The National Nuclear User Facility
Opportunities for Industry

NNUF
National Nuclear User Facility

Engineering and Physical Sciences Research Council

Contents

The National Nuclear User Facility

Opportunities for Industry

The National Nuclear User Facility (NNUF) is a Government investment in the UK's nuclear future, providing state-of-the-art experimental facilities for research and development in nuclear science and technology. This flagship project is also designed to support the economic competitiveness of UK nuclear industries, providing advanced training opportunities for new and existing nuclear scientists and engineers.

NNUF was established to support the Government Nuclear Industrial Strategy launched in 2013 and has been successfully running for several years, with facilities in the University of Manchester's Dalton Cumbrian Facility, UKAEA's Materials Research Facility and the National Nuclear Laboratory available for external access to undertake work on nuclear materials.

As an exciting new development in 2019, the UK Government awarded £80m to create further national facilities for the study of radioactive materials. This second phase of NNUF will run until April 2023 and supports 20 facilities in UK universities and national laboratories, including a neutron source at the University of Birmingham, nuclear robotics at Bristol, Manchester and UKAEA, and an active Atom Probe Tomography facility in Oxford. This brochure gives details of the full list of projects, including capabilities and key contact points.

Representatives from the UK nuclear sector were closely involved in the conception of NNUF. Many of the facilities will be available to industrial users (both UK-based and international) on an ongoing basis. Please reach out directly to any of the facilities to discuss potential projects: they will be delighted to hear from potential industrial users, and will be able to support you from initial enquiry through to creating a fully scoped-out research plan and access timetable.

Many facilities offer a range of access options, including facility scientists performing experiments on behalf of, or under the (remote) direction of, external users. This may be particularly relevant in the COVID era. The facilities can advise you of the options available.

Access rates

For information on industrial access rates, please contact the facilities directly. UK-based university researchers (i.e. those employed by HEIs) can apply for the **NNUF funded user access scheme**, which runs until April 2023 and enables external usage of NNUF facilities to be free at the point of access.

Further information

This brochure was correct at the time of going to press. For the latest information – including the details of further NNUF facilities which will be announced in 2021 – please consult **www.nnuf.ac.uk**.

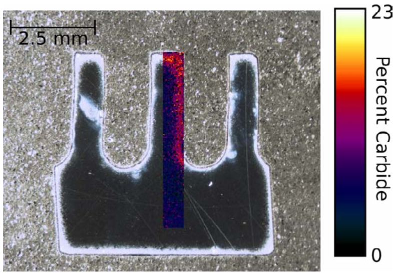
Contact details

For enquiries about individual facilities, please contact the facility directly using the details provided on each page. For queries about NNUF as a whole, please contact Francesca McGowan, NNUF Administrator, University of Oxford, on **francesca.mcgowan@materials.ox.ac.uk**.

Active Nano Mapping Facility

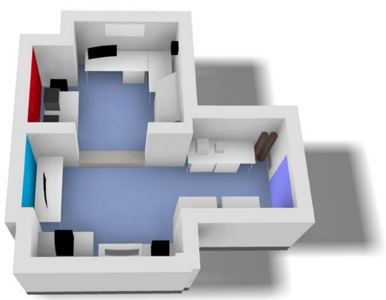
PI: Dr Neil Fox

The ANM Facility, based at the University of Bristol, hosts the world's fastest atomic force microscope, a high-speed AFM. The microscope is housed in a dedicated active lab capable of handling samples up to a contact dose of 50 µSv/hr (or higher if the safety case can be made). Full glovebox facility enables the processing and imaging of samples without exposure to ambient conditions.



The distribution of carbides in a cooling fin as measured by HS-AFM and processed on the NanoMapper software package.

Data from Liu et al.


A render of the ANM NNUF Laboratory at the University of Bristol showing the active (red) and non-active (blue) sections.

About the microscope

HS-AFM is a Bristol Nano Dynamics Ltd. contact mode AFM that can collect video rate topography maps of surfaces with sub-atomic height and nanometre lateral resolution in ambient, controlled gas, and controlled liquid environments. The system has significantly higher throughput when compared to a conventional AFM, being able to collect and process a year's worth of AFM data in a matter of hours. This can be used in three main ways:

1. *To observe dynamic nano and micro scale processes in controlled liquid, gaseous, inert or ambient environments*
   Easy-to-use navigation software and the ability to image under *in-vivo* conditions allows the ANM Facility to observe processes such as corrosion, oxidation, or cracking with sub nanometre resolution and frame rates up to 100 frames per second. The imaging window can be easily moved around the sample to find structures of interest. It is often the case that the nanoscale structures of interest are not homogeneously distributed on a surface and that most of the challenge in their measurement is in locating them in the first place. HS-AFM has proven itself to be the perfect tool for this task. To aid in this process optical images are collected simultaneously with topography and stored with the metadata.

2. *To map areas millimetres in size with nanometre resolution*
   The HS-AFM can make use of the high frame rate by moving between frames to build up a composite image. This allows areas up to millimetres in size to be imaged without a reduction in resolution.

3. *To collect spatial maps of the distribution of the physical dimensions of nanostructures with world-leading statistical validity over centimetre sized areas.*
   The imaging window can be moved across the sample surface in an automatic fashion in order to collect a sparse data set of thousands of frames in a matter of minutes. Custom software then characterises over 80 physical properties of every identified nanostructure on the surface. The processing can be filtered to only measure the nanostructures of interest. The spatial distribution of the nanostructure of interest can then be mapped on top of a calibrated macro image to enable a complete understanding of the macro scale distribution of nano and micro scale structures. The example shown left maps the carbide content in a 9 chrome steel boiler component. This process could also, for example, give you the distribution of mean diameter for all nanostructures orientated at between 30 and 50 degrees and below 2 microns in size.

Imaging modes

The system has the following capabilities:

- Dynamic strain ≥200 N
- Heated sample stage up to 200°C
- Image in ambient, liquid, gas environments with controllable humidity
- Ability to exchange liquid and gas environments while imaging
- Ability to load samples within an inert glovebox environment
- Sub-atomic height resolution, ~1 nm lateral resolution
- Topography, electrical, thermal and stiffness imaging modes
- Macro and micro optical images

Contact details

Please contact us for more information so that we might help you plan your experiments using the active HS-AFM in the ANM NNUF at the University of Bristol.

Please email **Oliver.Payton@bristol.ac.uk** for more information

Availability

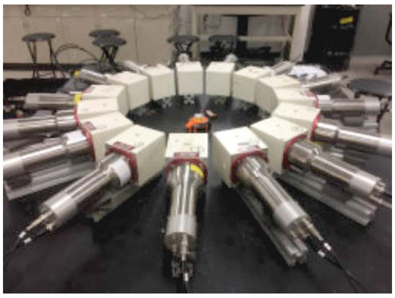
The Active Nano Mapping Facility is currently scheduled to be available for access by external users from mid November 2020. Please reach out to the Active Nano Mapping Facility team, to start discussing access, at any point. Up-to-date information about availability, in light of the COVID situation, is available at **www.nnuf.ac.uk/active-nano-mapping-facility**.

ADRIANA
Advanced Digital Radiometric Instrumentation for Applied Nuclear Activities
Project lead: Prof. Malcolm Joyce

ADRIANA is a suite of digital radiometric instrumentation which forms part of the UK National Nuclear User Facility. It was funded and set up in 2014 and comprises three separate facilities at Lancaster University, the University of Liverpool and the UKAEA Culham Centre for Fusion Energy (CCFE).

The high-sensitivity Broad Energy Germanium detector with Compton Suppression capability. The detector is hosted and managed at the Culham Centre for Fusion Energy, Abingdon

© Malcolm Joyce



15 of the 32 liquid scintillation neutron assay system hosted and managed at Lancaster University. The image was taken during work at the Oak Ridge National Laboratory, USA, using a selection of their high-activity sources to measure neutron multiplicity

Reproduced from **https://doi.org/10.1016/j.nima.2018.06.056** *(© R. Sarwar, V. Astromskas, C.H. Zimmerman, G. Nutter, A.T. Simone, S. Croft, M.J. Joyce, 2018, published by Elsevier B.V.) under a* **CC BY-NC-ND license**

Capabilities

ADRIANA was established to provide researchers in the UK and their collaborators worldwide with access to state-of-the-art digital radiometric detection and measurement instruments not otherwise widely available in the UK. It comprises:

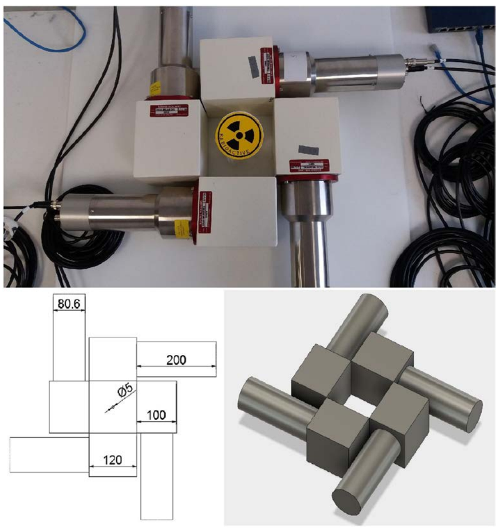
- a digital neutron assay system (Prof. Malcolm Joyce, Lancaster)
- digital position-sensitive CZT/germanium detector array with mechanical cooler (Dr Laura Harkness-Brennan, Liverpool)
- digital systems for environmental radioactivity assay including a broad energy germanium (BEGe™) and small anode germanium (SAGe™) detector systems (Dr Chantal Nobs, CCFE).

Example Uses

The digital neutron assay system at Lancaster comprises > 32 organic liquid scintillation detectors (EJ-309) and, given the frequent need to access sources of neutrons, this component of ADRIANA is portable. Users are responsible for shipping costs and arrangements (UK-based university researchers can apply to the **NNUF funded access scheme** to recoup shipping costs). The system can be used with its associated 32 channels of digital pulse-shape discrimination firmware to separate neutron events from γ-ray events and to explore coincidence phenomena or time-of-flight correlations between these events.

