The UK Atomic Energy Authority's mission is to lead the delivery of sustainable fusion energy and maximise scientific and economic benefit

UK Atomic Energy Authority

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UK Atomic Energy Authority

Fusion Technology

Year in Review 25/26

The UK Atomic Energy Authority's mission is to deliver sustainable fusion energy and maximise scientific and UK economic benefit.

Foreword

The 2025/26 financial year marks an important moment for fusion in the United Kingdom. The publication of both The UK's Modern Industrial Strategy and UK Fusion Strategy 2026 during this period provide a clear and ambitious vision for the nation's future: to combine scientific leadership, industrial strength, and the spirit of innovation to establish the UK as a global leader in commercial fusion energy. Together with the strategic direction set by UKAEA and UK Fusion Energy Ltd in their associated roadmaps, these documents provide a strong framework for transforming fusion from a scientific endeavour into a new clean energy industry.

The work of the Fusion Technology Division sits at the heart of these ambitions. Throughout FY2025/26, our teams have delivered significant advances across materials and manufacturing qualification, neutronics and thermal fluids research, magnet technology development, and integrated power plant systems design. A key example of this delivery is through developments on our high heat flux qualification facility, HIVE (pictured on cover). As it enters its tenth year of operation, we continue to develop HIVE for component qualification and validation by integrating a suite of frontier diagnostic tools that, through an advanced digital-physical interface, deliver credible systems-level qualification data under extreme-environment testing. Activities such as this serve to strengthen confidence in fusion technologies, accelerating the technology readiness of power plant systems and enabling the transition from research to deployment.

Our impact extends beyond technology development alone. We are placing strong emphasis on building a sustainable fusion economy and ensuring that the benefits of fusion are realised through growth, investment and industrial opportunity. Through initiatives such as the Fusion Futures Industry Capability programme, the NEURONE advanced steels development consortium, and the Vanadium Strategy project, the Division has worked closely with industry, academia, government and private fusion companies in FY2025/26 to strengthen supply chains, accelerate qualification pathways, develop advanced manufacturing capability and support the growth of the UK's expanding fusion sector. Technologies we have developed, particularly in neutron transport modelling, have driven direct support into private fusion endeavours, securing notable partnerships with General Fusion, First Light Fusion, Gauss Fusion and Tokamak Energy.

As we look ahead, the challenges associated with delivering commercial fusion energy remain substantial. However, the opportunities present to the Division are equally significant. Our next task is to convert the full breadth of our capability into a suite of visible, nationally significant design and qualification platforms, notably in the magnet technology space, which will help fusion developers and their supply chains move towards commercial deployment faster and with greater confidence. For the moment however, I invite you to join me in celebrating some of the fantastic achievements captured in our FY2025/26 Fusion Technology Year in Review.

Cory Hamelin
Interim Director, Fusion Technology
UK Atomic Energy Authority

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Introduction

The Fusion Technology Division's vision is to develop a qualified suite of all technologies needed to realise deployable commercial fusion power plants.

The department consists of the following groups:

- The **Applied Materials Technology Group** focuses on materials engineering challenges of fusion reactors, including: development and screening of novel materials, supporting the establishment of materials supply chains, fusion specific environmental testing, development of small specimen testing techniques and supporting progress on new fusion design codes and standards.
- The **Applied Radiation Technology Group** supports and develops fusion technologies and underpinning research and development programmes by leading the application and development of nuclear modelling codes, tools and nuclear data. This includes multi-physics simulation tools to research and develop advanced simulations in areas such as neutronics, waste management and magnet safety.
- The **Manufacturing Technology Equipment Qualification Group** specialises in research and testing projects that require innovative manufacturing solutions for customers, such as global fusion projects. This includes assessing existing components, advancing manufacturability of new component designs, supporting commercial manufacture of components and providing technical support.
- The **Power Plant Modelling and Integration Group** focuses on conceptual design relevant to fusion power plants, including creating the EUROfusion baseline DEMO conceptual design, with the use of the comprehensive systems code – PROCESS and Bluemira.
- The **Technology Development Group** bring best practice techniques to the maturation of technologies from proof-of-concept to technology demonstration. Focusing on progression of technologies through TRLs 1-6, the group develops efficient test programmes and prototyping strategies, and leads on defining and delivering the requisite test rigs. This is grounded in test rig operations, a capability rooted in the group's responsibility for the HIVE high heat flux testing facility.
- The **Thermal Hydraulics Group** specialises in applied research in reactor cooling and heat transfer for fusion and related areas. This includes modelling complex fluid and heat transfer processes as well as performing experimental validation of these phenomena.
- The **Magnet Technology Group** is a new group which specialises in the design, development and testing of superconducting magnet systems and high-field technologies for fusion applications.

This document details the successes and technical highlights of the Division's work over the 2025/26 financial year.

Acronyms

Acronym	Name
ACP	Activation Corrosion Product
AM	Additive Manufacturing
AMT	Applied Materials Testing
API	Application Programming Interface
BeHF	Beryllium Handling Facility
BSSM	British Society for Strain Measurement
CAF	Credibility Assessment Framework
CFD	Computational Fluid Dynamics
DAQ	Data Acquisition
DIC	Digtal Image Corrrelation
DSIT	Department for Science, Innovation and Technology
D-T	Deuterium-Tritium
EPRI	Electric Power Research Institute
FBG	Fibre Bragg Grating
FIV	Flow-induced Vibration
FNG	Frascati Neutron Generator
FSI	Fluid-structure Interaction
HEBT	High Energy Beam Transport
HHFTVF	High Heat Flux Testing and Verification Facility
HIVE	Heating by Induction to Verify Extremes
HTS	High Temperature Superconducting
IFMIF-DONES	International Fusion Materials Irradiation Facility – Demo Oriented NEutron Source
IR	Infrared
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
JSI	Jozef Stefan Institute
L-BPF	Laser-Powder Bed Fusion
MaLBEC	Machine Learning Based Efficiency Calculator
MCNP	Monte Carlo N-Particle
MHD	Magnetohydrodynamic
MLCSA	Machine Learning Compton Suppression Algorithm
N1S	Novel-1-Step
NBI	Neutral Beam Injector
NPL	National Physics Laboratory
ORNI	Oak Ridge National Laboratory
PFC	Plasma Facing Components
PPMI	Power Plant Modelling and Integration
RADLab	Radiological Assay and Detection Laboratory
RAFM	Reduced-Activation Ferritic-Martensitic
RMJ	Remountable Joint
SEM	Scanning Electron Microscopy
TSA	Thermoelastic Stress Analysis
UDV	Doppler Velocimetry
UKACM	UK Association of Computational Mechanics
WP-DIV	Work Package Divertor

Delivery and dissemination of high-impact research in fusion technology development

Over the last financial year, the Fusion Technology Division has pursued an ambitious programme of research communication and knowledge sharing. This has included a strong focus on high-impact publication output, with 16 first-author peer-reviewed journal papers submitted, alongside a significant presence at national and international conferences through invited talks and oral and poster presentations.

Strategic work has progressed on establishing robust data infrastructure, ensuring our research outputs are findable, accessible, interoperable, and reusable for the long term.

In 2025/26, engineers have been working on the development of a digital tool to support simulation-led experimental design in materials and component testing. The tool is a significant step forward in our smart, evidence-based approach to building confidence in fusion technologies.

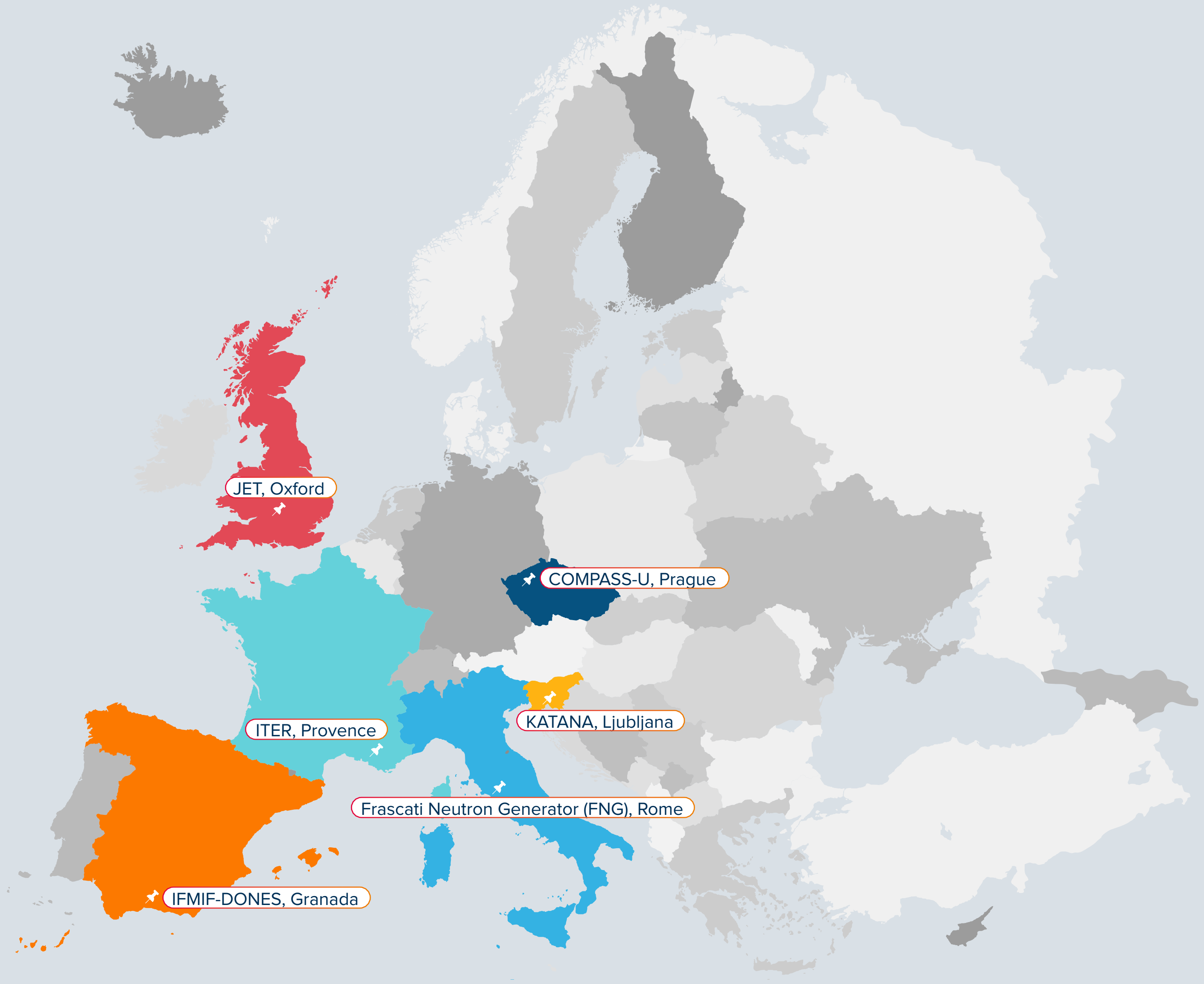
Together, these achievements demonstrate the group's ambition, capability, and continued progress towards fusion energy delivery.

EUROFusion Highlights

The 2025/26 programme delivered a broad and high-impact portfolio focused on building confidence in fusion design through validated, reusable evidence. A total of 31 projects spanned these key areas: neutronics and radiometrics, materials and manufacturing, and component validation. The programme demonstrates strong technical depth and integration across the design-to-validation workflow.

Overall, the programme delivered strong outputs, across publications, datasets, tools and facilities, with an emphasis on reusable capability rather than one-off results.

Projects have contributed to facilities across Europe, including:



Research papers submitted: 8	Journal	Authors
“Design of a Materials Testing 2.0 Creep Test using the Virtual Fields Method and Open Source Tools”	Experimental Mechanics Journal	R. Spencer, L. Fletcher, R. Hamill, C. Hamelin, A. Harte
“BLUEMIRA: a modular, open-source framework for designing tokamak fusion reactors”	Nuclear Fusion	M. Coleman, J. E. Cook, F. Franza, I. A. Maione, S. McIntosh, A. I. Blair, S. Desai, O. Funk, G. Graham, J. Matthews, J. Morris, C. Mould, A. Nilima, H. Saunders, D. Short, D. Vaccaro, O. Wong
“Investigating the manufacturability of different unit cell designs in L-PBF tungsten lattice structures for potential sacrificial limiter application”	Additive Manufacturing	M. Zavala-Arredondo, A. Tawfik, L. Blunt, J-H. You
“On the use of specific point energy as a design parameter in L-PBF process energy maps for additive manufacturing of tungsten parts with high mechanical stability”	Materials and Design	M. Zavala-Arredondo, A. Tawfik, L. Blunt, J-H. You
“Outcomes of activation measurements and analyses of ITER materials during JET DTE3 operations”	Plasma Physics and Controlled Fusion	L. W. Packer, P. Batistoni, S. C. Bradnam, M. Fabbri, N. Fonnesu, M. R. Gilbert, Z. Ghani, M. Gorley, C. L. Grove, A. Harte, L. Jones, R. Kierepko, E. Laszyńska, I. Lengar, X. Litaudon, S. Loreti, J. W. Mietelski, M. I. Savva, C. R. Shand, I. E. Stamatelatos, A. N. Turner, T. Vasilopoulou, R. Villari, A. Wójcik-Gargula, J. Włodarczyk and JET Contributors
“IFMIF-DONES Concrete Neutron Shielding Benchmarks”	Fusion Engineering and Design	H. Chohan, M. Ansorge, R. Běhal, A. Cassisa, T. Eade, T. Germany, M. Gilbert, V. Glagolev, C. Grove, I. Kodeli, D. Koliadko, J. Kozic, K. Lennon, M. J. Martínez-Echevarría Romero, J. Mrázek, J. Neilson, J. Novák, T. Piotrowski, Y. Qiu, E. Šimečková, R. Smith, M. Štefánik, O. Wong, C. Shand, A. Harte
“Further development of JADE as a tool for validation and verification of nuclear data libraries and particle transport codes”	Fusion Engineering and Design	A.Valentine, S.Bradnam, J.Moorehead, D.Laghi, M. de Campos, A. Bittesnich, M di Giacomo, M. Fabbri, A. Harte
“A High Fidelity Model of the IFMIF-DONES Accelerator for Nuclear Analysis”	Fusion Engineering and Design	L. Taling, T. Berry, A. Cufar, T. Eade, J. Hodson, A. Lopez-Revelles, V. Lopez, A. Madur, I. Podadera, Y. Qiu, D. Regidor, A. Valentine, A. Harte

Neutronics and Radiometrics

A number of EUROfusion projects have involved developing codes and models for radiation and neutronics modelling for a variety of fusion research laboratories around the world. The below highlights demonstrate how the developments of these codes will strengthen confidence in their use for future fusion facility studies.

JADE Verification & Validation

The JADE framework was developed for the verification and validation of nuclear data in fusion neutronics. Originally conceived to work with Monte Carlo N-Particle (MCNP) code, JADE has been extended to support cross-code comparisons. This development allows benchmarking across both codes using established nuclear data libraries.

Novel-1-Step Code

Off-load source movement was implemented in the Novel-1-Step (N1S) code for shutdown dose rate calculations. The capability was applied to a real-world scenario of calculating integrated dose throughout the IFMIF-DONES facility during removal of the High Energy Beam Transport (HEBT) scraper (Figure 1). This work expands the capabilities of N1S, providing researchers and engineers with a validated tool for modelling dynamic scenarios, and strengthening confidence in its use for future fusion facility studies, such as IFMIF-DONES.

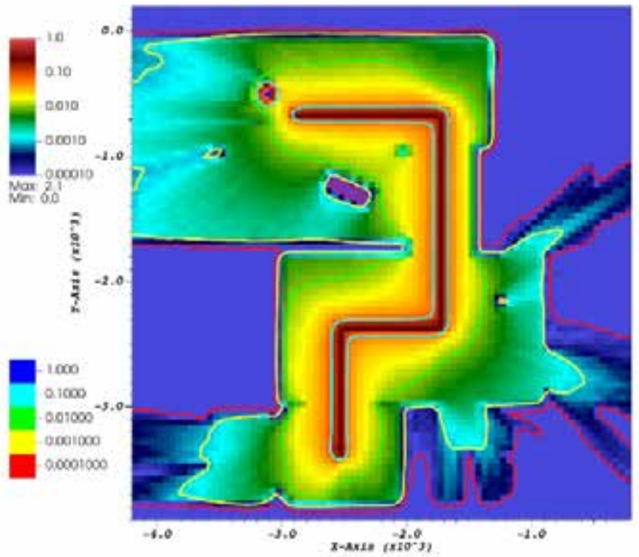


Figure 1 Integrated dose through DONES building level 1, due to HEBT scraper movement, calculated with N1S code.

