclear Materials and Modelling

Theme Summary

In safety-critical industries like nuclear energy, expert experimental and theoretical knowledge is vital to secure reliable cost effective and safe operation over the long, up to 60 years operating, lifetime for both fission and fusion plant. This theme focuses on underpinning industrial fundamental understanding of the inter-relationship between material 'microstructure', nano- to micro-metre length-scale, and their physical, chemical and mechanical properties in the associated extreme environmental conditions.

Specific research in this area includes:

- Materials characterisation – relationship between 'microstructure' and mechanisms
- A range of materials addressed including metals, alloys, ceramics, including reactor graphite and composites
- Modelling – from nano- to micro-metre length-scale
- Fundamental actinide physics
- Accident-tolerant nuclear fuels and fuel performance
- Physical, chemical and mechanical properties of materials subject to extreme environmental conditions
- Applications for nuclear fission and fusion (and Gen IV technologies such as molten salt reactors)
- Fuel cycle and management

Theme lead: Professor Peter E J Flewitt FREng

Honorary Professor, University of Bristol and Visiting Senior Fellow, University of Oxford

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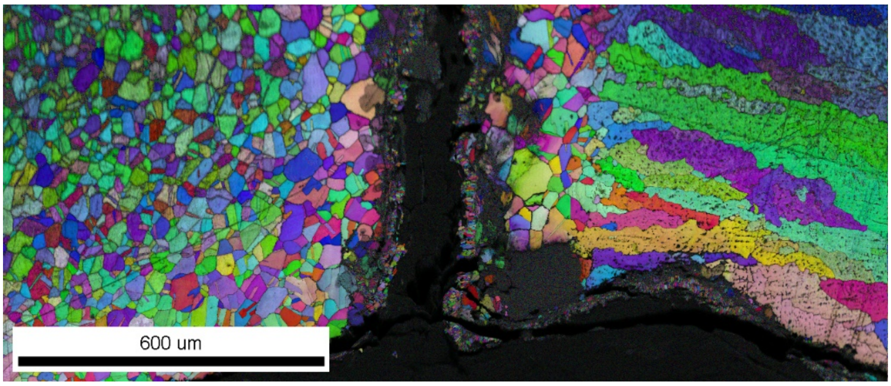
Peter's research interests are in the relationship between microstructure and the physical, chemical and mechanical properties of materials at the micro- and nano- metre length-scale and structural integrity for the fission and fusion, civil nuclear power industries.



Research Capabilities and Facilities

Nuclear Fuels and Actinide Behaviour

Key academics: Dr Ross Springell, Professor Tom Scott (University of Bristol)

The UK has a large and complex inventory of spent nuclear fuels, requiring safe storage in both legacy and long-term, ‘final resting place’ scenarios. Research in this area is developing the techniques for identification, analysis and prediction of the behaviour of nuclear fuel materials. This will inform legacy fuel retrieval and relocation operations by enhancing understanding of how the fuel and its storage environment will behave, through processes such as corrosion.

There is also focus on the development of advanced nuclear fuels that are more accident tolerant and environmentally sustainable, for use in the next generation of reactor technologies.

Advanced Fuel Cycle Programme (AFCP)

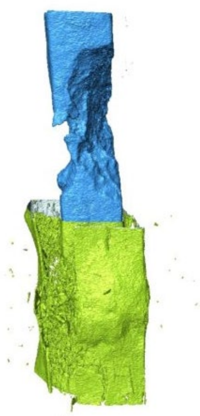
Funded by the UK Government, the AFCP is investigating the role of advanced nuclear fuels and fuel cycles for a Net Zero future. It focuses on 11 themes throughout the nuclear fuel cycle with the aim of creating a more integrated and sustainable approach from uranium supply all the way through to final disposal.

As a partner in AFCP, the University of Bristol contributes expertise to the Accident Tolerant Fuels theme, involving the fabrication and testing of safe, affordable fuels of the future.

Corrosion and oxidation

Key academics: Dr Tomas Martin, Professor Peter Flewitt, Dr Nicolas Larrosa (University of Bristol)

Materials degradation is an important factor in the long-term operation of nuclear reactors and radioactive waste storage. Structural materials in reactor coolant circuits and waste canisters react with water, CO_2 and other more aggressive species through the processes of corrosion, carburization and oxidation. This can lead to failure modes like stress corrosion cracking, breakaway oxidation and corrosion fatigue that can shorten the working life of a component.



These processes are very complex, and occur over long time-frames. In the corrosion and oxidation theme, we use advanced autoclave testing and microscopy to understand how materials evolve under these conditions, coupled with detailed materials modelling to develop mechanistic understanding of how these processes evolve over the lifetime of the component.