In the figure to the left, part of the system (15 detectors) is shown, courtesy of Elsevier, in use at the Oak Ridge National Laboratory, USA. In this set-up the system was used to record high-order neutron multiplicity events (triples and quadruples events) to investigate the angular distribution of these emissions from spontaneous fission in ^{252}Cf, for safeguards applications.

The broad energy germanium (BEGe™) and small anode germanium (SAGe™) detector systems have been used for a variety of trace-level analyses of environmental samples. For example, these systems have been used to assess the abundance of ^{241}Am in soils from contaminated land at legacy nuclear facilities, and to compare this to the contribution from other sources, such as that from the atmospheric nuclear weapons testing activities of the 1950s and 1960s. Trace assay of ^{241}Am can be used to infer minor actinide abundance and can be used to compare to complementary assessment techniques, such as accelerator mass spectrometry.



A photograph and drawings of a detector array used for the assessment of spontaneous fission neutrons from 0.3% wt. DUO2 in research utilising the ADRIANA facility at Lancaster University. The dimensions stated here (in mm) were used to verify simulation of the detector set-up in MCNP-6

Reproduced from **https://doi.org/10.1016/j.jhazmat.2018.08.018** *(© H.M.O. Parker, J.S. Beaumont and M.J. Joyce, 2018, published by Elsevier B.V.) under a* **CC BY-NC-ND license**

Contact details

As a first step, please email either Lee Packer (**lee.packer@ukaea.uk**) or Chantal Nobs (**chantal.nobs@ukaea.uk**) for a discussion about the practical feasibility of your proposed research project.

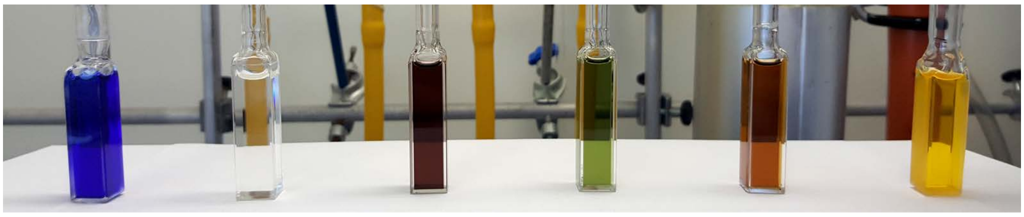
Availability

The ADRIANA facility was open for external user access at the time of going to print. Up-to-date information about availability, in light of the COVID situation, is available at **https://nnuf.web.ox.ac.uk/adriana**.

Centre for Radiochemistry Research

Prof. Stephen T. Liddle, Prof. Nikolas Kaltsoyannis, Dr Louise S. Natrajan, Dr David P. Mills

MANCHESTER 1824
The University of Manchester



Actinide complexes in solution.
Image reproduced with permission of Dr David P. Mills

Our vision is that the 'NNUF@CRR' will be an accessible 'one-stop-shop' for making and studying compounds of relevance to academic and industrial radiochemistry and other nuclear-related research, enabling new generations of researchers to overcome the barriers that have long prevented discovery, analysis, and synthesis in this area.

The CRR will be composed of controlled and supervised areas underpinned by state-of-the-art analytical techniques. HEPA-filtered controlled areas will support medium-activity level radiochemistry in low-pressure glove boxes for synthesis, molten salts, and recycling. The supervised areas will be laboratories equipped with fume cupboards for handling aqueous and organic solvents and large quantities of acids to support more traditional, low-activity level radiochemistry.

The facility will hold radioisotopes, and as such the NNUF@CRR will support a wide range of radiochemistry and other nuclear-related research.

An indicative list of science that the NNUF@CRR will support includes:

(i) speciation of coordination/organometallic complexes
(ii) spectroscopy
(iii) magnetism
(iv) reprocessing
(v) computational modelling
(vi) precursors to materials, fuels (e.g. ATFs), and molten salts, the latter in the **MSNTL NNUF Facility**.
(vii) collaboration with the **RADER NNUF Facility**, including environmental radiochemistry, geochemistry, mobility, nuclear forensics, decommissioning, colloids.

The NNUF@CRR will feature a range of capabilities, especially to underpin medium-activity level work, indicatively including:

- Single crystal X-ray diffraction with Mo and Cu Kα sources
- 400 MHz NMR spectroscopy with multi-nuclear and variable temperature capability
- SQUID 7 Tesla Magnetometry with variable temperature, VSM, and AC susceptibility capability
- Low-pressure glove boxes for handling, synthesising, and recycling of transuranic compounds
- Alpha counters
- Liquid scintillation
- Gamma counters
- Fluorescence spectroscopy
- 2-Photon spectroscopy
- Laser-induced breakdown spectroscopy
- Attenuated total reflectance infrared spectroscopy
- Ultra-violet, visible, and near infrared spectroscopy
- Ball milling
- Centrifugation
- Stocks of various actinides and other radioisotopes.

Contact details

Please email the CRR Co-Directors, **steve.liddle@manchester.ac.uk** and **nikolas.kaltsoyannis@manchester.ac.uk**, copying in the CRR Administrator (**aqsa.aziz@manchester.ac.uk**), to discuss a potential project.

Availability

The CRR is currently under development.

Please consult **https://www.nnuf.ac.uk/centre-radiochemistry-research** for the latest information.

Dalton Cumbrian Facility

Project lead: Prof. Fred Currell

MANCHESTER 1824
The University of Manchester
Dalton Nuclear Institute

DCF provides the experimental infrastructure and expertise to allow universities and industry to carry out fundamental research in the area of radiation science. DCF is collocated with the largest concentration of nuclear industry facilities in the UK and incorporates large-scale irradiation equipment, complemented by instruments supporting a wide range of *in-situ* and *ex-situ* analytical techniques.

Studying the effects of gamma rays on materials

Courtesy of The University of Manchester Dalton Nuclear Institute

On-site technical expertise to support research projects

Courtesy of The University of Manchester Dalton Nuclear Institute

Ion beam accelerators

DCF houses two accelerators, a 5MV tandem Pelletron and a 2.5MV Pelletron, configured to provide for a range of ion irradiation and ion beam analysis capabilities across 8 beam lines. Ion beam irradiation allows rapid achievement of materials damage levels accumulated during many years of in-reactor exposure and provides data on the effects of radiation under very specific conditions of temperature, radiation dose rate and radiation dose.

The technique also allows for tightly controlled *in-situ* interrogation of materials properties during irradiation, providing data for use to develop and validate predictive radiation effects models. Dual ion beam capability allows for simultaneous gas implantation with radiation damage creation.

The two accelerators are:

- An NEC model 15SDH-4 delivering M^{z+} ions with energy 5(z+1) MeV, e.g. $^{1}H^{+}$ ions up to 10 MeV, $^{4}He^{2+}$ ions up to 15 MeV and heavy ions up to a possible maximum of 35 MeV. Six beam lines are available for selection from the 5MV tandem, including a high dose 'hot cell' and an Ion Beam Analysis end station. Two ion sources; one for high current $^{1}H^{+}$ and $^{4}He^{2+}$ beams, with a second source for lower currents of heavy ions.
- An NEC Model 7.5SH-2, capable of accelerating ions to energies up to 2.5 MeV. Equipped with an RF plasma source capable of producing $^{1}H^{+}$, $^{4}He^{2+}$ ions or heavier gas ions. Two beam lines, one of which can be configured to coincide a beam line from the 5MV tandem accelerator to provide two dual beam irradiation.

Gamma Irradiator(s)

The FTS Model 812 cobalt-60 high dose rate gamma irradiator is designed and operated to support a wide range of research applications, with the aim of developing understanding of the mechanistic effects of gamma radiation on exposed materials. The instrument is capable of delivering dose rates from around 25 kGy/hr to less than 100 Gy/hr.

DCF also houses a Precision X-ray Multi-Rad 350 irradiator, capable of dose rates up to 140 Gy/min (unfiltered beam), for experiments where lower energy photons are more applicable.

Material modification, characterisation and analytical equipment

DCF provides a range of *in-situ* and *ex-situ* techniques designed to carry out detailed interrogation of the effects of radiation exposure on materials. Our laboratories are well suited to produce and analyse a wide range of materials, from spark plasma sintering innovative materials, such as nuclear ceramics, to identifying molecules with Raman spectroscopy, or to determine and map the texture and crystal structure of metals and composites (with our high end XRD and SEM). We also provide facilities and guidance for sample preparation, making all necessary steps of characterisation easily accessible in one place. This capability is complemented by a growing range of *in-situ* techniques to be used in conjunction with ion beam irradiations.

Experimental expertise

The DCF has a dedicated team of experimentalists to help the user community design, develop and deliver experiments and interpret data and outcomes.

Contact details

Please email **dcfreception@manchester.ac.uk** to discuss your potential project.

Availability

DCF was open for research at the time of going to press, within appropriate COVID-19 control measures, accommodating external users either in person or by delivering experiments on samples provided. Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/dalton-cumbrian-facility**.

Diamond Active Materials Laboratory

PI: Prof. Fred Mosselmans

Delivering new opportunities for active materials research at Diamond Light Source: an Active Materials Laboratory.

Overhead view of Diamond Light Source

© Diamond Light Source

Callum Robinson, University of Manchester PhD student, demonstrating the loading of a sample containing uranium onto Diamond's I20-scanning beamline

© Diamond Light Source

Understanding structural change in materials due to operation and radiation damage is a major challenge for the nuclear industry. Scientific research is essential to provide evidence and support in decision-making, for instance when reviewing ageing infrastructure and making decisions to extend its lifetime or when designing brand new nuclear facilities. Diamond, the UK's national synchrotron science facility, already offers analytical instruments for active materials research. The construction of a new dedicated Active Materials Laboratory building will significantly improve the capabilities for researchers ranging from those involved in construction materials for nuclear energy facilities to waste management.

