UK Atomic Energy Authority

UKAEA

Overview of Materials R&D and opportunities for collaboration

James Wade-Zhu – LIBRTI Mock-up Lead and Non-metallics Group Lead

Introduction to UKAEA

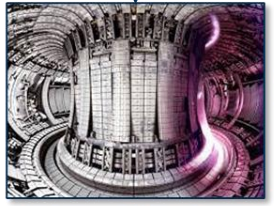
UK Atomic Energy Authority

UKAEA mission is to lead the delivery of sustainable fusion energy and maximise the scientific and economic benefit.

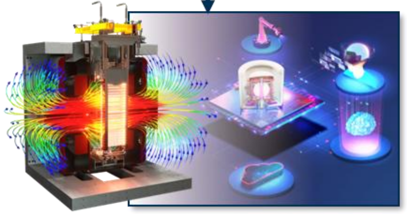
- Be a world leader in fusion research and development
- Enable the delivery of sustainable fusion power plants
- Drive economic growth and high-tech jobs in the UK
- Create places that accelerate innovation and develop skilled people for industry to thrive.

UK Atomic Energy Authority Group

UK Atomic Energy Authority



Plasma Science and Fusion Operations



Integrated Engineering + Computing

RACE + ARC

Tritium Fuel Cycle

Fusion Technology

Materials

UK Industrial Fusion Solutions

STEP

Overview of the Materials Division

Materials division

- Collaborate closely with **fusion technology drivers, sector suppliers,** and **academia,** to assess the performance of materials in nuclear and fusion environments.

- **£50m nuclear materials** development and testing facility,
- Division of ~80 people, including scientists, engineers, operators, technicians and graduates
- Hosting secondees, summer students and apprentices
- 40+ PhDs and masters projects

Driving the National Materials Strategy through the UK Fusion Materials Roadmap (v2 available: uk-materials-roadmap-2-0.pdf)

Materials division – Groups

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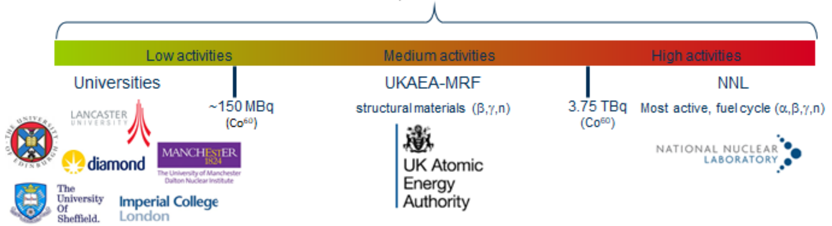
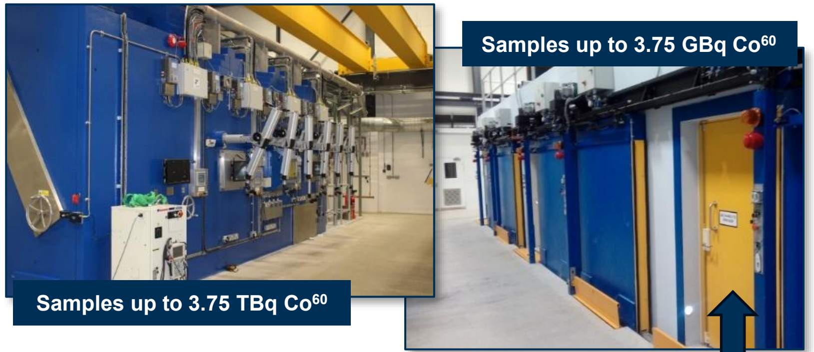
Materials research facility (MRF): See the damage

MATERIALS RESEARCH FACILITY

NNUF

HENRY ROYCE INSTITUTE

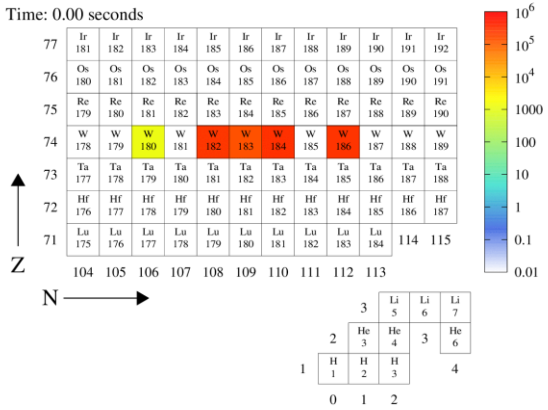


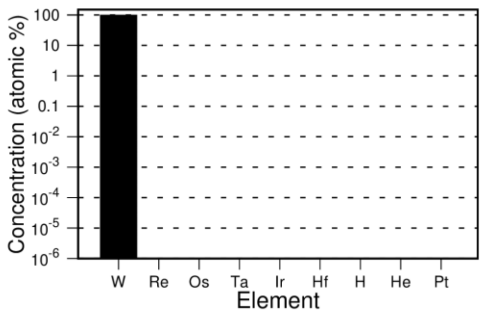


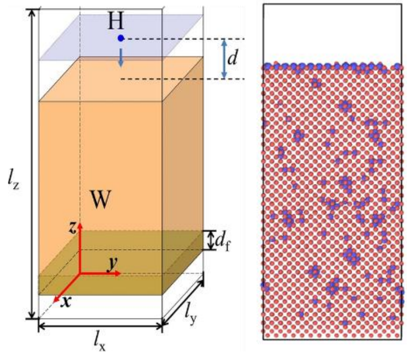
- Scanning electron microscopy,
- Transmission electron microscopy,
- Focused ion beam (FIB + P-FIB)
- Raman spectroscopy,
- X-ray Diffraction (XRD),
- Nanoindentation,
- Atomic force microscopy (AFM)
- Thermophysical (DSC, TGA, DIL),
- Thermomechanical (up to 800°C)
- Gas pycnometry