MCNP Modelling

A high fidelity model of the IFMIF-DONES accelerator was created in MCNP code and organised in such a way that it can be integrated with additional models of supporting components, such as the building and test cell. The model was designed for nuclear analysis, comprising over 22,000 geometric bodies with assigned materials.

Crucially, the model uses a hierarchical structure, meaning individual components can be swapped or updated without rebuilding the entire system, saving significant time as the design evolves. Validation was applied through a beam-on analysis of the HEBT section, with magnet heating results successfully demonstrated. The design is fully compatible with IFMIF-DONES neutronics workflows to hand over to the project team for licensing and safety analysis.

MCNP Calculations

Performed MCNP and count rate calculations as pre-analysis to estimate the required surface activity measurement times for the FNG ACP experiment. The results suggest that acceptable statistics (<3% uncertainty) are achievable for all pipes (Figure 2) and inform on detector position and collimation.

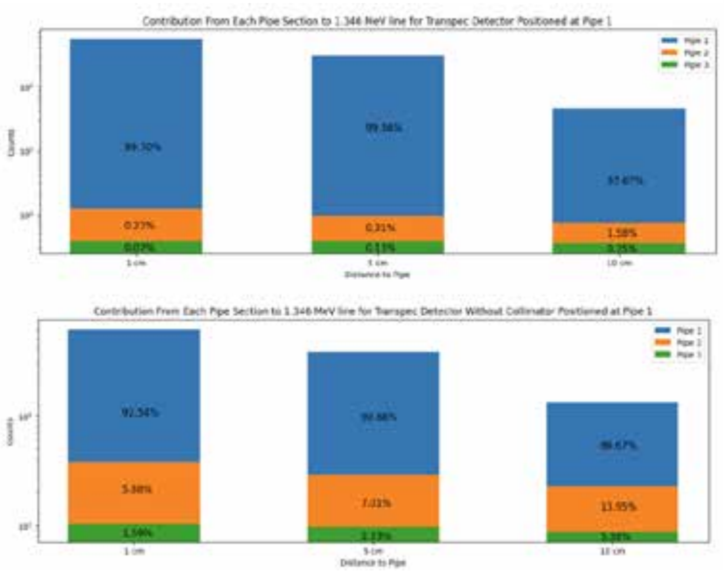


Figure 2 Count contribution of each pipe with the detector observing pipe 1. The top graph is with collimator included whilst the bottom graph is for the collimator excluded.

Analysis of JET Water Activation Experiment

Models of the JET Octant 4 Neutral Beam Injector (NBI) duct scraper water cooling circuit were created, allowing fluid activation calculations for code validation (Figure 3). Nuclear analysts modelled the JET pipe system in their activation codes to accurately predict radiation levels in future fusion reactors. The experiment is the first validation dataset for water activation in a Deuterium-Tritium fusion machine and will be an important test of fluid activation modelling capabilities for an extended pipe circuit in a fusion environment. Analysis (Figure 4) shows that the code produces accurate results and performs well compared to the experimental results.

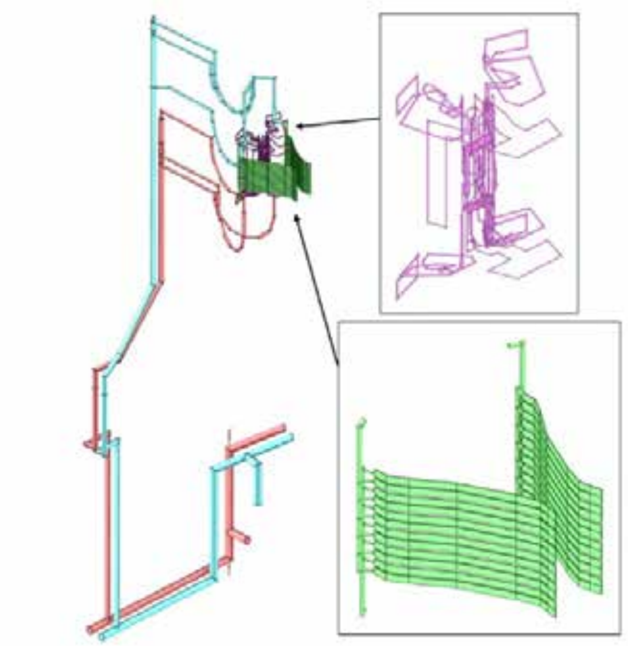


Figure 3 JET WACT CAD Model

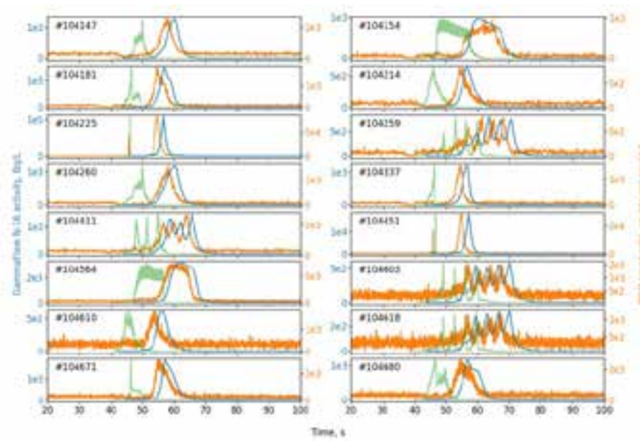


Figure 4 Plot of WACT data for the full set of pulses evaluated. This includes the JET neutron pulse (green), measured gamma pulse (orange) and the prediction by our GammaFlow code (blue).

FARBASE Application

FARBASE (Fluid Activation Residence time dataBASE) is a novel approach to fluid activation modelling, designed for application to the complex cooling and breeding circuits anticipated in future fusion machines. Users can build circuits of standard parametrised components (such as pipes, tanks and bends), and perform automated computational fluid dynamics (CFD) calculations in OpenFOAM to build a database of fluid residence time data. This can then be used by a fluid activation code, such as GammaFlow, to account for the fluid flow throughout the whole circuit, without needing to perform computationally expensive full-circuit CFD calculations.

The full range of components has now been implemented in FARBASE for the first time. The combined GammaFlow-FARBASE workflow was applied to the Frascati Neutron Generator (FNG) benchmark analysis, and the results were presented at the International Symposium on Fusion Nuclear Technology (ISFNT-16) conference in November 2025.

CFD Simulations

Modifications to OpenFOAM inputs and meshing have largely resolved previous problems with CFD simulations of the KATANA "snail head" components at the Jožef Stefan" Institute (JSI) in Slovenia. The modifications allow ActiFlow fluid activation calculations of the circuit accounting for CFD (Figure 5), which can be validated against experimental results. Testing water activity levels as it passes through the complex components inside KATANA have provided a good test base for the code and will lead to improved fluid activation calculations for the circuit, which will help to benchmark the ActiFlow code.

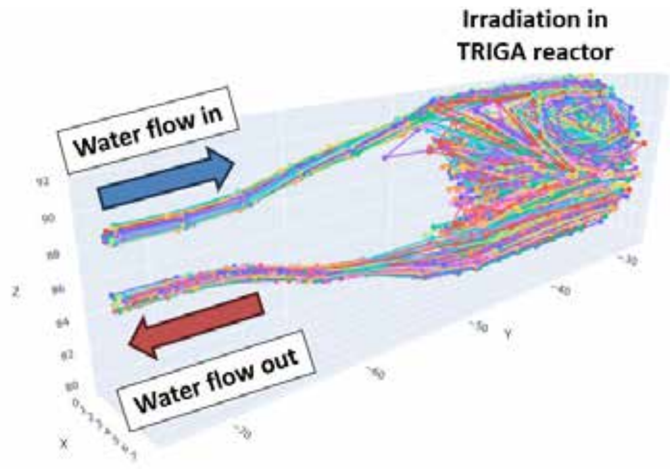


Figure 5 OpenFOAM CFD streamlines for water flow through the irradiation "snail" head component.

Research Paper: "Outcomes of activation measurements and analyses of ITER materials during JET DTE3 operations"

Published in the Journal of Plasma Physics and Controlled Fusion, this paper analyses a range of ITER material samples following their exposure in a Long-Term Irradiation Station within the JET nuclear environment.

The samples were exposed to neutron fluxes up to 2×10^{13} n/cm^2/s, reaching total fluences of 7×10^{15} n/cm^2, the highest achieved in a tokamak.

The DTE3 results, combined with those from prior Deuterium-Tritium (D-T) campaigns, provide a highly valuable dataset for ITER, supporting the validation of predictive modelling tools towards sustained high-power D–T operations.

Read more:

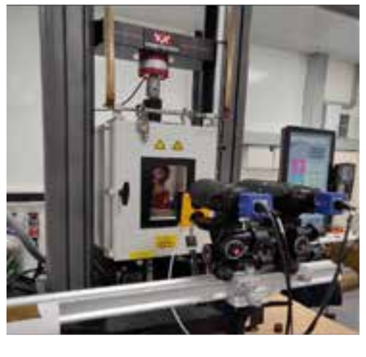
[Outcomes of activation measurements and analyses of ITER materials during JET DTE3 operations - UKAEA Scientific Publications]

Materials and Manufacturing

Materials and manufacturing work advanced physics-informed design rules, improved materials data credibility, and demonstrated promising new manufacturing routes, particularly in additively manufactured tungsten components.

Small-scale High-temperature Testing

Developed and applied full-field measurement techniques, including Digital Image Correlation (DIC) and Thermoelastic Stress Analysis (TSA), tailored for small-scale mechanical testing under demanding conditions (Figure 6). Fusion Technology's broader vision is to build a robust full-field measurement capability that enables data-driven analysis across the entire lifecycle of fusion-relevant components, from accelerated material qualification and component design validation to in-service performance assessment. This year, DIC was successfully deployed and demonstrated to extract tensile properties of Eurofer 97 using miniature testing geometries at elevated temperatures up to 550 °C (Figure 7), a key milestone in small-scale high-temperature testing.



DIC parameters based on iDICS guidelines

Stereo-DIC setup details	
Cameras	12 bit, 2056×2464 pixels^2
Lens focal length	200 mm
Stereo angle	12°
Scale	125 pixel/mm
Image correlation details	
Software	DaVis 10.2.1 (LaVision GmbH)
Subset size	35 px
Subset spacing	5 px
Shape function	Affine
Image interpolant	Bicubic polynomial
Correlation criterion	Zero-normalised sum of square differences

iDICS best practice guide: https://www.idics.org/guide/

Figure 6 Stereo-DIC setup for high-temperature tensile testing of small-scale geometries in a non-vacuum, sealed chamber

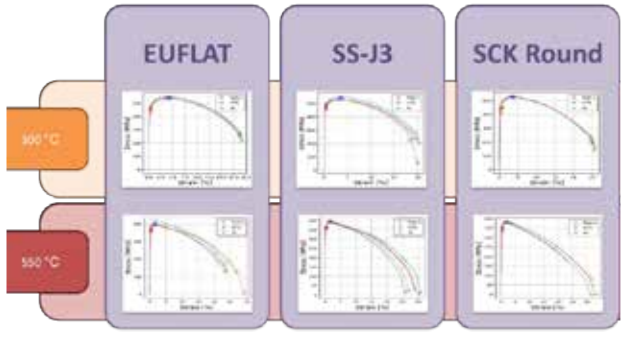


Figure 7 Tensile test curves acquired from a stereo-DIC setup for Eurofer97 material at 300 °C and 550 °C, using three small-scale geometries: SCK (round), EUFLAT, and SS-J3, with gauge lengths of 10 mm, 9.2 mm, and 5 mm, respectively

Manufacturability of Tungsten Lattice Structures

Developed the Laser-Powder Bed Fusion (L-PBF) process with selective laser pre-heating as an effective method that can be used to produce complex tungsten parts. The project presents as an efficient approach for L-PBF process optimisation on this difficult-to-process material. Through this approach, the ultimate tensile strength of L-PBF tungsten with no substrate preheating was effectively increased by an order of magnitude with good repeatability. An average UTS of 253 ± 18 MPa was achieved and validated by an independent laboratory. Post thermal treatment, at a relatively low temperature of 1100 °C, was demonstrated for improved high-temperature performance.

Dissimilar Joining of Tungsten

Built upon the L-PBF process to explore new limiter plasma facing components for DEMO. Engineers tested the manufacturability of a novel design for the limiter component: tungsten lattice, infiltrated with Cu and then brazed the CuCrZr to a reduced-activation ferritic-martensitic (RAFM) steel (Figure 8). there is potential to create some interlocking between the two materials.

Initial results are promising, with analysis revealing no voids in the diffusion bond (Figures 9 and 10), though a well-defined bond line remains visible. This work represents a significant step forward in demonstrating the manufacturability of advanced limiter components for future fusion energy applications.

Figure 8 W lattice infiltrated with Cu, then diffusion bonded to CuCrZr

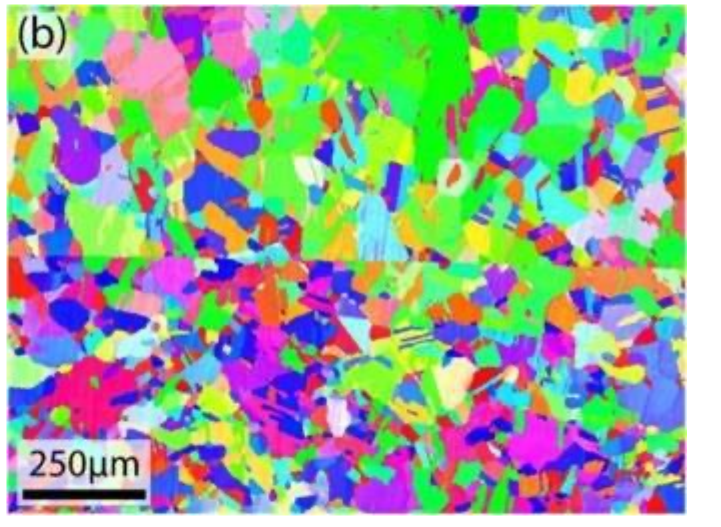


Figure 9 EBSD inverse pole figure map showing the bonding interface between Cu and CuCrZr: no voids, but well defined bond line still visible

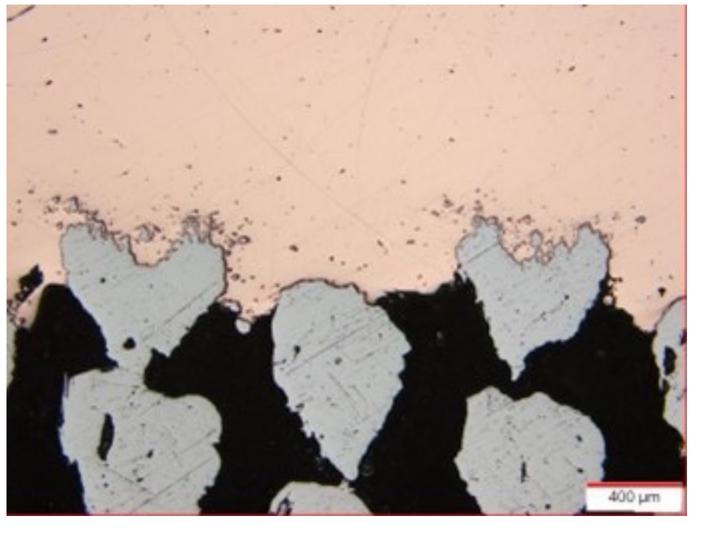


Figure 10 Close up of CuCrZr deposited, by laser powder bed fusion, on a W lattice: there is potential to create some interlocking between the two materials

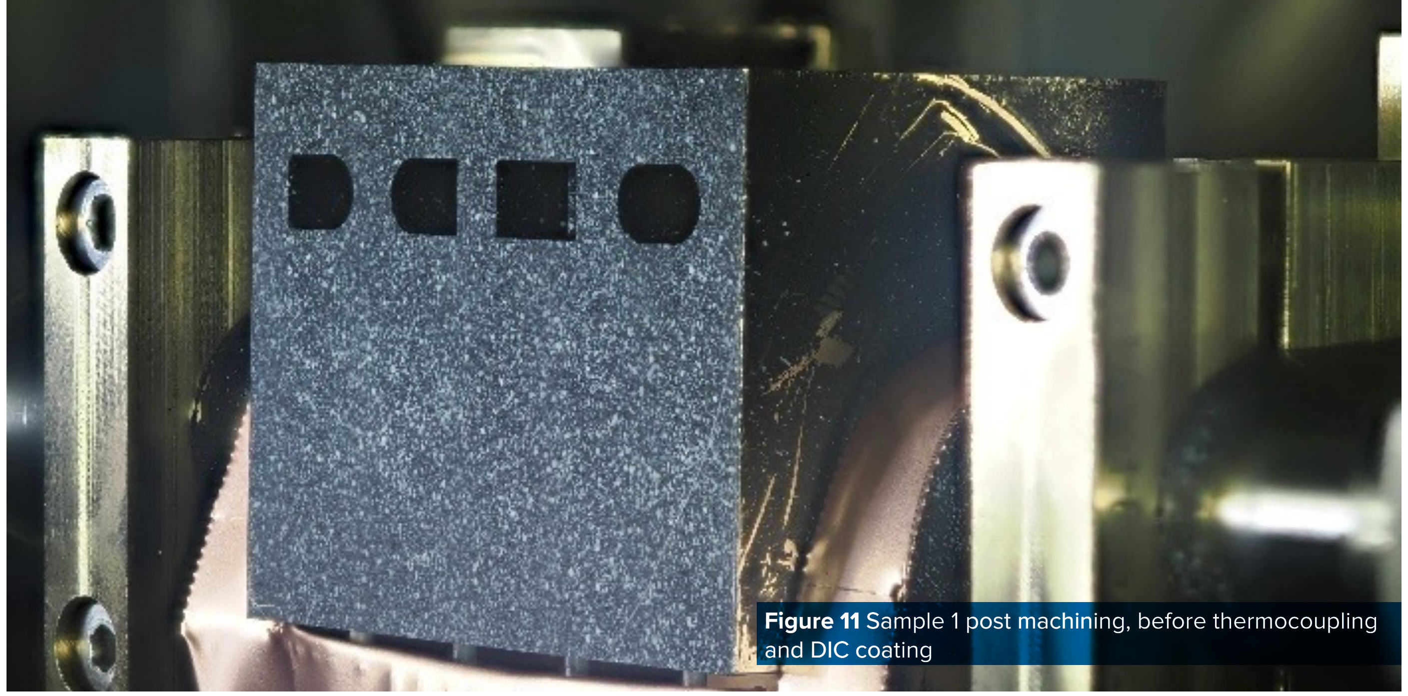


Figure 11 Sample 1 post machining, before thermocoupling and DIC coating

Component Validation

Component validation saw the development of new experimental facilities and multi-diagnostic approaches, enhancing confidence in simulation–experiment comparison and supporting qualification pathways.