The new Active Materials Laboratory

The new building will have both wet and dry laboratories equipped for handling a wide range of active materials. There will also be a counting room for active materials to be characterised and a secure storage as appropriate.

The dry laboratory will house an argon glove box with an inbuilt microscope. This will enable sample cells, such as a bespoke cell for use in a loading rig on I12, to be assembled on-site before being taken in appropriate containment to a beamline. There will also be a fume hood containing a furnace so samples can be treated offline before being studied on a beamline.

The wet laboratory will house an argon glove box for handling samples that need to be kept dry and oxygen-free such as molten salts, a Coy anaerobic chamber for handling wet anaerobic samples, a fume hood, a centrifuge, and chemical store cupboards for common solvents and acids.

Beamline I12 and DIAD are investing in *in situ* loading rigs with tension, compression and cyclic capability. These will have a 10 kN capacity for time-resolved tomography and imaging. This 10 kN load capacity was specified to accommodate the broadest possible range of user requirements, from soft biomaterials and polymers to high strength engineering alloys. Bespoke cells are being procured to safely contain samples to go in the I12 rig. This rig will be fitted out with a furnace to enable *in situ* testing of active material under controlled environments at temperatures up to at least 800°C.

New possibilities for users

With the new laboratory, users will be able to manipulate and prepare (very) active and also relatively shortlived samples to study them at Diamond. Users will be able to do experiments at Diamond that were previously impossible in the UK. Being able to load samples into suitable sample cells means that active materials properties can be studied under temperatures and particular atmospheres. It is necessary to understand the impact of prolonged radiation on the mechanical performance of a range of materials such as graphite and Zircaloy used in fission and fusion facilities.

Understanding the corrosion impact on radionuclide behaviour in encapsulated or enclosed form is vital in understanding the state of our current waste stockpile and making the most economical choices in its handling and disposal. Understanding the future behaviour of the UK's proposed geological disposal facility requires intimate knowledge of the interaction of radionuclides with the materials used in the construction of the facility. Furthermore, being able to run long-term experiments on site for sampling at suitable intervals and also the ability to prepare solutions on-site and manage the samples post-experiment for further non-synchrotron study will add crucial capability.

Contact details

Please contact the Diamond Industrial Liaison Office (**https://www.diamond.ac.uk/industry.html**) at **industry@diamond.ac.uk**.

Availability

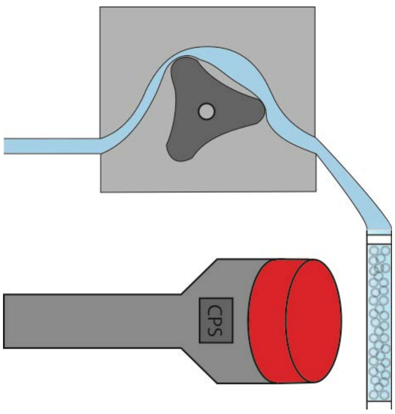
The Diamond Active Materials Laboratory is currently planned to open in September 2021. Please consult **https://www.nnuf.ac.uk/diamond-active-materials-laboratory** for the latest information.

EXACT

Next Generation Accelerated Characterisation Technologies

PI: Prof. Phil Warwick

NNUF-EXACT (Next Generation Accelerated Characterisation Technologies) at the University of Southampton aims to be a world-leading radiochemistry facility enabling research and training in accelerated nuclear characterisation and remediation technologies underpinning civil nuclear programmes, decommissioning and site clean-up, and new nuclear infrastructure.



The NNUF-EXACT laboratory facility will feature a customisable aqueous test rig to permit active testing of in-line and on-line sensors.

© F. Burrell, University of Southampton

Aims

To provide an easily accessible state-of-the-art test-bed facility and supporting infrastructure for research, technology development / validation and training in *in-situ*, on-site and off-site characterisation and remediation methods, including for complex/problem waste streams.

Objectives

- To provide a state-of-the art, flexible facility to support world-leading research on accelerated nuclear characterisation and remediation technologies.
- To lead in the development of automated and rapid measurement techniques for *in-situ*, on-site and off-site radionuclide measurement, including those that can be integrated into robotic delivery systems.
- To develop technologies and enhanced methodologies for separation, characterisation and remediation of complex waste forms including oils, sludges, and reactive metals.
- To promote monitoring and characterisation technology transfer from the non-nuclear sector (including the latest ocean / aerospace / oil and gas sensor developments) by facilitating testing of novel technologies in a nuclear relevant environment.
- To lead in the development of robust method testing and validation processes for *in-situ* and on-site characterisation.
- To provide a comprehensive training platform for the next generation of radiochemists, site engineers and other nuclear professionals.
- To act as a focal point for international collaboration in the field of radionuclide separation, radioanalytical chemistry, characterisation and remediation technologies.

Training

In addition to the comprehensive training offered to all users of the facility including safe working practices in a radiochemical laboratory and training in characterisation techniques and radiometric instrumentation (including sensor and on-site technologies), a series of training courses and workshops are offered. These courses are held in lecture theatres and classrooms at the University of Southampton's Waterfront Campus and delivered by leading industry and academic professionals in collaboration with NNUF-EXACT partner organisation **NPL**.

NNUF-EXACT laboratory facility

The laboratory facility provides a flexible space for the development and testing of new methodologies and technologies with low level active reference materials and radiotracers. The laboratory features fume cupboards and bench and floor space with a customisable aqueous test rig to permit active testing of in-line and on-line sensors. The facility contains a portable gamma detector, an automated gamma spectrometer, a benchtop liquid scintillation counter and an SBET analyser as well as access to a vast range of radiometric and non-radiometric instrumentation via the supporting facilities.

Supporting facilities

Users of NNUF-EXACT have access to the following supporting facilities:

- **GAU-Radioanalytical Laboratories (GAU)**
- The University of Southampton's **Geochemistry Research Group**
- **The Stable isotope lab** at the University of Southampton's newly established SEAPORT laboratories.
- Access to the **Bristol interface analysis centre** is provided through the NNUF-EXACT partner organisation, the **South West Nuclear Hub**.

Contact details

Please email **NNUF-EXACT@soton.ac.uk** at any point for a discussion about your potential project.

Availability

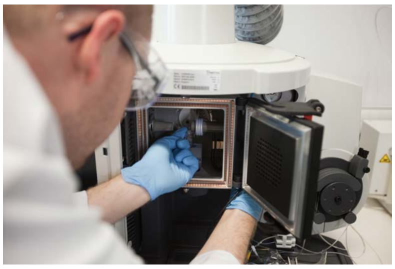
NNUF-EXACT is currently scheduled to be available for access by external users from April 2021. Please consult **https://www.nnuf.ac.uk/exact** for the latest information.

HADES

A User Facility for High Activity Decommissioning Engineering Science

PI: Prof. Neil Hyatt

The HADES Facility at the University of Sheffield is a national centre of research excellence supporting the UK nuclear decommissioning and disposal programme, as part of NNUF. HADES is accommodated within 500 m^2 of high quality radiomaterials chemistry laboratories, refurbished in 2015, with state-of-the-art equipment and instrumentation for materials formulation, processing, characterisation and performance assessment.



Inductively coupled plasma optical emission spectroscopy

Multimodal thermal analysis

All HADES laboratories are designed and operated as supervised areas, for research with limited inventories of radioactive materials (unsealed sources). Controlled area laboratories enable work with MBq quantities of α and $\beta\gamma$ nuclides. The integrated nature of the Facility enables acceleration of materials optimisation, through rapid feedback between synthesis and characterisation.

The Facility is organised in a suite of capability platforms, for working with radioactive materials:

- **Materials handling.** Enabling glove box manipulation of α and $\beta\gamma$ nuclides under air or inert conditions (<ppm O_2, <ppm H_2O); comprehensive metallography suite with equipment for cutting and sectioning of materials, grinding and polishing.
- **Materials processing.** Thermal treatment of materials up to 1800°C under controlled atmosphere, with off gas analysis and quenching capability; the platform incorporates the UK's only radiological Hot Isostatic Press operating up to 2000°C and 200 MPa; suite of ball mills.
- **Diffraction and spectroscopy.** Including: X-ray diffraction (room temperature; high temperature and controlled atmosphere to 1200 °C; grazing angle capability); Raman and IR, ^{57}Fe Mossbauer; X-ray absorption and emission spectroscopy (XES, XANES, EXAFS).
- **Microscopy and microanalysis.** Optical microscopy; SEM with energy-dispersive X-ray analysis; and – via the Sheffield Hub of the Royce Institute – AFM, optical profilometry, and electron probe microanalysis.
- **Thermal and physicochemical analysis.** Coupled thermo-gravimetric, differential thermal/scanning calorimetry, and mass spectroscopy analysis; surface area analyser; pycnometer; particle size analyser; and high temperature glass rheology.
- **Chemical and radiochemical analysis.** ICP-OES; ICP-MS; ion chromatography; liquid scintillation counting; wavelength dispersive X-ray fluorescence analysis; total carbon and nitrogen analysis (coming soon).
- **Wasteform alteration and dissolution.** Suite of ovens and equipment for batch and dynamic corrosion experiments, under controlled atmosphere, for short and long duration corrosion experiments.
- **Radiometrics and radiological protection.** High resolution γ-spectroscopy; fixed personal contamination monitors in controlled area; a suite of large area survey meters, contamination monitors, and dose rate detectors available; personal dosimetry if required.

HADES was established with investment of £1M by UKRI EPSRC and the University of Sheffield, in new state-of-the-art materials processing and characterisation equipment, to enable higher throughput research and work with high radionuclide inventories. The Facility incorporates prior investment of c. £8M in laboratory refurbishment, space, and equipment within the **MIDAS facility** and allied Royce Institute, to provide a single point of user access. It incorporates the **STX Facility**, the UK's first capability for laboratory based X-ray Absorption Spectroscopy.

A team of experienced researchers and experimental officers support the Facility, providing user training, supervision, and equipment calibration and servicing. Access to the facility may be in person, remote, or sample mail in.

