# LIBRTI Conference on Breeder Blanket Technology


# Report of Contributions

https://indico.ukaea.uk/e/LIBRTI_Conference_2026

Contribution ID: **2** Type: **Talk**

# Current Status and Future Plans for US Tritium Production

*Thursday 5 February 2026 09:15 (30 minutes)*

Tritium-producing burnable absorber rods (TPBARs) are irradiated in a commercial power plant to produce tritium for US defense purposes. The presentation will review the current state of the US tritium production program, production history that led to the present state, and discussions of a few planning scenarios for the future. The organization of the National Nuclear Security Administration's Tritium Modernization Program will be presented, with emphasis on the roles of the Pacific Northwest National Laboratory, including both production and supporting science activities. An overview of the Tennessee Valley Authority's Watts Bar Nuclear reactors, where TPBARs are irradiated, will be provided along with an overview of the TPBAR design and how the TPBARs interface with the reactor fuel assemblies. Finally, a brief discussion of TPBAR and core design constraints will be provided, along with a summary of operational impacts of tritium production on the reactors.

## Speaker affiliation

Pacific Northwest National Laboratory

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**Session Classification:** Session 3-9

**Track Classification:** LIBRTI Conference

Contribution ID: **3** Type: **Talk**

# Increasing the heat: Developing the next-generation of high-temperature steels to deliver commercial fusion energy

*Wednesday 4 February 2026 10:15 (30 minutes)*

As the UK nuclear 'renaissance'continues apace, steels continue to demonstrate incredible versatility and performance, particularly as we consider next-generation structural materials to use in the most demanding environments ever developed. Proposed commercial fusion powerplants contain plasmas ten times hotter than the sun, with materials witnessing extreme levels of radiation damage. This is coupled with challenging mechanical loads, and other environmental factors such as corrosion. Yet nano-structuring and carefully designed steel microstructures can be tuned to manage these effects.

A LIBRTI-funded, UK consortium, NEURONE (Neutron Irradiation of Advanced Steels), operating across academia, national labs and industry are tackling the challenge of developing steels to use in fusion plants, and utilising existing national infrastructure to deliver the tonnages of material required for commercial fusion plant breeder blankets, by the end of the decade. This talk will explore some of the key challenges we face within this programme, as well as the science behind the steels being developed. Importantly, the immediate opportunities for wider industry engagement in this emerging sector will be outlined.

## Speaker affiliation

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**Session Classification:** Session 2-5

**Track Classification:** LIBRTI Conference

Contribution ID: **4** Type: **Talk**

# Uncertainty and multiphysics for predictive breeder blanket modelling

*Wednesday 4 February 2026 16:40 (30 minutes)*

Predicting tritium generation, retention, and release in a breeder blanket is essential for the design of fusion experiments, reactor prototypes, and ultimately commercial systems. Sensible and reliable design choices requires close alignment between simulations and experiments overseeing a variety of processes and physical scales. Assessing the predictive accuracy of tritium transport simulations therefore demands close attention to several factors: the completeness of the participant physical phenomena; the reliability of material property values used as simulation parameters; and the translation of coupled phenomena across physical scales.

Because any simulation is necessarily imperfect in each of these aspects, understanding how uncertainties combine to affect the model's final predictive capability is a challenging but extremely important question. The Tritium Reaction Integrated Multiphysics Analysis eXperiment (TRIMAX) project is addressing this through the development of a materials-level multiphysics tritium transport model equipped with an Uncertainty Quantification (UQ) wrapper. In addition to predicting key performance metrics, this approach explicitly captures uncertainty within input parameters and propagates it through the model to produce self-consistent distributions of outputs. This enables identification of the most influential material parameters, highlighting where new measurements or modelling efforts will yield the greatest improvements in yield or reduction in uncertainty, and where current tolerances may be relaxed without compromising safety or performance.

By revealing the drivers of predictive confidence, TRIMAX supports efficient research prioritisation to provide a robust foundation for breeder blanket design considerations in forthcoming fusion systems.

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**Session Classification:** Session 2-8

**Track Classification:** LIBRTI Conference

Contribution ID: **5** Type: **Talk**

# Development of analytical techniques for tritium accountancy around the fusion fuel cycle

*Thursday 5 February 2026 14:50 (30 minutes)*

The Tritium Fuel Cycle (TFC) division at UKAEA is working in collaboration with the LIBRTI project to develop analytical techniques for tritium accountancy. For a fusion power plant to be fully operational, tritium will need to be analysed throughout the entire fuel cycle whether it is in gas stream or in materials such as breeder materials. Two projects are currently on-going and will develop a wide range of analytical methods and instruments to answer the challenges around tritium analytics.
HERA is looking at testing analytical methods for real-time analysis of tritium in gas streams. The project is a glovebox experiment installed in the Active Gas Handling System (AGHS) building on the Culham campus. The glovebox has been entirely designed by UKAEA engineers and is currently being built in the facility, once the build phase comes to an end, the glovebox will enter commissioning where the instruments installed inside will be tested and calibrated. HERA will be testing 2 analytical instruments: a mass spectrometer (MS) and a Raman spectrometer. The HERA glovebox will be capable of generating its own gas calibration standards thanks to calibrated vessels and PVTc calculations. The instruments will be able to quantify H2, D2 and T2 from limit of detection up to 100% gas streams. A Palladium catalyst will also be installed in the glovebox to allow for isotopic exchange and semi- quantification of HD, HT and DT.
THALIA's goal is to develop and validate a method for tritium accountancy when trapped in liquid breeder materials such as liquid lithium, LiPb and FLiBe, the first phase of the project will focus on FLiBe. The project consists of 2 sub-projects, ERATO and CLIO, each looking at an analytical technique. ERATO will focus on developing a sample preparation technique suitable for analysis of tritiated lithium-based salts for Liquid Scintillation Counting (LSC). Meanwhile, CLIO will develop a hydrogen analysis technique using ICP-MS, commonly used for a wide range of analysis but currently not developed for analysing small atoms such as hydrogen and its isotopologues. Both techniques are considered to be low technology readiness level (TRL) due to the difficult of getting the tritiated lithium matrix into a suitable state for analysis.
THALIA and its sub-projects are facing quite a few challenges such as difficulty of working with lithium-based materials, unknown tritium speciation in the materials, very low concentrations, storage of samples.
The presentation will go through:
- The need for real-time analysis of tritium and its challenges.
- What is the HERA project
- Analytical instruments integrated in HERA
- The challenges of tritium accountancy in breeder materials
- What are the THALIA project and its sub-projects CLIO and ERATO

## Speaker affiliation

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**Session Classification:** Session 3-11

**Track Classification:** LIBRTI Conference

Contribution ID: **7** Type: **Talk**

# The Effect of Ion Irradiation and High Temperatures on the Highly Lithiated Octalithium Ceramics

*Tuesday 3 February 2026 16:55 (30 minutes)*

In order to most efficiently produce tritium from a high energy neutronic reaction, lithium dense tritium breeding materials (TBMs) are required. TBMs must operate under high temperatures and neutron radiation, whilst producing extractable tritium and being compatible with the surrounding materials. Ceramic TBMs offer material compatibility and do not suffer from magnetohydrodynamic (MHD) effects, however, traditionally they have lower tritium breeding ratios (TBRs) in addition to concerns over radiation damage.

With the current industrial interest in spherical tokamak arrangements with less space for TBMs, materials with higher TBRs are required. Neutronics simulations suggest that the octalithium compounds, with their high lithium densities, offer significantly higher TBRs than Li4SiO4 and Li2TiO3 which are designated for use in ITER –however most of these compounds lack basic physical data (melting points, phase stability, mechanical properties) and none have been subject to micro mechanical and ion irradiation testing.

This work presents the mechanical properties (Youngs modulus, hardness and fracture toughness) of dense octalithium ceramics (Li8MO6, M = Zr, Pb, Sn and Ce) from nanoindentation, how these experimental values correspond with those predicted using density functional theory modelling (DFT), and the impact of high energy (12 MeV, 1e17cm-2) He ion irradiation on these properties. Further we examine how the octalithiums will perform in the hostile environment of a future reactor, by exploring the phase stability at high temperatures (500℃, 700℃ and 900℃) using X-ray diffraction and mass loss.

## Speaker affiliation

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**Session Classification:** Session 1-4

**Track Classification:** LIBRTI Conference

Contribution ID: **8** Type: **Talk**

# Digital Twin Development for Breeder Blanket Systems: Bridging Physics and Engineering

*Thursday 5 February 2026 12:05 (30 minutes)*

In support of the LIBRTI programme, we have developed a multi-physics simulation tool for generic breeder systems, initially focused on liquid lithium technologies. A key objective of the work is the ability to accelerate the optimisation of a breeder system design with many free parameters (related to geometry, chemical compositions or operational conditions), and in the presence of various competing requirements. These requirements include tritium generation, heat extraction targets and corrosion resistance. Ultimately, this tool is planned to undergo further developments to serve as a digital twin to support operation, maintenance and decommissioning of the breeder system, so has been built to be adaptable. It can integrate with various software packages and security considered design has been utilised to support the ultimate goal of supporting an operational plant. The implemented simulations include neutronics calculations based on Monte Carlo methods coupled with nuclear activation calculations as well as analytical models. Machine Learning based surrogate models have been adopted for the neutronics/activation calculations. Trained with simulated data, these Machine Learning models are integrated into the simulation of the entire liquid lithium system and enable the multi-targeted optimisation of the system. In addition, we are exploring Machine Learning models in support of the simulation of corrosion effects. The Machine Learning models predict, along with the response values, the uncertainties on these values. This enables the targeted provision of additional training data to reduce uncertainties in regions of the parameter space where it is of most interest.

## Speaker affiliation

Amentum

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**Session Classification:** Session 3-10

**Track Classification:** LIBRTI Conference

Contribution ID: **9** Type: **Talk**

# Uncertainty Quantification of breeder blankets using MOOSE

*Wednesday 4 February 2026 17:10 (30 minutes)*

In the design, construction and operation of breeder blankets, there is large uncertainty in a range of properties including the geometry, material properties, physical parameters, isotope composition and nuclear cross-sections. Uncertainty quantification (UQ) methods aim to quantify how variability in each of the properties drives variability in the performance of the system. This allows design engineers to understand the key drivers and variability in their system, leading to more robust, feasible and reliable designs.

CFMS has been collaborating with UKAEA to perform UQ on the pin-cell breeder blanket design used in the LIBTRI programme. Two models were considered to simulate different processes in the system: an OpenMC neutronics model for tritium production, and a MOOSE finite element based model for tritium advection and extraction. Each model was fully parametrised, allowing for arbitrary variation of various parameters within given bounds. Automated pipelines were created for geometry generation, meshing, simulation execution and results extraction which allowed for a large number of models to be evaluated on HPC.

A fourier-based UQ method was applied to both models and the first order sensitivity indices were extracted. The key drivers for both models were identified and can now be targeted by UKAEA to reduce variability. Parameters with little contribution can have their tolerances loosened, saving cost. Overall, a better understanding of the system was achieved, which can help inform future design choices.