Archive of irradiated materials – variants of steel, V, W, Ta, Ti, Ni, Cu alloys

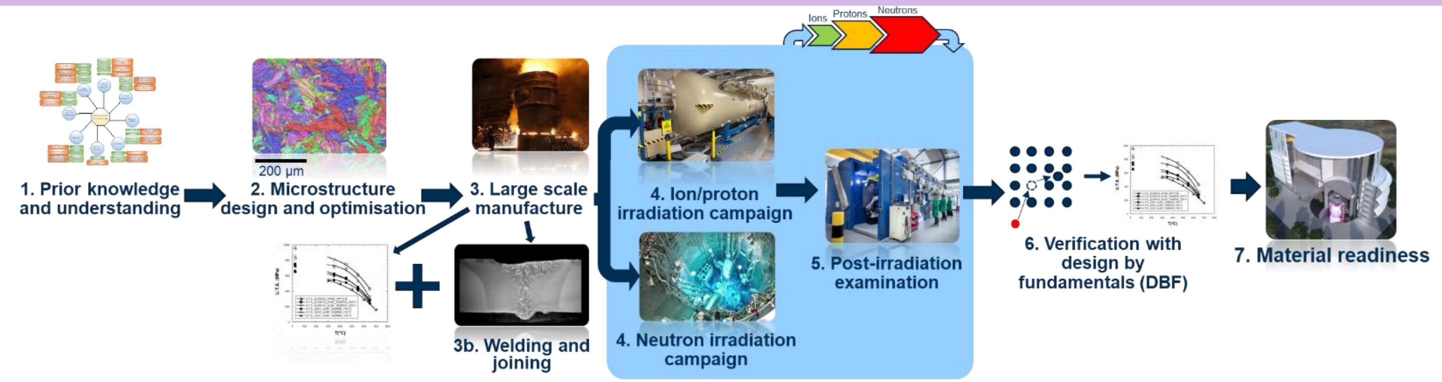
Fusion Material Interfaces (FMI): Understand the damage







Materials Science and Engineering (MSE): Survive the damage



Metallics projects

Contact: James.Gibson2@ukaea.uk

neurone

NEUtron iRradiatiOn of advaNced stEels

£15m (including in-kind) until 2028

70+ collaborators across 12 organisations

UK Atomic Energy Authority

Develop and deliver an industrially scalable fusion-grade advanced steel capable of operating at 650°C in a fusion breeder-blanket environment

Year 1	Year 2	Year 3	Year 4
Iterative alloy design process	First pass down selection	Second pass down selection	Material assurance
TRL 3	TRL 4-5	TRL 5-6	TRL 6-7
Many alloy variants	~15 alloy variants	~3 alloy variants	1 alloy variant
Design	Irradiate	Assess	Deliver
Make the alloys and iterate depending on findings from experimental campaign	Irradiate the alloys and assess properties based on proton/ion effects	Irradiate the alloys and assess properties based on neutron performance	Long-term material performance and range of mechanical property assessments

Inputs:
- TMT refinement and industrial upscaling of process
- Thermodynamic stability of microstructure
- Creep & radiation damage interaction
- Precipitate stability under irradiation

Findings fed back into alloy design efforts
'Next-generation' NEURONE steel

Material Property Handbook & Breeder blanket mockup

Understand and manipulate defect sinks controlled precipitate evolution, second phase interface optimisation and novel microstructure design.

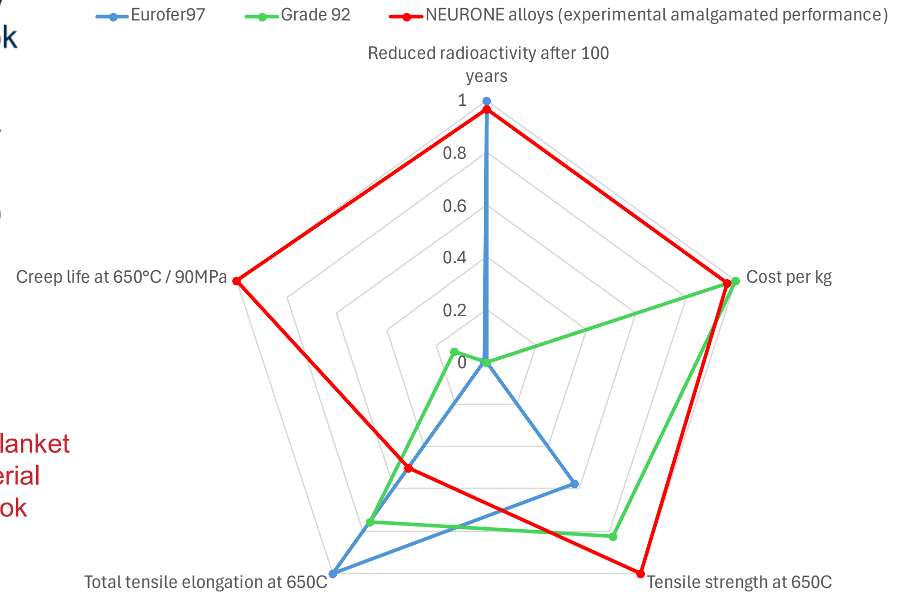
Development of thermomechanical treatments (TMTs)

Ensure thermodynamic and irradiation stability under fusion conditions

Better understand the interaction of thermal creep, irradiation damage and synergistic effects.