Contact details

Please email **n.c.hyatt@sheffield.ac.uk** for a discussion about your potential project.

Availability

HADES is currently expected to be available for external users from early 2021. Please consult **https://www.nnuf.ac.uk/hades** for the latest information.

High Flux Accelerator-Driven Neutron and Cyclotron Facilities

PI: Prof. Martin Freer

UNIVERSITY OF BIRMINGHAM

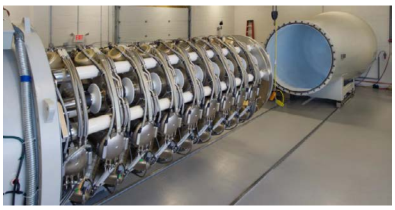
Birmingham is able to offer access to two facilities: a high flux accelerator-driven neutron facility will be available from spring 2022, and an MC40 cyclotron accelerator is available immediately.

UNIVERSITY OF BIRMINGHAM

BIRMINGHAM ENERGY INSTITUTE

A schematic of the new bunker that will house the accelerator

The University of Birmingham campus



The Neutron Therapeutics proton accelerator will be used for the generation of the neutrons

The High Flux Accelerator-Driven Neutron Facility will support the study of neutron interactions in materials for the nuclear sector, both fission and fusion. It will also offer a broader programme, extending to nuclear medicine and space.

This is the first UK neutron facility capable of providing fluxes for the characterisation of degradation of materials in the reactor periphery. It will also be the first UK facility to possess a dual beam ion facility capable of providing the necessary fluxes to easily simulate the damage incurred by highly irradiated components such as cladding in current generation plant or structural materials in Gen IV or fusion reactors.

The new irradiation capability of this facility will combine with the existing high-energy light-ion accelerator to create a single UK user irradiation facility. This will form the most intense accelerator-driven neutron source worldwide.

Nuclear materials

There has been a tendency to rely on the use of protons as a surrogate when studying materials degradation under neutron irradiation, but the validity of this is questionable. The present facility is targeted at materials which lie beyond the reactor pressure vessel, and would also support research associated with the UK nuclear defence programme.

Nuclear fission and fusion data

The measurement of a series of key reactions, many involving neutron capture with higher energy neutrons, will enable a more precise understanding of the nuclear processes associated with fusion and fission.

Nuclear waste management

The safe storage of nuclear waste requires a detailed understanding of the effects of nuclear radiations on the storage media.

High power targets

The development of many new facilities such as accelerator-driven subcritical reactors, or next generation spallation sources, involves development challenges around target design.

Medical physics

The radiobiology of neutron interactions is very important, from cancer therapy to the effect of nuclear radiation from industrial, medical and space environments. For example, the facility will be used to test drugs for boron neutron capture therapy treatment and to develop imaging modalities to better understand the doses delivered to patients.

Nuclear metrology

A well-calibrated and controllable neutron source will be useful for nuclear metrology, the testing of radiation monitoring systems, and the development and characterisation of radiopharmaceuticals.

Nuclear physics

Neutron capture reactions are an important tool in nuclear spectroscopy and nuclear astrophysics, particularly in mapping the s-process paths close to the valley of stability. The spectrum of neutrons produced will be very close to that in stellar environments.

The MC40 Cyclotron Facility is a particle accelerator capable of accelerating light ions (protons, deuterons, helium-3 and helium-4) to energies of up to 50 MeV. It performs a number of activities which range from materials irradiation and isotope production.

The **MC40 Cyclotron Facility** is available in advance of the new neutron facility being developed to support the NNUF science programme.

Contact details

Please contact **energy@contacts.bham.ac.uk** to discuss your potential project.

Availability

The High Flux Accelerator-Driven Neutron Facility, commonly referred to as the ADNIF, is currently scheduled to commence operations, and be available for access by external users, from spring 2022. Up-to-date information about the availability of the MC40 cyclotron, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/high-flux-accelerator-driven-neutron-facility**.

High Temperature Facility

The HTF, located in Warrington, was built in 2016 using funding from DECC (now BEIS). The facility can generate high quality mechanical performance data for non-active structural materials used in Gen IV nuclear fission reactors, nuclear fusion reactors and non-nuclear high temperature applications. The HTF enables environmental interactions with reactor coolants to be studied, predictive models to be developed, and new data to be generated.

© Jacobs

Set-up of a servo-hydraulic fatigue test station
© Jacobs

The HTF complements the existing Second and Third generation high temperature water and gas testing facilities at Birchwood. The Gen IV fission reactor technologies include: Sodium-cooled Fast Reactor (SFR); High Temperature Gas-cooled Reactor (GFR); Lead-cooled Fast Reactor (LFR); Supercritical Water-cooled Reactor (SCWR); Molten Salt Reactor (MSR) and the Very High Temperature Reactor (VHTR).

The HTF provides:

- in-depth knowledge of advanced nuclear fission systems design, manufacture, operation and regulation
- track record in internationally leading R&D in conventional water-cooled reactors and high temperature fission systems
- experience of solving problems across the TRL scale and helping partners meet regulatory compliance
- quality systems in place to undertake UKAS evaluations
- experience of high temperature materials, structural integrity testing, material damage mechanisms and materials testing in novel, demanding environments.

Testing Capabilities

The HTF offers rigs up to 1000°C (higher in some circumstances), with temperature cycling in a range of novel, demanding environments (pressurised gas for VHTR/HTR, liquid metal for SFR/LFR, inert atmospheres).

We can incorporate specialised, bespoke equipment into tests to allow the construction of innovative experimental configurations. All our equipment is in a temperature- and humidity-controlled laboratory, to maximise data stability over long-term tests.

The HTF team includes engineers, materials scientists, chemists and structural integrity specialists, who can help interpret test data and design solutions to the most complex problems.

Testing includes:

- Tensile testing (loads up to 100 kN in tension and compression)
- Fracture testing (loads up to 250 kN and in the temperature range -1000 to 1000°C)
- Creep strain / rupture (loads up to 30 kN)
- Impression creep testing (deadweight-loaded)
- Creep crack growth (loads up to 30 kN)
- Strain and load-controlled low cycle fatigue initiation (loads up to 100 kN in tension and compression)
- Fatigue crack growth (loads up to 100 kN in tension and compression)
- Creep-fatigue initiation / growth (loads up to 100 kN in tension and compression)
- Thermo-mechanical fatigue initiation / growth (loads up to 100 kN in tension and compression)
- Miniaturised tensile / creep / fatigue testing (loads up to 10 kN)
- High cycle fatigue endurance / crack growth (up to 100 Hz test frequency and loads up to 10 kN).

To enable detailed analysis of tests, the rigs can be equipped with the following analytical instrumentation:

- Digital image correlation (DIC) for full field strain measurement (especially useful where welds are present), including microscopic capability
- Acoustic emission monitoring equipment for monitoring crack initiation and propagation
- Potential difference monitoring equipment for monitoring crack initiation and growth.

Operation

Jacobs provides training to staff from external organisations. Various operating models can be offered, including testing conducted by Jacobs staff; testing witnessed by partner organisations; and testing undertaken by partner organisations.

Contact details

Please submit research proposals via email to:

- Dr Mark Callaghan, HTF Lab Manager (**Mark.Callaghan3@jacobs.com**)
- Dr Andrew Wisbey, Principal Consultant (**Andrew.Wisbey@jacobs.com**)
- Dr John Stairmand, Technical Director (**John.Stairmand@jacobs.com**)

Telephone:

+44 (0) 1925 462842 (MC)
+44 (0) 1925 462721 (AW)
+44 (0) 1925 462703 (JS)

Please also consult **www.htfalliance.com** for further information.

Availability

Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/high-temperature-facility**.

Hot Robotics Facility

PIs: Prof. Tom Scott and Dr Rob Buckingham

The National Nuclear User Facility for Hot Robotics (NNUF-HR) is an EPSRC-funded facility to support UK academia and industry to deliver ground-breaking, impactful research in robotics and artificial intelligence for application in extreme and challenging nuclear environments.

Partners and facilities

The facility is arranged across three regional nodes with four research partners.

UKAEA - RACE Facility

Remote Applications in Challenging Environments, Oxfordshire

RACE forms the primary NNUF-HR hub where a large array of robots and mock-ups are housed. Additional functionality is provided through 'hot' test capabilities and portable solutions.

Collaboration with academia and industry is facilitated by RACE's proximity to Harwell, AWE and a multitude of academic institutions.

University of Bristol

Fenswood Facility, North Somerset

The University of Bristol's facility will provide substantial space for developing mobile robotic applications as enhanced tools for environmental field surveying.

Its main capabilities will focus on UAVs and mobile ground vehicles and it offers 245 acres of space for test deployments.

University of Manchester

Dalton Cumbrian Facility

Located at the centre of the UK's nuclear industry in West Cumbria, this facility provides mock-ups and robotic equipment to enable researchers to address nuclear decommissioning challenges.

Specific capabilities include a pond equipped with an underwater position system, robotic manipulators and a variety of mobile robots.

National Nuclear Laboratory

Workington Facility, Cumbria

NNL's facility comprises of equipment and flexible floorspace to develop, test, and demonstrate robotic solutions for the nuclear industry.

The research test rigs available at the NNL Workington Laboratory will be on an industrial scale, acting as a link between low TRL robotics research and technology progression to TRL 9.

Facilities will include:

- Robot laser cutting
- Sort and segregation capability
- A flexible decommissioning cell
- Flexible operating enclosures for development and testing of ROVs.

Contact details

RACE: **nnuf-hr@race.ukaea.uk**.

University of Bristol: **nnuf-hr@bristol.ac.uk**.

University of Manchester: **nnuf-hr@manchester.ac.uk**.