Heat Sink Structural Integrity Assessments

Engineers designed and executed an experiment in HIVE using 316L Stainless Steel monoblocks to compare and verify the EUROfusion RCC Script simulation.

Five monoblocks with cooling channels and shaped cuts on their front faces were fabricated, and heat flux simulations were conducted to determine the thresholds at which each block would undergo elastic deformation, plastic deformation, and eventual ratcheting under cyclic loads.

Temperature diagnostics were provided by a Spectropyrometer, an infrared camera, and eight thermocouples per sample, while Stereo Digital Image Correlation was used to track surface deformation (Figures 11 and 12). Findings are being compared to the RCC Script and will contribute to the further developments alongside the broader effort to refine design and methodologies for DEMO.

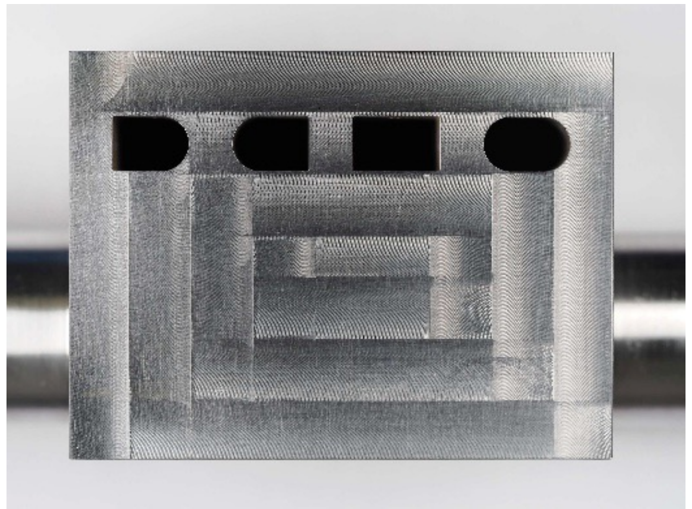


Figure 12 Sample 2 within HIVE

COMPASS-U Divertor

Fusion Technology supported COMPASS-U's tungsten qualification studies for plasma facing components. The HIVE facility tested samples from three suppliers across 100 cycles, reaching temperatures of around 2,000°C (Figure 13).

Pre and post-test surface roughness measurements and scanning electron microscopy (SEM) imaging were used to assess microstructural changes (Figure 14). Initial results showed that surface roughness remained broadly consistent across all three supplier samples following testing.

However, SEM analysis revealed a notable difference where one sample developed significantly larger recrystallisation grain sizes compared to other two samples, which both showed smaller grain development (Figure 15). The test campaign also marked a series of firsts for HIVE. A spectropyrometer was used for the first time to record temperatures, and the campaign ran at HIVE's maximum available power of 45kW — the highest ever used in the facility.

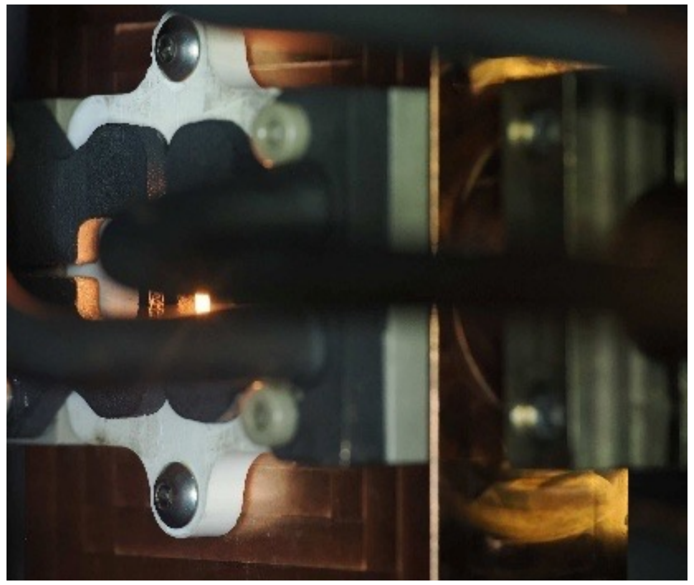


Figure 13 Digital image captured mid-pulse of sample 1 (AT&M/ATTL H1) at around 2000deg Celsius

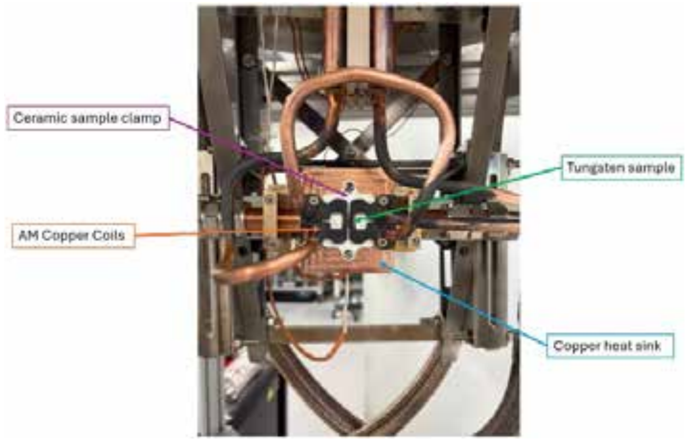


Figure 14 Experiment set-up before testing

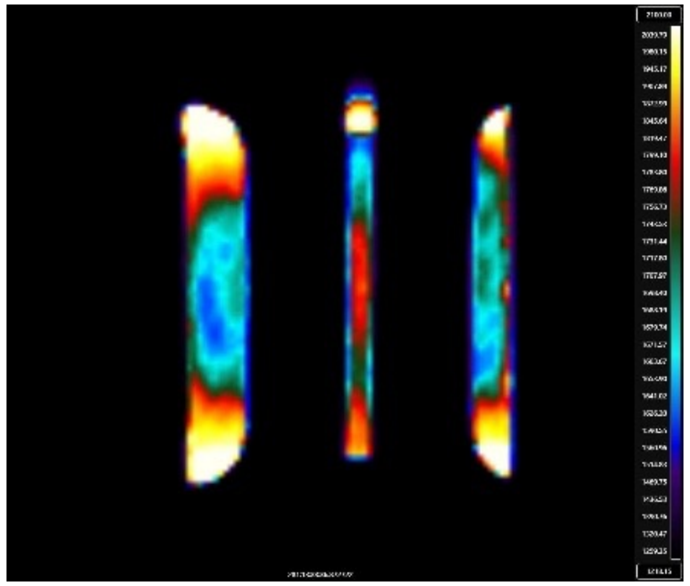


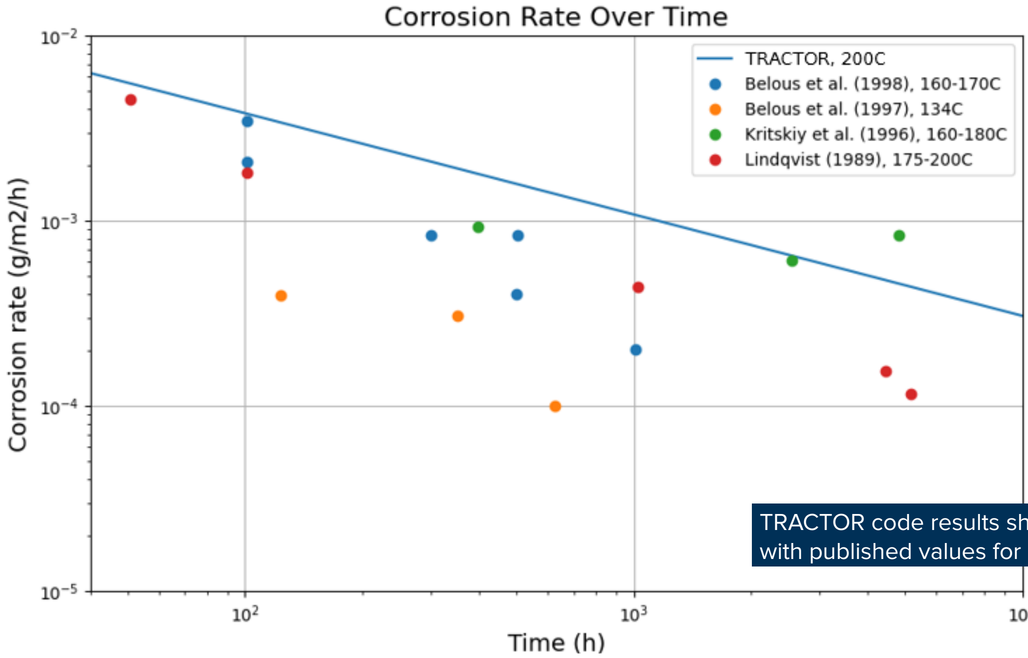
Figure 15 Infrared (IR) image captured mid-pulse sample 1 (AT&M/ATTL H1) at around 2000deg Celsius

EPSRC Highlights

Across a portfolio of 13 workstreams in 2025/26, the EPSRC programme has produced frameworks such as virtual component qualification and credibility assessment approaches, alongside modelling tools, experimental rigs, diagnostic techniques, and prototype manufacturing evidence.

Overall, the EPSRC programme has strengthened the UK's leadership in fusion technology by producing credible, decision-ready evidence, enabling earlier industrial engagement and reducing risk in the pathway to fusion commercialisation.

Research papers submitted: 8	Journal	Authors
"Microstructure sensitive recurrent neural network surrogate model of crystal plasticity"	International Journal of Plasticity	M. D. Atkinson, M. D. White, A. J. Plowman, P. Shanthraj
"Pyvale: A Fast, Scalable, Open-Source 2D Digital Image Correlation (DIC) Engine Capable of Handling Gigapixel Images"	Experimental Mechanics Journal	J. Hirst, L. Sibson, A. Tayeb, A. Marsh, M. Sampson, W. Bielajewa, R. Spencer, M. Atkinson, K. Amjad, C. Hamelin, L. Fletcher
"Establishing a Coherent Qualification Pathway for Fusion Technologies"	Journal of Fusion Energy	A. Allison
"A Multiscale System Code for Transient Simulation of Fusion Blanket Cooling Systems"	Fusion Engineering and Design	M. McDermott, J. Bailey, N. Sashidharan, M. Margulis, C. Harrington, S. He
"Towards virtual qualification in nuclear fusion: demonstrating probabilistic model validation on a high heat flux component"	ASME Journal of Verification, Validation and Uncertainty Quantification	J. T. Horne-Jones, M. Baxter, A. Tayeb, L. Fletcher, J. Paterson, S. Biggs-Fox, A. Harte
"Development of a Methodology for the Automated Spatial Mapping of Heterogeneous Elastoplastic Properties of Welded Joints"	Computer Methods in Applied Mechanics and Engineering	R. Hamill, A. Harte, A. Marek, F. Pierron
"Machine Learning Based Efficiency Calculations (MaLBEC) for Improvements to Nuclear Fusion Diagnostics"	PhDiaFusion2025 [Conference], Poland, 9-13 June 2025	K. S. Lennon, C. R. Shand, G. L. Wilson, R. Smith
"Enabling non-contact deformation measurements at cryogenic temperatures for large deformations"	The Journal of Strain Analysis for Engineering Design	K. Amjad, R. Spencer, L. Fletcher, C. Hamelin, A. Harte



TRACTOR code results show corrosion rate is consistent with published values for a simple case

Digital Simulation and Code Capability

Corrosion Modelling Code (TRACTOR)

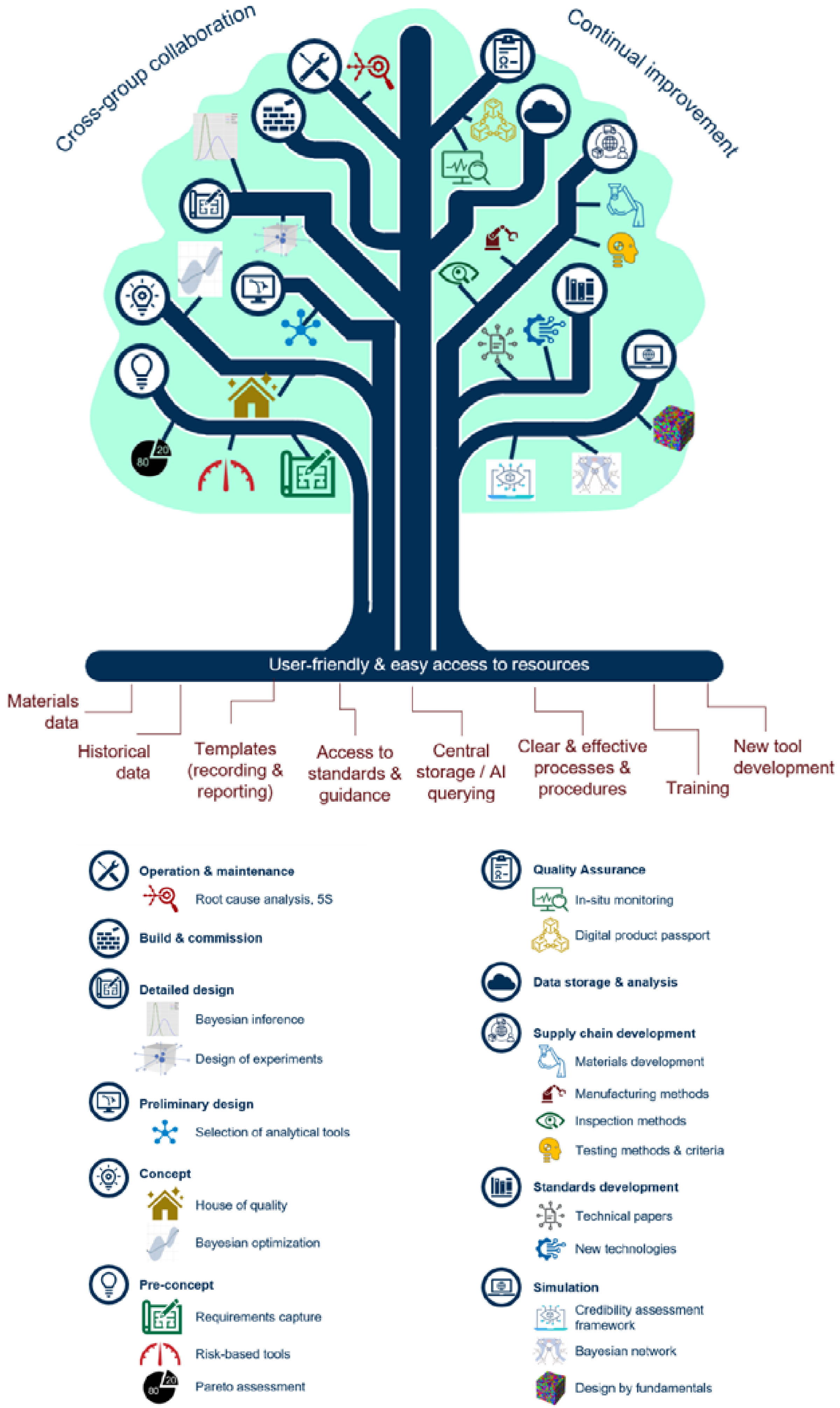
Activation Corrosion Products (ACPs) are a critical contributor to dose rates in fusion machines. Having the ability to accurately model their behaviour is essential for understanding and managing radiation safely.