## Speaker affiliation

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**Session Classification:** Session 2-8

**Track Classification:** LIBRTI Conference

Contribution ID: **10** Type: **Talk**

# Tritium breeding capabilities & progress at the tritium breeding research facilities by the University of Bristol & Astral Systems

*Tuesday 3 February 2026 14:35 (30 minutes)*

The University of Bristol and Astral Systems are establishing a tritium breeding research facility in the north of Bristol. This leverages the expertise of the University of Bristol on material manufacture and instrumentation design and Astral's revolutionary compact neutron sources.
The facility consists of a gas management system (GMS), a breeder blanket module (BBM) and a DD neutron source. The GMS has been developed to manage the purging gas flow through the breeder material during neutron irradiation. Flow, pressure, and gas composition can be modified in in real-time within the breeder module. The temperature of the breeder can also be controlled via an inductive heater. The BBM encloses the vessel where the breeder material is encapsulated and conditions the neutrons to maximise breeding efficiency. The current neutron source leverages Inertial Electrostatic Confinement Fusion (IECF) technology and is capable of generating I $\approx$ $1\times10^8$ n/s DD neutrons (E = 2.45 MeV).
The current research on the facility is exploring the use of 6LiD as a tritium breeder material, fabricating solid pellets of various sizes to prevent contamination. These pellets will be tested under quasi-operational conditions to study tritium production.
An overview of the results obtained to date will be presented as well as and status update and future steps of the whole facility.

## Speaker affiliation

University of Bristol

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**Session Classification:** Session 1-3

**Track Classification:** LIBRTI Conference

Contribution ID: **11** Type: **Talk**

# Lithium Aluminate Pellet Irradiation Experiment

*Tuesday 3 February 2026 14:05 (30 minutes)*

Lithium aluminate (i.e., y-LiAlO2) pellets were subjected to neutron irradiation during the TMIST-3 in-reactor experiment, which was designed to evaluate tritium release rate and speciation from various pellet designs. The TMIST-3 experiment consists of a short-term and a long-term test train to study the effects of burnup, burnup rate, and time on tritium release rate and speciation. The short-term test train, TMIST-3A, was irradiated for a total of 8 cycles in the Advanced Test Reactor (ATR) at Idaho National Laboratory between September 2016 and January 2019 to achieve ~ 350 effective full power days (EFPD) at 23 MWth. The long-term test train, TMIST-3B, was subsequently irradiated for a total of 15 cycles in the ATR between November 2019 and October 2025 to achieve ~700 EFPD at 23 MWth. Pellets irradiated in the TMIST-3 test trains are contained separately in either "open"(i.e., flow-through) or "closed"(i.e., hermetically sealed) capsules. Pellets contained within closed capsules will be evaluated during post-irradiation examination to assess the fractionation of tritium released as either elemental tritium (i.e., 3H2) or tritiated water vapor (3H2O). However, the focus of this presentation will be on results obtained from the open capsules of TMIST-3B, which provide in-situ measurement of tritium release via an ex-reactor tritium monitoring system. Details of the TMIST-3B test train layout will be provided as well as an overview of the open and closed capsule designs. A total of 19 capsules were included in TMIST-3B and six of them were open capsules with dedicated sweep gas lines flowing to an ex-reactor tritium monitoring system adjacent to the ATR. This ex-reactor system will be described as well as the various pellet designs considered in this study. Different pellet designs were included in TMIST-3 to evaluate the influence of microstructure and pellet microstructures were tailored to possess specified grain sizes and pore distributions. In addition to these lithium aluminate-based pellets, a unique cermet pellet consisting of lithium aluminate particles dispersed within a zirconium matrix was also included among the pellet designs of TMIST-3. Results of tritium release rate measurements obtained from TMIST-3B for these different pellet designs will be presented and compared.

## Speaker affiliation

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**Session Classification:** Session 1-3

**Track Classification:** LIBRTI Conference

Contribution ID: **12** Type: **Talk**

# Tritium Breeding Testing with an Intense DT Neutron Source

*Thursday 5 February 2026 13:50 (30 minutes)*

SHINE Technologies has been selected as the DT neutron source supplier for the LIBRTI tritium breeding test facility. As part of UKAEA's broader Fusion Futures initiative, the LIBRTI program focuses on pioneering fusion fuel advancements and stimulating general industry capacity through international collaboration. Over its four-year span, the program aims to demonstrate controlled tritium breeding, which is a critical step for future fusion power plants. The paper will discuss SHINE's contribution to the LIBRTI program and interface considerations between the neutron source and breeding test blanket.

The DT neutron driver to be delivered to the LIBRTI facility in is based on the high-flux, steady-state neutron source technology that SHINE has already deployed as the Fusion Linear Accelerator for Radiation Effects (FLARE) in Janesville, Wisconsin, United States. FLARE is comprised of a neutron generator, a tritium purification system, an irradiation bunker, and related facility infrastructure. FLARE routinely operates with an accessible DT neutron flux of ~ $5\times10^9$ n/cm$^2$s. Fast neutron flux levels of up to $1.8\times10^{10}$ n/cm$^2$s have been measured with this technology at a maximum DT neutron output of $4.6\times10^{13}$ n/s.

In addition to the planned delivery of the LIBRTI neutron driver, SHINE is collaborating with UKAEA on upgrades to the DT neutron source technology to further increase the neutron flux available for tritium breeding testing. These upgrades, including the implementation of a plasma window to allow for higher tritium gas pressures in the target, are expected to increase the maximum accessible flux by 1-2 orders of magnitude.

SHINE is also in the planning stages for tritium breeding experiments using FLARE starting in 2026. These include tests in collaboration with the University of Edinburgh and Commonwealth Fusion Systems under the TRIBAL (TRItium Breeding to Advance LIBRTI) project, and with the University of Wisconsin-Madison and the Massachusetts Institute of Technology under a Fusion Innovation Research Engine (FIRE) Collaborative award from the U.S. Department of Energy.

## Speaker affiliation

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**Session Classification:** Session 3-11

**Track Classification:** LIBRTI Conference

Contribution ID: **13** Type: **Poster**

# OpenMC modelling of tritium breeding experiments

As part of the LIBRTI programme, the University of Birmingham is developing capability to (a) breed tritium from lithium ceramic in a metal capsule with the HF-ADNeF neutron source [1] and (b) detect tritium with a tritium bubbler and liquid scintillator system. To predict tritium activity, an OpenMC [2] model of the facility has been developed using the existing HF-ADNeF source term developed at Birmingham [3]. The model predictions should be comparable to experimental results and allow further investigation into where the tritium escapes between breeding and measurement.

The OpenMC model allows multiple parameters to be easily adjusted depending on the experiment being run: including ceramic pebble packing density, pebble size, ceramic composition, capsule composition, and the incident neutron spectrum. The neutron spectrum is dependent on the incident proton energy on the HF-ADNeF target and the shielding surrounding the experiment. Model outputs can include the rate of tritium bred, rate of heating, and the neutron spectrum inside the ceramics. Uncertainties on the outputs are propagated from the specific reaction nuclear data and Monte-Carlo statistics. OpenMC is an ideal tool for neutronics modelling of ceramic tritium breeding experiments, although validation of the model and further development of some methods is necessary.

[1] HF-ADNeF: https://www.nnuf.ac.uk/high-flux-accelerator-driven-neutron-facility
[2] OpenMC paper: https://doi.org/10.1016/j.anucene.2014.07.048
[3] The HF-ADNeF source term: https://github.com/mconroy101/UOB_HFNF/

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**Track Classification:** LIBRTI Conference

Contribution ID: **14** Type: **Talk**

# Progress of Breeding Blanket Technology Development in Korea

*Tuesday 3 February 2026 13:35 (30 minutes)*

The development of breeding blankets is critical for the realization of fusion energy, as they are essential in fuel production and energy generation in fusion reactors. The pre-conceptual design for the K-DEMO blanket has commenced, with the HCCP blanket concept adopted as the reference design following the KO-EU HCCP TBM project, while other potential design options are being explored. To efficiently support and validate these designs, a conceptual study has been conducted to derive the strategy and infrastructure necessary for breeding blanket development.

In the meantime, with the "Strategy for Accelerating Fusion Energy Realization" approved in Korea in 2024, it is expected to further accelerate the development of key fusion technologies, including breeding blankets. While the strategy and infrastructure for blanket development will need to be realigned in accordance with this new strategy, basic R&D activities for breeding blankets will continue. These efforts include the development of tools, modeling and data for design and safety, manufacturing technologies, tritium extraction and cooling technologies, and materials and their database.

This study addresses the breeding blanket development strategy and provides an overview of the current status of technology development in Korea, highlighting ongoing R&D activities and key advancements in breeding blanket technologies.

## Speaker affiliation

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**Session Classification:** Session 1-3

**Track Classification:** LIBRTI Conference

Contribution ID: **15** Type: **Talk**

# Experimental Investigation of Tritium Release Behavior from Li2TiO3 Pebbles Irradiated by D-T Neutron Source

*Thursday 5 February 2026 09:45 (30 minutes)*

Solid-type tritium breeders are typically used in pebble form to ensure suitable packing behavior, stress distribution, thermal conductance, and purge gas flow. Beyond these physical characteristics, tritium release behavior is a key performance factor for breeder materials in fusion reactors. The Korea Institute of Fusion Energy (KFE) has developed the core technology for fabricating tritium breeder pebbles, while the Institute of Nuclear Energy Safety Technology (INEST) in China operates a D–T fusion neutron source and tritium handling facility. Leveraging these complementary capabilities, a Korea–China international collaboration has been initiated to investigate the tritium release behavior of breeder pebbles. This study presents the preliminary results of Li2TiO3 pebble fabrication, D–T neutron irradiation, and post-irradiation tritium release experiments.
Li2TiO3 pebbles with a diameter of 3.43 mm were fabricated by the Powder Injection Molding (PIM) process as a feasibility assessment, marking the first attempt by KFE to develop pebble manufacturing capability. Although breeder pebbles of around 1 mm in diameter are typically foreseen for breeding blanket, those with 3.43 mm in diameter were manufactured to validate the PIM process. The fabricated pebbles exhibited an average grain size below 1.00 μm and a porosity of approximately 39.7 %, predominantly consisting of open-pore structures. During 6 h of irradiation, a total of 1.104 x 1015 fusion neutrons were produced. After irradiation, the total tritium activity released from 274.1 g of pebbles was measured to be about 1866.4 Bq. The tritium release behavior, including the relative amounts of HTO and HT collected in water bubblers, was examined at elevated temperatures. Before heating, HTO and HT activities were 54.4 Bq and 23.6 Bq, suggesting surface-dominated tritium breeding. The released tritium increased gradually up to 400 oC and decreased at higher temperatures, reaching background levels after 4 h at 800 oC. At 400 oC, the HTO/HT ratio was approximately 79.3 % to 20.7 %. These results provide initial insight into the release characteristics of neutron-irradiated Li2TiO3 pebbles and contribute to future optimization of breeder pebble fabrication and evaluation.

