Nuclear energy research at ISIS: engineering-focused showcase

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Science and Technology Facilities Council

ISIS Neutron and Muon Source

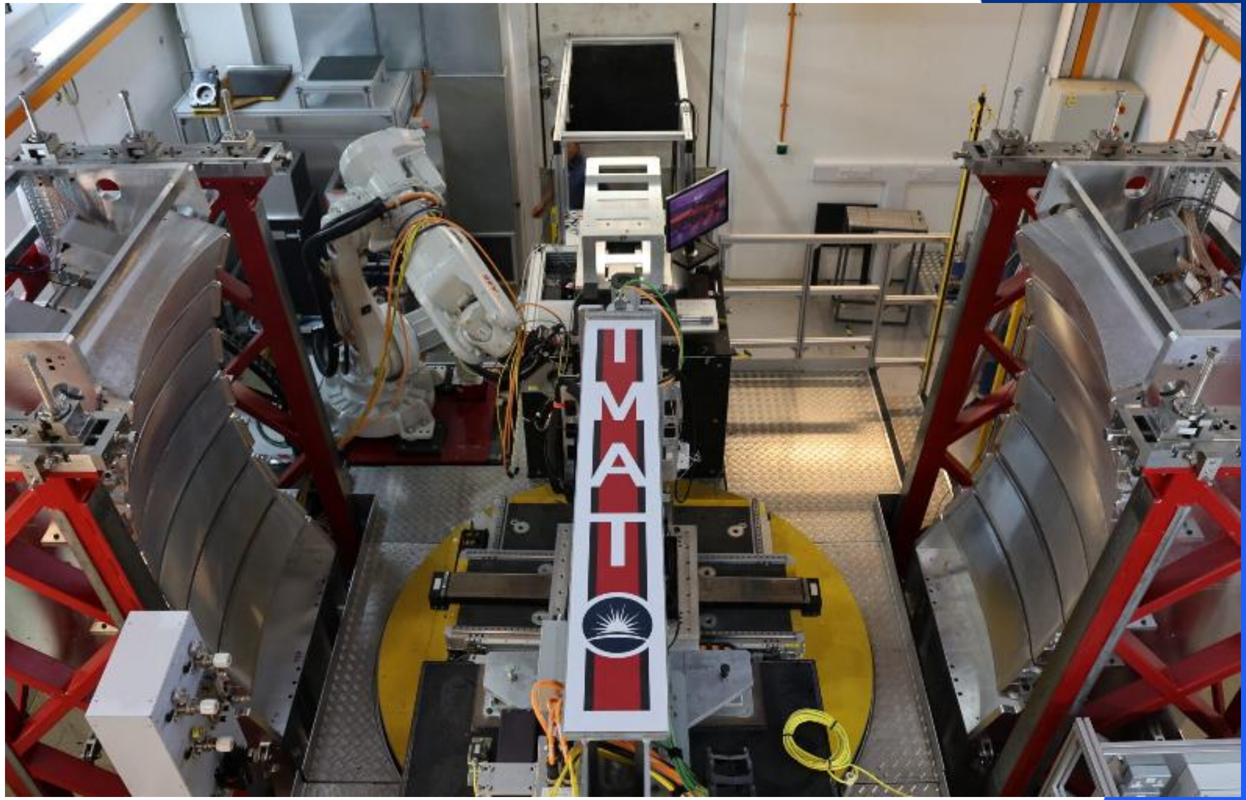
Nuclear energy research at ISIS

- Engineering-focused characterisation technique
    - Engineering diffraction & Imaging
    - Probe materials and components non-destructively at different length scale
    - High penetration on many nuclear energy materials (structural steels to tungsten to nuclear fuels)
    - Sensitivity to light element such as hydrogen
- Irradiation
- A very narrow overview, more things going on…