The ART group has achieved a significant first with the development of a corrosion modelling capability through the development of the TRAnsport, ACTivation and CORrosion (TRACTOR) code.

A corrosion modelling code Application Programming Interface (API) has been successfully built for TRACTOR, with basic oxidation-release power laws now implemented. Mass transfer equations have been provisionally defined across five different media and implemented for bulk metal and oxide, providing a solid foundation for more complex modelling work to follow.

Preliminary calculations have shown good agreement between the modelled oxidation rates and compiled experimental data, an early validation that the approach is developing as predicted.

The TRACTOR code provides the basis from which more sophisticated and comprehensive models can be developed, supporting UKAEA's long-term ambitions in fusion engineering and safety analysis.



Novel Qualification and Credibility

Cross-Group Collaboration on Qualification

The cross-group collaboration project focused on improving visibility and connectivity between qualification activities using Key Challenge 3 and Key Challenge 4 as test beds. This involved mapping qualification workflows, identifying process gaps, and developing supporting tools and templates.

The purpose of the work explored how qualification data, standards and evidence could be better linked across programmes to support more consistent and reusable qualification approaches.

A Qualification Working Group was established and brought together UKAEA colleagues from various divisions and programmes to improve collaboration and stakeholder engagement across the organisation. The project improved understanding of how qualification activities, data, and workflows connect across fusion programmes and identified key gaps limiting traceability, reuse, and interoperability.

Outputs from the Group's work has provide a foundation for future work on connected qualification approaches, reusable qualification data structures, and integration between testing, modelling, and digital qualification workflows.

The EPSRC programme addresses fundamental challenges in the fusion sector. UKAEA categorise these challenges, including:

Key Challenge 3
Delivery of a qualification strategy for advanced steels deployed in fusion blanket designs

Key Challenge 4
Development of an in-vessel component digital replica working towards component virtual qualification

Representative Environments, Diagnostics & Experimental Validation

These projects develop the ability to observe, quantify and validate behaviour in extreme environments where fusion design decisions need evidence.

Enhancing Liquid Metal Capabilities through Testing and High Temperature Operations

In 2025 SMALLAB (Surrogate Magnetohydrodynamic Liquid-metal Laboratory) began its experiments.

SMALLAB is one of the few facilities worldwide employing surrogate fluids to gain deeper insights into phenomena relevant to real-world fusion conditions within a cost-effective and safe experimental environment.

The facility uses room-temperature liquid metal Galinstan (GaInSn) within a closed-loop system to investigate flow dynamics and test component designs.

Magnetohydrodynamic (MHD) pressure drop tests (Figure 16) were successfully executed, resulting in robust datasets for benchmarking.

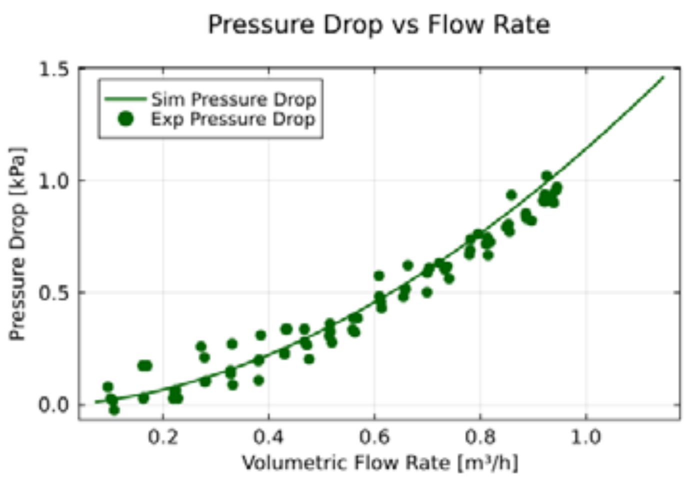


Figure 16 An example of SmaLLab pressure drop tests

These findings have been co-authored into a technical paper accepted for presentation at a leading international nuclear thermal-hydraulics conference, and the research will be presented by a PhD student in the group.

SMALLAB is now ready for upcoming heat transfer experimental campaigns, with thermocouples installed in preparation. These combined achievements position SMALLAB as an increasingly capable and internationally relevant experimental facility.

Cryogenic Benchmarks for the Fusion Component Experimental Data Library

The cryo-mechanical test landscape is rapidly changing, requiring fast paced activity to develop testing capability. The Applied Materials Technology group were able to enhance cryo-mechanical testing and DIC capability using existing rigs in the AMT lab (Figure 17).

Visualisation of Heterogeneous Strain Fields in 316L Stainless Steel at Cryogenic Temperatures using DIC

Stereo DIC was deployed to resolve the evolution of full-field strain distributions in 316L stainless steel at temperatures down to 13 K (Figure 18). The methodology enabled direct visualisation of spatially heterogeneous deformation associated with slip-dominated plasticity under extreme cryogenic conditions.

Full-field strain measurements revealed a transient necking-like localisation phase preceding secondary strain hardening, providing new insight into the deformation mechanisms governing the low-temperature mechanical response of 316L stainless steel.

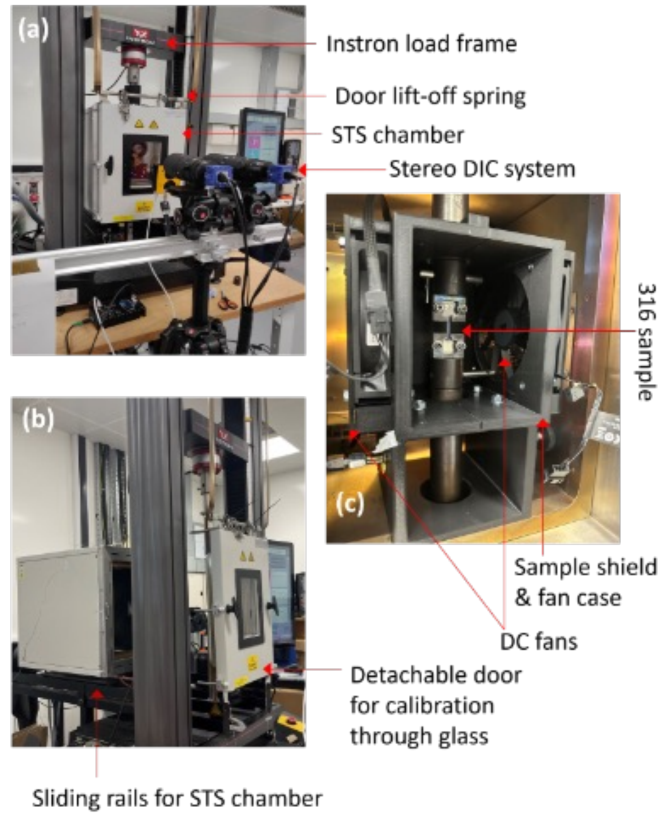


Figure 17 Full-field strain measurement using stereo-DIC on Instron-STS rig, with capability for testing at temperatures down to −150°C

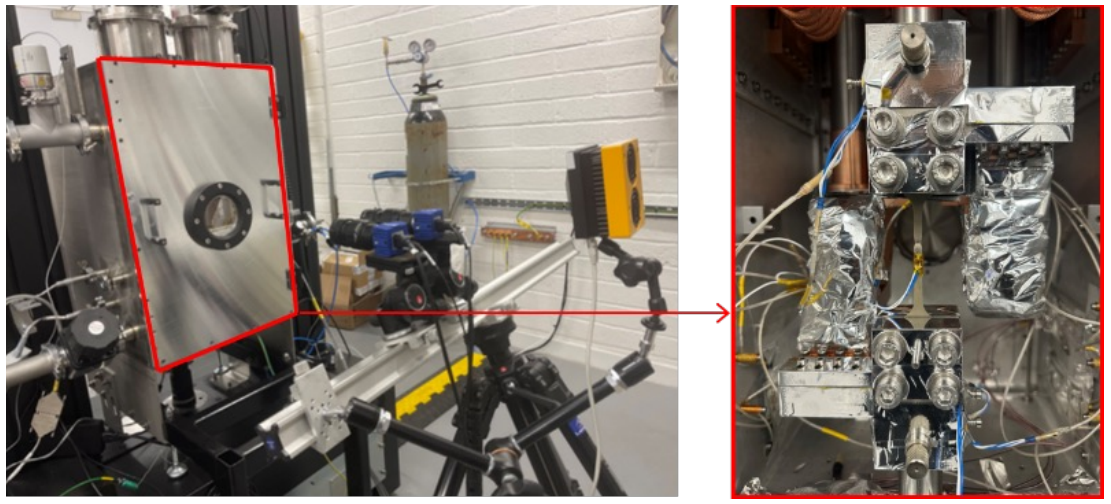


Figure 18 Cryo-mechanical test rig with temperature diagnostics, strain-gauge instrumentation, and DIC-based full-field strain measurement for mechanical testing at temperatures down to 13 Kelvin

High Heat Flux & Thermal Management

Harnessing the Full Potential of Nucleate Boiling Flows through Advanced Manufacturing

Nucleate boiling flows offer excellent heat transfer performance, but utilisation is limited by conventional design and a lack of understanding.

Fusion Technology's Thermal Hydraulics group investigated the enhancement of heat transfer performance in hypervapotron cooling channels for high heat flux fusion reactor applications.

Using CFD, fine geometries were designed and compared to improve boiling heat transfer while minimising pressure drop.

Three optimised prototypes and one reference straight channel were manufactured with the Division's MTEQ group, and planned for experimental testing in the Technology Development group's HIVE facility (Figure 19).

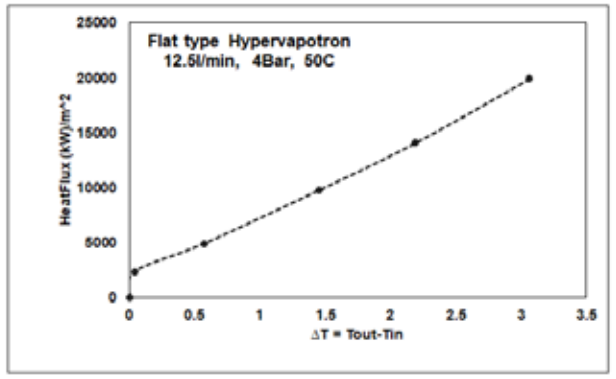


Figure 19 Heat flux vs temperature difference (ΔT = Tout − Tin) of the water for a flat-type Hypervapotron operated at 12.5 L/min, 4 bar, and 50°C

The study evaluated the thermal hydraulic performance of the designs under single-phase and two-phase flow conditions and supports the development of pressure drop and heat transfer correlations for advanced boiling flow cooling systems (Figure 20).

Advancing the design of hypervapotron improves the heat removal capability and increases the thermal hydraulic performance of divertor plasma facing components (PFCs) of fusion reactors, such as ITER, DEMO, STEP etc.

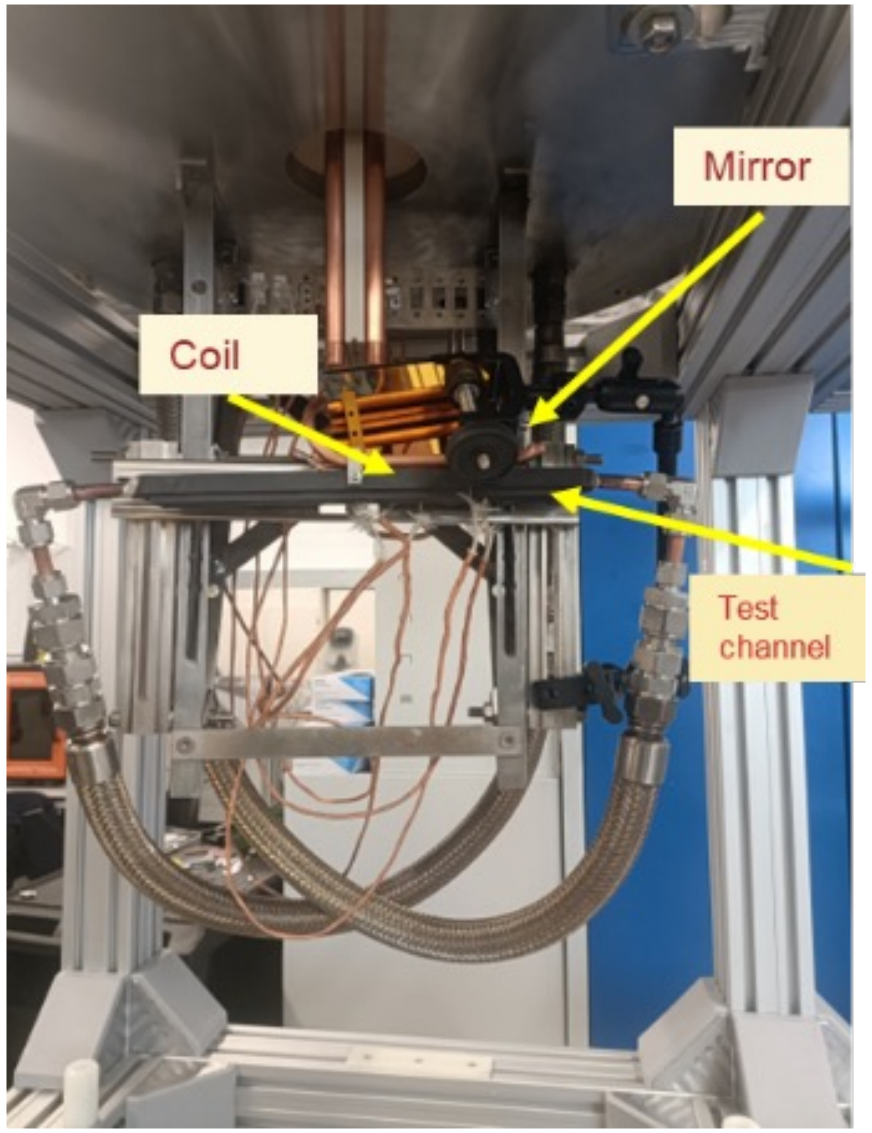


Figure 20 Inside view of the experimental setup

UKAEA Reactor Codes

UKAEA has made significant advances to its two flagship fusion power plant design codes, PROCESS and Bluemira, improving usability and strengthening the organisation's position as a global leader in systems codes.

PROCESS Modernisation

Substantial development has been made in the completion of PROCESS's Fortran-to-Python conversion, eliminating decades of accumulated technical debt. The migration delivers meaningful improvements across the board: model development and debugging are more straightforward, more thorough validation of existing models is now possible, and the code now supports interactive use in Jupyter notebooks (Figure 21). Users can also run PROCESS examples directly in a web browser via Binder (Figure 22), removing the need for local installation entirely.

Individual models can now be developed and validated in notebooks without running the full solver, and solutions are visualised more clearly, displaying optimisation parameters and constraint values to fully define a design point (Figure 23). The next development phase will convert the global data structure to an object-oriented architecture, further embedding modern research software engineering practices.

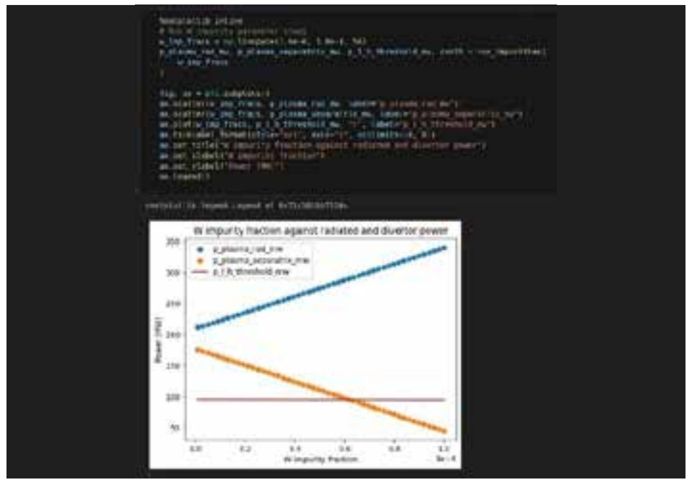


Figure 21 PROCESS model analysis in Jupyter notebook

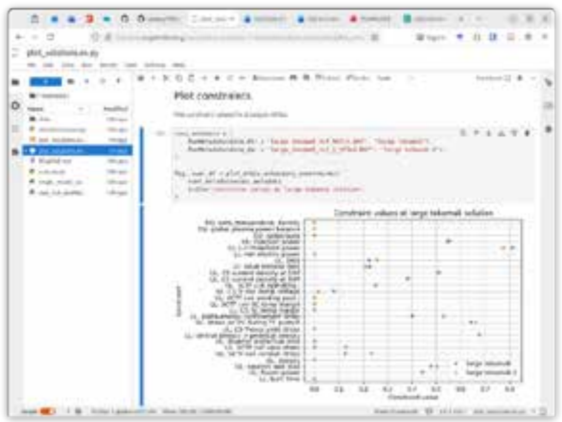


Figure 23 PROCESS example notebook comparing two "large tokamak"solutions, running in a web browser, hosted on Binder.