## Speaker affiliation

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**Session Classification:** Session 3-9

**Track Classification:** LIBRTI Conference

Contribution ID: **16** Type: **Poster**

# Electrochemical measurements in molten salts

Recently, molten salts have been proposed for numerous applications: as coolants for advanced nuclear fission and fusion reactors, and as thermal vectors for thermal energy transfer. The characterization and understanding of the chemical behavior and mass transport of corrosion products and other solutes in the molten salt is critical for the design, licensing and operation of the various plants. Electrochemical techniques provide a powerful set of tools to investigate these phenomena. In addition, electrochemical techniques provide a direct approach to continuously monitor salt quality during operation, avoiding the need for sampling and subsequent analysis. The present study aims to investigate high temperature electrochemical techniques for the study and monitoring of corrosion in molten salt environments. A further objective is to assess the applicability in field cases of interest and to explore challenges in key areas of the energy transition (e.g. fusion, TES, CCUS). In order to carry out these analyses, an experimental cell for molten salts electrochemistry is proposed that can operate up to 800℃, in controlled environment, with the possibility of gas sweep, gas sampling and analysis. The cell can support a variety of materials and electrode configurations and potentiodynamic sweep, linear polarization resistance and other DC techniques have been applied.

## Speaker affiliation

Eni SpA

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**Track Classification:** LIBRTI Conference

Contribution ID: **17** Type: **Poster**

# Design and Fabrication of a EUROFER97–316L Tritium Breeding Module Incorporating Solid $Li_2TiO_3$ Ceramics

As a part of LIBRTI programme, the University of Birmingham has designed and manufactured a Tritium Breeding Module (TBM). The module is required to house a solid Li2TiO3 breeder block capable of producing tritium under neutron irradiation, which can subsequently be captured using a bubbler system and quantified via liquid scintillation techniques. Helium–hydrogen purge gas (95% He, 5% $H_2$) is supplied through 316L stainless-steel pipework integrated into a EUROFER97 chamber. The dissimilar joints between the 316L tubing and EUROFER97 body were produced using TIG welding in air, ensuring a fully sealed assembly; alternative joining approaches, including laser welding in argon, have also been evaluated.

The TBM geometry was iteratively refined to optimise internal gas flow, minimise tritium trapping sites, and enhance flushing efficiency. This ensures uniform purge-gas circulation through the breeder material and effective tritium recovery. Following fabrication, helium leak testing was performed to confirm the integrity of the enclosure and the welded interfaces. This presentation will outline the design rationale and manufacturing considerations that underpin reliable tritium extraction.

## Speaker affiliation

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**Track Classification:** LIBRTI Conference

Contribution ID: **18** Type: **Poster**

# Overview of Tritium Breeding and Activation of Fusion Blankets

The reliable design and effective deployment of tritium breeding blankets are critical challenges for realizing fusion energy. The fusion neutronics group at the University of Tennessee, Knoxville (UTK) has conducted integrated research focused on evaluating fusion blanket performance using the Fusion Nuclear Science Facility (FNSF) as a testbed. This research has analyzed TBR performance using rapid 1D reduced-order models and fully resolved 3D CAD-based geometries, including liquid Pb-15.7Li and a wide range of solid breeder systems that include Li-ceramics with Be-based neutron multipliers [1]. These studies include realistic material deviations, such as $Be_{12}Ti$ with excess Be, to evaluate fabrication-driven effects on breeding performance. This research has also addressed critical safety and maintenance challenges through comprehensive radioactivation analysis, including activation and decay-heat calculations to quantify material transmutation, radiological inventory, and waste classification for structural components [2,3]. Furthermore, shutdown dose rate (SDR) evaluations are performed using the rigorous R2S OpenMC workflow, comparing the maintenance feasibility of various blanket concepts. These studies were derived from a verified, open-source simulation where OpenMC-DAGMC is benchmarked against MCNP, SERPENT, and ORIGEN [3,4]. Comprehensively, this work establishes a consistent, open, and fully traceable methodology for assessing blanket concepts, identifying the neutronic trade-offs that govern tritium breeding sufficiency, activation hazards, and remote-handling requirements in next-generation fusion systems.

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[4] Nikolas G. Nelson, Son N. Quang, Nicholas R. Brown & G. Ivan Maldonado
(23 Apr 2025): Shutdown Dose Rate Analysis of Various Blanket Concepts, Fusion Science and Technology, DOI: 10.1080/15361055.2025.2478542

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**Track Classification:** LIBRTI Conference

Contribution ID: **19** Type: **Poster**

# A System Analysis Approach to Fusion Breeder Blanket Modelling and Design

A major challenge for fusion reactors is the production of tritium fuel for sustained fusion reactions, as well as the extraction of heat to generate electricity. Both aspects are directly linked to the breeder blanket (BB) components in a reactor. An extensive literature indicates that various blanket designs have been proposed worldwide, including solid-pebble breeders, liquid lithium-lead breeders, and molten breeders, with different coolant options such as helium, water, or self-cooling mechanisms. However, all these designs remain at the conceptual stage and lack a generalized strategy for initial design methodology. The primary criterion for selecting a breeder blanket includes Tritium Breeding and power extraction. While ensuring the blanket's key function, it is essential to consider multiple factors, including electromagnetic loads, thermal cycling, material temperature constraints, neutronic parasitic capture, and structural integrity due to pressure loss. Addressing all these factors leads to an interconnected neutronic–hydraulic–thermal–structural problem, a complexity not effectively addressed in most existing designs. Although considerable studies have explored breeder blanket designs, limited attention has been given to a solution-agnostic blanket description. Furthermore, performing high-fidelity simulations of many blanket designs during the preliminary stage can result in high computational cost and complexity. To overcome these challenges, we aim to develop a systems engineering approach for breeder blankets, enabling the study of multiple concepts and the down-selection of design options at later stages. Current research focuses on developing the system analysis (SA) methodology based on energy balance to perform thermo-fluid analysis of the breeder blanket unit. The SA method addresses key challenges in fusion blanket modelling by providing a balanced approach between lumped models and high-fidelity simulations. It enables faster computation while maintaining reasonable accuracy and requires fewer assumptions than current lumped methods. Additionally, SA captures a higher level of physics than lumped models and supports multi-dimensional analysis as needed. Its computational efficiency allows rapid evaluation of different geometries, material properties, and operating conditions. Initial analysis and validation against CFD results demonstrate confidence in the SA approach in terms of both accuracy and computational speed compared with high-fidelity simulations. However, the robustness of the method is compromised due to the simplification of complex geometries and High-Fidelity flow physics. The next step of our research addresses this with the introduction of a correction function by employing Reduced Order Model (ROM) or Machine Learning (ML) techniques to augment the standard SA result accuracy and ability to handle complex geometries. This approach effectively maintains computational efficiency while delivering the high accuracy required for complex breeder unit designs.

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**Track Classification:** LIBRTI Conference

Contribution ID: **20** Type: **Talk**

# Validation In Ceramics Experiments (Project VICE) – Project progress and outcomes so far

*Tuesday 3 February 2026 15:05 (30 minutes)*

Project VICE has demonstrated the manufacture of multiple morphologies of lithium metatitanate of a controlled quality at kg scale, with the potential to scale up manufacturing capabilities for future commercial fusion power stations. The project will irradiate samples of these ceramics in a controlled irradiation environment using the ISIS NILE D-T neutron source to generate tritium. An engineered rig, including shielding and supports, has been designed to contain a ceramic-loaded capsule and minimise the potential dose from ionising radiation. Handling and transport requirements for low activity samples have also been identified and explored, with the radiological hazards from activated materials assessed with the support of neutronics analyses. Under conditions of elevated temperature complete tritium recovery has previously been demonstrated using a helium purge gas [1], [2], [3], [4]. Project VICE has therefore developed a tritium extraction and measurement system to understand in more detail the impact of temperature and morphology of the ceramic breeder material on the rate and extent of tritium extraction.

[1] Y. Kawamura et al., 'Effect of sweep gas species on tritium release behavior from lithium titanate packed bed during 14 MeV neutron irradiation', Fusion Eng. Des., vol. 87, no. 7–8, pp. 1253–1257, Aug. 2012, doi: 10.1016/j.fusengdes.2012.02.125.

[2] W. Wu et al., 'Experiment study on tritium release behavior of Li2TiO3 ceramic breeder irradiated by 14 MeV fusion neutron', Int. J. Hydrog. Energy, vol. 68, pp. 1393–1397, May 2024, doi: 10.1016/j.ijhydene.2024.04.256.

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**Session Classification:** Session 1-3

**Track Classification:** LIBRTI Conference

Contribution ID: **21** Type: **Talk**

# Machine-learning interatomic potential development for an atomistic study of tritium diffusion in liquid lithium and lithium-vanadium interfaces

*Thursday 5 February 2026 11:35 (30 minutes)*

Liquid lithium is a candidate material for tritium breeding and as a coolant in fusion reactors. Vanadium is proposed as the corresponding structural material surrounding the liquid lithium, owing to their compatibility. However, tritium retention and transport in liquid lithium and across a lithium-vanadium interface is either ambiguous or unknown from literature, which prevents an accurate modelling of the tritium inventory. Atomistic simulation techniques such as molecular dynamics (MD) provide a way to understand the mechanism and calculate relevant properties. The accuracy of the results relies on the interatomic model used for the system. In the first part of this work, we show MD simulations of hydrogen isotope diffusion in liquid lithium using a newly developed atomic cluster expansion (ACE) machine-learning interatomic potential (MLIP) [1]. We resolve long-standing deviations in experimental data of diffusivities (shown in Fig. 1), and analyze the diffusion mechanism in the liquid metal. In the second part, we discuss the development of two comparable MLIPs –the ACE and a neuroevolution potential (NEP) [2] –to study the lithium-vanadium-tritium system. Specifically, we calculate the solution energies of tritium at different interfaces and the temperature-dependent transport of tritium across the interface. The results from MD simulations will be useful for parameterizing and formalizing gas transport equations in future.

Acknowledgements: The project is funded through the LIBRTI programme at the UKAEA.

[1] P. Srinivasan, S. Puri, K. Pacho Dominguez, A.P. Horsfield, M.R. Gilbert and D. Nguyen-Manh, Atomic cluster expansion interatomic potentials for lithium: investigating the solid and liquid phases, Physical Review B 112, 054108 (2025) https://doi.org/10.1103/q4nm-qyk4
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**Session Classification:** Session 3-10

**Track Classification:** LIBRTI Conference

Contribution ID: **22** Type: **Talk**

# The Tritium Breeder (TriBreed) demonstrator

*Tuesday 3 February 2026 11:20 (30 minutes)*

The Tritium Breeder (TriBreed) demonstrator project aims to develop a prototype breeding device that will enable accurate measurements of tritium production and develop novel breeding materials. TriBreed will act as a stepping stone between previous and planned tritium breeding experiments based on low flux neutron generators (typically $10^{10}$ n $s^{-1}$) and LIBRTI, by taking advantage of the high neutron flux produced by University of Birmingham's new High Flux Accelerator-Driven Neutron Facility ($2.5\times10^{12}$ n $s^{-1}$) to produce more tritium than previous experiments, significantly reducing uncertainty in measurements of tritium production without excessively extending experiment times. The TriBreed prototype is a flexible device that enables the creation of a realistic breeding environment with an online and post hoc diagnostic system, enabling precise measurements of the neutron flux and tritium production and determination of an accurate Tritium Production Ratio (TPR). Manufacture of the prototype is coupled with the development of a high-fidelity neutronics model to enable a prediction of the TPR in the TriBreed device. By combining high precision measurements with accurate neutronics predictions, we aim to increase confidence in the modelling tools being used for the design of reactor blanket designs.