Neutron techniques and instruments

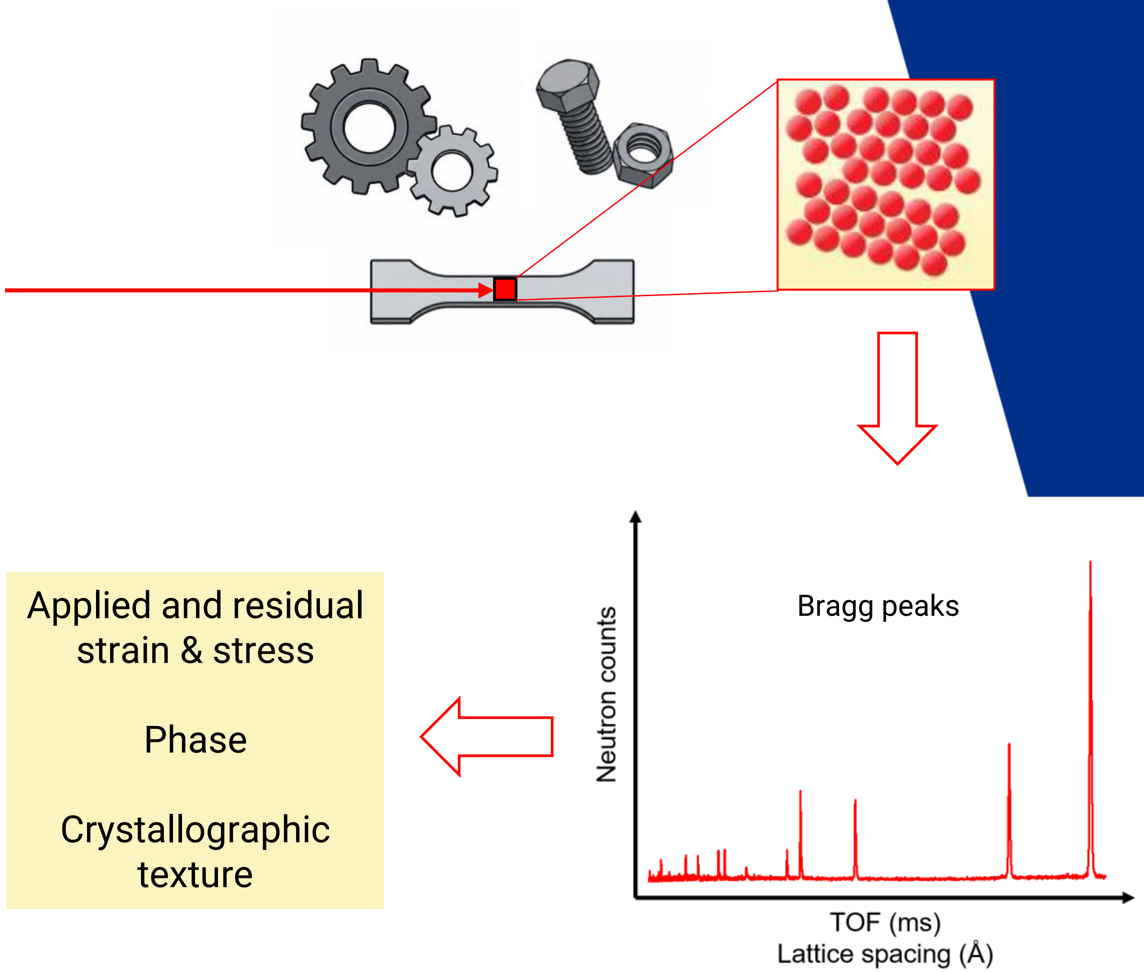
ENGIN-X: Engineering diffraction

IMAT: Neutron imaging



Neutron techniques and instruments

ENGIN-X: Engineering diffraction