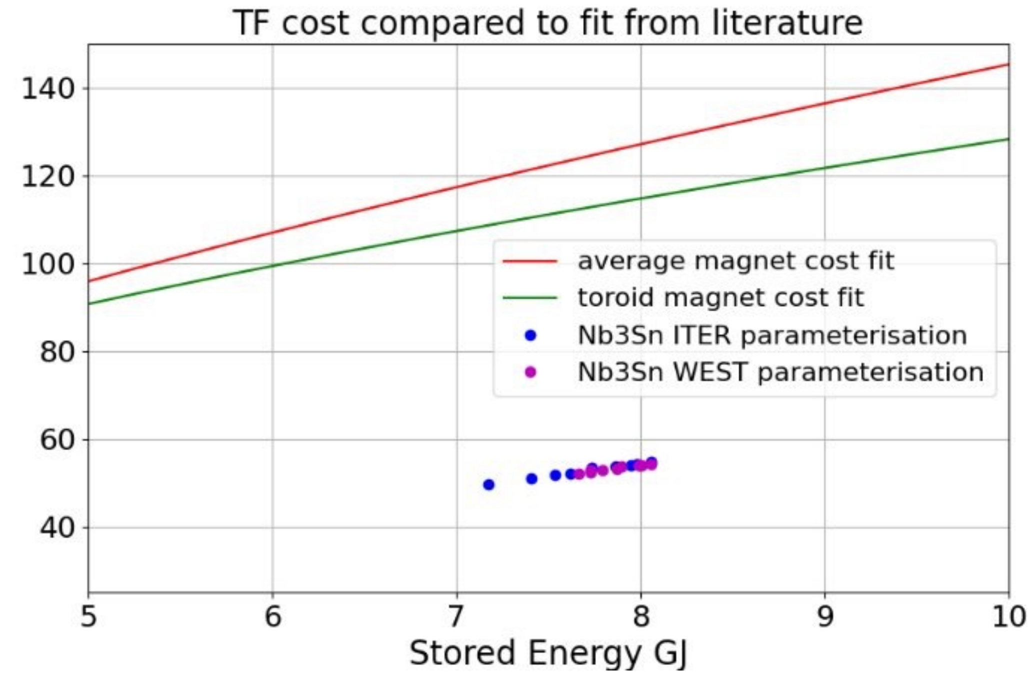


Figure 22 Optimisation parameters show comparison of PROCESS TF coil costs (dots) and literature fits (lines).

Paper Spotlight:

BLUEMIRA: a modular, open-source framework for designing tokamak fusion reactors

BLUEMIRA is presented in this paper as the first version of an open-source tokamak reactor design framework. The code is the complementary 3D plan design capability, linking radial build, equilibrium design, 3-D CAD, neutronics, magnets and materials. BLUEMIRA goes beyond the classical systems code paradigm and enables the user to parametrise their reactor designs at higher fidelity. Reactor design workflows ranging from 0-D "radial build" design, equilibrium design, to 3-D CAD and automated neutronics analyses can be run within minutes.

This paper was submitted to the Journal of Nuclear Fusion in December 2025.

Bluemira and Shared Improvements

Both system reactor codes have undergone simplified installation procedures, reducing barriers to adoption and, therefore, increasing the number of users. Bluemira has seen growing uptake across the EUROfusion consortium and is now being applied by the University of Illinois Urbana-Champaign for blanket modelling studies.

Together, these developments ensure that both codes continue to support confident design decisions across the EUROfusion and STEP Fusion programmes.

Conferences and talks

Fusion Technology colleagues attended a variety of conferences in 2025/26 in both fusion and non-fusion fields. Of these events, UKAEA's work in fusion technology was recognised with three awards.

International Conference on Fusion Reactor Materials

Fusion Technologist Frances Livera was the recipient of the "Young Researcher Excellent Poster Award" at the 22nd International Conference on Fusion Reactor Materials in Shizuoka, Japan.

The award-winning poster (Figure 24) was one of 521 exhibited over the course of the conference and formed part of Frances' EUROfusion research on a work package divertor (WP-DIV) which focussed on brazing a copper-based alloy (CuCrZr) to Eurofer97 at the tempering temperature of the steel. The goal was to minimise the impact of the joining process on the base material microstructures, whilst forming a good joint. The poster detailed the copper germanium (CuGe) brazing alloy used, and the resultant joint.

Frances Livera said: *"It was an honour to be recognised for the award! I had a lot of engagement about the concept of low temperature joining and the importance of minimising the impact of the manufacturing steps on the base material microstructure."*

Waste Management Symposium

Graduate Nuclear Physicist, Georgi Keyser, presented the Applied Radiation Technology group's work on nuclear waste at the 52nd annual Waste Management Symposium in March.

The conference in Arizona brought together over 2,900 experts in radioactive material and waste management from 30 countries.

Georgi won a Best Conference Poster award at the event. The poster, entitled "Gamma Spectroscopy of Samples Originating Within the JET Torus Hall to Assist JET Decommissioning and Repurposing Research", represented the finest in technical and policy innovations. The posters were also judged on their technical quality and presentation.

Figure 24 Frances Livera (third in from the right) at the 22nd International Conference on Fusion Reactor Materials

The winning posters all received a rosette and a return invitation to the 2027 Waste Management Symposium.

More information on the waste management work can be found on page 39 of this review.

International Conference of Pressure Vessel Technology

David Hardacre, a Qualification Specialist, delivered a keynote presentation on 'The Landscape for Additive Manufacturing in the UK and Europe' at the 15th International Conference of Pressure Vessel Technology in September 2025.

The conference was hosted by the Institution of Mechanical Engineers' Pressure Systems Group at the University of Strathclyde. Over three days, a global community of delegates, exhibitors and speakers gathered to listen and discuss requirements in pressure vessel systems and technologies to achieve a net-zero global energy economy.

David Hardacre reflecting on the event: "The conference brought together high-quality papers and presentations from across the world and across the full supply chain of pressure vessel technology. It was a privilege to engage in discussions that were both technically insightful and forward-looking."

David's presentation covered the development of standards for additive manufacturing (AM) and showed how these can be applied to an established, highly regulated field like pressure equipment to demonstrate compliance with existing legal and technical requirements.

The presentation explained why AM was crucial for fusion and how utilising new technologies, such as AM, can help to solve complex problems, but must be done in a way that also evolves the methods for demonstrating compliance.

Following his keynote speech, David was presented with the Highland Quaich, a cup of friendship, from the conference organisers.

Figure 25 David Hardacre (right) at the end of delivering his keynote speech, receiving the Highland Quaich from Paul Smith (left) who chaired the conference and is also chair of the American Society of Mechanical Engineers (ASME) Section III, Division 4 committee

Enhance our operations to maximise research impact

UKAEA's research impact supports internal programmes, international projects, private fusion research and beyond. Effective, well-managed operations are essential to ensuring that scientific excellence translates into meaningful outcomes for the UK's fusion energy ambitions.

A central focus has been strategic planning, with the development of a new five-year research strategy for the Fusion Technology Division to provide clear direction and alignment across the group. Alongside this, rigorous financial oversight has been applied across all divisional and delegated funded projects, with a target of less than 5% budget deviation by the end of the financial year.

The group has maintained strong delivery across UKAEA group's major programmes, including STEP Fusion, EPSRC, EUROfusion, LIBRTI, Fusion Futures, and JET Decommissioning and Repurposing (JDR), targeting at least 90% completion of FT staff-led tasks, with quality and impact assessed through programme metrics.

Quality assurance has remained a priority throughout the year, with preparations for the ISO surveillance audit, the introduction of new quality and risk management platforms, and the rollout of a formal continual improvement approach within the Division's laboratories and facilities.

Together, these efforts reflect a commitment to operational excellence as a driver of research impact.

Figure 26 Animation shows side of Hi-CrIS whilst measuring

Hi-CrIS Animation Supports Designs for HTS Tapes Testing

Jane Ambler from the Technology Development group has been working with the STEP programme on the High neutron fluence Cryogenic Irradiation of Superconductors (Hi-CrIS) test rig, which aims to test high temperature superconducting tapes under fusion-like conditions. Hi-CrIS, currently being designed by a team across UKAEA, will be installed in one of the user channels at the LVR-15 test reactor, a research fission test reactor at the Centrum výzkumu Řež (CVŘ) in the Czech Republic.

Building upon existing CAD designs, Jane has developed an animation of the Hi-CrIS rig (Figure 26). Created using Blender, the animation demonstrates how the rig will transport the HTS tapes whilst maintaining cryogenic temperature of approximately 20K, between the reactor core, where they receive neutron irradiation, and the sample measurement position, where the sample will be subjected to magnetic fields while the critical current of the sample is measured. Overall, the purpose of the experiment is to understand how the HTS tapes are affected by high energy neutron irradiation.

Jane Ambler, creator of the Hi-CrIS animation, said: "The animation is useful to all stakeholders including UKAEA and UK Fusion Energy Limited researchers, the Hi-CrIS team and the CVŘ team. By seeing the rig's placement and movements, individuals can understand how the rig will operate and can work together to mitigate any challenges with the design (Figure 27). It's been particularly helpful for working out how people will interact with the rig when we change over the sample. It also facilitated a discussion with the CVŘ team about how we would install radiation shielding."

Fiona Harden, Hi-CrIS Technical Lead said: “The support from the Fusion Technology division in developing these visualisations has been very beneficial to the project design. It provides a 3D overview of the operational sequence of the whole rig and has enabled critical discussion with CVR colleagues on how the test rig will be used at the LVR-15 facility.”

About Hi-CrIS

Hi-CrIS will subject HTS tapes to fusion-like conditions (magnetic field, high fast energy neutron radiation and current) to understand how neutron radiation will affect current carrying capacity of the HTS tapes. The samples will be irradiated with high energy neutrons using CVŘ’s LVR-15 light water tank-type research reactor and kept at 20 Kelvin during transportation and measurement within the rig.

The testing will support research into the performance lifetime of HTS magnet components inside STEP and other future fusion power plants.

UKAEA entered a multi-year use agreement with CVŘ in 2024. Read more about the Hi-CrIS project: UKAEA signs agreement with CVŘ to progress UK fusion plant design - GOV.UK

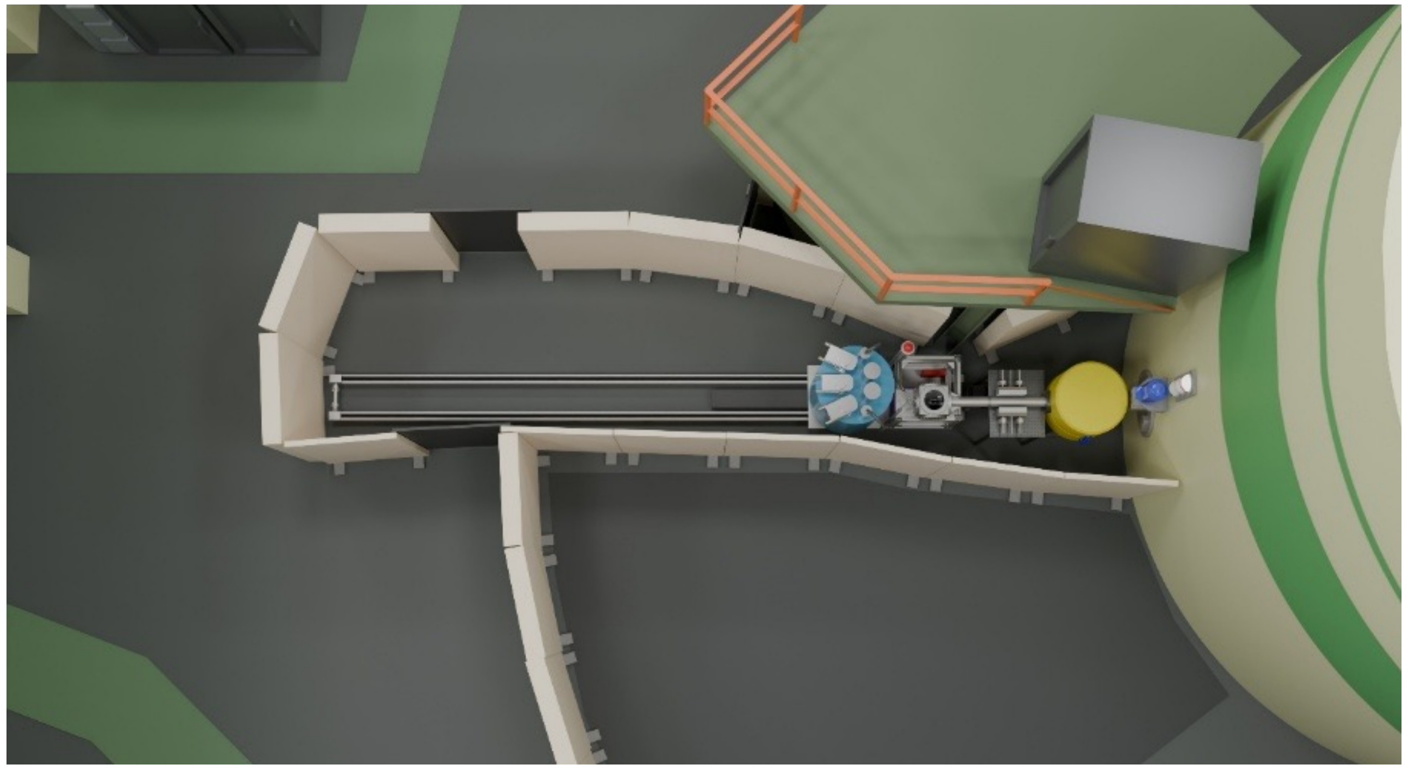


Figure 27 Hi-CrIS animation - bird’s eye render of crane

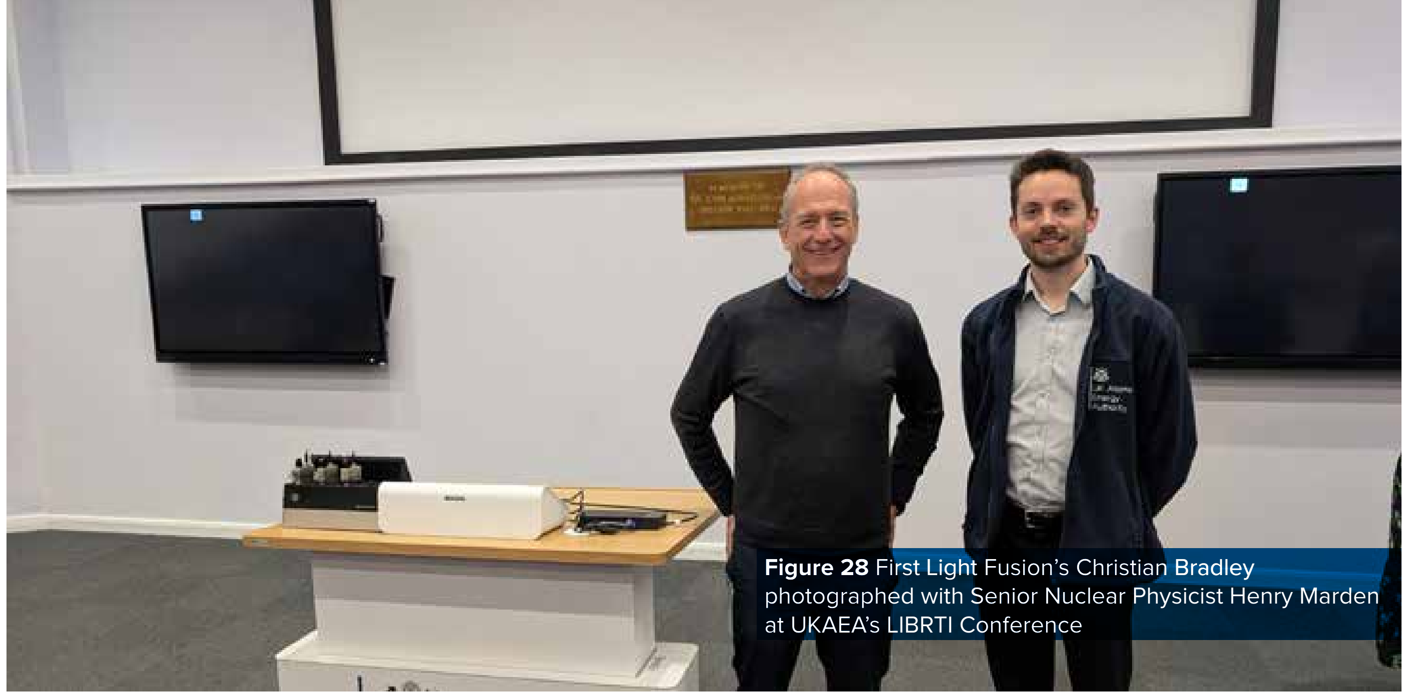


Figure 28 First Light Fusion’s Christian Bradley photographed with Senior Nuclear Physicist Henry Marden at UKAEA’s LIBRTI Conference

Supporting the Private Fusion Sector

UKAEA supports both international and private fusion research to support the world’s mission. The Fusion Technology Division has been working with a number of private fusion companies over the years, providing expert technical support to help advance their fusion concepts and commercial machines.