The TriBreed project will also adopt a novel approach to examining tritium release by using a highly sensitive Accelerator Mass Spectrometer that can detect femtograms of material to determine what fraction of tritium remains in the breeder material after purging, something that cannot be determined using existing approaches. This will enable identification of tritium retention that might compromise the sustainability of the fuel cycle.

Therefore, the TriBreed project addresses both the generation of tritium and its accurate measurement and its recovery from the ceramic breeder materials.

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**Session Classification:** Session 1-2

**Track Classification:** LIBRTI Conference

Contribution ID: **23** Type: **Talk**

# Flowing breeder LIBRTI experiments –concept design and stakeholder engagement

*Wednesday 4 February 2026 14:20 (30 minutes)*

Liquid breeder-based blanket concepts have been proposed for fusion power plants around the globe. While there are ongoing projects addressing key challenges, such as flow under magnetic fields, safety, and heat transfer; the tritium breeding via neutron irradiation in flow is only scheduled to take place in over a decade from now [1] [2]. This has motivated the demonstration of flowing breeders under DT-neutron irradiation in the LIBRTI facility. This new UKAEA facility will offer a unique engineering-scale testbed for flowing breeder experiments before other planned large neutron sources (e.g. IFMIF-DONES [1], WCLL-TBM (ITER) [2], EU-VNS⋯), this enables early integrated performance assessment and validation of blanket mock-ups, accelerating scientific progress and liquid blanket development that the mock-ups in larger neutron sources will achieve. In this presentation we will show the progress towards a concept design of a flowing breeder LIBRTI experiment, including definition of sub-systems and functions, geometry analysis, tritium quantifiability, hazard identification, and preliminary neutronic results. We will also discuss progress related to facility integration and interfacing (for example lifting, filling, and draining the mock-up), and stakeholder engagement –key objectives of the work. Future work will focus on onboarding partners, including national programmes and industrial collaborators, progressing the facility integration, and refining the designs of the mock-up and support systems.

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[2] F. Rueda et al., 'Major improvements in the WCLL TBM design towards next review gates', *Fusion Engineering and Design*, vol. 201, p. 114225, Apr. 2024, doi: 10.1016/J.FUSENGDES.2024.114225.

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**Session Classification:** Session 2-7

**Track Classification:** LIBRTI Conference

Contribution ID: **24** Type: **Talk**

# Towards Scalable Digital Engineering Experiences for LIBRTI through NVIDIA Omniverse

*Tuesday 3 February 2026 15:55 (30 minutes)*

In this talk, we present the ongoing work on creating a high-fidelity digital twin of the LIBRTI facility using NVIDIA Omniverse and illustrate how design processes, real-time simulation, robotics, and visual analytics integrate to enable future operational workflows. The prototype interactive experience illustrates an example end-to-end irradiation sequence within the facility, including payload transport on an omnidirectional scissor lift, robotic service connection, neutron source activation with volumetric radiation visualisation, and shielded payload retrieval. The digital twin also integrates dose-rate modelling to support operational planning. By combining radiation simulations with Omniverse data processing and visualisation pipelines, users can visualise dose distributions, evaluate shielding strategies, and assess workflow timings to help optimise safe and efficient operations. Additional autonomous inspection concepts, such as the integration of Spot robots, demonstrate how digital twins can be leveraged to explore future operational envelopes. The scene is constructed from optimised CAD geometry of facility layouts, simulation data incorporated through Omniverse pipelines and visualised using Index volumetric rendering combined with RTX surface rendering to provide a realistic operational environment. Altogether, the elements will demonstrate a technology development pipeline of how digital twins can further improve the design understanding, safety assessment, and stakeholder communication of the overall LIBRTI program. To complement the demonstration, we describe the emerging Omniverse ecosystem at UKAEA and its deployment on the OVX cluster to enable scalable, multi-GPU real-time rendering and simulation. We present the architectural choices behind the platform, the necessary workflows and pipelines to support CAD and simulation assets, and the roadmap for integrating AI-driven capabilities such as robotic training and scenario generation via Isaac Sim. The resultant framework forms the basis for a wider operational digital twin strategy supporting immersive design review, operational workflow rehearsal, and decision support for LIBRTI and wider fusion programs.

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**Session Classification:** Session 1-4

**Track Classification:** LIBRTI Conference

Contribution ID: **25** Type: **Talk**

# ST-E1 Dual-Cooled and Self-Cooled Blanket Concepts

*Thursday 5 February 2026 11:05 (30 minutes)*

In this work, we analyse and compare different liquid metal blanket designs that are based on alternative approaches to achieving heat balance, with a primary focus on understanding the MHD drag associated with these options. Specifically, we consider three concepts:
(i) Helium-cooled blanket: All heat is removed by helium flow, which is compressed and pumped at very high velocities through channels in the blanket module walls and cooling pipes embedded within the bulk of the blanket. In this design, lithium (the liquid metal breeder) is circulated through the blanket at a low velocity, as dictated by tritium extraction requirements. Consequently, the MHD drag associated with this flow is minimal, which is highly advantageous and accounts for the selection of this concept as the basis for the ST-E1 powerplant design. Nevertheless, the difficulties and costs associated with helium compression and pumping significantly reduce the overall efficiency of the concept and raise concerns regarding helium purity and availability. Therefore, we elected to investigate alternative approaches.
(ii) Dual-cooled blanket: Surface heat is removed by helium flowing through channels in the blanket walls, while volumetric heat is managed by lithium flow. Based on the heat removal requirements, we calculate the lithium mass flow rate and, using empirical relationships together with fully developed MHD flow calculations and ST-E1 design parameters, estimate the associated MHD pressure drop. These calculations account for flow through the inlet and outlet pipes (including sections influenced by the fringing magnetic field) as well as through the blanket itself. The blanket is subdivided into several channels by stiffening plates, and we propose an efficient flow arrangement that ensures a uniform outlet temperature. Our analysis indicates that the total MHD drag associated with this flow is approximately 0.5 MPa, which is well below the typical upper allowable pressure limit of 2 MPa.
(iii) Self-cooled blanket: Both surface and volumetric heat are removed by lithium flow. In this design, lithium is first pumped through a thin slot adjacent to the first wall at sufficiently high velocity, and then redirected to flow slowly through the main blanket volume. The flow through the breeder volume is therefore identical to that in the dual-cooled design. Using a 2D model for fully developed MHD analysis, we calculate the additional MHD drag associated with the fast flow near the first wall, which is shown to be negligibly small (~1 kPa) due to the slotted channel geometry.
In conclusion, the self-cooled blanket concept eliminates the inefficiencies associated with helium flow, substantially reduces the complexity and cost of the blanket module, and enhances the TBR value—all in exchange for the cost of MHD pumping, which we demonstrate to be acceptable for the ST-E1 design. The MHD drag remains low because, in a spherical tokamak, the breeder blanket is located exclusively in the outboard region, where the magnetic field is relatively weak (3T in the case of ST-E1). Nevertheless, more detailed 3D MHD analysis is required for the full validation of this concept.

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**Session Classification:** Session 3-10

**Track Classification:** LIBRTI Conference

Contribution ID: **26** Type: **Poster**

# Role of Magnetoconvection in the Thermal Balance of a Liquid Metal Breeder Blanket

Tokamak Energy is developing a liquid metal breeder blanket for the ST-E1 power plant. Due to spatial constraints, the blanket in a spherical tokamak can only be installed in the outboard region. The breeder material is natural lithium, while the walls are designed to be manufactured from the vanadium alloy V44.
The breeder circulates through the blanket at a very low flow rate, determined by the requirements of tritium extraction. In the baseline design, both surface and volumetric heat are removed by helium flow. To achieve this, the blanket walls incorporate channels for helium circulation, and the blanket volume also contains a network of cooling pipes.
The strong temperature gradients generated within the blanket induce natural convective flows, whose intensity can at least be comparable to that of the externally imposed throughput flow. These convective flows exhibit a distinctive structure, strongly influenced by the intense toroidal magnetic field. Fluid motion in the poloidal direction is significantly suppressed. In contrast, fluid movement in the toroidal direction (along magnetic field lines) occurs with velocity magnitudes on the order of mm/s.
Our 3D numerical analysis, conducted for a representative section of the blanket module, indicates that natural convection can make a significant contribution to the thermal balance under the conditions and dimensions specified in the ST-E1 blanket module design. Moreover, understanding these convective flows is essential for accurately predicting the tritium distribution within the blanket volume.

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**Track Classification:** LIBRTI Conference

Contribution ID: **27** Type: **Poster**

# UKAEA Vanadium Strategy Poster

V-4Cr4-Ti/Liquid Lithium breeder blankets have been considered for a long time in Fusion as an option for tritium breeding. Vanadium base alloys represent potentially promising candidate structural materials for use in nuclear fusion reactors due to vanadium's low activity, high thermal strength, and good swelling resistance. This poster will serve as a literature study, state of play in today's fusion industry, and start presenting UKAEA International positioning or strategy (which is being developed this FY) for exploring Vanadium alloys in Liquid Lithium environments.
https://doi.org/10.1016/j.cossms.2025.101224
https://doi.org/10.1016/j.fusengdes.2024.114739
https://doi.org/10.1016/S0022-3115(00)00311-1
https://doi.org/10.1016/S0022-3115(98)00209-8

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**Track Classification:** LIBRTI Conference

Contribution ID: **28** Type: **Talk**

# Develop a small solid lithium ceramic breeder with in-line tritium detection capability for calibrated neutron sources

*Thursday 5 February 2026 16:40 (30 minutes)*

The supply of tritium fuel within a tokamak design fusion reactor remains an ongoing challenge for the developing nuclear fusion industry. Tokamak-design fusion reactors will need to be self-sufficient for the supply of tritium fuel into their fusion reaction. To satisfy this self-sufficiency criteria, numerous breeder blanket concepts for tritium generation exist, with liquid lithium and solid lithium sources arguably the most popular. Whilst lithium has a modest melting temperature, advantages of a solid lithium breeder blanket design over a liquid one include (i) avoidance of complex magnetohydrodynamic effects that electrically conductive liquids bring, (ii) good thermal stability, and (iii) preferable tritium release characteristics. As such, this work studies the breeding of tritium from solid lithium sources. Further, research into the structural materials for the exterior of a breeder module, which can withstand tritium containment, is of equally critical importance.
This presentation will report the recent progress of a project in developing the tritium breeding and detection capability at the University of Birmingham. The development includes the manufacturing of a Eurofer-97 made breeder module which contains sintered lithium ceramics (Li2TiO3) which will be exposed to a neutron beam. The produced tritium will then be collected using a bubbler-liquid scintillator counter system assisted with purging helium gas. The project is part of a campaign to ultimately develop a comprehensive tritium breeding, storage and characterisation capabilities.