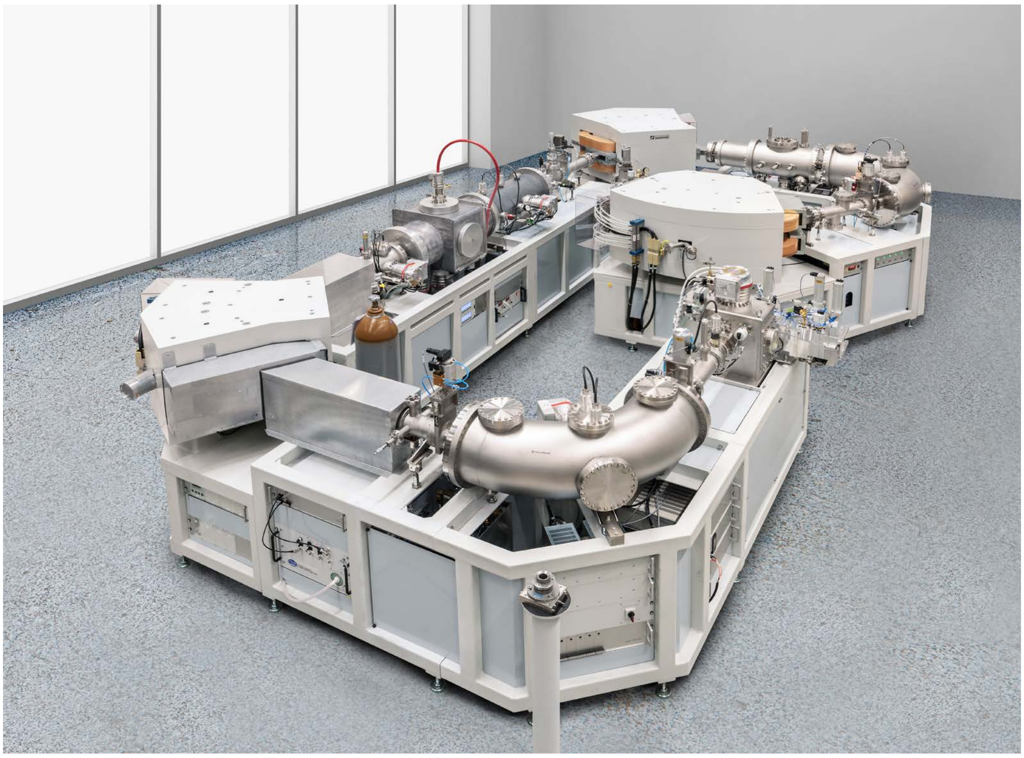
NNL: **nnuf-hr@uknnl.com**.

Availability

Facilities will be available from April 2021. In the interim, users can access a reduced selection of equipment either onsite or offsite. This capability will progressively increase over time. To view the current available equipment, please see **https://www.nnuf.ac.uk/hot-robotics**.

Lancaster Accelerator Mass Spectrometer (LAMS-UK)

PI: Prof. Malcolm Joyce



IonPlus manufactured Accelerator Mass Spectrometer. Pictured is the Multi-Isotope Low Energy AMS (MILEA) to be used at the Lancaster University based facility

© IonPlus

Mission: Establishing a state-of-the-art, university-based facility for the quantification of trace actinide levels to support the decommissioning and development of nuclear fission sites around the UK. The aim is to increase understanding of the baseline concentration of actinides in various matrices, and this is expected to focus predominantly on soils during the initial phase.

AMS Capabilities

- Ability to analyse 55 different radionuclides at femtogram-picogram per gram concentrations, with plutonium and uranium as the facility's primary foci.
- Distinguish samples to a greater extent utilising isotopic ratio measurement.
- Analyses are carried out with small sample masses (1-5g), easily allowing for multiple repeats.

Research Applications

- Environmental monitoring for nuclear installations.
- Fallout material monitoring in the environment.
- Ecological sample measurements of isotopes.
- Hydrology.
- Nuclear physics.
- Pollution.
- Age-dating.
- Materials analysis.
- Etc.

LAMS-UK Facilities

- Sample spiking.
- Raw sample preparation.
- Strong acid digestion for variety of samples.
- Dehydration of samples.
- In-house AMS measurements.
- Visitor workspace.
- Dedicated enclosed facility for safe storage of sensitive sample materials.

Contact details

Please email **c.tighe@lancaster.ac.uk** to discuss your potential project at any point (including ahead of the facility opening).

Availability

LAMS-UK is currently scheduled to be available for access by external users from Autumn 2021. Up-to-date information about availability is provided at **https://www.nnuf.ac.uk/lancaster-accelerator-mass-spectrometer**.

Materials Research Facility

Project lead: Dr Steven Van Boxel

The UKAEA's **Materials Research Facility** at Culham in Oxfordshire specialises in processing and analysing radioactive materials, to support research in fission, fusion and particle accelerator design. We can take material that is far too radioactive for a university laboratory but does not need to be handled at a nuclear licensed site. The MRF has been funded by EPSRC, through the **NNUF** and **Henry Royce Institute** initiatives, as well directly by Government.

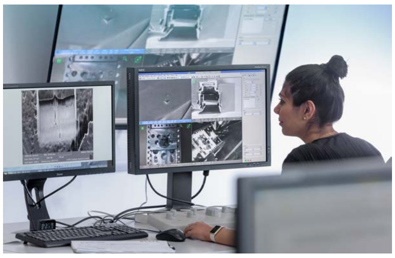
The materials inside both fission and fusion reactors face a unique combination of high temperatures and fast-moving neutrons. Developing materials that can survive for long periods in these conditions is therefore a high priority for the nuclear industry. Data from MRF helps researchers understand the properties of materials for:

- Existing nuclear power stations and designs for future, more efficient power stations
- Fusion reactors
- Particle accelerators – for targets and other components that operate in an extreme environment.

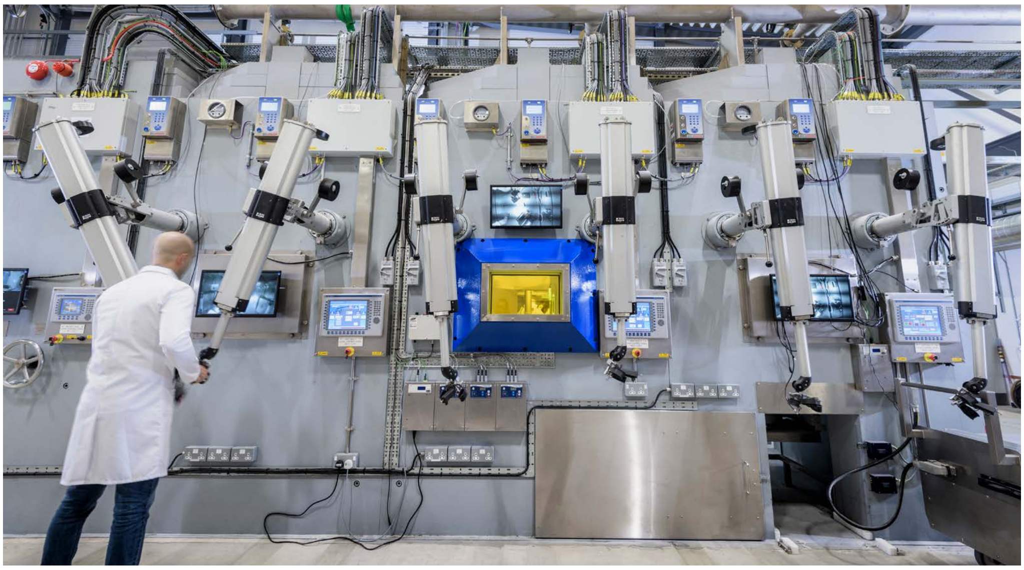
In MRF we can cut and prepare samples in hot cells, using remote handling systems, up to TBq levels (Cobalt-60 equivalent). The resulting smaller specimens, which have much reduced radiation levels, can then be analysed on site in shielded enclosures (up to GBq levels) or at university laboratories. MRF uses advanced scientific methods and specialist equipment to perform microstructural analysis, mechanical testing and thermo-physical characterisation, and has a range of equipment to prepare samples for these tests. MRF also has an experimental area for tritium, beryllium and other hazardous materials.

Scientific equipment can be operated remotely from the MRF control room by users after training. The training will allow the user to operate the equipment safely and focus on the science that needs to be done, with support available from in-house experts.

For more information on the equipment and the MRF visit **our website**, consult the **MRF Brochure**, or use our **contact form**.


Radioactive sample preparation using FIB


Operator and manipulator arms as seen from inside the hot cell


Hot cell wall with operator using manipulator arms

Contact details

Please use the **contact form on the MRF website** to initiate a discussion about your potential project.

Availability

MRF was available for access by external users at the time of going to press. Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/materials-research-facility**.

Molten Salts in Nuclear Technology Laboratory

PI: Dr Clint Sharrad

Dalton Cumbrian Facility

Np(IV) in molten LiCl-KCl eutectic

Image courtesy of Hugues Lambert and Clint Sharrad – University of Manchester

The MSNTL aims to provide a molten salt R&D capability for studying fluoride salts in nuclear systems within the UK for the first time:

- Enabling the UK's expertise in chloride salts from pyroprocessing research to alternative salt systems in order to explore expanding research areas such as Molten Salt Reactor technologies.
- Providing an interdisciplinary hub for molten salts research with radioactive materials.

Equipment to include

- Numerous materials corrosion test rigs
- Gravity-fed molten salts flow loop
- Molten salts irradiation test rig
- High temperature column for dynamic ion exchange studies with molten salts
- Bespoke gloveboxes and supporting infrastructure for handling molten salts with radioactive material
- Supporting furnaces of various types
- TGA/DSC coupled with GC-MS
- High temperature rheometers
- Potentiostats
- Various existing spectroscopic and electrochemical kit.

Network of locations

- Prime hub in the **Centre for Radiochemistry Research** (University of Manchester) for medium active to "hot" work
- University of Edinburgh for low active work, also linking with the **Pyrochemical Research Laboratory**
- **Dalton Cumbrian Facility** for radiation studies
- Input from UCL and University of Sheffield.