With Gauss Fusion and General Fusion, the Applied Radiation Technology group deployed neutronics workflows, delivering nuclear analysis to support the design progress of their respective machines.

General Fusion

UKAEA and ART have been working with General Fusion for a number of years now. In the past year, ART have focussed on modelling neutron diagnostics for General Fusion’s various experimental campaigns. This computational work is laying the groundwork for in-person validation support during operations of the company’s Lawson Machine 26 fusion demonstration. The work has fed into a paper published by General Fusion on diagnostics publicly traded pure-play fusion company.

Gauss Fusion

The Gauss Fusion partnership presented a particularly interesting challenge for the group. As a stellarator concept, it sits outside UKAEA’s day-to-day operational experience, which required the team to adapt and enhance existing workflows. These adaptations mean UKAEA can now support a wider variety of fusion machines.

“Together with UKAEA, we have taken an important first step towards quantifying the nuclear environment and key performance parameters of Gauss-GIGA, the 3 GW fusion power stellarator proposed by Gauss - from global TBR, nuclear heating, flux maps, activation and shutdown dose rates to the local analysis on engineering models that will shape Gauss HEXA breeding blanket design.”

EGOR VEZHLEV

NEUTRONICS ENGINEER, GAUSS FUSION

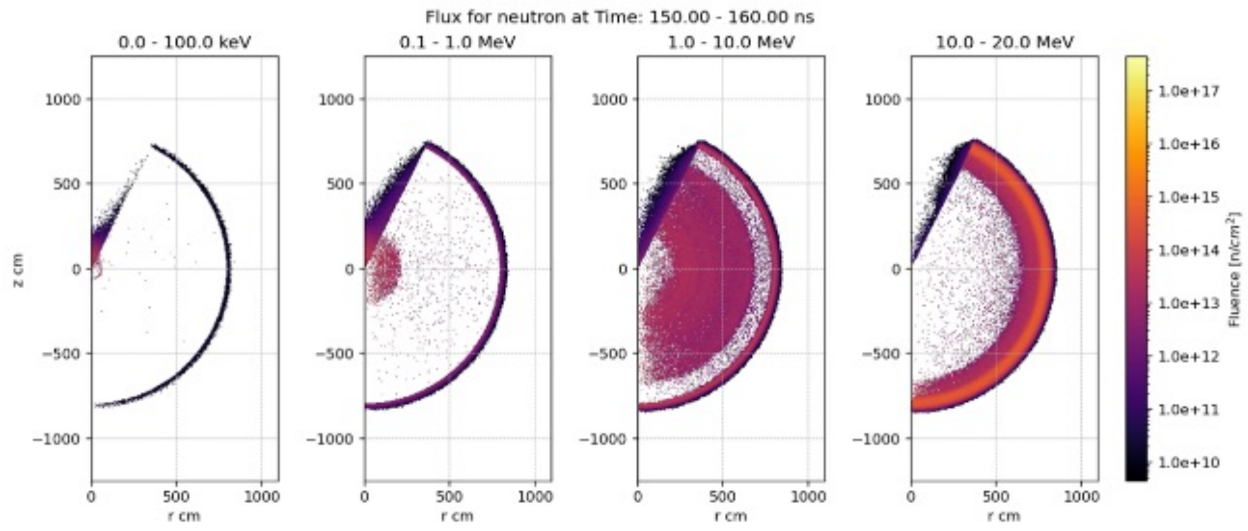


Figure 29 Snapshot of the OpenMC simulated neutron fluence in First Light Fusion's FLARE reactor concept at the point when fusion energy neutrons first reach the surrounding lithium blanket 150 ns after target implosion at the origin. Neutron fluence is binned temporally in a 10 ns time-of-flight window, spatially in cylindrical (r,Z) coordinates and energetically in four groups from low energy (left) to fusion neutron energy (right). The target is at the vertex of a lithium cone used for pulsed power transfer and is at the centre of an 8m radius argon gas bubble within a naturally enriched liquid lithium pool at the time of implosion. It can be seen that lower energy source neutrons trail behind the 14 MeV source neutrons, and that downscattered and secondary neutrons from reactions such as Li-7(n,nt)α are produced in the lithium blanket.

First Light Fusion

Working with First Light Fusion, Fusion Technology seconded a colleague directly to their organisation, providing dedicated on-site expertise to help them navigate the nuclear challenges associated with their conceptual machine design. Senior Nuclear Physicist, Henry Marden, joined First Light Fusion for around three months.

"First Light Fusion undoubtedly gained considerably from the secondment. Henry's work directly helped to increase our understanding of how natural lithium is unexpectedly able to achieve high tritium breeding ratios (Figure 29) and our confidence in these results as well as consolidation and cross-code validation of numerous existing results.

We rate this secondment very highly and would welcome any opportunity to extend or repeat such collaborations with the UKAEA. We have had the opportunity meet and discuss with other UKAEA staff through this secondment, including Henry's line manager and Division head and future interactions and presentations are already planned."

CHRISTIAN BRADLEY

LEAD ENGINEER, FIRST LIGHT FUSION

Tokamak Energy

Tokamak Energy received support with waste characterisation following their most recent operations. Members of ART carried out on-site measurements (Figure 30) to help the company understand and manage the waste produced, continuing a relationship that spans several years. More information on this work can be found on page 39.

The work reflects UKAEA's growing role in supporting the wider private fusion ecosystem across the UK and beyond.

Figure 30 ART group carried out gamma spectroscopy measurements on Tokamak Energy's AT-40 reactor.

Exploit our research through business development

Alongside the significant milestones in fusion research, Fusion Technology colleagues have been working hard to translate this research into real-world impact through targeted and strategic business development activity.

A key milestone for the year has been to grow the group's income base, with a target of more than £6 million to UKAEA from grants and contracts involving the FT Division and its industrial and academic partners. To support this, a formal business development process has been introduced across the directorate, providing clear guidance and a consistent approach to identifying and pursuing new opportunities.

A significant area of activity has been the Fusion Futures Industry Capability programme, which is investing in the development of UK supply chain capability to position domestic industry for future opportunities with international fusion programmes and developers. Complementing this, work with the DSIT Tactical Fund has further supported supply chain development, helping to translate cutting-edge fusion research into economic opportunity and long-term industrial benefit for the UK.

Fusion Futures Industry Capability

Addressing a Materials Qualification Challenge

UKAEA's Applied Materials Technology group worked with Severn Thermal Solutions to deliver a pioneering initiative. The work addressed a critical technology gap in materials testing and qualification for fusion and other industries.

Materials qualification in representative hostile environments is essential for building fusion power plants and pushing the known limits of materials, yet commercial testing equipment currently cannot test materials at extreme temperatures under vacuum.

Through UKAEA's Fusion Futures Industry Capability programme, the AMT group mobilised world-leading experts, Severn Thermal Solutions, to develop commercial products that enable materials testing over a range of in-vacuum temperatures up to, and exceeding, 3000°C.

Severn Thermal Solutions worked with materials testing machines supplier ZwickRoell UK to design and deliver the vacuum furnace systems capable of materials testing within fusion-relevant environments (Figure 31).

This successful demonstration of industrial capability has led to an established UK industry-owned solution to a materials qualification challenge. This highly novel induction and direct-resistance heating technology is ready to be deployed across Severn Thermal Solution's client base to build an ecosystem for fusion, nationally and internationally, and other industries.

About Fusion Futures Industry Capability programme

The Fusion Futures Industry Capability Programme is an investment to develop the capability within the UK supply chain to prepare for future opportunities with international fusion programmes and developers.

Figure 31 ZWICK Cappa vacuum furnace inside the AMT lab

Radial Forging of ingot to cylindrical rod at Independent Forging and Alloys (IFA)

NEURONE Programme

LIBRTI aims to build an R&D testbed using a neutron source to validate breeder concepts.

NEURONE (NEUtron iRradiatiOn of advaNced stEels) is an ambitious programme developing an industrially scalable, fusion-grade advanced steel capable of withstanding 650°C in a fusion breeder-blanket environment. NEURONE involves working with over 70 collaborators across 12 organisations and is funded through UKAEA's LIBRTI (LIthium BReeding Tritium Innovation) programme.

The steels developed will be directly relevant to a wide range of breeder blanket concepts, including those underpinning STEP (Spherical Tokamak for Energy Production), the UK's flagship commercial fusion programme.

Running from April 2024 to March 2028, NEURONE spans seven work packages. Work Package 6, covering manufacturing and joining, is led by Fusion Technology's MTEQ group.

In Year 2, MTEQ has made significant progress, including a critical assessment of manufacturing technologies suited to breeder blanket production, and investigations into welding parameter variation for friction stir welding with Stirlight and electron beam welding (with Cambridge Vacuum Engineering) on UK-RAFM plate.

The team has also supplied joined material for neutron irradiation testing in Belgian Reactor 2 (BR2), Belgium, processed UK-RAFM ahead of pipe manufacturing trials with the Advanced Forming Research Centre (AFRC) at the University of Strathclyde, and created LIBRTI pin cell mock-ups to support manufacturability assessments (Figure 32). Additionally, MTEQ has helped identify qualification requirements and evidence gaps for the advanced RAFM steels produced under NEURONE.

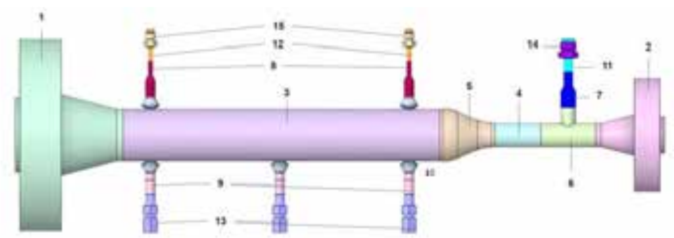


Figure 32 Pin cell body and sub-sections for assembly lab

Figure 33 The consortium involved in the DSIT tactical project (UKAEA, DigiLab, ATI materials, Tokamak Energy, EPRI, University of Birmingham) and present for the kick off meeting

Vanadium Strategy Development

UKAEA, together with private fusion, industry and academia have developed a novel qualification method and strategy for international positioning in the vanadium-alloy landscape.

Vanadium alloys, combined with liquid metal breeder blankets, have long been considered a promising option for tritium breeding in fusion reactors. These vanadium-based alloys exhibit excellent high-temperature creep resistance, high thermal strength and strong resistance to swelling under irradiation. Their low activation characteristics make them attractive structural materials; an alternative candidate to conventional reduced-activation ferritic/martensitic steels.

The Vanadium alloy novel qualification development project, sponsored by the Department for Science, Innovation and Technology (DSIT) Tactical Fund, aimed to develop and validate a digital qualification approach for V-4Cr-4Ti. By combining innovative Bayesian Optimisation processes with materials tensile testing and communicating findings through Standards Development Organisations, the project demonstrated an accelerated, probabilistic qualification pipeline for fusion-relevant materials.

Fusion Technologists worked alongside five partners: Electric Power Research Institute (EPRI), ATI Materials, the University of Birmingham, DigiLab, and Tokamak Energy; with Oak Ridge National Laboratory (ORNL) in technical advisory capacity – bridging academia, industry, and the private fusion sector.

The project delivered a novel qualification strategy and roadmap, a trialled and validated qualification method, and regulatory acceptance through sandboxing via EPRI and international networks.

Beyond technical innovation and assurance, the project generated economic value for the UK, strengthened US-UK strategic relationships, and secured investment in the SME supply chain through DigiLab, supported Tokamak Energy as a UK private fusion company, and developed specialist skills across the sector.

Vanadium is stronger than steel yet flexible enough to bend, and capable of reducing steel's carbon footprint by up to 30%. Already used in wind and solar energy storage through Vanadium Redox Flow Batteries, it is now emerging as a critical material for commercial fusion energy.

Figure 34 Lead Fusion Technologist, Davidson Sabu pictured with a plasma arc melted V44 ingot, ready for rolling into plate in ATI's Pittsburgh facility

"The Vanadium-44 accelerated qualification project tackles one of the key challenges facing the fusion community. UKAEA brought together specialists from multiple teams and created a highly collaborative environment where all parties were willing to share expertise and learn from one another. This enabled valuable insights and key findings to be generated within a short timeframe."

DAN GREENHOUSE, DIGILAB

"Tokamak Energy was very grateful to collaborate with UKAEA and others on the DSIT-funded Advanced Qualification project, which was established to investigate the potential of the latest machine learning and uncertainty quantification techniques for qualifying fusion materials (using vanadium alloy yield strength as an example). The project clearly demonstrated the potential of these new techniques to accelerate the qualification process and optimise experimental campaign design, reinforcing the view that such tools are essential if the UK fusion timelines are to be met. The success of the project is particularly notable given the very short timeframe (six months) and the UKAEA project team's ability to establish such a complex international collaboration in just a few months beforehand."

JIM PICKLES, TOKAMAK ENERGY

"This project is ATI's first involvement with the DSIT program. The collaboration across nations to work to a common goal of helping realize fusion for has been an outstanding experience. WE look forward to future collaborations with this group of researchers."

BENJAMIN EICK, ATI MATERIALS

Introduce new and upgrade existing capabilities in our laboratories to advance fusion technology readiness

Significant investment of time and resource has been made over the past year in building, upgrading, and modernising the Division's laboratory capabilities, a critical foundation for advancing fusion technology readiness.

Across the facilities, substantial progress has been made in expanding the range and sophistication of experimental tools available to researchers. In the Applied Materials Testing (AMT) laboratory, a comprehensive re-organisation has seen the commissioning of new rigs for creep, fatigue, and environmental testing, alongside enhanced imaging capabilities.

In the Radiological Assay and Detection Lab (RADLab), a programme of upgrades has improved detection capabilities, automated key processes, and expanded neutron diagnostics, strengthening the group's capacity for high-quality radiological measurements.

The Heating by Induction to Verify Extremes (HIVE) laboratory has seen operational improvements driven by lean working principles, with feasibility work underway to support future automation.

In South Yorkshire, major milestones have been achieved in the ELSA programme, marking important steps forward in the group's ability to test and validate fusion components at scale.

Together, these developments represent a significant strengthening of the group's experimental infrastructure.

AMT Lab

The **Applied Materials Technology (AMT) Laboratory** is a world-class facility focused on developing and enabling cutting-edge materials testing technologies to accelerate innovation in materials for fusion as well as other emerging sectors where materials are pushed beyond their known limits.

Driving testing technology

AMT is at the forefront of developing and delivering enabling technologies for materials testing in key areas, including small-scale mechanical testing, mechanical testing under extreme environments (such as cryogenic and ultra-high temperatures), and the integration of advanced measurement techniques to deliver data-rich mechanical testing. This technology is essential for the development and qualification of materials in extreme environments.

Among many noteworthy achievements, this year marks a significant step forward in AMT's ultra-high temperature testing capability with the installation and commissioning of two novel in-vacuum elevated-temperature mechanical testing systems: (i) a resistive heating system capable of reaching impressive temperatures of 3,000 °C and beyond; and (ii) an induction heating system, currently capable of operating at temperatures up to 1,200 °C (Page 32).

These advanced mechanical testing systems are fully compatible with the next generation diagnostic tools (e.g., digital image corelation and full field thermal imaging) required for both small-scale mechanical testing and the transition to Materials Testing 2.0, enabling richer, more comprehensive materials datasets. They are now being applied to the development and qualification of materials for fusion, as well as for other demanding industries where materials must operate under extreme conditions.

Figure 35 is Laser scanning confocal microscope

Technology for Materials characterisation

AMT's advanced microscopy suite positions Fusion Technology at the cutting edge of advanced microscopy for the development of revolutionary fusion materials technologies.

A recent addition to this suite is a laser scanning confocal microscope, which has already been deployed to strengthen confidence in the small-scale mechanical testing techniques developed within the group.

This capability is providing new insights into material behaviour at the microscale and supporting the development of robust, high throughput approaches to materials characterisation and qualification.

AMT's automated in-situ mechanical testing capability is enabling a new generation of data-rich materials characterisation. By combining automated mechanical testing with high-resolution strain mapping inside a scanning electron microscope, AMT can capture the evolution of deformation mechanisms with unprecedented spatial and temporal resolution.

This exciting capability recently enabled the direct observation of grain boundary sliding in copper prior to macroscopic yielding, providing new insights into the fundamental deformation behaviour of engineering materials.

This same in-situ technology is now providing experimentally validated, microstructurally informed data, that is critical to the development and validation of next-generation predictive models that have the potential to rewrite the rules of engineering design for fusion systems.