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**Session Classification:** Session 3-12

**Track Classification:** LIBRTI Conference

Contribution ID: **29** Type: **Talk**

# UKAEA's Programme for Breeding Blanket Design and Validation through Contributions to EUROfusion's WPBB

*Wednesday 4 February 2026 15:20 (30 minutes)*

UKAEA is advancing the design and experimental readiness of scaled mock-ups for breeding blanket concepts through its contributions to the EUROfusion Work Package Breeder Blanket (WPBB). A major challenge in breeder blanket R&D is the absence of reactor-relevant experimental platforms capable of simultaneously reproducing the coupled thermal, hydraulic, magnetic and structural environments representative of future fusion plants. To address this, UKAEA has developed an experimental plan based on the dimensionless scaling of incremental blanket-like geometries which enables fusion relevant Proto-typical Mock Ups (PMUs) that reproduce key operating and fault condition parameters.
Work applicable for the Water-Cooled Lead-Lithium (WCLL) concept has included geometry definition, manufacturability assessment, material selection, and evaluation of long-term degradation mechanisms such as corrosion and erosion in flowing PbLi under magnetic fields. In parallel, UKAEA has advanced tritium extraction R&D by developing new hydraulic and mass-transfer models for PbLi-He counter-current flows, enabling full-system design of plant tritium extraction units and by progressing modelling of Permeation Against Vacuum (PAV) vacuum systems and optimisation of the Gas Liquid Contactor (GLC) planned for the WCLL-TBM in ITER. To support these experiments, UKAEA has also developed a large capacity PbLi loop, addressing challenges in coolant compatibility, high-temperature instrumentation, operational control and maintainability and ensuring compliance with industrial safety and design standards. Last but not least, since the design cannot be fully verified through experimental studies, within EUROfusion's Work Package Materials we are developing the European DEMO Design Criteria for In-Vessel Components (DDC-IC) to support design assessment, iteration, and verification via finite element simulation. To strengthen the link between WPBB and WPMAT, a dedicated structural integrity assessment of HCPB has been carried out to facilitate information exchange between the WPBB design and the development of DDC-IC under more representative operational conditions.

Combined with the multi-physics capability of CHIMERA and dedicated fusion-specific design criteria, this methodology enables the first integrated, fusion-relevant blanket experiments and assessments of their kind. This provides a platform that can bridge the gap between single-physics lab-scale experiments and the operational demands of DEMO paving the way for continued breeding blanket development for future reactors.

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**Presenter:** HORSLEY, David

**Session Classification:** Session 2-7

**Track Classification:** LIBRTI Conference

Contribution ID: **30** Type: **Poster**

# Structural integrity assessment of HCPB breeding blanket against exhaustion of ductility using the EU-DEMO Design Criteria for In-Vessel Components

The Helium Cooled Pebble Bed (HCPB) is one of the breeding blanket concepts under investigation by EUROfusion for the EU DEMO fusion reactor. The DEMO Design Criteria for In-Vessel Components (DDC-IC), currently being developed within EUROfusion, aims to reduce over-conservatism and enhance performance by employing an in-elastic design-by-analysis approach based on advanced non-linear finite element analysis.

In this study, we performed the structural integrity assessment of the HCPB breeding blanket conceptual design based on the newly developed design rules within the DDC-IC, particularly against the exhaustion of ductility failure mode, aiming to form a basis for future component-level assessments employing inelastic analysis. The assessment results revealed several critical locations where the finite element strain prediction exceeds the allowable limits, specifically at the joints between the pressure tubes and the first wall as well as the breeder pin assembly. Additionally, a sub-modelling approach was developed to perform high-fidelity analyses of the region-of-interests containing joints, with advanced materials constitutive models more efficiently. All these results will support the breeding blanket design optimisation by mitigating mechanical failures and improving its lifetime. Another observation from the analysis is that the failure surface depends on both triaxiality and the Lode parameter, and their ranges observed in the components are often quite wide. These results will feed into the development of the DDC-IC to establish a more representative testing matrix for experimental validation of design criteria.

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**Track Classification:** LIBRTI Conference

Contribution ID: **31** Type: **Poster**

# MBSE-derived DCLL Breeder Blanket mock-up for testing in the LIBRTI facility

This work deploys an integrated Model-Based Systems Engineering (MBSE) framework for guiding the verification and validation (V&V) of a dual-cooled lithium–lead (DCLL) breeder blanket mock-up, with a focus on neutronics, tritium behaviour and material performance under fusion-relevant irradiation. By formalising stakeholder needs and design requirements, the framework establishes a traceable pathway from high-level functional objectives to a targeted experimental programme to be carried out on the LIBRTI Facility. This campaign prioritises: neutron spectrum characterisation, tritium production, permeation kinetics, and corrosion–permeation interactions. A sequence of complementary tests is proposed. Solid PbLi intermetallic specimens and activation foils provide neutron spectrum and reaction-rate measurements to validate cross-section data, refine neutronics models and inform Li-6 enrichment strategies. Dedicated tritium production capsules quantify yield as a function of enrichment and geometry, improving predictions of tritium breeding ratio (TBR) and tritium residence time. A liquid PbLi eutectic campaign investigates permeation behaviour on candidate structural steels to determine diffusion coefficients, solubility limits and activation energies supporting the development of neutron and tritium diagnostics instrumentation. Combined corrosion–permeation exposures evaluate how material degradation influences tritium uptake and leakage, offering insight into long-term structural integrity and operational envelopes.
The resulting data sets are linked directly to MBSE requirement nodes, acceptance criteria and analytical model elements, enabling rigorous traceability through each stage of verification and validation. This MBSE oriented approach enhances confidence in model predictions, highlights design sensitivities and provides a scalable template for breeder blanket maturation, where engineering design and operational science co-evolve to deliver comprehensive, synergistic solutions.

Acronyms:
PbLi –Lithium-Lead

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**Track Classification:** LIBRTI Conference

Contribution ID: **32** Type: **Talk**

# A Machine Learning approach to Breeder Blanket optimisation for Fusion Tokamaks

*Thursday 5 February 2026 16:10 (30 minutes)*

Neutronics plays a vital role in the design, operation, and decommissioning of nuclear facilities, requiring accurate assessments of neutron energy distributions, activation calculations, and gamma decay fields. Transport codes, either deterministic or Monte Carlo-based, are used for these assessments. Deterministic methods are faster but less detailed, while Monte Carlo-based methods, though more resource-intensive, provide higher accuracy and are widely adopted.

Machine learning (ML) models have recently emerged as a promising tool to reduce computational resources in various fields, including neutronics. By applying ML algorithms to datasets generated from Monte Carlo neutronics simulations (e.g. OpenMC [1]), faster design iterations can be achieved.

This presentation will explore the application of Monte Carlo-informed neural network models to optimise tritium generation in a Tokamak breeder blanket design, a critical but underdeveloped component due to tritium scarcity [2]. The model predicts neutron energy distribution throughout the system and utilises a volume-analogous approach, dividing the breeder blanket into layers with varying breeding, multiplier, coolant, and structural materials. It calculates the effect of each material choice on neutron energy distribution and sequentially predicts subsequent layers, accounting for neutron multiplication and reflection.

The neutron flux spectrum and nuclear cross-sectional data can used to determine reaction rates, such as the tritium breeding ratio, enabling rapid development of blanket designs. These designs can later be verified by traditional Monte Carlo calculations. The output neutron energy spectrum can also be used to inform activation calculations and reactor shutdown dose rates. Due to the flexibility of the ML model, any blanket geometry can be predicted; therefore, providing an efficient design loop especially in the initial down selection phase.

References

[1] P. K. Romano, N. E. Horelik, B. R. Herman, A. G. Nelson, B. Forget, K. Smith, Openmc: A state-of-the-art monte carlo code for research and development, Annals of Nuclear Energy 82 (2015) 90–97.

[2] M. Sawan, M. Abdou, Physics and technology conditions for attaining tritium self-sufficiency for the dt fuel cycle, Fusion Engineering and Design 81 (2006) 1131–1144.

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**Session Classification:** Session 3-12

**Track Classification:** LIBRTI Conference

Contribution ID: **33** Type: **Talk**

# Systematic development of breeder blankets using model-based systems engineering (MBSE) and a new systems-simulation library

*Thursday 5 February 2026 17:10 (30 minutes)*

The development of fusion power is heavily dependent on performant breeder blankets. They are key to achieving both fuel self-sufficiency and net power for a continuously operating powerplant. Yet breeder blankets remain at a low technology readiness level, with none yet tested in an operational tokamak environment. Achieving these key blanket functions, while also withstanding multiple thermal, structural and neutronic loads, provides an integrated design challenge for the blanket itself. This challenge must be fulfilled within the highly constrained environment of a tokamak, while integrating the blanket with the tritium-handling and power-generation functions of the powerplant.

In this work we demonstrate the development and down-selection of a blanket concept through the application of systems-engineering processes and systems simulation. Systems engineering is an industry-standard approach to enable the successful development of highly complex and integrated systems, such as a fusion powerplant. Here we apply model-based systems engineering (MBSE) to systematically gather requirements, evaluate risk for designs and define the verification activities to qualify a design. The outputs from this focus analysis work around risk reduction, and define the required virtual and physical qualification activities.

The definition of the blanket and its risks feeds into the down-selection of blanket concepts. We demonstrate this down-selection, initially from material choices and potential architectures to a shortlist of concepts. This shortlist is evaluated in a fast, consistent and repeatable manner using systems simulation and automated workflows. A new systems-simulation library, ARTEMIS, has been developed using Modelica to quickly enable representation of new concepts and their assessment for a wide design space. The systems simulations are linked in automated workflows to neutronics simulations in OpenMC to enable, in this first stage, integrated neutronic-hydraulic-thermal-structural analysis. The analysis workflow is then linked directly back to the set of requirements for the blanket, defined using MBSE. This provides a comparative assessment between blanket architectures and designs to enable design-driving decisions.

We demonstrate the analysis and down-selection process for a pin-breeder architecture, demonstrating how this approach enables quantitative assessment of the trade-offs inherent in the designs and the size of the design space, as well as optimisation for a best-performing design.

## Speaker affiliation

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**Session Classification:** Session 3-12

**Track Classification:** LIBRTI Conference

Contribution ID: **34** Type: **Poster**

# Analysis of non-metallic impurities in lithium using Raman spectroscopy

Tritium breeding blankets are essential to fuel the fusion reaction, and lithium-containing liquid metals are proposed as breeding materials since they can effectively absorb neutrons from the fusion reaction and produce tritium.1,2 However, liquid metals pose chemical challenges, e.g., high alkalinity and/or corrosiveness, which can be exacerbated by non-metallic impurities.3 Whilst understanding these factors and developing suitable monitoring is crucial in optimizing the safe and efficient performance of the breeding blanket, only limited data on impurity effects are available. This is in part due to measurement challenges.

To address this, we have designed and fabricated a setup for the measurement of the Raman spectra of samples under fusion relevant conditions (from ambient temperatures up to 500 ℃ under an argon atmosphere) and will present our work on the chemical identification and monitoring of impurities in lithium in both solid (room temperature) and liquid (high temperature) forms.