Applied and residual strain & stress

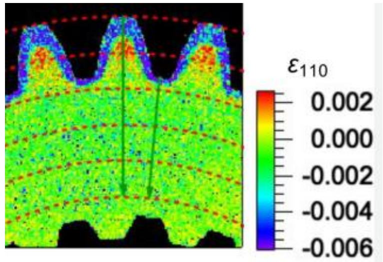
Phase

Crystallographic texture

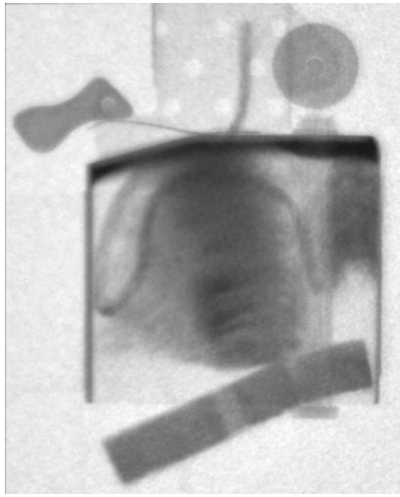
Neutron techniques and instruments

Tomography

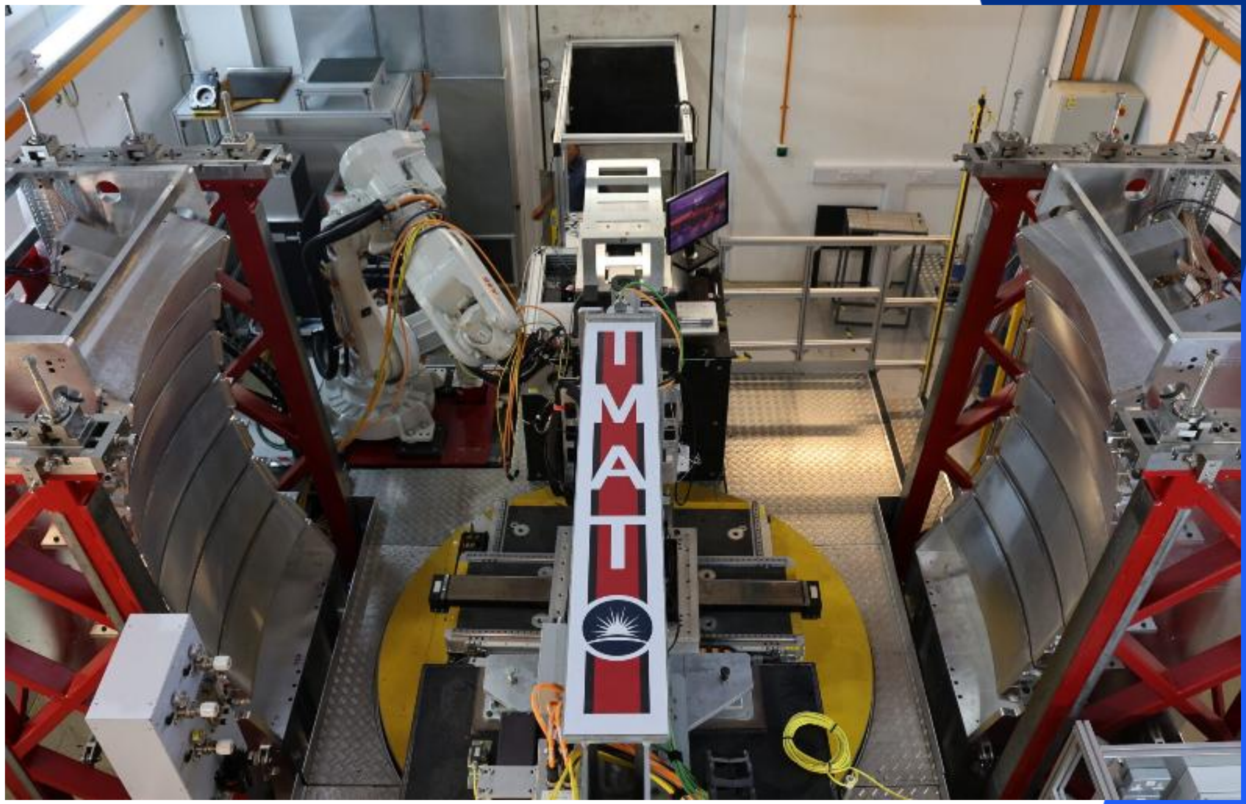
Bragg edge



Radiography



IMAT: Neutron imaging



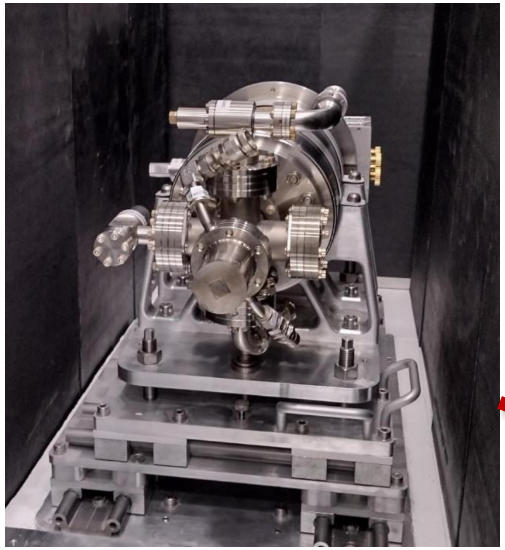
Neutron techniques and instruments

NILE: Irradiation