Contact details

Please email **clint.a.sharrad@manchester.ac.uk** to discuss your potential project.

Availability

The Molten Salts in Nuclear Technology Laboratory is currently under development. Please consult **https://www.nnuf.ac.uk/molten-salts-nuclear-technology-laboratory** for the latest information.

National Nuclear Laboratory

Project lead: Prof. Jonathan Hyde

The National Nuclear Laboratory operates some of the world's most advanced nuclear facilities across the UK, delivering scientific innovation to our customers and collaborating with academia.

FEI Helios 600i Nanolab
© NNL

Bruker Skyscan 1172
© NNL

Contact details
Please email **amanda.kenway-jackson@uknnl.com** and cc **access.liaison@uknnl.com** with your general user access enquires.

Availability
Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/national-nuclear-laboratory**.

NNUF and EPSRC funding has enabled NNL to procure a range of scientific equipment for characterising irradiated materials:

- A high-resolution FIB-SEM
- A high-resolution X-ray CT capability
- A 200 kV (S)TEM with EELS capability
- A 200 kV aberration-corrected FEG-TEM (expected to be available from late 2021).

In addition, NNL are procuring state-of-the-art robotic equipment which will enhance NNL's current in-house robotic capabilities to support Robotics and Artificial Intelligence (RAI) technical programmes. This capability will be located at our Workington Facility and will form part of the **NNUF Hot Robotics Facility**.

FIB-SEM at NNL's Central Laboratory, Sellafield - FEI Helios 600i Nanolab with EDS & EBSD with TKD

A high-resolution FIB-SEM with a full complement of analytical capability is available for use at NNL's Central Laboratory (Sellafield).

Installed in the active area of Central Laboratory on Sellafield site, the instrument combines a UHR electron microscope with energy-dispersive X-ray analysis (EDX) and electron back-scatter diffraction (EBSD) analysis, as well as an ion column for sputtering materials and preparing size-reduced specimens for TEM analysis.

Previously the instrument has been involved in examining AGR fuel cladding, vitrified waste, MTR fuel, uranium powders and precipitates, and preparing atom probe tomography needles.

Technical contact: Dr Adam Qaisar (**adam.qaisar@uknnl.com**).

X-ray computed microtomography at NNL's Central Laboratory, Sellafield - Bruker Skyscan 1172

A high-resolution X-ray CT capability is available for use at NNL's Central Laboratory. Installed in the active area of Central Laboratory on Sellafield site, the Bruker Skyscan 1172 allows non-destructive imaging of specimens with a peak resolution of 0.9 µm.

Comprising a 100 kV, 10 W X-ray source, 11 MP CCD detector, and a micropositioning stage, the 1172 is capable of scanning samples as large as 50 mm in diameter and can perform z-stacking for particularly long specimens.

Previously the instrument has been involved in examining carbonaceous deposits, uranium foil in cement, Magnox simulant sludge, various cements and grouts.

Technical contact: Dr Adam Qaisar (**adam.qaisar@uknnl.com**).

200 kV (S)TEM with EELS capability at NNL's Central Laboratory, Sellafield - JEOL 2100

A 200 kV (S)TEM with EELS capability is available for use at NNL's Central Laboratory (Sellafield site). The instrument combines the high spatial resolution of a transmission electron microscope with chemical analysis by EDS, and EELS.

The instrument is further supported by NNL's FIB and PFIB instruments, as well as ion mill and electropolishing equipment for TEM sample preparation.

Previously the instrument has been involved in examining AGR fuel cladding, zirconium cladding, MTR fuel, and wasteforms.

Technical contact: Dr Simon Dumbill (**simon.dumbill@uknnl.com**).

200 kV aberration-corrected FEG-TEM (to be installed in NNL's Central Laboratory, Sellafield) - JEOL ARM-200F with EDS and Gatan GIF Quantum

A 200 kV aberration-corrected FEG-TEM with EELS capability is expected to be available for use at NNL's Central Laboratory from late 2021.
Installed in the active area of Central Laboratory on Sellafield site, the instrument is capable of sub-Angstrom imaging resolution, and atomic resolution chemical analysis by EDS (0.98 Sr Oxford Instruments X-Max 100 TLE detector), and Gatan GIF Quantum 965 ER with Dual EELS and EFTEM capabilities.

The instrument is further supported by NNL's FIB and PFIB instruments, as well as ion mill and electropolishing equipment for TEM sample preparation.

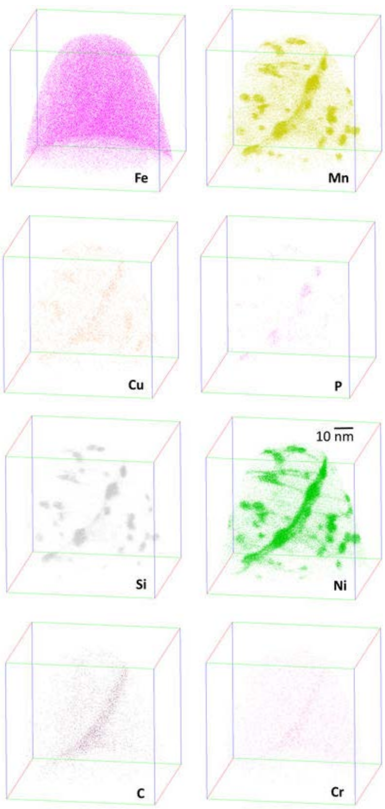
Technical contact: Dr Simon Dumbill (**simon.dumbill@uknnl.com**).

Nuclear Materials Atom Probe (NuMAP) Facility

PI: Prof. Michael Moody

UNIVERSITY OF OXFORD

A new state-of-the-art atom probe user facility has been established to routinely deliver atomic-scale characterisation of active nuclear materials. Working closely with the UKAEA Materials Research Facility (MRF), the Department of Materials at the University of Oxford can provide the UK's nuclear research community with fully supported access to atom-by-atom characterisation generated by Atom Probe Tomography (APT).



Atom Probe Tomography analysis of an ion-irradiated steel. APT images show a distribution of irradiation-induced Ni-Mn-Si clusters, P clusters, solute segregation to irradiation-induced dislocations and solute segregation to a grain boundary.

Courtesy of James Douglas

Many aspects in the design of new materials, and assessment of their performance in harsh reactor environments, need to be addressed at the atomic scale; and in many cases APT is now considered an essential characterisation tool. Hence, APT is increasingly needed to underpin research across all stages in the nuclear energy cycle: materials design for new reactor manufacturing, component safety/failure analysis, waste/storage and accident investigation.

Unique nanoscale insights can be provided by APT: atomic-scale solute clustering, segregation to microstructural interfaces, and locating low concentration transmuted elements – vital information for developing engineering materials for nuclear applications.

NuMAP offers a streamlined procedure to request user access and support across every stage of APT analysis. The key to this is synergy between the MRF and Oxford. The MRF provides vital expertise and equipment to receive active materials that Oxford cannot process, such as neutron-irradiated materials from UK or overseas partners, and prepare active APT samples. The close proximity of the two institutes enables efficient exchange of researchers/expertise and ready transport of APT samples.

This process is underpinned by a dedicated Atom Probe Scientist: the single point of contact for users, providing ongoing, tailored experimental support. This ranges from training new users to guiding more complex experimental programs, along with undertaking industrial commercial work.

Our strategy is optimised to remove barriers for non-expert users, promote the technique and rapidly expand the facility user-base. This, combined with enhanced capabilities to address increasingly challenging scientific topics, aims to encourage diversification of research projects in the UK underpinned by APT, including materials for geological disposal, Gen IV reactors, fusion candidates and even fuels.

Services provided by the facility

- **Tailored experimental design** – users are given expert advice on how APT characterisation can assist their work.
- **Specimen preparation** – the facility facilitates and supports access to a dual-beam FIB instrument managed by the UKAEA MRF, dedicated to sample preparation of active materials. The Atom Probe Scientist provides consultation, training and specimen fabrication tailored to the needs and expertise of the user.
- **Active sample handling** – users receive assistance in all aspects of radioactive material handling, including support from MRF health physicists and waste management advisors during sample preparation and radiation transport advisors for transfer to Oxford.
- **Atom probe** – users are provided with access to the latest atom probe instruments. Expert support is provided to optimise material specific analysis.
- **Data analysis** – raw experimental data is reconstructed into a 3D atomistic map using proprietary software, with visualisation and statistical tools used for data interpretation. Facility users are provided with supported access to imaging and analysis software.
- **Training** – for ongoing users of the technique the facility provides expert level training in all aspects of the technique.
- **Commercial services** – the facility undertakes bespoke packages of APT analysis upon commission by industrial partners. We provide imaging, data analysis and formal reports.

Availability

The NuMAP Facility is currently scheduled to be available for access by external users from January 2021. While COVID-19 restrictions remain in place, we cannot currently undertake hands-on training within the facility. However, we are strongly committed to supporting the research of new users with experiments performed by NuMAP scientists. Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/nuclear-materials-atom-probe-facility**.

Contact details

Please email **james.douglas@materials.ox.ac.uk** to discuss your potential project.

PANAMA

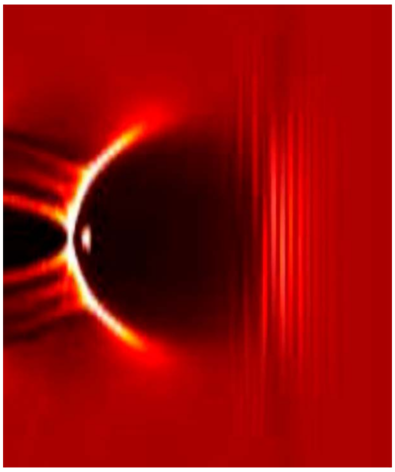
Plasma Accelerators for Nuclear Applications and Materials Analysis

PI: Dr Joanna Renshaw

The PANAMA facility, based in the **Scottish Centre for the Application of Plasma Accelerators** (SCAPA) will provide state-of-the-art characterization and testing capabilities for nuclear materials from across the nuclear sector, from new build and fuel development and manufacture, to decommissioning, waste management and geological disposal.