We will present and discuss our pioneering work, which has shown that Raman spectroscopy is capable of detecting the presence of specific non-metallic impurities at solid or liquid lithium metal surfaces; impurities studied include oxides, nitrides and carbides. In addition, we will present work to determine the characteristic responses of hydrides and deuterides, which opens up the prospect of tritide detection and monitoring, and increased process understanding and control.

References:

[1] https://doi.org/10.1016/j.fusengdes.2021.112933
[2] https://doi.org/10.1016/j.fusengdes.2024.114333
[3] https://doi.org/10.1016/0022-5088(77)90263-6

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**Track Classification:** LIBRTI Conference

Contribution ID: **36** Type: **Talk**

# TRItium Permeation Real-Time In-line Sensor for Monitoring (TRI-PRISM): Development of hydrogen isotope permeation sensors for tritium monitoring in LIBRTI and fusion liquid metal breeder systems

*Thursday 5 February 2026 14:20 (30 minutes)*

The transition to commercial fusion energy hinges on robust, real-time tritium monitoring within breeder blanket systems. This work, developed under the TRI-PRISM Project and led by Kyoto Fusioneering UK in collaboration with ENEA, Canadian Nuclear Laboratories, and the University of Birmingham, presents the latest advances in hydrogen isotope permeation sensor (HPS) technology for lithium-lead (LiPb) breeder applications.
HPS technology, established as the reference for ITER and a leading candidate for DEMO [1-3], enables near real-time, in-line detection of hydrogen isotopes in liquid metal breeders. This capability is critical for operational safety, tritium accountancy, and performance optimisation in next-generation fusion reactors. The project aims to elevate HPS from Technology Readiness Level (TRL) 4 to 6 by addressing key challenges: quantifying performance indicators (response time, accuracy, precision, and limit of detection), ensuring material compatibility with tritium, characterise best welding techniques, mitigating oxidation effects on sensor membranes. Experimental campaigns are being conducted at ENEA HyPer-QuarCh II facility (Italy) in gas phase and static LiPb, and Kyoto Fusioneering UNITY-1 facility (Japan), in flowing LiPb (see Figure 1), leveraging advanced manufacturing and welding techniques developed at the University of Birmingham. These campaigns will validate sensor performance, using protium and deuterium as proxies for tritium, and will calibrate computational models for scaling to tritium. Tritium compatibility assessment has been developed by CNL.
The project outcomes directly support the LIBRTI facility mission to develop and demonstrate breeder technology, while also generating new UK intellectual property and strengthening domestic supply chains. Beyond fusion, the developed HPS technology has potential applications in fission reactors, metallurgy, and hydrogen purification industries. The collaborative, international approach ensures knowledge transfer, environmental stewardship, and the upskilling of UK-based engineers and researchers.

References:
[1] L. Candido, et al., "Overview of Tritium Management in WCLL Test Blanket System of ITER," Fus. Eng. Des. 200, 114163 (2024). https://doi.org/10.1016/j.fusengdes.2023.114163
[2] L. Candido, et al., "Characterization of Pb-15.7Li Hydrogen Isotopes Permeation Sensors and Upgrade of Hyper-Quarch Experimental Device,"IEEE Trans. Plas. Sci. 48(6), 1505-1511 (2020). https://doi.org/10.1109/TPS.2020.2992345
[3] L. Candido, et al., "Development of advanced hydrogen permeation sensors to measure Q2 concentration in lead-lithium eutectic alloy,"Fus. Eng. Des. 124, 735-739 (2017). https://doi.org/10.1016/j.fusengdes.2017.02.011

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**Session Classification:** Session 3-11

**Track Classification:** LIBRTI Conference

Contribution ID: **37** Type: **Poster**

# Manufacturing in fusion-grade steels for breeder blankets applications within the Neurone programme

The deployment of new, enhanced performance, low activation, fusion-grade steels for in-vessel components such as breeder blankets can only be realised through advances in material science, industrial supply chain capability, component design and manufacturing technologies. The process of manufacturing a breeder blanket component will include many of the following steps: casting, rolling, forming, forging, machining, assembly, joining, coating, heat treatment, inspection, non-destructive evaluation, testing and qualification. The combination of novel materials, complex component designs and harsh operating conditions presents many challenges.

This presentation will provide an overview of activities within the 'Manufacturing and Joining' work package within the LIBRTI funded Neurone programme. This work covers:

1) Development of processing routes for conversion of ingots to plate and tube components
2) Manufacturing trials to enable the assessment and down selection of manufacturing technologies
3) Production of subcomponents, leading to the final build of a mock-up assembly in support of the LIBRTI programme

Stakeholders have selected the pressure pin assembly from the LIBTRI solid breeder pin-cell concept for the mock-up build.

Through the Neurone consortium, advanced reduced activation ferritic martensitic (ARAFM) steels have been developed and produced in 5.5 tonne heats via the industrially scalable electric arc furnace and continuous casting process. This steel has subsequently been forged and rolled to plate, for use in joining trials including friction stir welding, electron beam welding and brazing among others. Meanwhile seamless pipe production is being explored by multiple routes including radial forging, flow forming and additive manufacturing. This work is supported through extensive characterisation, mechanical testing and production of a qualification roadmap. This work is led by the Manufacturing Technology & Equipment Qualification (MTEQ) Group at UKAEA, in close collaboration with the Neurone programme partners and a wide range of supply chain organisations spanning RTOs, industry and academia. MTEQ is open to further engagement, and all interested parties are encouraged to attend.

## Speaker affiliation

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**Track Classification:** LIBRTI Conference

Contribution ID: **39** Type: **Poster**

# Open-source thermal-hydraulic assessment of the HCPB breeder blanket

Reliable thermal-hydraulic assessment of Helium-Cooled Pebble Bed (HCPB) breeder blankets is essential to guarantee temperature limits, tritium extraction performance, and structural integrity under fusion-relevant loads. In this work, an open-source workflow for HCPB thermal–hydraulic analysis is presented, spanning from pin-level conjugate heat transfer to system-level blanket modelling within a unified framework.

At the pin scale, a coupled 2D axisymmetric-3D conjugate heat transfer model of a representative HCPB pin is developed, resolving the solid breeder, multiplier, structural materials, and both helium purge-gas and coolant domains. The approach explicitly captures purge-gas heat-transfer behaviour and coolant thermal-hydraulic response, enabling the evaluation of local temperature distributions, effective heat-transfer coefficients, and thermal resistances across the pebble bed and structural interfaces. These high-fidelity simulations are performed using the SALAMANDER platform based on the MOOSE ecosystem, driven by volumetric power fields consistently obtained from neutronic calculations.

The pin-level results are subsequently upscaled to a reduced-order, system-level thermal-hydraulic model of a full HCPB breeder blanket. Effective properties and closure relations derived from the detailed conjugate-heat-transfer calculations are used to parameterize one-dimensional network models of the coolant and purge-gas circuits. This enables rapid exploration of operating conditions, coolant and purge-gas flow configurations, and design variants, while preserving a clear link to the underlying high-fidelity physics.
All components of the workflow from parametric geometry generation (CadQuery) and meshing (Gmsh) to multiphysics simulation (SALAMANDER/MOOSE) are fully open source, facilitating transparency, reproducibility, and collaborative development.

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**Track Classification:** LIBRTI Conference

Contribution ID: **40** Type: **Talk**

# Correlation of Scaled Breeder Mock-ups toFull-Scale Using Multiphysics

*Tuesday 3 February 2026 11:50 (30 minutes)*

The efficient and accurate design of tritium breeder blankets is essential for the success of nuclear fusion reactors, playing a vital role in achieving optimal performance and safety. This study, developed within the LIBRTI programme funded by UK Atomic Energy Authority (UKAEA), introduces a comprehensive workflow that integrates parametric geometry generation, meshing, and multiphysics simulation to analyze tritium breeder blanket architectures, with particular emphasis on the methodology for correlating scaled mock-up results to full-size blanket performance.

The workflow begins with parametric geometry modeling using ParaBlank, an open-source Python tool developed by IDOM for the STEP programme. ParaBlank integrates CadQuery-based parametric geometry generation, high-quality conformal meshing with Gmsh, and geometry conversion to DAGMC for neutronics. Material properties, boundary conditions, and physical parameters are embedded directly during geometry creation, ensuring geometric consistency across disciplines by preserving face-level tags.

The SALAMANDER platform, developed by Idaho National Laboratory, serves as the core simulation framework, integrating key physics domains: neutronics via OpenMC, thermal-hydraulics and thermomechanics via MOOSE, and multiscale tritium transport via TMAP8 for predicting tritium release to the purge gas.

A key methodological contribution addresses the computational challenge of full-scale blanket simulation. At the mock-up scale, detailed multiphysics simulations produce data for global sensitivity analysis to identify parameters governing blanket performance. These parameters inform surrogate models that represent detailed pin-level physics at reduced computational cost. At full-size blanket scale, where detailed 3D simulations become computationally impractical, system-level analyses leverage these surrogate models combined with the MOOSE Thermal Hydraulics Module to efficiently capture essential local physics within each breeder unit.

The analysis focuses on critical performance metrics including neutronic heat deposition, Tritium Breeding Ratio, thermal performance, structural integrity, coolant behavior, and tritium release characteristics. The derived correlations between mock-up and full-scale behavior provide insights for experimental validation and their implications at fusion reactor level.

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**Session Classification:** Session 1-2

**Track Classification:** LIBRTI Conference

Contribution ID: **41** Type: **Poster**

# Data-Driven Surrogate Models for Multiphysics Tritium Breeding Blanket Performance Prediction

This work presents a data-driven surrogate modeling framework developed within the LIBRTI project to enable computationally tractable full-scale tritium breeder blanket analysis. High fidelity multiphysics simulations coupling neutronics, thermal-hydraulics, and tritium transport are prohibitively expensive for system-level parametric studies due to the computational burden of resolving 3D transport phenomena across engineering-scale domains.

To address this challenge, we employ machine learning surrogates trained on a structured dataset generated through coupled SALAMANDER simulations of parametrically varied geometries produced by ParaBlank. The primary methodological focus is managing the curse of dimensionality inherent to tritium transport modeling, where the parameter space exceeds 20 dimensions spanning material properties, geometric configurations, and operational conditions. We conduct a rigorous comparative evaluation of surrogate architectures, including Gaussian Process Regression with various covariance kernels and deep Artificial Neural Networks with optimized layer topologies, to identify optimal mappings from high-dimensional input spaces to critical Quantities of Interest (QoIs) such as spatially-resolved tritium production rates, inventory distributions, and permeation fluxes.