Two **compact neutron sources** are operated as an instrument of ISIS.

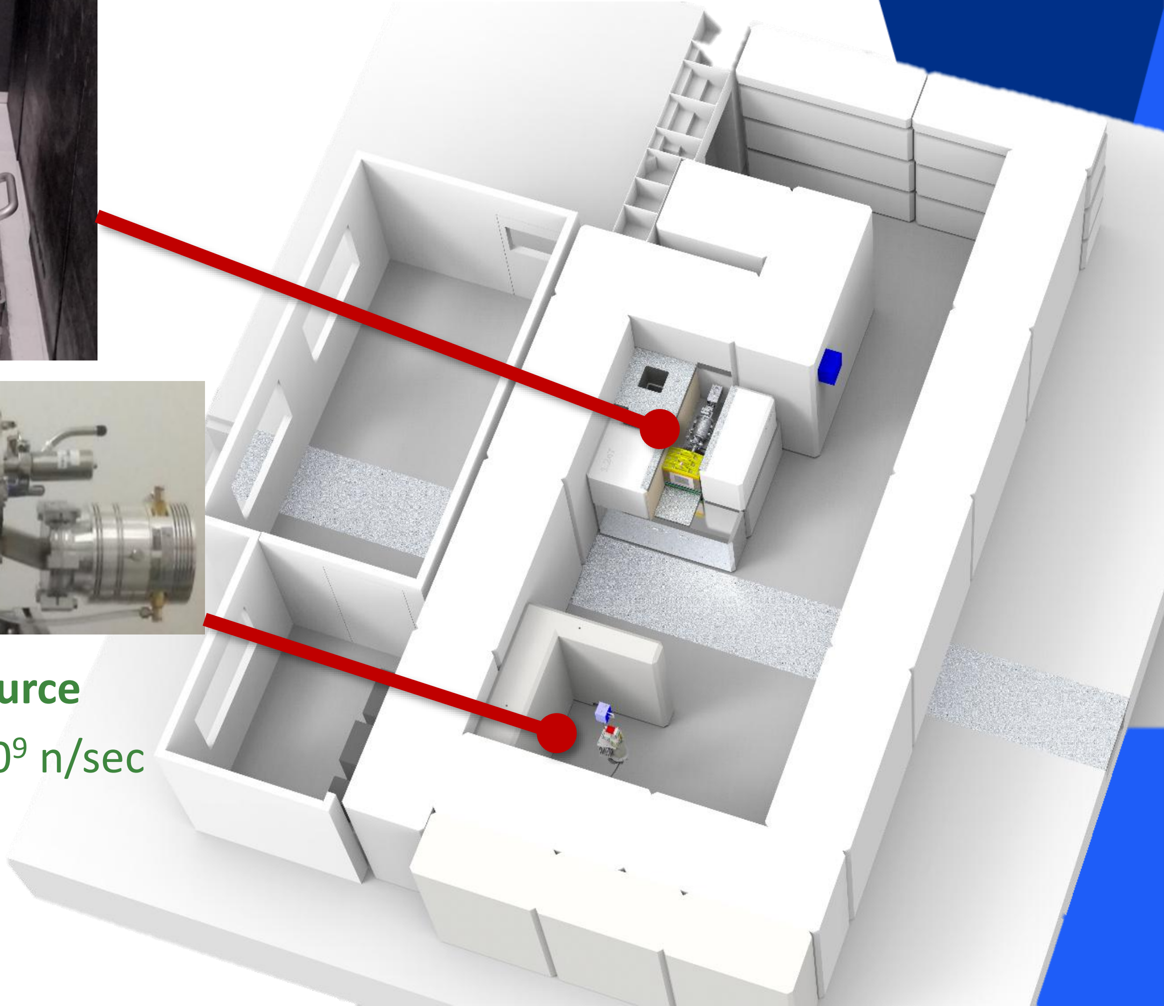
Neutron production is based on **Deuterium-Tritium** and **Deuterium-Deuterium** fusion reaction.