Assess and down select optimal joining/welding approaches.

Produce a breeder blanket mock up and Material Property Handbook



Non-metallics projects

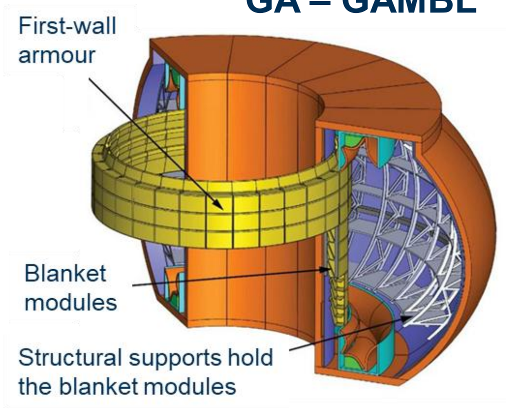
Contact: Alex.Leide@ukaea.uk

Ceramic structurals (SiC, SiC_f/SiC)

High-temperature structural materials for the breeder blanket and supports:

- Better thermal efficiency,
- Good neutronics,
- Radiation and corrosion tolerance,

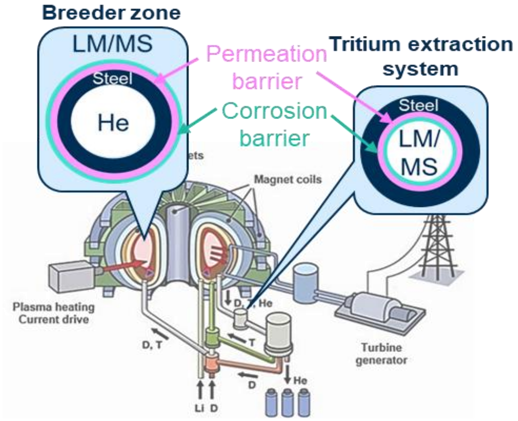
GA – GAMBL



Ceramic coatings (oxides, nitrides)

Prevent deuterium and tritium permeation into the structure, and corrosion protection:

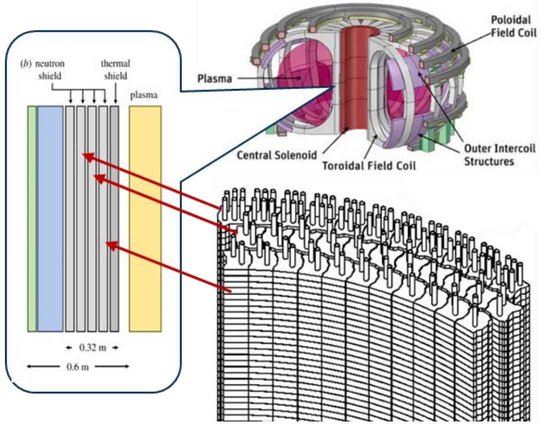
- Ensure fuel is available,
- Inhibits activation of structural materials,
- Protect against hydrogen embrittlement,
- Prevent corrosion,



Ceramic shielding (borides, carbides)

Protect superconducting magnets and diagnostics from neutron and gamma irradiation:

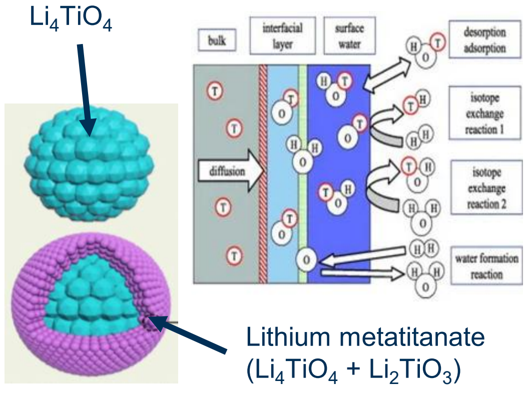
- High efficiency neutron moderator and absorber,
- Supports inboard first-wall,
- High expected turnover means it must be low activation



Ceramic Breeders (Li compounds)

For the breeding of tritium as part of the fusion fuel cycle:

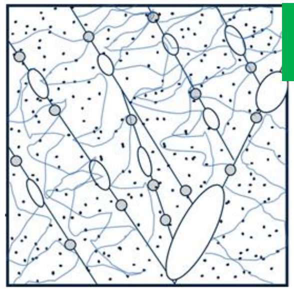
- Li dense to maximise tritium production,
- High-temperature stability,
- Compatibility with surrounding structural materials and environment (e.g. He + dopants)



Opportunities for collaboration

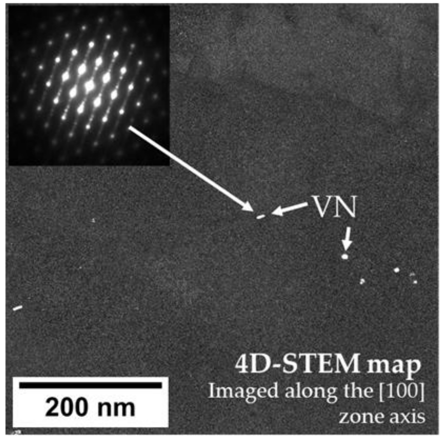
Metallics - Use of SANS to provide statistics to precipitate sizes in advanced steels:

Contact: Alex.Dickson-Lomas@ukaea.uk

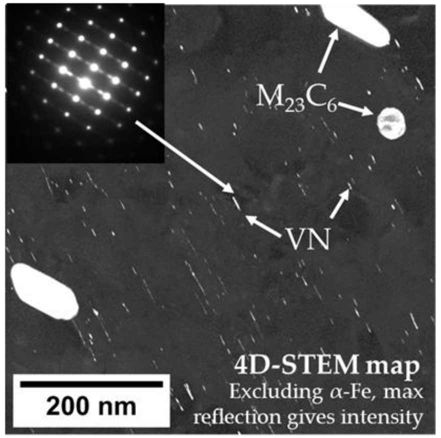


>200× increase in precipitate density

Baseline

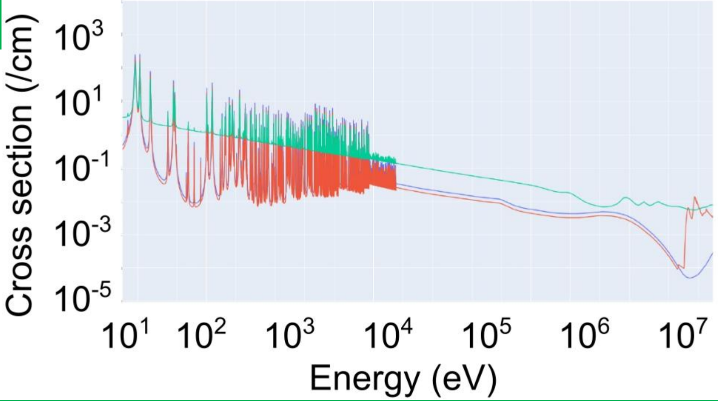


Advanced



Size distribution and quantity of precipitates measured under TEM and with Atom Probe. Better statistics needed across a larger volume of material.

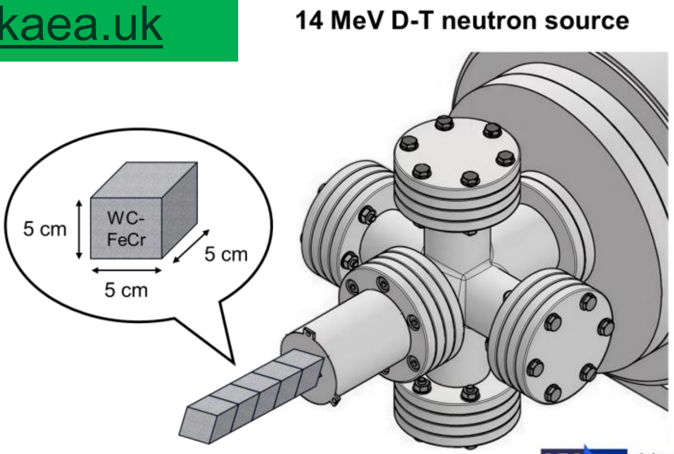
Non-metallics - Validation of neutron shielding performance:



Shielding evaluated based on neutron transport models that use ideal materials and make assumptions.

Contact: Tamas.Zagyva@ukaea.uk

Will test shielding efficiency using NILE 14 MeV source with foils for detection. Samples provided by Hyperion are cemented WC with an FeCr (binder)