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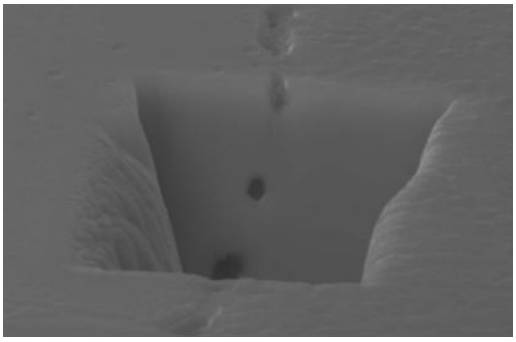
Phase and microstructural evolution of materials

Key academics: Professor Alan Cocks, Professor Felix Hoffmann, Dr Dave Armstrong, Dr Ed Tarleton (University of Oxford)



The extreme environment of a nuclear reactor exposes components to high temperatures, stresses and irradiation, which causes evolution of material microstructure which can change the mechanical properties of a component.

This phase and microstructural evolution of materials theme aims to understand how the phases and microstructure of materials evolve in these extreme environments. This includes the use of novel micromechanical testing, advanced microscopy and modelling. For example, how do the mechanical properties of tungsten change as it is exposed to high energy neutrons in a fusion reactor, and what do irradiation cascades and transmutation of elements do to its microstructure?

Another important long-term phenomenon is the development of creep, where high temperatures and stresses over extended periods of time result in the formation of creep cavities that grow and coalesce into cracks. This is an important mechanism in high temperature applications in fission, fusion and aerospace, but is a complex and challenging process to fully characterise.

The theme members use the cutting-edge techniques at their disposal to understand how this important mechanism develops and design new materials and management processes to minimise failure and maximise the life of a component.

The Physics and Mechanics of creep cavity nucleation and sintering in energy materials

This £1.1m EPSRC project focuses on the high temperature performance of creep strength enhanced ferritic (CSEF) steels, with different compositions and microstructures, that currently limit power plant life and legacy.
By improving design methods and modelling, the research will minimise creep failure in service, and offer the potential for extending plant life.

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Facilities and Capabilities

Key facilities for this research area are the Interface Analysis Centre at the University of Bristol, and the Department of Materials at the University of Oxford. Both centres host a wide range of advanced materials science analysis equipment for academic and industrial research. These techniques include:

X-Ray Tomography (XRT) and X-Ray Diffraction (XRD)

Advanced XRT works by illuminating a specimen with a known x-ray energy, imaging the transmission through 180° or 360° and reconstructing the data to give a truly 4D representation of a material with internal and external feature development throughout in-situ testing.

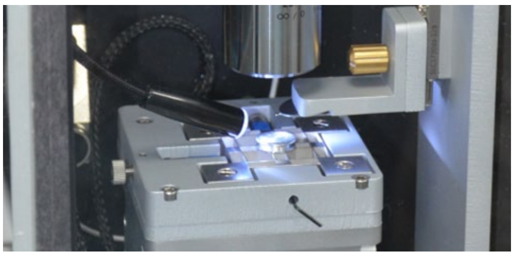
Using our x-ray diffractometers, we can provide information on the sub-nanometer length-scale. We are able to investigate powders, polycrystalline samples, single crystals and even thin films. We have hot stages that can heat to 1200K and a cryostage that can reach liquid nitrogen temperatures - these can be used in combination with high vacuum or a controlled gas atmospheres.

Thin Film Deposition Chamber

The University of Bristol has a unique thin film deposition chamber that allows it to 'grow' single crystals of uranium and its compounds, and engineer surfaces and interfaces to mimic those found in the storage environment.

Active Nano Mapping Facility

The Active Nano Mapping Facility hosts the world's fastest atomic force microscope (AFM), a high-speed AFM (HS-AFM). The microscope is housed in a dedicated active lab capable of handling samples up to a contact dose of 50 μSv/hr. Full glovebox facility enables the processing and imaging of samples without exposure to ambient conditions.



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SOUTH WEST NUCLEAR HUB

NNUF
National Nuclear User Facility

Irradiated Materials Archive Project

University of BRISTOL

UK Atomic Energy Authority

NATIONAL NUCLEAR LABORATORY

The UK has a wide range of material samples stored at various sites in the country of known pedigree including thermal and neutron radiation history, often inserted in reactors for surveillance purposes. Although the mechanical properties of some were measured, more limited high resolution microstructural information has been obtained severely limiting the development of mechanistic understanding that is necessary to predict materials behaviour in SMRs, AMRs and fusion reactors.

Most of these materials are not currently available for academic study and, unless action is taken, will gradually be disposed of as they are expensive to store. For this reason, it was recommended the establishment of a national archive of neutron irradiated material.

The University of Bristol, UKAEA and NNL have completed the options study for the archive (Stage 1), which was submitted to EPSRC in mid-March 2021 and recommended an overarching archive should be established involving a mix of distributed stores (leaving material in existing locations) and central stores (at Sellafield and Culham). We await funding for Stage 2 to establish the archive, including a central database and procedures for requesting and releasing samples.

The main functions of the archive would be:

- Provide a repository for storage of irreplaceable neutron-irradiated materials that are relevant to the UK's future nuclear ambitions.
- Provide researchers with cost-efficient and timely access to neutron-irradiated materials enabling the UK to maintain world leading expertise in radiation damage.
- Provide a general resource for future nuclear research in the UK, allowing training of young researchers using authentic, neutron-irradiated materials.
- Demonstrate, on an international stage, how such samples can be managed at a national level.

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