Monoenergetic neutron fields are relevant for fusion technology.



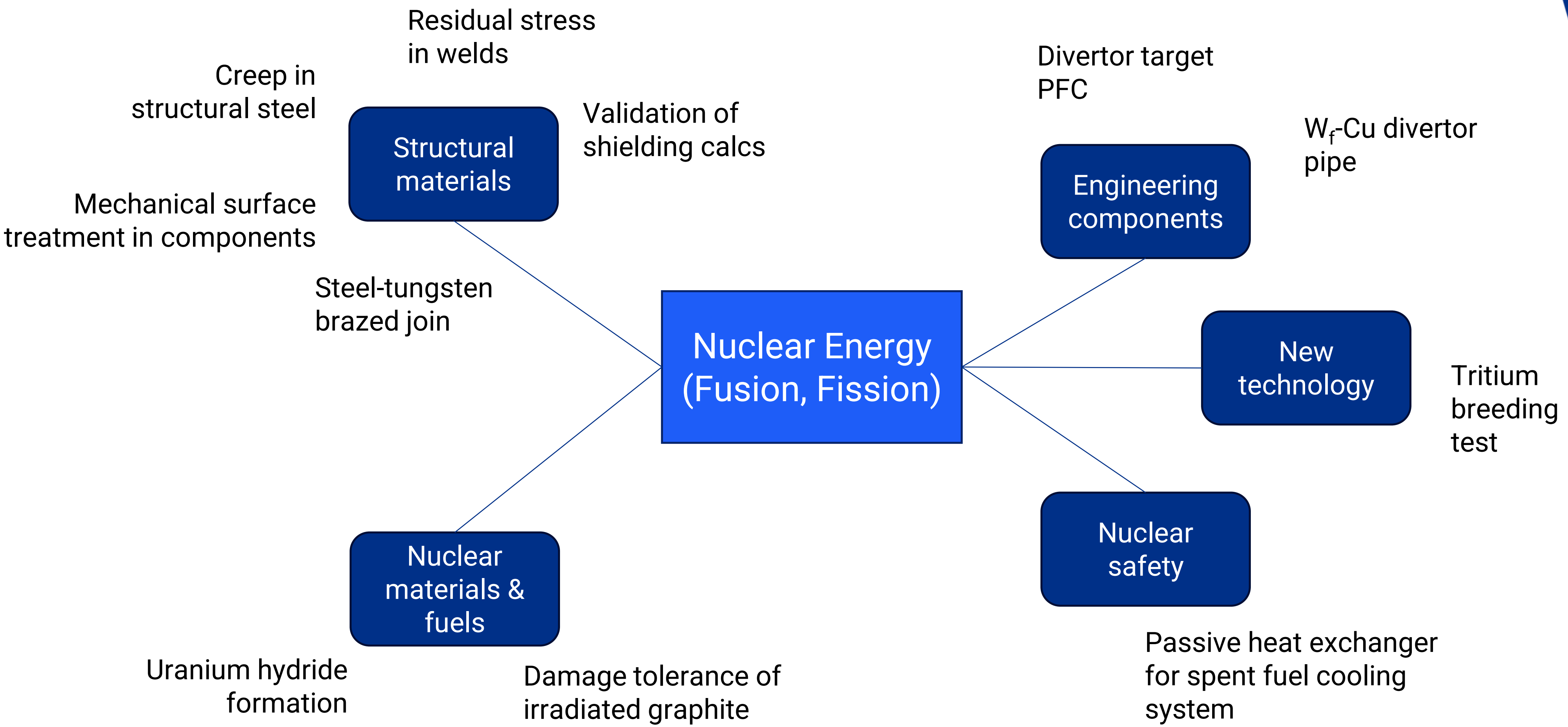
14 MeV D-T Source

Nominal Yield 10^{10} n/sec



2.5 MeV D-D Source

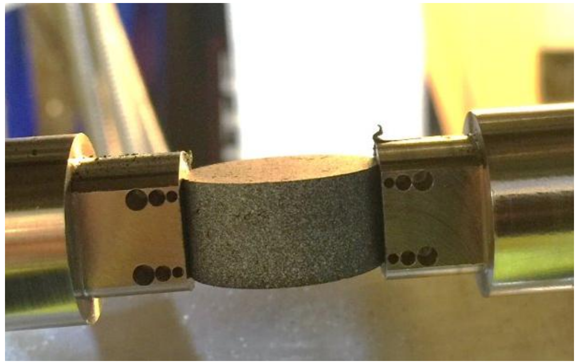
Nominal Yield 10^{9} n/sec


Nuclear Energy (Fusion, Fission)
Structural materials
Residual stress in welds
Creep in structural steel
Validation of shielding calcs
Mechanical surface treatment in components
Steel-tungsten brazed join
Engineering components
Divertor target PFC
W_f-Cu divertor pipe
New technology
Tritium breeding test
Nuclear safety
Passive heat exchanger for spent fuel cooling system
Nuclear materials & fuels
Uranium hydride formation
Damage tolerance of irradiated graphite

Nuclear Energy (Fusion, Fission)