Radiation shielding concrete door to Bunker A in SCAPA

© Dept of Physics, University of Strathclyde



Computer simulation of a micrometer-scale intense X-ray source (small bright blob to the left of centre) created in a laser-plasma accelerator

© Dept of Physics, University of Strathclyde

Capabilities being developed at PANAMA include:

- X-ray and γ-ray Computed Tomography (X-CT/γ-CT)
- γ-radiography imaging
- X-ray Absorption Spectroscopy (XAS)
- X-ray Diffraction
- Time-resolved diffraction & spectroscopy
- Radiation damage (particle beams, including protons and ^{4}He ions)
- Pump-probe on radiation damage combining particle beams with diffraction/spectroscopy/imaging.

Laser-driven plasma accelerators derive their energy from a high intensity laser (generally a Ti:sapphire laser) that irradiates a low density plasma target with femtosecond light pulses. The light pulses produce a density wake in plasma thus separating the charge to produce accelerating fields 1000 times stronger than possible in conventional accelerators. The resulting self-injected electrons form ultra-short duration bunches, which can directly produce THz radiation, X-rays or gamma rays up to 10 MeV or through interacting with a secondary target or counter-propagating laser beam produce 100 s MeV photons. Radiation produced in laser-plasma interactions include: electrons, muons, protons, neutrons and light ion beams, and electromagnetic radiation pulses from the IR to gamma rays.

The SCAPA facility uses two state of-the-art Ti:sapphire lasers: a 40 TW (1.4 J, 35 fs; at 10 Hz) and a 350 TW (8.75 J, 25 fs; at 5 Hz) system, to generate:

Radiation pulses:

- High brightness THz and infra-red radiation;
- Partially coherent betatron (plasma wiggler) radiation in the X-ray to γ-ray (10 s of MeV) range;
- Coherent radiation from a free-electron laser (FEL) in the VUV-X-ray (sub-nm) range.

Particle beams:

- Monoenergetic electron beams of energy 100 MeV – 4 GeV;
- Proton and light ion beams of energy up to 100 MeV/c.

At the PANAMA beamline, these SCAPA capabilities will be exploited for advanced materials characterization. The high energy range of the produced X- and γ-rays (100 s of keV to MeV) can penetrate very dense (or very large) materials for detailed imaging of such materials. Additionally, the ultrashort duration of the high intensity hard X-ray pulses (e.g. 7-20 keV) can be utilized for time-resolved diffraction and spectroscopy at ultrashort timescales. Perhaps most important, the flexibility of the X- and γ-rays produced and the possibility to (nearly) simultaneously produce particle beams enables combining imaging, spectroscopy or diffraction with radiation damage on the same sample to enable *in-situ* real-time observations of the precise mechanism of damage relevant to the nuclear energy sectors, including structural materials, waste matrices, and cladding.

A new dedicated active lab will also enable safe manipulations of radioactive samples, including subsequent analysis at the PANAMA beamline.

Contact details

Please email **pieter.bots@strath.ac.uk** to discuss your potential project.

Availability

PANAMA is currently scheduled to be available for access by external users from Spring 2021 (for the X-CT in the first instance). Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/panama**.

Pyrochemical Research Laboratory

Project lead: Prof. Andrew Mount

THE UNIVERSITY *of* EDINBURGH

The Pyrochemical Research Laboratory (PRL) is an open-access national user facility, established to provide academic, public, and private sector organisations with access to state-of-the-art equipment to support world-leading research in molten salt pyrochemical processing.

The laboratory consists of a suite of interconnected controlled atmosphere dry-boxes. These are equipped with the necessary furnaces, cell systems, potentiostats and other equipment for characterisation, required for research into, and development of, each of the essential elements of pyrochemical reprocessing at the laboratory scale.

There is flexibility in the configuration of the PRL, with users able to request individual modules to demonstrate the feasibility of individual components of pyrochemical reprocessing. Alternatively the entire facility may be utilised to demonstrate a complete pyrochemical process, including monitoring and analysis.

Access to the PRL facility is facilitated by the lab manager, Dr Justin Elliott (**Justin.Elliott@ed.ac.uk**) who can provide advice and guidance on utilising facility equipment to meet your research needs.

Aims of the PRL

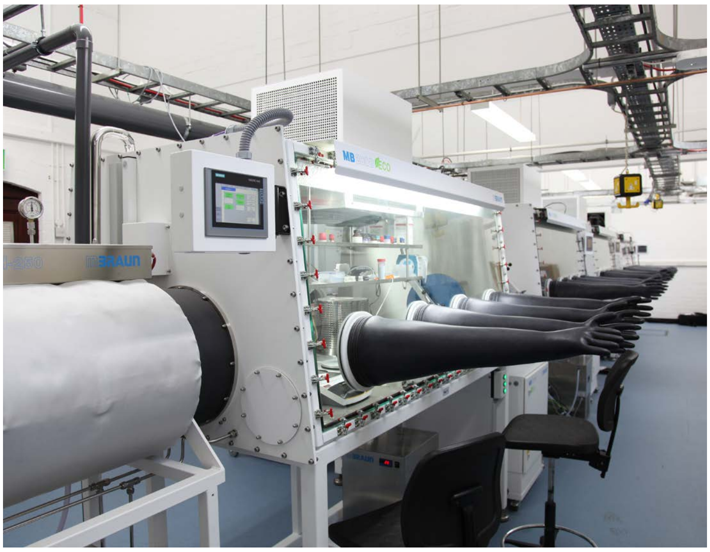
The University of Edinburgh established the PRL facility, in partnership with the Department of Energy and Climate Change (DECC now BEIS), and it is affiliated with the National Nuclear User Facility (NNUF). The PRL facility is unique in providing the facilities to develop and demonstrate integrated pyrochemical reprocessing of nuclear fuel, using fuel-relevant non-radioactive compositional mixtures at laboratory scale, along with the required process monitoring.

The PRL facility is therefore a unique research capability, providing hands-on user access to state-of-the-art equipment and instrumentation, utilising medium scale inventories, enabling the UK to deliver internationally competitive R&D.

Capabilities and Equipment

The PRL facility has four interconnected but individually bookable glove boxes, each tailored to a given stage of a pyroprocessing system with associated equipment.

Please consult **http://www.prl.chem.ed.ac.uk/capabilities-and-equipment** for more details.



Contact details

Please email **Justin.Elliott@ed.ac.uk** to discuss your potential project.

Availability

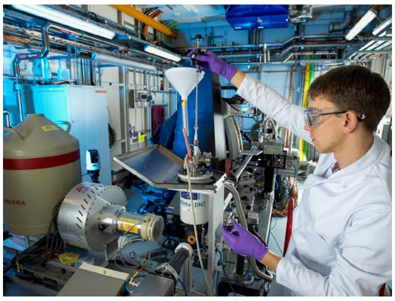
Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/prl**.

RADER
RADioactive waste management and Environmental Remediation
PIs: Prof. Katherine Morris and Prof. Jon Lloyd

The NNUF RADioactive waste management and Environmental Remediation (RADER) user facility will support research into characterising and understanding the behaviour of radioactive species in engineered and natural environments. This science base is crucial for underpinning large parts of the UK's >100 year, >£130 billion nuclear decommissioning, clean-up and waste management programmes.

Sediment column set up in the environmental radioactivity lab

© Dalton Nuclear Institute



University of Manchester PhD student demonstrating the loading of a sample containing uranium onto Diamond's I20-scanning beamline

© Diamond Light Source

To support this work, the RADER user facility will deliver a suite of laboratories designed to handle and analyse radioactive samples from engineered and natural environments. The facility will be co-located with Manchester University's Research Centre for Radwaste Disposal (RCRD) and embedded within the NERC-funded Williamson Research Centre for Molecular Environmental Science (WRC), drawing on established complementary skills and expertise.

Uniquely in the UK, RADER will offer dedicated laboratories enabling users to undertake Low Level Radiometrics, Environmental Characterisation of Solids (inorganic and biological), Environmental Characterisation of Solutions and Sample Preparation, all in one location and with dedicated Experimental Officer support. Combined, these integrated state-of-the-art facilities will enable low level separations and microbiological, mineralogical and molecular-scale environmental research with a wide range of environmentally relevant radionuclides. RADER will support experiments across realistic radionuclide concentration ranges, and offer comprehensive authentic sample analyses.

Relevant topics for investigation within RADER will include radioactive waste disposal, decontamination, land management, effluent treatment and radionuclide transport in the biosphere, especially where radioactive sample handling and characterisation are required.

The new infrastructure being delivered to the RADER user facility is summarised in key areas below, and augments the already strong infrastructure in the **WRC**. Support is also provided from '**NNUF@CRR**' (Centre for Radiochemistry Research) on aspects of spectroscopy, magnetism, reprocessing and computational modelling. This will create a suite of RADER laboratories able to handle low-level radiochemical separations and environmental chemistry/biogeochemistry experimental work with radioactive samples.

RADER facility development was informed by experience of working with radioactive, environmental samples and devised in close consultation with the UK and international academic and industrial user community.

Low level radiometric counting

- Low level scintillation counting for environmental samples
- Alpha spectroscopy
- Autoradiography to identify radioactive regions in samples

(with access facilitated to existing ORTEC Profile S low-level gamma spectrometer)

Environmental characterisation - solutions

- ICP-MS/MS. Ultra-dilute element concentrations, isotopic information.
- Capillary IC. Small volume anion analyses.
- Zetasizer. Colloid molecular particle size, zeta potential, and molecular weight
- Nanoparticle Tracking Analysis (NTA). Nanoparticle size distribution and concentration

(with access facilitated to existing WRC HPLC for ICPMS speciation and ICP-AES)

Environmental characterisation - solids

- Powder X-ray diffraction
- Surface Area Analyzer
- Fourier Transform Infra-Red Spectrometer
- UV Visible Near Infra-Red Spectrometer

(with access facilitated to existing WRC Quanta 650FEG Environmental Scanning electron microscope)

Environmental characterisation - biological

- Real-Time PCR & Homogenzier for DNA extraction

(with access facilitated to existing Illumina Next Generation Sequencing Platform. DNA sequencing and bioinformatics platforms)

Sample preparation

- Chemostat. Controlled reaction vessel
- Isocratic / Peristaltic Pumps for flow-through Column experiments
- Sectioning saw and polisher/grinder
- Anaerobic Cabinets. O_2 / CO_2 control.