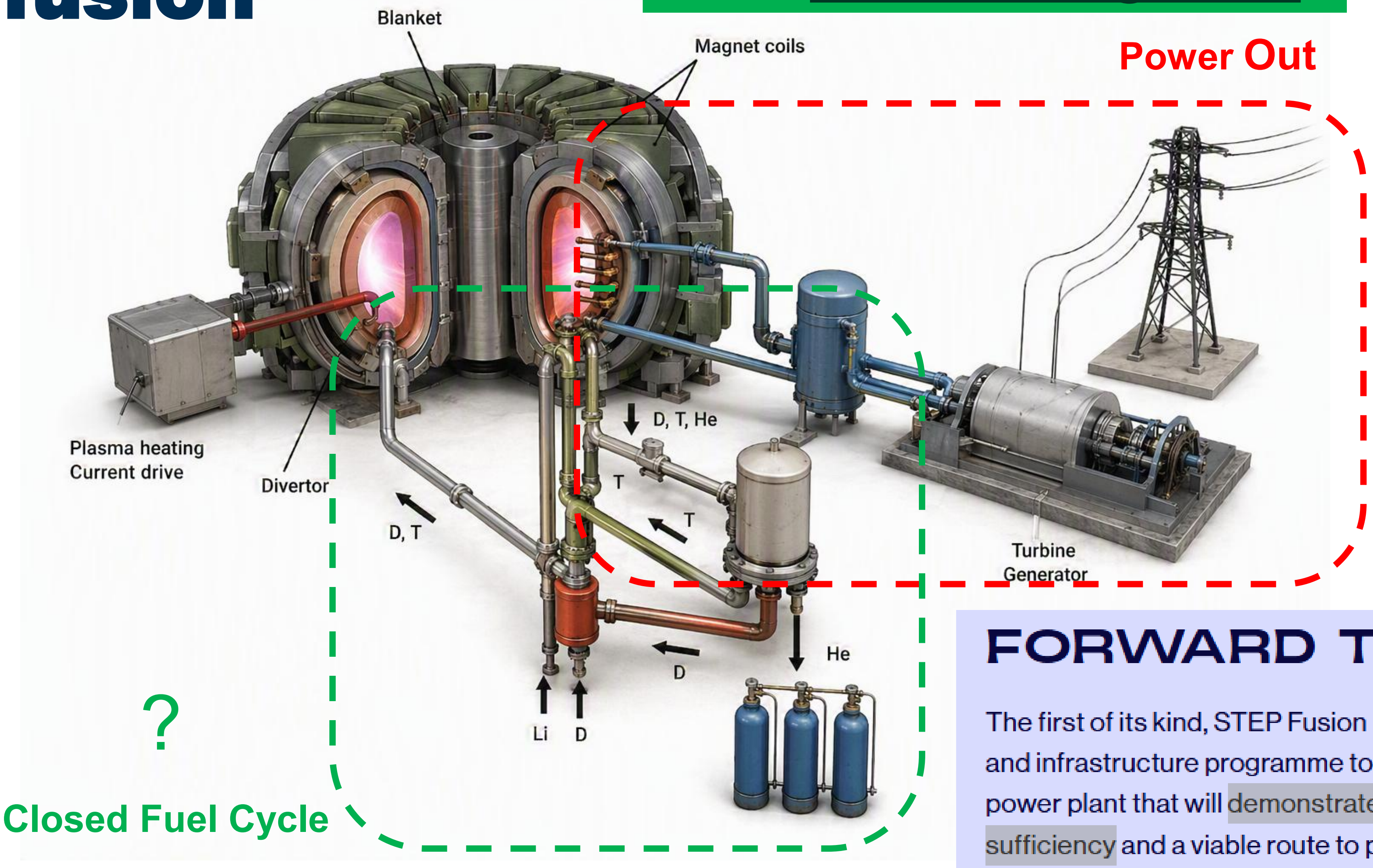


Science and Technology Facilities Council
ISIS Neutron and Muon Source

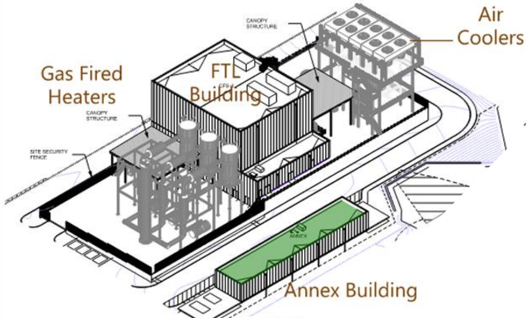
LIthium BReeding Tritium Innovation (LIBRTI) Programme

Key challenges in the realisation of fusion

Contact: James.Wade-Zhu@ukaea.uk



KYOTO FUSIONEERING



Commonwealth Fusion Systems

FORWARD TO FUSION

The first of its kind, STEP Fusion is the UK's major technology and infrastructure programme to build a prototype fusion power plant that will demonstrate net energy, fuel self-sufficiency and a viable route to plant maintenance.

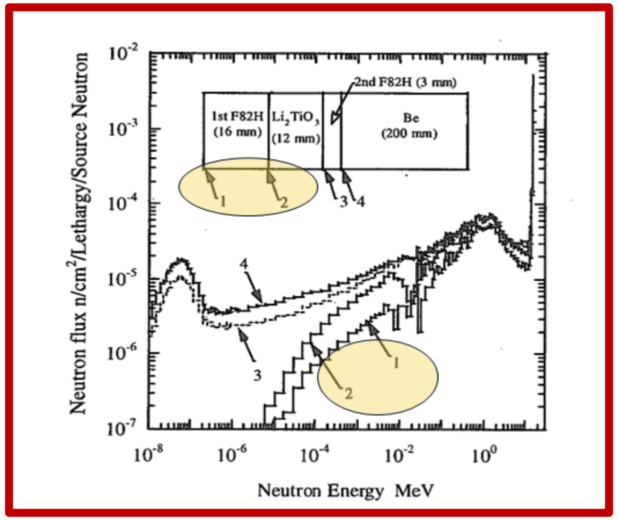
LIBRTI: LIthium BReeding Tritium Innovation
A £200m Fusion Fuel Capability Programme

UK Atomic Energy Authority

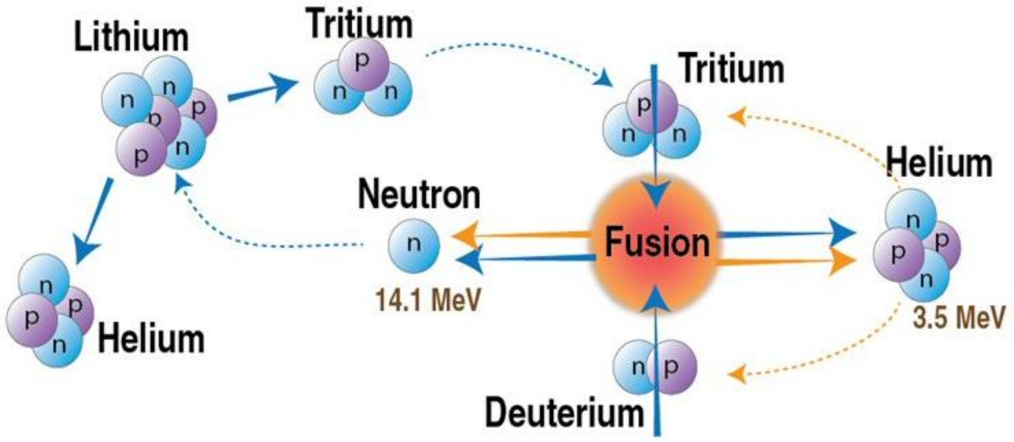
LIBRTI aims to demonstrate that for a given neutron flux into a specified lithium substrate, we can predict and reproducibly achieve, quantified tritium breeding (***neutron transport + n → t***) and output (***tritium transport***) at scales relevant to fusion powerplants.