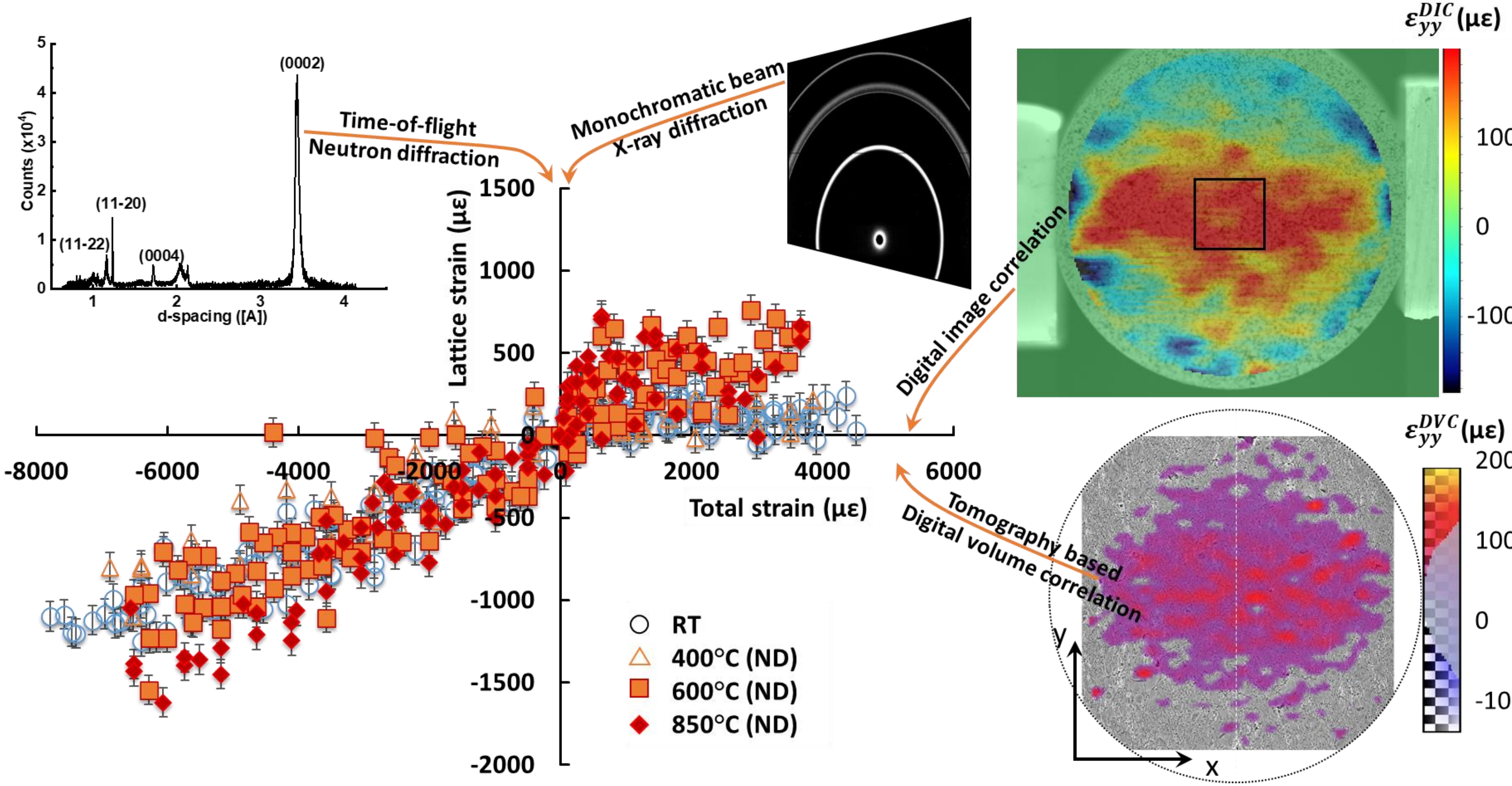
- **Structural materials**
  - Residual stress in welds — Neutron diffraction
  - Creep in structural steel — Neutron diffraction
  - Validation of shielding calcs — Irradiation
  - Mechanical surface treatment in components — Bragg-edge imaging
  - Steel-tungsten brazed join — Bragg-edge imaging
- **Engineering components**
  - Divertor target PFC — Neutron tomography
  - W_f-Cu divertor pipe — Neutron tomography
- **New technology**
  - Tritium breeding test — Irradiation
- **Nuclear safety**
  - Passive heat exchanger for spent fuel cooling system — Neutron radiography
- **Nuclear materials & fuels**
  - Uranium hydride formation — Neutron radiography
  - Damage tolerance of irradiated graphite — Neutron diffraction

Damage tolerance of polygranular graphite



Elastic lattice strain – total strain relationship of nuclear-grade graphite at high temperature

Neutron diffraction revealed higher tensile lattice strain sustained at high temperature