Figure 36 is In-situ mechanic testing stage used to evaluate fundamental modes of deformation

RADLab

The Radiological Assay and Detection Laboratory (RADLab) specialises in advanced radiometric diagnostics using gamma-ray and neutron detectors.

UKAEA's RADLab offers specialist knowledge in fusion diagnostics and has the facilities and expertise needed for the development of advanced detector technologies and techniques to progress fusion.

Significant R&D has taken place in the facility over the past 12 months, developing specialist techniques required for fusion research.

Radiation technologists successfully developed state-of-the-art machine learning detector methods, with a paper published in the Journal of Fusion Energy. Two detectors have been modelled using MCNP and experimental validation tests have been performed on the radiation transport models. When fully validated, these models will enable accurate activity quantification for samples with high complexity geometry, such as activated components that will be characterised during the decommissioning of JET.

Members of the RADLab team have also received expert training in CAD modelling, MCNP and neutron diagnostics. Technicians participated in a collaborative experimental campaign, testing novel neutron detection methods at the National Physical Laboratory (NPL). The campaign included researchers from the University of Birmingham, University of Surrey, NPL and AWE.

On Culham Campus, trials of two gamma imager systems were performed. The systems were deployed around several test locations, including UKAEA's JET torus hall and the BeHF (Beryllium Handling Facility). The Gamma Imaging measurements investigated localised hotspots of the facilities, navigating highly complex geometry and restricted measurement configurations. The results were presented at the Waste Management Symposium 2026.

RADLab Waste Management

This year, two Fusion Technology graduates have developed a new operating model for the RADLab, showing great results within its first year.

An early test of the new model came in the form of a major waste characterisation project. Between August and December 2025, the team conducted eight measurement campaigns across 399 pre-packed waste drums (an amount covering roughly half a tennis court).

Using state-of-the-art high-purity germanium detectors, each drum was scanned, sorted by radioactivity level and correctly consigned to UKAEA's Waste Consignment Team (Figure 37).

The project cleared considerable space on site and demonstrated what the new model can achieve at scale.

The success was an ART team effort, made possible by RADLab's specialist detector capability, gamma spectroscopy training delivered to the Tritium Analysis Laboratory team, and the energy and commitment of the newly onboarded graduates.

RADLab's new cost model and portable systems management has enabled the project's first external customer. Working with Tokamak Energy, ART deployed portable gamma spectroscopy systems on-site at their ST-40 tokamak to analyse materials potentially activated by neutrons, a significant step in RADLab's commercial development (Figure 38).

Figure 37 Drums were manually sorted and scanned using state-of-the-art high-purity germanium detectors

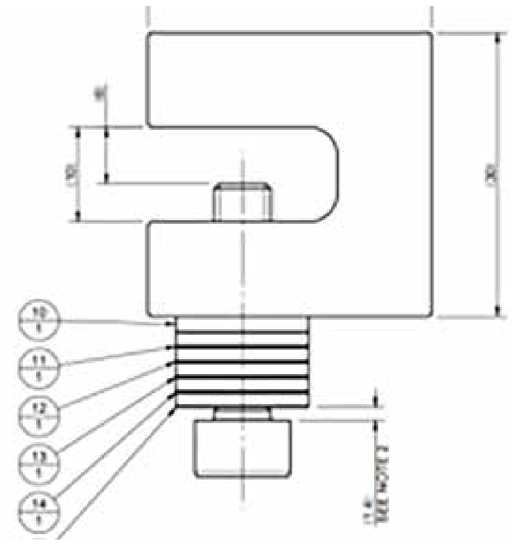


Figure 38 Illustration shows points where each individual washer and screw was tested for levels of radiation

HIVE

Heating by Induction to Verify Extremes (**HIVE**) is a unique facility capable of testing components under high heat fluxes in a high vacuum environment, validating complex engineering models, and verifying advanced manufacturing techniques.

The Heating by Induction to Verify Extremes (HIVE) facility has built upon its capabilities this year through operational improvements, significant research achievements and exciting progress on a next generation testing platform.

This year, the facility embraced the 5S methodology, a set of workplace organisation procedures originating from the Toyota Production System, to improve efficiency and safety. Through sorting, ordering, standardising and sustaining defined workspaces, the lab has seen real improvements in how tools are logged, stored and accessed day-to-day.

On the financial side, HIVE reached a significant milestone by achieving cost neutrality in 2025/26, in its third year of a cost modelling programme. The Technology Development group continues to share this model with other labs and wider UKAEA divisions.

The facility improved its capabilities following tests using an additively manufactured copper induction coil. The coil was used as an inductor to apply heat loads onto components inside the facility, and successfully demonstrated the facility's ability to test samples of varying geometries.

A booster pump for coil coolant was also successfully installed to address issues with pressure drop. This enables smaller cross-sectional coils, ensuring adequate cooling for induction heating on smaller samples.

The team is making strong progress on the High Heat Flux Testing and Verification Facility (HHFTVF), a UKFE-funded second-generation platform that will offer higher heat fluxes, larger sample capacity and enhanced diagnostics.

Through UKAEA's JET Decommissioning and Repurposing (JDR) programme, the team has acquired a laser which will be extracted from JET and integrated into HHFTVF to increase the capability of high heat flux testing in both induction and laser conditions. The acquisition of this equipment will enhance future testing capabilities within the lab.

ELSA
Cryogenic Testing Advances STEP Design

ELSA, a first-of-a-kind facility, produces temperatures on a cryogenic scale between 20 and 70 Kelvin (-253.15 to -203.15 degrees Celsius) to simulate the operating temperatures for the high temperature superconducting (HTS) magnets. HTS coils are critical to confining and shaping the plasma within a fusion machine, by generating high magnetic fields with very little resistive losses.

Fusion Technology's latest testing facility, ELSA, uses extreme temperatures to inform engineering and design under fusion-relevant plant conditions.

Remountable Joint Components

ELSA began operations in 2025, testing novel 'remountable joint' (RMJ) components.

Traditionally, fusion magnets are built as solid, permanent structures, making repairs slow and costly. This novel RMJ design has been developed by the STEP Magnets team and the samples were delivered to UKAEA's South Yorkshire site for testing.

Fusion Technology's expertise in extreme temperature testing has accelerated the research into this novel design, which will lower operational costs, reduce downtime and enable faster maintenance inside a future fusion power plant.

Extreme Temperature Testing

ELSA test campaigns have enabled detailed characterisation of the STEP RMJ clamping mechanism and the distribution of electrical performance across multi-joint assemblies.

In one representative test, a "Baby Toro" configuration comprising of three RMJs within an HTS cable was operated over a week-long campaign, during which joint resistance and thermal behaviour were assessed through cooldown from 300 K to 30 K. At cryogenic conditions and approximately 20 MPa contact pressure, measured joint resistances were of the order of $3 \times 10^{-8}\ \Omega$, in good agreement with simulation predictions and providing confidence in the design approach.

Complementary testing of the novel bladder-based clamping system, including shortduration mechanical trials of around two days, demonstrated that the system can deliver uniform pressure across the joint interfaces at low temperatures, reaching around 25 MPa at ~30 K. These results confirm the viability of the concept while also highlighting areas for further refinement, particularly in aligning detailed mechanical behaviour with finite element models to support ongoing optimisation of the RMJ design.

Aurobindo Siddarth Swaminathan, Principal Engineer for magnets at STEP Fusion, said:

"The ongoing realisation of STEP's RMJ technology is a multi-million-pound project. But what's notable is we've gone from a concept sketch to delivering and shipping a product for testing in one financial year.

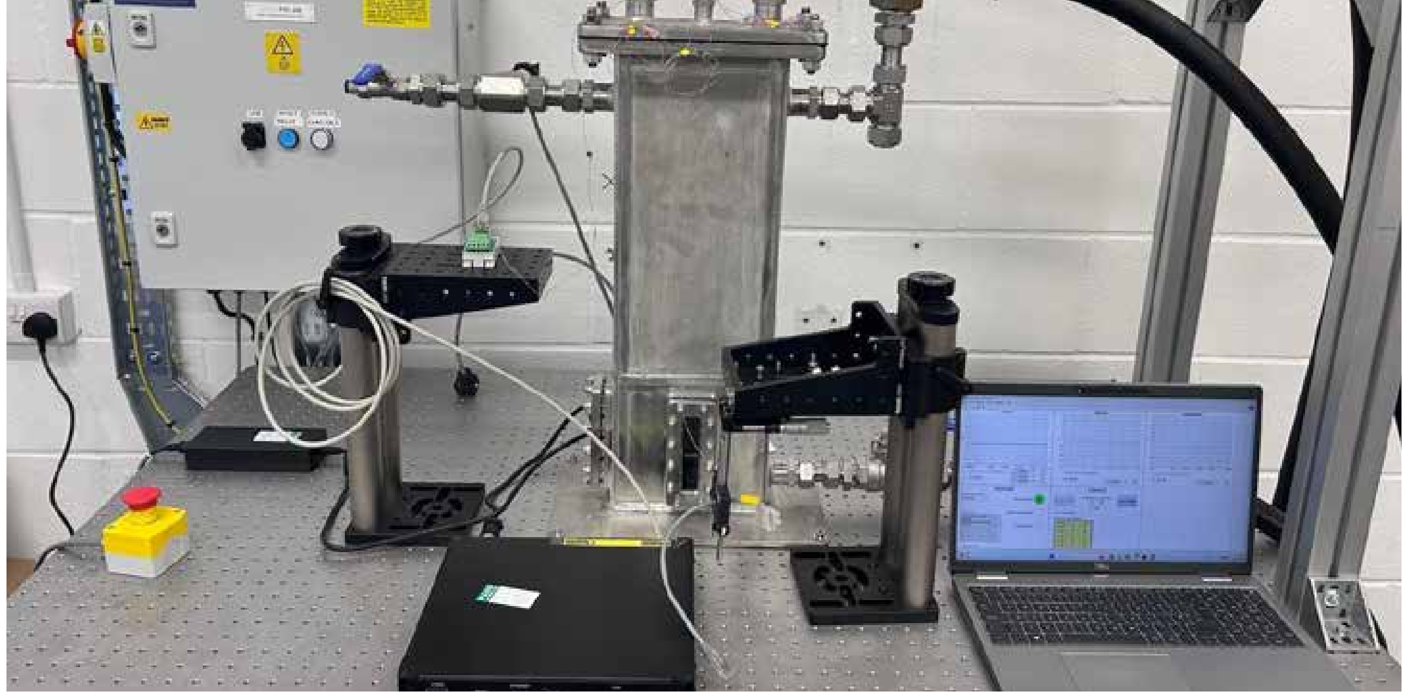
This has only been possible through successful collaboration with industry partners, UKAEA as fusion partner, and UKFE – bringing their combined expertise to the STEP programme."

Remountable Joint Components

RMJs form part of a tokamak's toroidal field coils and will allow sections of a magnet to be taken apart and reassembled for maintenance, much like industrial scale plug and socket connectors.

The system uses a bladder-based clamp: a sealed bladder containing a liquid that expands as it freezes during cool-down, helping to apply an even contact pressure across the electrical interface at cryogenic temperatures.

ELSA test facility at UKAEA South Yorkshire



Flow-induced Vibration Validation Studies

In fusion systems, several breeder blanket designs are expected to incorporate curved pipes as cooling elements. These components are subjected to high-temperature, high-pressure fluid flow, which may induce flow-induced vibrations (FIV) during operation.

Understanding and characterising these vibrations is critical to the design and safe operation of fusion components. Given the complex, non-linear nature of fluid-structure interaction (FSI) phenomena, numerical simulations of such problems require rigorous experimental validation.

To address this need, the FIVLAB experimental facility has been established through the EUROfusion programme at UKAEA South Yorkshire and has been specifically designed to support the validation of FIV models under controlled conditions.

The FIVLAB facility is equipped to measure the vibration response of various U-bend pipe configurations, including variations in pipe diameter and radius of curvature, under different internal flow conditions characterised by varying flow rates/Reynolds numbers. The facility supports experiments with the U-bend exposed to three different environments: air, water immersion, and Galinstan immersion.

Flow variability is achieved using a flow control valve and a mass flow meter, both integrated with a data acquisition (DAQ) system for precise monitoring and control.

The facility is equipped with two diagnostic systems for vibration measurement fibre Bragg grating (FBG) sensors and ultrasound Doppler velocimetry (UDV). The facility has been commissioned at the South Yorkshire site and is now ready for operation. Preliminary testing of the diagnostics has been carried out to evaluate the sensitivity and effectiveness of each measurement system.

FIVLAB strengthens confidence in numerical tools used for fusion component design., supporting the design and qualification of breeder blanket cooling channels. FIVLAB is in its early operation stages and results from testing will support FIV research across academia and the fusion industry.

Develop our people and culture, targeting growth mindset

Fusion Technology is committed to nurturing talent, fostering an inclusive culture and building the people and skills needed to sustain world-leading fusion research for the long term.

Over the past year, significant progress has been made in developing the capabilities of UKAEA's technical community. A dedicated programme of training, workshops, and peer support has been delivered to upskill colleagues, across teams and divisions within the organisation.

A significant milestone has been the formal establishment of a High Temperature Superconducting (HTS) Magnet group, providing dedicated expertise and a clear strategic roadmap in this important and growing area of fusion technology.

The Division has also maintained a strong focus on inclusive recruitment, championing diversity networks across the organisation. This sits alongside the ongoing roll-out of UKAEA's behaviours framework, embedding robust appraisal and performance processes to ensure the organisation's values are reflected in everyday working life.

Underpinning all of this has been a genuine commitment to staff wellbeing, with dedicated caring moments developed to support a positive and resilient team culture built on a growth mindset.

PhD Highlights

The number of PhDs projects has increased, from 8 projects in 2024, to 13 in 2025. This year's cohort are sponsors from eight UK universities, including Sheffield, Southampton, Liverpool, Birmingham, Bristol, Strathclyde, Manchester and Imperial College London.

Also this year, six Fusion Technology colleagues became first-time PhD supervisors for the Division. This uptake in supervisor roles has allowed the Division to increase the number of projects and has been a positive step forward in upskilling staff in their professional development.

The projects cover a strategic range of topics within fusion technology research, expanding into materials, computing and engineering divisional fields.

Figure 39 Word cloud summary depicting most popular topics and research studies in the 2025/26 PhD cohort

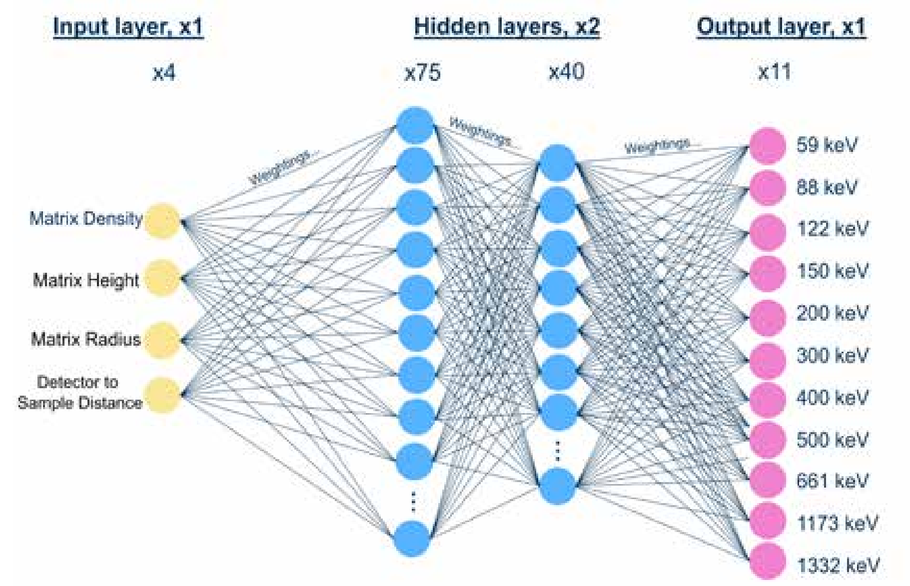
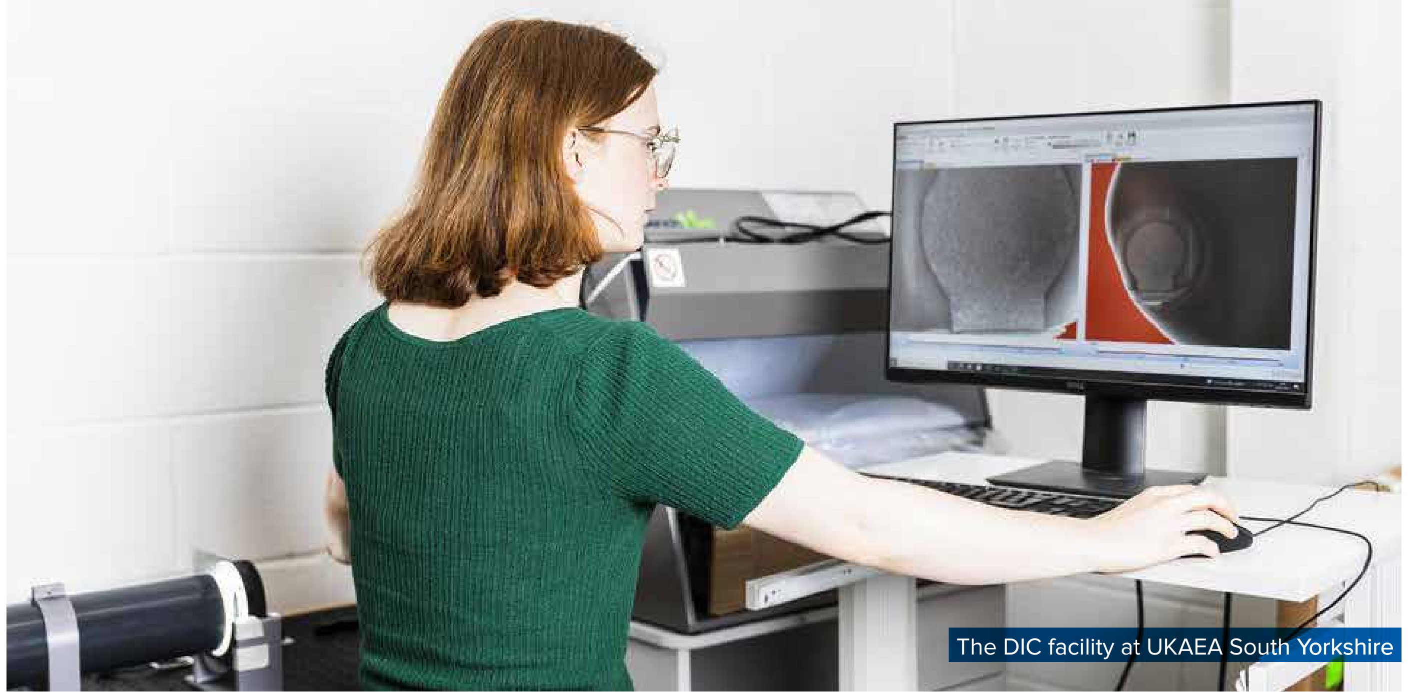