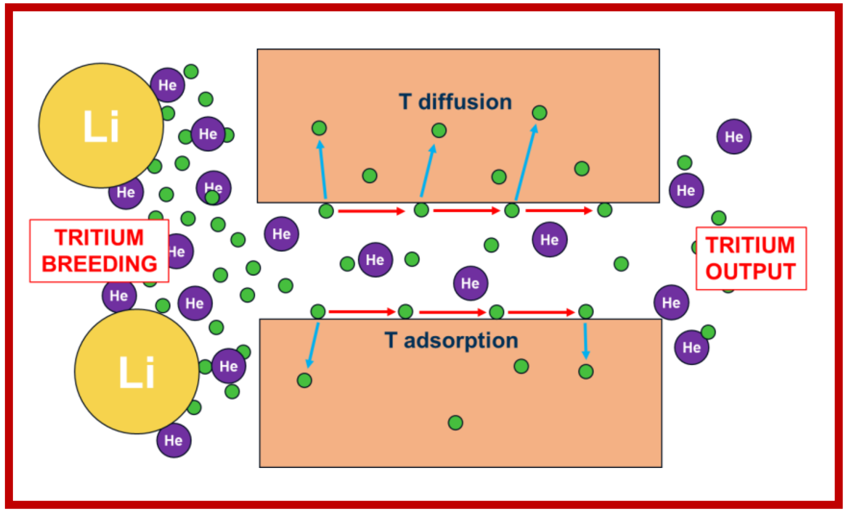
- Deuterium-Tritium fusion requires D and T as fuel and the intention is to breed the T from Lithium.

Neutrons change energy and direction with each material interaction in the breeder, so breeding prediction requires foresight of the engineering materials (thickness, interfaces etc.)



Courtesy: K. OCHIAI, IAEA CoNDERC, Westinghouse





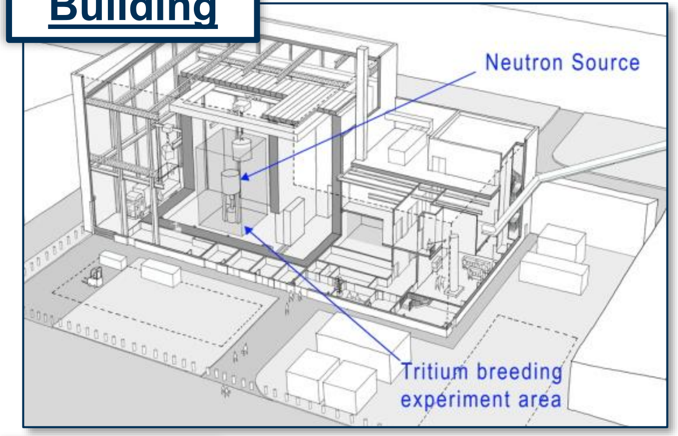
Tritium output is of greater importance at the engineering-scale, as bred tritium may be lost during transport and extraction. Improved models, verified and validated by experiments, are needed for better predictions.

LIBRTI: Programme Areas

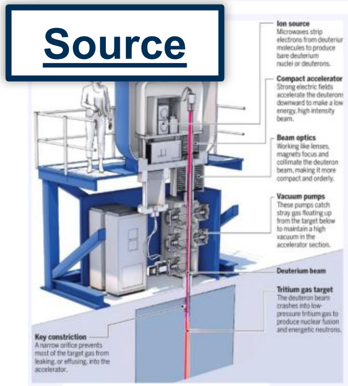
UK Atomic Energy Authority

Facility and Neutron Source

Building



Source

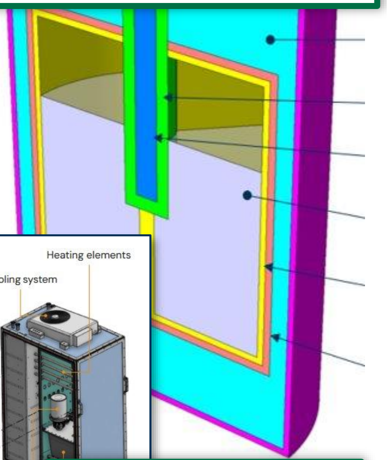


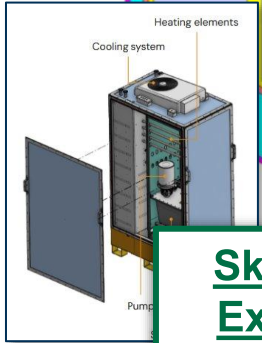
SHINE

- 125 kW system
- 75 mA deuteron beam injection
- ~300 keV deuterons
- Tritium at 40 Torr (0.05 bar) in target chamber
- 2.7 10^{13} n/s total DT-neutron output
- 500+ hours per year of operational availability expected
- Dedicated tritium management system included from supplier
- ~ 14 tonnes total floor loading (attached above and below a supported floor within LIBRTI)