Contact details

Please email **Jon.lloyd@manchester.ac.uk** and **katherine.morris@manchester.ac.uk** to discuss your potential project.

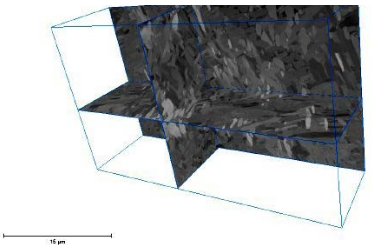
Availability

RADER is currently under development. Please consult **https://www.nnuf.ac.uk/rader** for the latest information.

SIMFUEL and Alpha-Active Material Manufacturing and Characterisation Facility

PI: Prof. Tim Abram

The SIMFUEL and Alpha-Active Material Manufacturing and Characterisation Facility, located in the Henry Royce Hub Building at the University of Manchester, is a world-leading laboratory for the manufacture and characterisation of a range of alpha-active nuclear materials. The NNUF facility consists of a FIB/SEM coupled to an inert atmosphere glovebox and a TEM dedicated to handling alpha-active materials.



3D BSE images of Zr-Nb Alloy
© University of Manchester

Uranium glovebox suite for sample production and preparation
© Marc Schmidt

Spark Plasma Sintering Furnace with attached glovebox
© Marc Schmidt

The facility is based within the Nuclear Fuel Centre of Excellence (NFCE) which gives users access to a wide range of sample manufacture, preparation, and characterisation techniques, including for samples containing uranium, thorium or higher actinides. This allows academic and industry users access to sample preparation and atom-scale microscopy to support research and technical problems across the nuclear fuel cycle, without the need to transfer material on and off nuclear licenced sites.

The complete range of equipment is operated as a user facility through NNUF(2) and the Henry Royce Institute, providing a manufacturing, characterisation, and testing suite that can be used in combination with other NNUF facilities (e.g. the **Dalton Cumbrian Facility**) to perform beginning-to-end of life studies of nuclear fuel materials.

FIB/SEM – Helios 5 CX with Glovebox Autoloader

The FIB/SEM is capable of electron and Ga ion beam imaging and milling of materials for the preparation of lamellae for further TEM analysis. This allows the preparation of site-specific areas as well as the ability to dramatically size reduce samples for further TEM analysis so they can be handled more easily or be sent to other institutes. The FIB/SEM is adapted for alpha-active material workflow, with a retractable sputter shield and is coupled to an inert atmosphere glovebox so the complete workflow can be undertaken without exposure of the user to alpha-active material. The facility is also capable of inert gas/vacuum transfer of the sample from the glovebox to the TEM to avoid exposure of the user to material and avoid exposure of the sample to air.

The microscope is equipped with EDS and EBSD which allows for chemical and crystallographic orientation/phase mapping. This allows the user to take FIB lamellae from specific regions in terms of chemistry or grain orientation. It is possible to perform BSE imaging, EDS and EBSD mapping with FIB milling to create and reconstruct 3D images.

- Electron column – 200 V - 30 kV Schottky FEG-SEM
- FIB column – 500 V - 30 kV Gallium ion Column
- EDS – Oxford Instruments 170 mm^2 Ultimax
- EBSD – Oxford Instruments Symmetry detector
- Glovebox transfer for complete inert atmosphere contained workflow.

TEM – Talos F200i

The TEM is equipped with an X-FEG capable of operating in TEM and STEM modes. This permits the study of nanoscale features which is crucial for the study of nuclear fuel materials through their life-cycle and is capable of lattice and atomic level resolution alongside electron diffraction analysis. It is equipped with dual-EDS detectors and EELS which can be used to determine chemical composition and oxidation states. A range of holders are available for the analysis of samples at temperatures from ambient to liquid nitrogen, as well as surface tomography and 3D reconstruction.

- X-FEG electron source, 80-200 kV
- Dual EDS detectors (2 x 100 mm^2)
- Gatan Continuum ER image filter
- Tomography holder and reconstruction software
- Cryogenic holder
- Inert gas/vacuum transfer holder to allow fully contained workflow.

Contact details

Please email **reyes.palacios@manchester.ac.uk** to discuss your potential project.

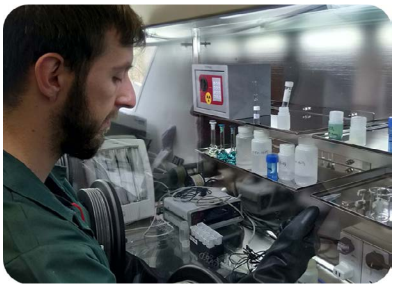
Availability

The SIMFUEL and Alpha-Active Material Manufacturing and Characterisation Facility is currently under development. Please consult **https://www.nnuf.ac.uk/simfuel-and-alpha-active-material-manufacturing-and-characterisation-facility** for the latest information.

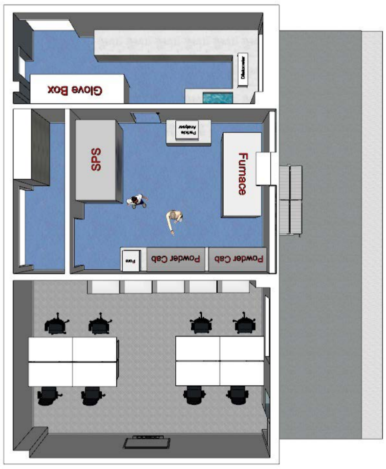
UTGARD Laboratory

PI: Prof. Colin Boxall

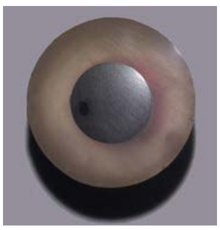
Mission: To establish a university facility for simulated spent nuclear fuel (SIMFUEL) fabrication and characterisation that is unique within the UK higher education landscape, in order to drive and accelerate UK spent nuclear fuel research.



A postdoctoral researcher prepares a radioactive liquid sample for analysis



Design sketch of UTGARD Phase II Laboratory space attached to the existing UTGARD



A uranium dioxide pellet electrode prepared in UTGARD Laboratory

Research Themes

UTGARD Phase II will focus on oxide SIMFUELs, including MOX and ThO_2-based fuels. The new facility will extend Lancaster's existing radiochemical lab for open sources, UTGARD, enabling research in the following themes:

1) **Development of new, advanced sintering routes for the fabrication of SIMFUELs** with porosities, fission product loadings, and defect microstructures that better simulate those of real spent nuclear fuel (UTGARD Phase II).
2) **Behavioural studies** of advanced SIMFUELs, as well as those prepared using conventional techniques, under a range of conditions relevant to the back end of the fuel cycle – including wet/dry interim storage, geological disposal and new reprocessing routes (UTGARD Phase I).

Facilities

Constructed in 2016, UTGARD Laboratory is a ~120 m^2 process chemistry laboratory for work on β/γ active fission products, uranium, thorium and low level alpha tracers.

UTGARD Phase II involves an extension to the existing UTGARD Laboratory, generating a further ~40 m^2 of new laboratory space. As with the existing laboratory, UTGARD Phase II will be rated to the highest level of university open source radiation protection, allowing for the handling of a wide variety of radioactive isotopes for use in SIMFUEL manufacture.

Equipment

UTGARD Phase II

SIMFUEL powder precursor preparation:

- Licence for the FISPIN fuel depletion code, for calculation of target SIMFUEL compositions as functions of burnup and cooling time.
- Planetary ball mill (Retsch) and particle sizer (Horiba) for control and measurement of the size of SIMFUEL precursor powders

Sintering of SIMFUEL precursors into pellet form:

- Up to 100% hydrogen tube furnace (Nabertherm) for conventional sintering of green pellets prepared using existing powder presses.
- SPS system for advanced binder-free field assisted rapid sintering studies.
- Modified dilatometer (Netzsch), for monitoring pellet densification during sintering and for the study of the novel route of flash sintering.

Post-sintering sample preparation and characterisation:

- Mercury porosimeter (Anton-Paar) to assess pellet porosity post-sintering.
- Powder cabinet-isolated diamond saw and grinding and polishing machine (Struers) for sample preparation.

UTGARD Phase I

Radiation handling and measurement

- α/β counter and multi-sample gamma counter/spectrometer
- HEPA filtered negative pressure and anoxic positive pressure gloveboxes
- Two banks of two centrifugal contactors

Electrochemistry

- Multiple potentiostats, rotating disk electrodes and quartz crystal microbalances

Spectroscopy

- Raman microscope (with hot stage), ATR FT-IR and UV-VIS-NIR (with stop-flow adaptor).

Chromatography

- HPLC and Anion/Cation Ion Chromatography system with combined Mass Spectrometer (IC-MS)

Thermal Analysis

- TGA/DSC system with combined gas mass spectrometer (TGA-MS)

Elemental characterisation/imaging

- SEM with EDX, Large chamber XRF system

Contact details

Please contact Dr Richard Wilbraham via email at **r.wilbraham@lancaster.ac.uk** or telephone on +44 (0)1524 594866 to discuss your potential project.

Availability

UTGARD is currently scheduled to be available for access by external users from January 2021, depending on social distancing measures on the Lancaster University campus. Up-to-date information about availability, in light of the COVID situation, is available at **https://www.nnuf.ac.uk/utgard-laboratory**.

NNUF
National Nuclear User Facility

UKRI Engineering and Physical Sciences Research Council