Performance metrics including prediction accuracy, extrapolation capability, and computational efficiency are systematically benchmarked against held-out validation sets. This surrogate accelerated workflow enables sensitivity analysis, and inverse design optimization at the blanket scale, facilitating the upscaling of mock-up experimental data to inform design decisions with quantified predictive confidence

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**Track Classification:** LIBRTI Conference

Contribution ID: **42** Type: **Talk**

# Overview of the TRIBAL project and current status

*Wednesday 4 February 2026 12:05 (30 minutes)*

Presenting on behalf of the TRIBAL consortium
The TRIBAL –Tritium Breeding to Advance LIBRTI project is a collaboration between the University of Edinburgh, Commonwealth Fusion Systems, Eni, the University of California Berkeley, and Xcimer Energy. This project was funded via the LIBRTI feeder stream projects in early 2025 and is unique in developing the FLiBe molten salt breeding blanket. As part of this project, the UK's first FLiBe- capable laboratory has been established at the University of Edinburgh, which is carrying out underpinning studies required for a FLiBe neutron irradiation experimental campaign scheduled for Q1 2026. The outcomes of this project will directly feed into informing and de-risking the LIBRTI molten salt mock up breeder experiment scheduled at the UKAEA Culham neutron source in 2030.
This presentation will present a summary of progress in the TRIBAL project, including the engineering and chemistry challenges of these experiments, and the required design, fabrication and testing of systems, materials and instrumentation.

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**Session Classification:** Session 2-6

**Track Classification:** LIBRTI Conference

Contribution ID: **43** Type: **Talk**

# The Fusion Blanket Programme at Kyoto Fusioneering

*Wednesday 4 February 2026 14:50 (30 minutes)*

One of the priorities at Kyoto Fusioneering is breeding blanket design and build. To achieve this, we are actively developing different blanket designs in-house, working alongside UKAEA, LIBRTI, and private fusion partners. Our research and development efforts are shaped by uncertainties in both design and manufacturing processes. As a result, we established UNITY-1 -a non-nuclear integrated testing facility- for mechanical, CFD, and MHD studies, as well as UNITY-2 -a nuclear facility- for component testing with tritium and tritium extraction from breeder materials, including tests of the integrated inner fuel cycle.

At UNITY-1, we are testing lithium-lead through a 4-tesla magnetic field at temperatures up to 1000 ℃, using two heat exchangers and a 20 kW Brayton cycle for power generation. The ongoing experiments focus on simple geometries within the magnetic field before progressing to more complex blanket mock-ups.

Construction of UNITY-2 has begun; its detailed design phase is nearly finished, and many components have already been acquired. We have scheduled the facility's commissioning for late 2026. Notably, a glove box housing the liquid metal loop has been upgraded from the UNITY-1 version, making it fully compatible with tritium but still able to provide data at relevant experimental scales.

Findings from these projects are also applicable to liquid metal testing at LIBRTI, which augments our program with opportunities for irradiation studies, tritium breeding, and real-time tritium transport investigations for blanket components.

This overview summarizes ongoing facility activities and their role in reducing uncertainties associated with breeding blanket design and testing in neutron environments like those at LIBRTI.

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**Session Classification:** Session 2-7

**Track Classification:** LIBRTI Conference

Contribution ID: **44** Type: **Talk**

# Neutron irradiation experiments for solid and liquid breeders

*Tuesday 3 February 2026 10:50 (30 minutes)*

Fusion blankets serve three primary functions: 1) breeding tritium fuel, 2) power harnessing to convert fusion energy to usable heat, and 3) shielding magnet systems from radiation damage. Liquid breeder blanket concepts include lead-lithium eutectic (PbLi), molten lithium and beryllium fluoride at eutectic composition (FLiBe), or liquid lithium (Li) as the breeding medium with self-cooled, water-cooled, and helium-cooled options for heat removal. Solid breeder blankets concepts include a wide variety of lithium-containing ceramics as the breeder and hydrogen-seeded helium as a purge gas to harvest bred tritium. A separate fluid (e.g., water, helium) then serves as the primary power harnessing medium for solid breeders. Multiple fission irradiation experiments are being designed to test the various breeding and power harnessing aspects of breeder materials in a nuclear environment.
Although a wide range of solid breeder materials have undergone irradiation testing over the past decades, numerous novel solid breeder materials have been fabricated but have never been irradiated. Consequently, the tritium release performance of these breeder materials is unknown. Fifteen different solid breeder materials will be irradiated in the Neutron RADiography reactor (NRAD) to produce a small amount of tritium in each specimen. The tritium release profiles for these solid breeder materials will be characterized through thermal desorption spectroscopy. A separate irradiation campaign will be performed on PbLi as a nuclear-driven thermal convection loop. The primary objectives of this irradiation are to differentiate the irradiation enhanced effect of corrosion and also characterize tritium transport in the experiment. This presentation will detail the designs of both irradiation experiments.

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**Session Classification:** Session 1-2

**Track Classification:** LIBRTI Conference

Contribution ID: **45** Type: **Talk**

# F4E and EUROfusion research programme on the EU-WCLL TBS and the potential use of the LIBRTI facility for tritium breeder blanket testing

*Wednesday 4 February 2026 13:50 (30 minutes)*

The Water-Cooled Lithium Lead (WCLL) concept is one of the reference breeding blanket options for the European Demonstration Fusion Power Reactor (DEMO) and a key focus of the joint EUROfusion and Fusion for Energy (F4E) research programme. Ensuring tritium self-sufficiency and adequate shielding performance requires robust experimental validation of neutronics predictions, together with a comprehensive qualification strategy for materials, technologies, and integrated blanket systems.
Within the EUROfusion framework, significant effort has been devoted to the development of representative WCLL breeding blanket mock-ups and to advanced neutronics analyses aimed at assessing tritium production, neutron and gamma attenuation, and associated uncertainties. Detailed Monte Carlo simulations have been performed to optimise experimental layouts capable of reproducing the essential nuclear features of the WCLL blanket foreseen for DEMO, while enabling accurate measurement of key quantities such as tritium production rate and shielding performance. These studies provide a solid basis for defining future experimental campaigns and for identifying the design margins required to guarantee tritium self-sufficiency.
In parallel, following extensive technical and programmatic evaluations, EUROfusion and F4E have strengthened their collaboration through an integrated Test Blanket Module (TBM) and Breeding Blanket (BB) programme. This joint approach aims to streamline European resources, avoid duplication of effort, and ensure coherence between DEMO-oriented breeding blanket development and TBM qualification activities. The collaborative R&D has been structured into four main pillars: system modelling, technology development, safety analyses, and materials qualification, with particular emphasis on functional materials, predictive tools, sensors, and the characterisation of EUROFER97 as a structural material.
This contribution provides an overview of the ongoing WCLL-related activities within the EUROfusion–F4E programme and discusses how facilities such as LIBRTI could play a key role in addressing remaining experimental gaps. In particular, the potential use of LIBRTI for neutronics-driven breeder blanket testing, tritium generation and transport studies, and integrated validation of WCLL-relevant technologies is explored. Such experiments would represent a valuable step towards the comprehensive qualification of tritium breeder blankets required for DEMO and future fusion power plants.

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**Session Classification:** Session 2-7

**Track Classification:** LIBRTI Conference

Contribution ID: **46** Type: **Talk**

# The development and implementation of a tritium inventory model in a digital twin for the LIBRTI project

*Tuesday 3 February 2026 16:25 (30 minutes)*

Within the context of deploying future fusion power devices, the breeder blanket system remains at a very low technology readiness level (TRL) and therefore requires substantial research and development to ensure long-term robustness, reliability, and safety. Breeder blankets are highly complex, tightly coupled systems involving neutronics, thermal hydraulics, materials behaviour, and tritium generation and transport. This complexity presents significant challenges for experimental development, particularly where physical testing is costly, time-consuming, or carries inherent safety risks. As a result, advanced digital approaches are increasingly critical to support the design, operation, and qualification of such systems.
For modern complex systems such as breeder blankets, the development and deployment of a digital twin is especially valuable. A digital twin provides a dynamic virtual representation of a physical system, enabling prediction of system behaviour, exploration of design changes, and interrogation of operational scenarios with minimal risk to the underlying hardware. When underpinned by low-code, surrogate modelling approaches, digital twins can be rapidly developed, updated, and deployed, allowing researchers and engineers to integrate experimental data, simulations, and uncertainty quantification in a flexible and scalable manner.
As part of the UK Atomic Energy Authority's LIBRTI (Lithium Breeding Tritium Innovation) programme, the University of Manchester has undertaken a proof-of-concept digital twin study using a Gas Driven Permeation System (GDPS) as an exemplar device. The GDPS was selected due to its relatively simple physical design while still providing rich, high-value data inputs and outputs that are directly relevant to fusion fuel cycle research. This makes it an ideal platform for demonstrating digital twin concepts applicable to more complex breeder blanket systems. In parallel, a new tritium transport modelling capability has been developed based on Bayesian inference techniques. This approach enables rapid prediction of tritium mobility and associated uncertainties within material specimens, even in cases where only limited microstructural information is available. The model has been validated using experimental data obtained from GDPS permeation studies.
This work presents preliminary results on a low-code digital twin architecture that leverages open-source software tools alongside NVIDIA Omniverse for system integration and visualisation. The architecture has been applied in a proof-of-concept implementation to a real fusion fuel cycle system through full GDPS digitisation. This includes integration of the Bayesian inference-based tritium transport model to capture tritium mass transfer behaviour relevant to GDPS permeation experiments. The digital twin demonstrates several key capabilities, including remote control of GDPS acquisition parameters, deployment of existing open-source surrogate models, and prediction of material properties derived from experimental permeation data.
Finally, this work is placed within the broader context of the LIBRTI programme. The extensible digital twin architecture provides a clear pathway towards full digitisation of LIBRTI activities, enabling improved decision-making for breeder blanket test module design, accelerating innovation in breeder concepts, and supporting enhanced preventative maintenance strategies. Ultimately, this approach offers a safer, more efficient framework for experimentation and development as fusion technology progresses toward deployment.

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**Session Classification:** Session 1-4

**Track Classification:** LIBRTI Conference

Contribution ID: **47** Type: **Talk**

# The IFMIF-DONES Test Blanket Units

*Wednesday 4 February 2026 09:15 (30 minutes)*

Breeding blanket designs considered for DEMO include not only materials but also technologies, whose behaviour under fusion-like conditions has not yet been tested. Therefore, it is urgent to evaluate these blankets in relevant environments, with emphasis on significant radiation levels. Looking for solutions to qualify and validate the breeding blankets, IFMIF-DONES has launched a new experimental program on Test Blanket Units (TBU). The primary objective is to contribute to the BB testing in an irradiation environment similar to that expected in a fusion reactor, by performing multi-physics experiments, and highlighting the capabilities of IFMIF-DONES to qualify tritium technologies in its medium-flux area.
A preliminary exercise has already been performed with the Helium-Cooled Pebble Bed (HCPB) and the Water-Cooled Lead Lithium (WCLL) blankets, demonstrating that the effective irradiation volume in IFMIF-DONES is sufficient for relevant tritium experiments. Additionally, the TBU can help demonstrate effective temperature control of the blanket or test the bonding quality between different materials or components under a high neutron flux.
IFMIF-DONES already comprises dedicated spaces to host the auxiliary systems necessary for a proper operation of the TBU, including those for tritium handling, as well as other supplies and services (e.g. cooling loops, power supply···). The auxiliary systems will, in turn, monitor the purity of the tritium carrier (gas or liquid) and will be compatible with the additional needs in terms of detritiation and tritium storage that the IFMIF-DONES plant will provide. The current baseline of the main irradiation area, the Test Cell, already considers supplies and services (via the PCPs, Piping and Cabling Plugs) to the modules and TBUs that will be positioned behind the lithium target. Some of these PCPs are already planned to extend to the rear wall of the TC Liner.
In summary, together with the TBM-Program and a possible validation of blankets in a future VNS, it is expected that IFMIF-DONES can help increase the TRL of this important component.