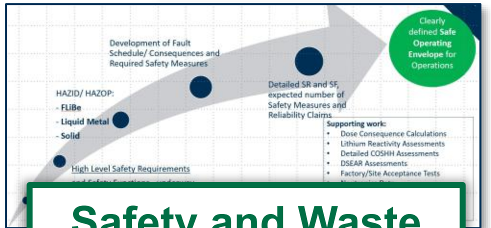
Mock-ups and Operations

Design/Integration/ Build





Skills and Expertise

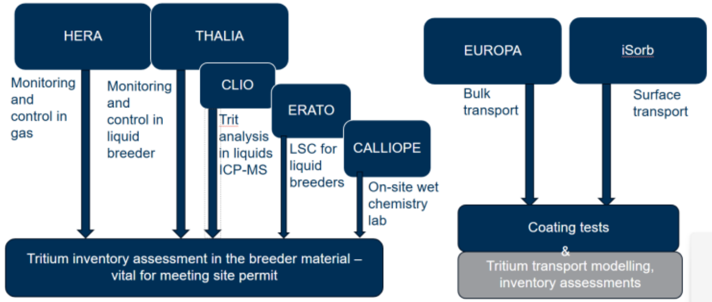


Safety and Waste

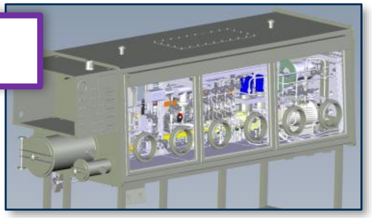
Feeder Stream R&D

Bangor University | amentum | Lancaster University | Kyoto Fusioneering | University of Edinburgh | Oxford Sigma | Tokamak Energy

£9m for Small-Scale Experiments for Tritium Production (SSETP)

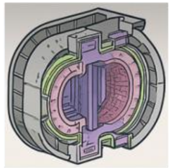


Tritium Rigs



Digital and Simulation

Multi-physics model for tritium output



Power plant concept

Relevant LIBRTI experiment

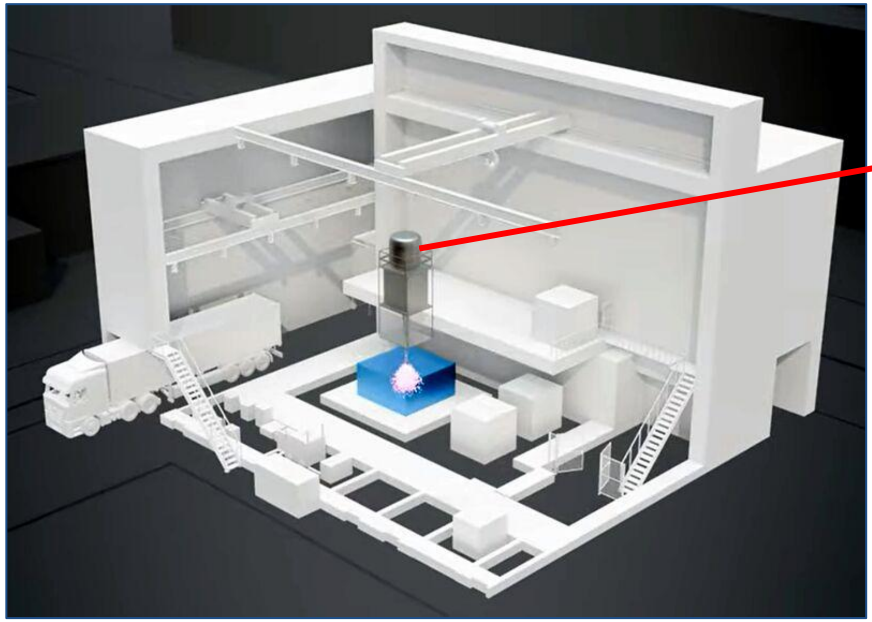
```
#include <iostream>
using namespace std;

int main() {
```

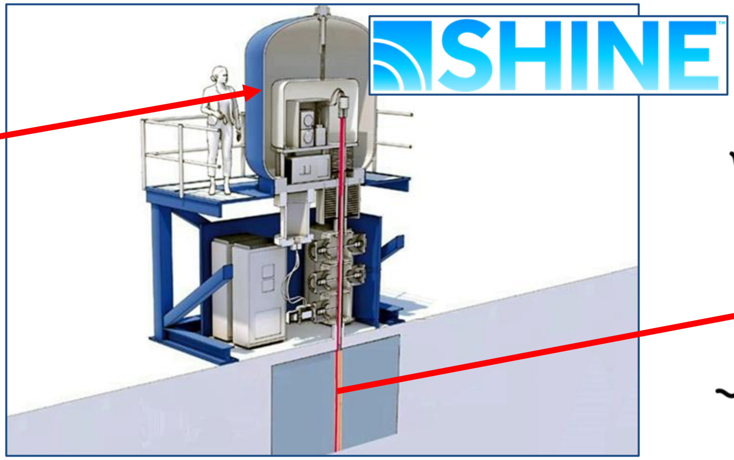
Multi-physics simulations

Visualizations
Sims. vs exp.