Figure 40 Illustration shows the AI/Machine Learning Architecture



The DIC facility at UKAEA South Yorkshire

PhD Spotlight

Publication of Machine Learning Based Efficiency Calculator (MaLBEC) for Nuclear Fusion Diagnostics

As part of Senior Nuclear Physicist's Kimberley Lennon's PhD work, together with Sheffield Hallam University and Applied Radiation Technology's Chantal Shand, a paper on Machine Learning Compton Suppression Algorithm (MLCSA) was developed and published in 2024.

This year, a second paper has been released under the PhD by Kimberley Lennon, Chantal Shand and Gemma Wilson from UKAEA's ART group, and Robin Smith from Sheffield Hallam University.

The paper, Machine Learning Based Efficiency Calculator (MaLBEC) for Nuclear Fusion Diagnostics, builds upon the MLCSA, to develop gamma spectroscopy analysis.

In fusion, gamma spectroscopy is used in waste characterisation, materials research for future fusion machines, plasma diagnostics (e.g. indirectly calculating the neutron flux, and therefore fusion power, via neutron activation analysis, and other areas.

Traditional methods for calculating efficiency values can be expensive, difficult to obtain and require extensive training.

This paper introduces a new tool called MaLBEC, which uses state-of-the-art machine learning to calculate detector efficiency faster than a traditional efficiency calculation method, such as MCNP (Figure 40).

When tested on fusion reactor data, MaLBEC produced results within 5% of the established traditional method — while being over 99% faster. When both methods were used to calculate the actual power output, the results were within 3% of each other (Figure 41).

Dr Lennon completed her PhD in 2026. The ART group hope to build on this work outside of the PhD project, exploring the tool's efficiency, speed, cost and commercial potential.

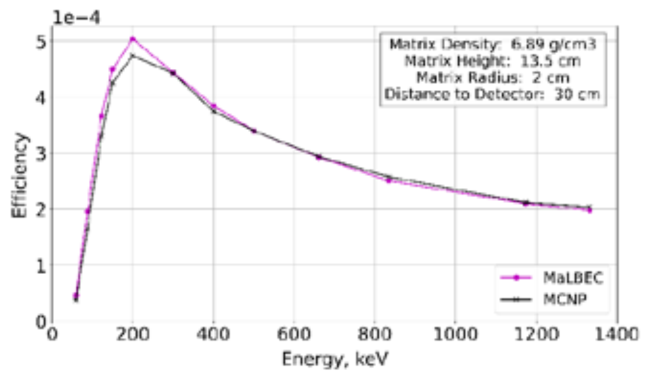


Figure 41 Results from MaLBEC tests on fusion reactor data

Future Leaders Fellowship

In 2024, Dr Lloyd Fletcher was awarded a UKRI Future Leaders Fellowship (£1.6M) to develop the next generation of engineering software tools for designing smart simulation validation experiments with image-based sensors.

In the last 12 months, Dr Fletcher's fellowship has built upon developing methods for engineering simulations.

Work within UKAEA

Cross-divisional collaboration with UKAEA's Integrated Engineering Division on Key Challenge 4 (development of an in-vessel component digital replica working towards component virtual qualification) explored how to qualify components for extreme and untestable environments. Tests inside Fusion Technology's HIVE facility quantified the accuracy of predicted thermal and mechanical response for components under high heat flux. A paper has been submitted on this work.

Publications

Research Software Engineer Joel Hirst, who was hired under the fellowship in 2024, has written a paper on the DIC module in the Pyvale software package.

The paper references the significant performance gains in DIC for high resolution images (Figure 42). Through the development of this module, the AMT group are able to analyse gigapixel resolution images. The package has improved the ability to produce high performance code with smaller computational resource – widening access for researchers with limited access to high memory workstations and computing clusters.

The code was demonstrated at a seminar with the micromechanics group from the Royce Institute at the University of Manchester and is beginning to help solve materials challenges for external collaborators within fusion, aerospace and other applications.

PYVALE

A Fast, Scalable, Open-Source 2D Digital Image Correlation (DIC) Engine Capable of Handling Gigapixel Images

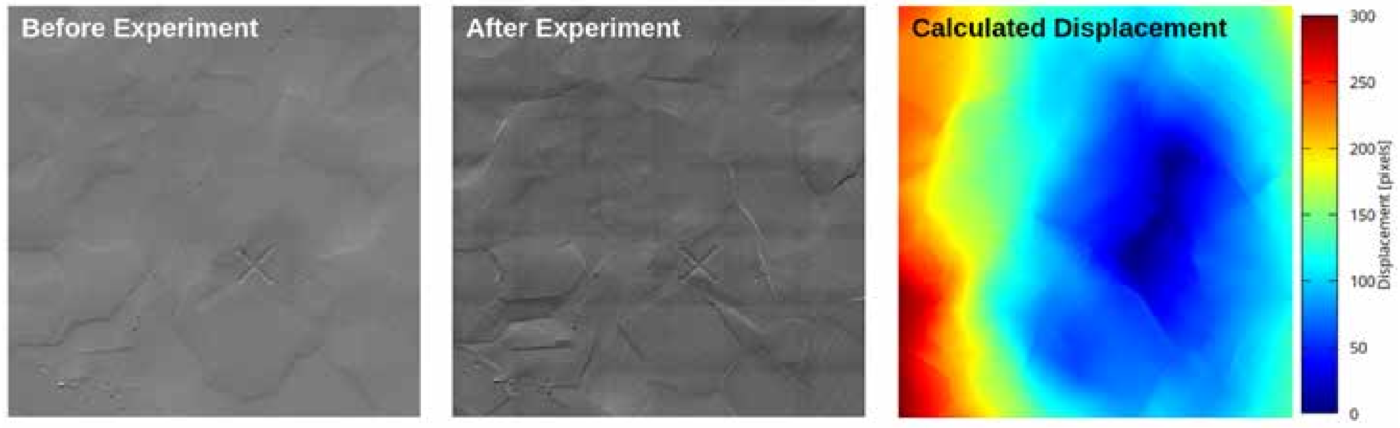


Figure 42 Scanning electron microscope (SEM) images acquired before and after a loading experiment, together with the corresponding deformation field calculated using the Pyvale software package

Industry

Dr Fletcher hosted a Digital Twins in Mechanics Workshop with the British Society for Strain Management (BSSM) and UK Association Computational Mechanics (UKACM). The event was designed to solve fusion engineering problems using the best of computational mechanics. The fruitful workshop has led to further work with both BSSM and UKACM.

Academic

The Fellowship is responsible for two PhD students and Adel Tayeb and Lloyd Fletcher are supervisors for two PhDs in:

- Smart Image-Based Sensor Array Optimisation for Fusion Simulation Validation (University of Liverpool)
- Multiphysics data-driven validation framework for component qualification in fusion (Imperial College London)

The work from the Fellowship is making a meaningful contribution to fusion and adjacent industries and providing upskilling opportunities to researchers and engineers.

Early Careers Highlights

UKAEA's Early Career schemes offer colleagues on the graduate scheme a structured and accredited professional development programme to gain skills and experience through role-specific, technical and leadership training, group activities, personal development, shadowing, mentoring, and project work.

Graduate projects provide networking opportunities for the cohort, as well as building their skills and knowledge in other areas of the organisation, which they then can bring back to their permanent role. These opportunities may also build the graduates' personal confidence.

Jane Ambler, within the Division's Technology Development group, worked with two other graduates at UKAEA on an educational outreach project.

Together the trio recognised a need to communicate a complicated area of fusion, creating an animation that simplified the tritium fuel cycle.

Much like her work in the Hi-CriS animation (page 27), Jane took on the technical side of the project, creating strong visuals and GCSE-level diagrams for the video.

The animation presented clear information on tritium, its function, challenges and potential dangers, and the opportunities it provides to nuclear fusion (Figure 43).

The video is available on the UKAEA YouTube channel: The Fusion Fuel Cycle.

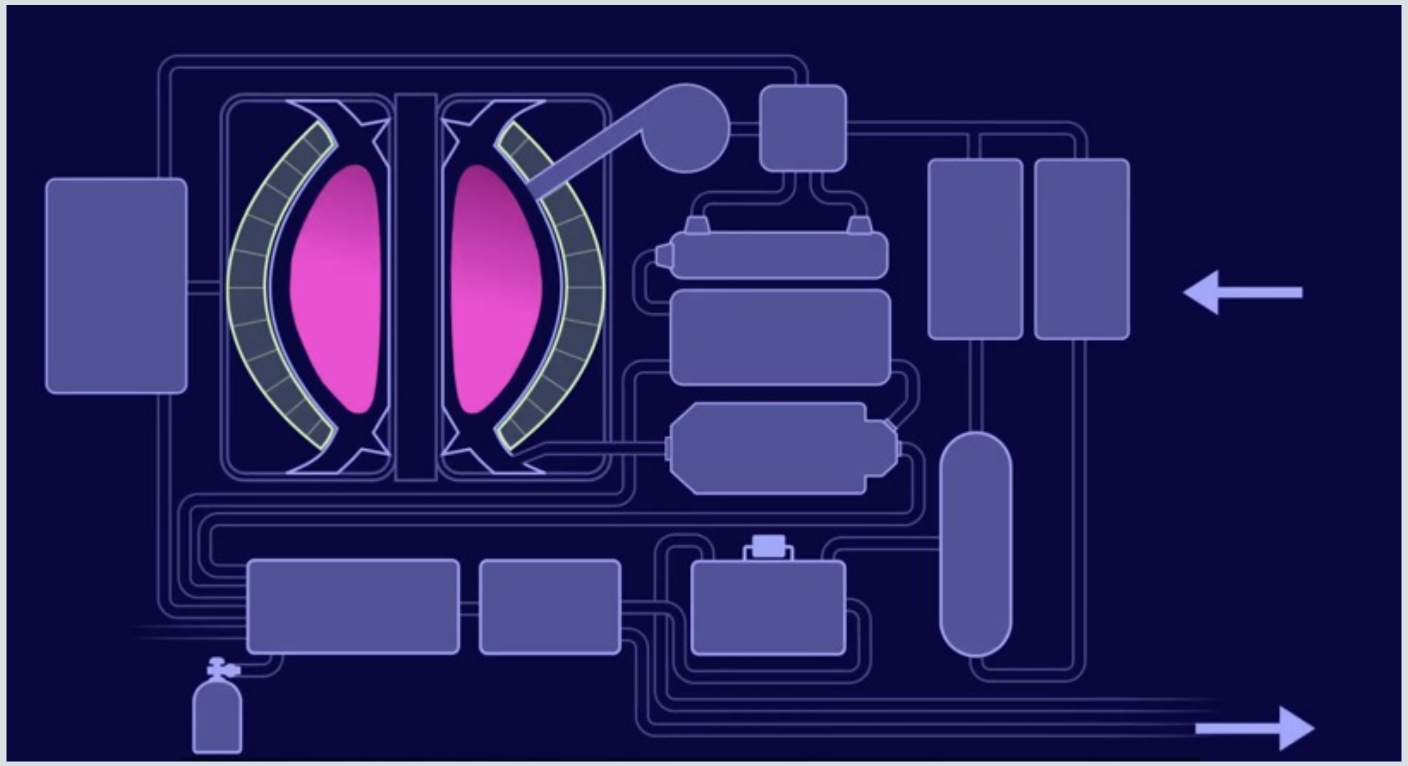


Figure 43 Screenshot from Jane Ambler's animation

Fusion Training Programme

UKAEA's internal Fusion Training Programme received its highest ever cohort in 2025.

The Fusion Training Programme covered key aspects of UKAEA research to provide an overview of the different components, systems and fields related to designing a fusion power plant.

Across 19 lectures delivered by UKAEA and UKFE experts, attendees learnt key aspects of the broad range of fusion fields to provide whole plant awareness and an understanding of cross-disciplinary collaboration.

Lectures covered a diverse range of topics including plasma physics, tritium, heating and current drive, remote maintenance and tokamak magnets. In addition to lectures supporting the 'how' of fusion and present tokamak design, presentations were given on the past, with a detailed history of UKAEA, and the future, how fusion power plants will operate sustainably through waste, safety and remote maintenance programmes.

The training provides new starters, graduates and colleagues from all areas of the organisation the opportunity to increase their understanding of fusion and the many elements involved in developing a commercial power plant.

The course feedback was overwhelmingly positive:

"The course gave me a good overall context, not only of the tokamak-based fusion plant but also of how it connects with my current role."

"I thought this was a valuable and enjoyable programme, and I have strongly recommended this to my line manager."

"All of the lecturers were clearly very knowledgeable and passionate about their field which was nice to see, and many were engaging in how they presented it."

The Fusion Training Programme was organised by Fusion Technology's Power Plant Modelling and Integration (PPMI) group. The group delivers the annual internal course, alongside bespoke training for industry and academia.

Over 120 UKAEA employees attended the 2025 Fusion Training Programme

Launch of a national superconducting magnets catalyst at the University of Strathclyde
Image credit: Guy Hinks Photography

Welcoming Expertise

Magnet Technology Group Established

In 2025, the Fusion Technology Division established the new Magnet Technology Group to support the development of superconducting magnet capability across UKAEA and future fusion programmes.

The group brings together magnet engineers, scientists, quality specialists and facilities experts to provide clearer technical leadership and long-term strategic direction for superconducting magnet technology. The team supports activities spanning HTS magnet design, qualification, cryogenic testing, supply-chain engagement and future facilities development.

Throughout the year, the group significantly expanded engagement with universities, industrial partners and international collaborators to help strengthen the UK's magnet capability ecosystem. Collaboration activities included work with the University of Strathclyde, University of Edinburgh, University of Bath, University of Nottingham Nottingham, University of Glasgow, University of Oxford, STFC, Tesla Engineering, SuperPower and other partners supporting HTS technology development and qualification activities.

The group also supported multiple Fusion Futures projects focussed on HTS magnet capability, cryogenic testing infrastructure and future qualification methodologies. This included delivery of HTS coil from Tesla engineering company, development of upgraded LN_2 testing capability and initiation of the FROST cryogenic test facility concept for intermediate-scale HTS magnet testing.

In parallel, the Magnet Technology Group continued development of their technology roadmap, helping define future capability priorities beyond STEP, including magnet testing infrastructure, industrial partnerships, workforce development and national collaboration opportunities.

The team also strengthened links with academia through collaboration discussions, PhD engagement and support for superconductivity training activities. UKAEA additionally supported upgrades to superconducting testing capability at the University of Edinburgh through Fusion Futures funding initiatives.

In a recent announcement with the University of Strathclyde, UKAEA launched the Superconducting Machines & Systems Catalyst programme to help build a national capability in HTS machines and systems, connecting universities, industry and national laboratories across the UK.