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**Session Classification:** Session 2-5

**Track Classification:** LIBRTI Conference

Contribution ID: **48** Type: **Talk**

# An Integrated Multi-physics Platform for the LIBRTI Facility

*Wednesday 4 February 2026 16:10 (30 minutes)*

The LIBRTI program seeks to de-risk fuel-cycle technology through physical demonstrations of specific breeder concepts, and accompany this with a digital representation of the facility to enhance the understanding of any measurements obtained. Such endeavours provide a route to in-silico design and qualification of breeder blanket technologies, thereby accelerating the critical pathway to commercializable fusion energy. In this contribution we review the ongoing effort for LIBRTI Integrated Modelling work-stream in support of this mission.
The primary function is to provide the core multi-physics modelling capability, and integrate this within the broader digital ecosytem. Since underlying the activity is the intention to develop scientific insights and capture complex emergent phenomena, the approach presumes a high level of fidelity and hence scalability is necessary. As such, having already been proven on high-performance computing (HPC) systems, the Multi-physics Object-Oriented Simulation Environment (MOOSE) software has been selected to provide our base functionality. Supplementing existing physics domains (which spans neutronics, fluid dynamics, heat transfer and tritium transport), we have developed new interfaces to FISPACT-II and FLUKA which enable inclusion of activation and charged particle transport respectively. In parallel, we have modelled molten salt, solid and liquid metal experimental breeder concepts in order to demonstrate current capabilities. Moving forwards, our focus will shift towards validation and uncertainty quantification (UQ), alongside reproducibility, automation, and connectivity with other digital systems. The current strategy to assess model confidence against experimental data, as well as the intention to leverage workflow orchestration software, is outlined. Finally, to provide an example of how such an integrated approach may in future be deployed to accelerate design, we describe a recent effort employing sequential learning to optimise the LIBRTI solid breeder experimental mock-up concept.

## Speaker affiliation

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**Session Classification:** Session 2-8

**Track Classification:** LIBRTI Conference

Contribution ID: **49** Type: **Talk**

# Experiences from tritium breeding experiments in molten salts

*Wednesday 4 February 2026 11:35 (30 minutes)*

We have undertaken tritium breeding experiments using 14.1 MeV neutron generators for irradiation of capsules filled with molten salts (ClLiF and FLiBe) at temperatures 600C - 700C. Tritium that is bred in the salt is collected by sweep gas into bubblers and then analyzed with Liquid Scintillation Counting. The collected tritium is compared to measured neutron fluences from the neutron generators via activation foils and diamond neutron detectors. The experimentally determined tritium breeding ratio (TBR) of collected tritium to neutron output is compared to neutronics simulations with salt volumes of 100 mL to 1 L and TBRs of $10^{-4}$-$10^{-3}$. The tritium releases from the two collection streams (surface release and wall permeation) are fitted using a simplified mass transport model with good agreement and only mass transport coefficients as free parameters. Advancement of the release model is underway to include greater detail and improved understanding of the tritium transport in the system. The goals of these experiments are just to study the behavior of tritium in breeder blankets, but also to project towards fusion reactor applications. Next steps include experiments with additional breeder types (lithium-lead and lithium oxide), further tritium accountancy experiments with FLiBe, and applying lessons-learned to the design and execution of larger experiments (100 to 700 L), where the neutron mean free path through the breeding volume is comparable to reactor blankets and TBR approaches unity.

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# Design Exploration and Technology Development of the Step Li2O Ceramic Breeder Blanket

*Tuesday 3 February 2026 10:00 (30 minutes)*

The breeder blanket for the STEP Prototype Powerplant (SPP) must provide high performance breeding for a spherical tokamak without inboard breeding, materials and coolant compatible with a 600 ℃ outlet temperature for net power confidence, and a system deliverable on the targeted timescales of the STEP programme. Following a comprehensive assessment of all breeder, coolant, and structural material options, solid ceramic lithium oxide (Li2O) has been selected together with a Ti-modified austenitic stainless steel structural material, CO2 coolant, and beryllium-based multiplier. This combination is considered to give the highest confidence of successfully meeting the SPP requirements.
However, engineering realisation of a deployable blanket on SPP timescales still requires rapid progress in design alongside fail-fast testing and technology demonstration, with continuous iterative feedback between the two. Underpinning this must be a clear definition of requirements, constraints, and areas of uncertainty to drive robust performance development. This paper details initial scoping of the design space and the technology development needs of the chosen system.
For the chosen palette of materials, identifying a performant architecture presents initial design challenges around achieving sufficient tritium breeding performance, respecting material temperature limits through robust heat management and hydraulic design, and ensuring compliance against availability and reliability requirements. We first present and explore these constraints for the SPP blanket. For an assumed annular pin geometry, analysis revealed that peak temperatures of breeder material below 900 ℃ can be achieved by varying pin dimensions, but this has a consequent trade-off with structural volume content (and hence tritium breeding ratio), and total part number (and hence reliability performance). A wider exploration of potential blanket architectures is being pursued, informed by this learning, with a view to downselection of a preferred architecture.
Meanwhile, use of Li2O as a breeder material has been well documented in literature to present challenges with material degradation, most frequently citing irradiation swelling, LiOH formation, and structural material compatibility. However, these issues have a strong dependence on temperature, environment, and operational duty cycle. The issues have therefore been reviewed from first principles and revisited in the context of the SPP requirements. From this, SPP-specific design constraints and opportunities have been identified that further refine understanding of the Li2O breeder blanket design space and feed back into the design process.
Remaining uncertainties and risks have led to a set of prioritised steps for testing and technology demonstration. Preliminary screening of the extent of degradation mechanisms (and sensitivity to operationally controllable parameters) can be carried out in unirradiated environment, before more costly and time-intensive irradiation tests are required. In the longer term, scale-up towards component-level functional testing is required, aiming for proof of mechanical, thermal, and electromagnetic performance demonstration, in parallel with nuclear and tritium transport performance demonstration. A timeline for this suite of development needs will be presented to give an overall outlook for development of the Li2O blanket concept.

## Speaker affiliation

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**Session Classification:** Session 1-1

**Track Classification:** LIBRTI Conference

Contribution ID: **51** Type: **Talk**

# Synergies of the LIBRTI platform to support nuclear data and radiation testing

*Thursday 5 February 2026 10:15 (30 minutes)*

AWE has a deep interest and experience in nuclear data, electronics testing in radiation fields and operational safety in radiological environments. LIBRTI is an exciting platform that offers the potential for these areas to be explored further. This presentation will discuss areas of interest to AWE that LIBRTI could enable and describe the AWE VENOM project, the potential capabilities this could offer and how this may synergise with the LIBRTI platform and wider UKAEA interests.

## Speaker affiliation

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**Session Classification:** Session 3-9

**Track Classification:** LIBRTI Conference

Contribution ID: **52** Type: **Talk**

# From Experimental Needs to System Architecture: Designing LIBRTI for Reactor-Scale Tritium and Neutron transport

*Wednesday 4 February 2026 09:45 (30 minutes)*

LIBRTI aims to drive world-leading innovation in the fusion fuel cycle by delivering a facility with a 14 MeV Deuterium-Tritium (DT) neutron source to support scientific work aimed at developing a better understanding of neutron and tritium transport at reactor scale. The facility will support experiments based on tritium breeder blanket concepts proposed by the fusion community, including solid ceramics, molten salts, and liquid metals as breeder materials.
Current tritium breeding experiments using fusion-relevant neutron spectra are limited to breeder volumes of around one litre. LIBRTI will scale this up by three orders of magnitude, exposing up to 6 $m^3$ of breeder material to DT-produced neutrons, a step that introduces significant hazards, demanding a robust engineering approach.
As a starting point, experimental needs were gathered from three consortia, each representing a specific breeding technology. The engineering requirements, centred around compliance with applicable UK legislation, were also considered. These needs were mapped into functions using MBSE and decomposed into traceable requirements which were assigned using a system architecture, and documented in System Requirement Documents and interface specifications, initially in Excel and later in IBM DOORS, which provides a hierarchical, traceable, object-oriented database. Having these initial functional and physical interfaces in place allowed design activities across different organisations to progress while remaining open to future development, subject to scrutiny and formal approval through change requests.
In parallel, a safety justification process was established. Concepts of operation were developed through life cycle wide and normal and off-normal operation CONOPS workshops, followed by hazard identification (HAZID) sessions. Collaboration with lithium-handling experts defined pathways for hazard quantification, while in-house studies informed risk-reduction design choices.
Through these cross-disciplinary efforts, LIBRTI now rests on a robust engineering and safety framework, ready to progress through design, construction, commissioning, operation and decommissioning. As a first-of-its-kind platform, it will validate tritium breeding technologies at reactor-relevant scale as well as the simulations which will allow in-silico design development of breeder blanket concepts.

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**Session Classification:** Session 2-5

**Track Classification:** LIBRTI Conference

Contribution ID: **54** Type: **Talk**

# LIBRTI: Plugging a key technology gap in fusion engineering ecosystems

*Tuesday 3 February 2026 09:30 (30 minutes)*

Aim of the programme - to bridge the gap between scientific experiment and self-sustaining future fusion power plants.

LIBRTI aims to foster world-leading innovation for fusion power plant fuel cycle development, while stimulating industry capability and capacity. The programme has been designed to help industry achieve demonstrations of controlled tritium breeding; a first step towards a predictable, controllable way of generating the fuel required within a self-sustaining fusion fuel cycle.

LIBRTI will deliver a first-of-a-kind testbed facility on the Culham Campus, containing a neutron source, which will produce neutrons to react with the lithium contained in different types of prototype breeder blankets to produce tritium. The facility will include space to assemble and dissemble the large-scale tritium breeding experiments, and to capture the knowledge gained from these experiments.

In addition, the programme will establish a digital simulation capability and skills to model solid, liquid and molten salt breeder technologies, to predict tritium breeding performance, analyse experimental results and provide guidance for future design development of breeder blankets ideas. This will be an in-silico replication of the physical experiment utilising the multiphysics models of tritium breeding, which will be a stepping stone for industry towards the qualification of breeders.

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**Session Classification:** Session 1-1

**Track Classification:** LIBRTI Conference

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# Tritium breeding landscapes: production and benchmarking

*Thursday 5 February 2026 15:20 (30 minutes)*

Tritium breeding is an essential element of civilian fusion nuclear energy technologies development paths as it provides a crucial constituent of the plasma fuel. Fusion research and development programs need to establish tritium production in line with fusion energy technologies deployment and development requirements. Tritium, as a radioactive isotope of hydrogen can be produced by nuclear reaction from Lithium compounds. Historically, present at scale production methods, from fission technologies are weighed, while novel fusion orientated needs build from experimental benchmarking using 14 MeV neutron sources and a modern digital twin framework.

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