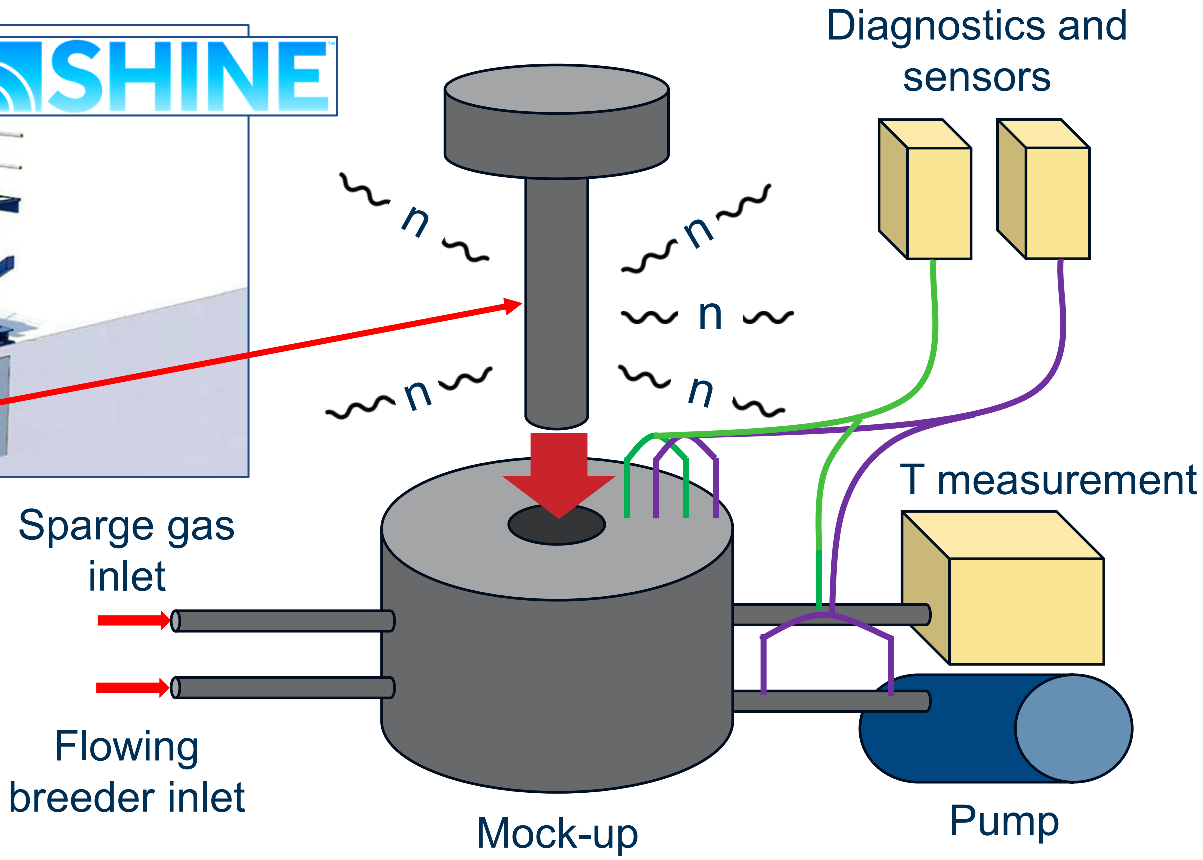
LIBRTI: Concept of Operations

Engagement → Design, develop, build → Receive → Position → Operate → Measure → Remove → Store/Dispose → Learn





- 10^{13} n/s
- 10^{9-10} n/cm^2/s



Types of experiments to be put in front of the LIBRTI source is driven by partners

Ramp-up neutron source facilities

Prior to a multi-tonne LIBRTI campaign, there are opportunities to conduct breeding experiments to:

- Design and develop novel breeder materials and breeder-multiplier composites,
- Better understand and quantify tritium release / recovery kinetics,
- Better understand and quantify tritium retention in breeders,
- Evaluate tritium measurement uncertainty and develop mitigations to improve experiments,

With a view to developing a breeding capability in the UK, LIBRTI funded 10 projects on “Small-Scale Experiments for Tritium Production”. **Three projects conducted irradiations using a 14 MeV source.**

Lancaster University

Tritium Breeder (TriBreed) small-scale breeder: design and demonstrate a simple, reusable tritium breeding experiment

NILE

ASTRAL SYSTEMS

LiD development culminating in neutron test with online tritium extraction

ASTRAL

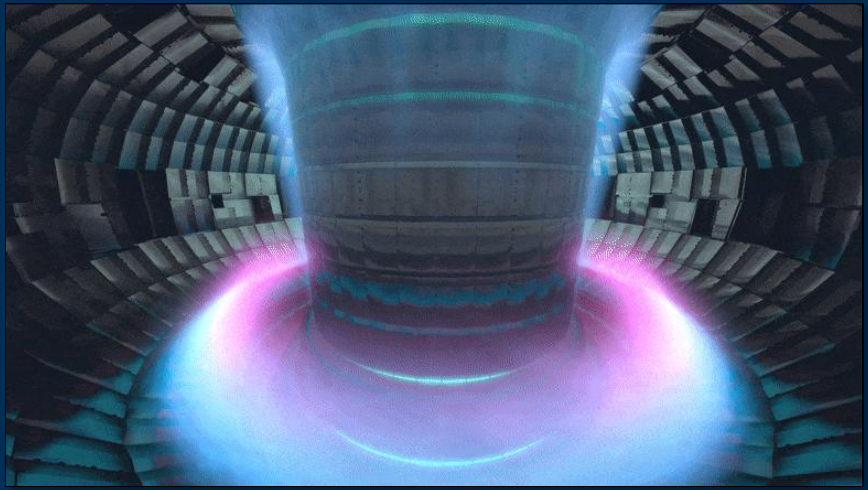
The University of Edinburgh

Breed tritium in FLiBe/FLiNaK in a fusion-relevant DT neutron source

SHINE

 |

Thank you for your attention (james.wade-zhu@ukaea.uk)



Acknowledgments

This work is part of the Lithium Breeding Tritium Innovation (LIBRTI) programme, funded by the **Fusion Futures Programme**. As announced by the UK Government in October 2023, Fusion Futures aims to provide holistic support for the development of the fusion sector. Part of the research presented used the UKAEA's Materials Research Facility, which has been funded by and is part of the UK's **National Nuclear User Facility** and **Henry Royce Institute** for Advanced Materials. The authors acknowledge EPSRC grant EP/W006839/1. JWZ is also supported by the **Henry Royce Institute** as the Research Area Lead for Nuclear.