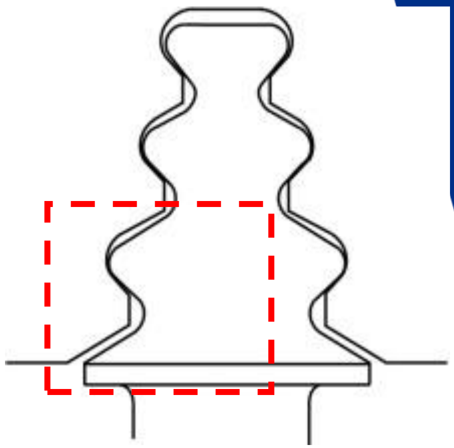


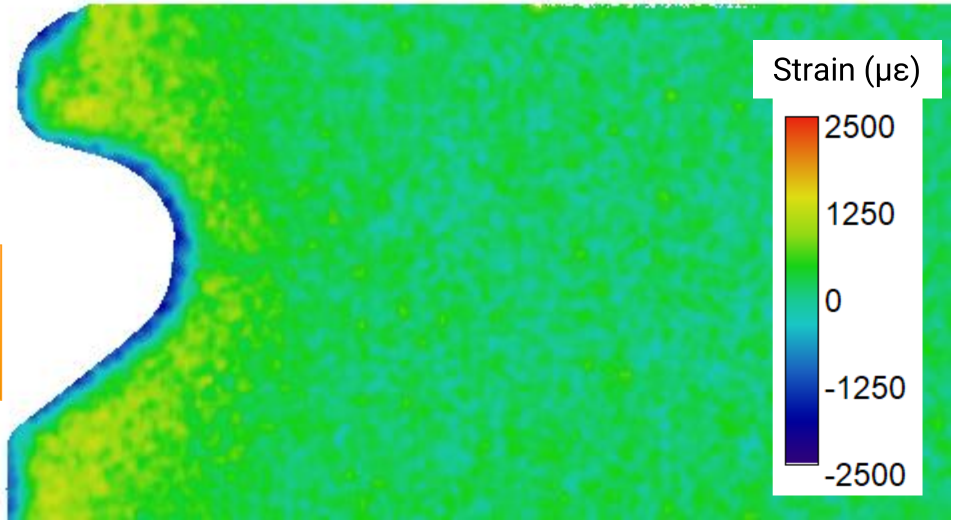
10.1016/j.carbon.2020.03.020

Laser peening to enhance fatigue life of steam turbine

Laser peening applied to surface, introduce compressive strain to mitigate fatigue crack initiation and growth

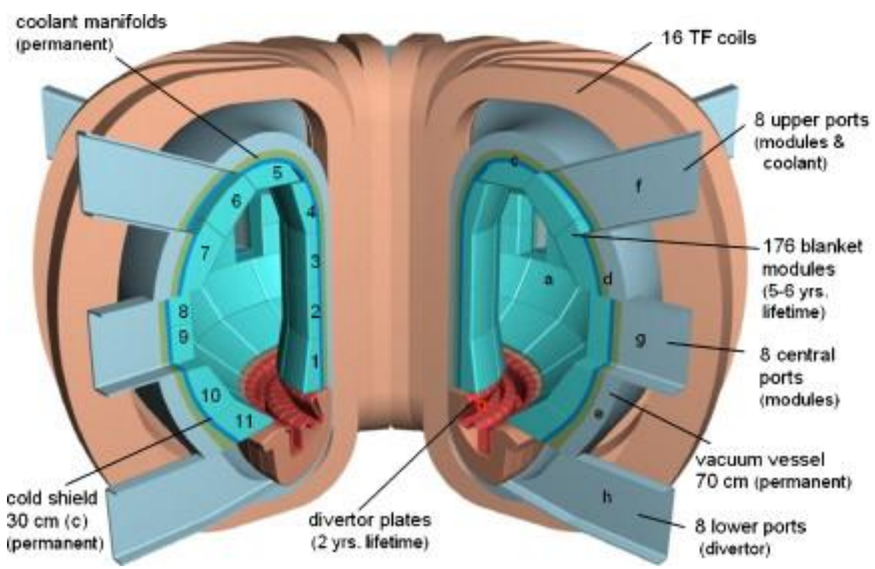
Bragg edge imaging provide map of residual strain in complex geometry



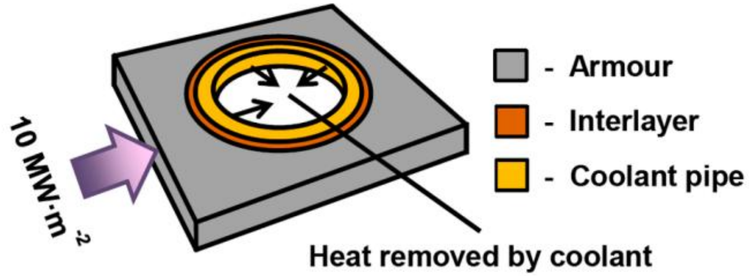


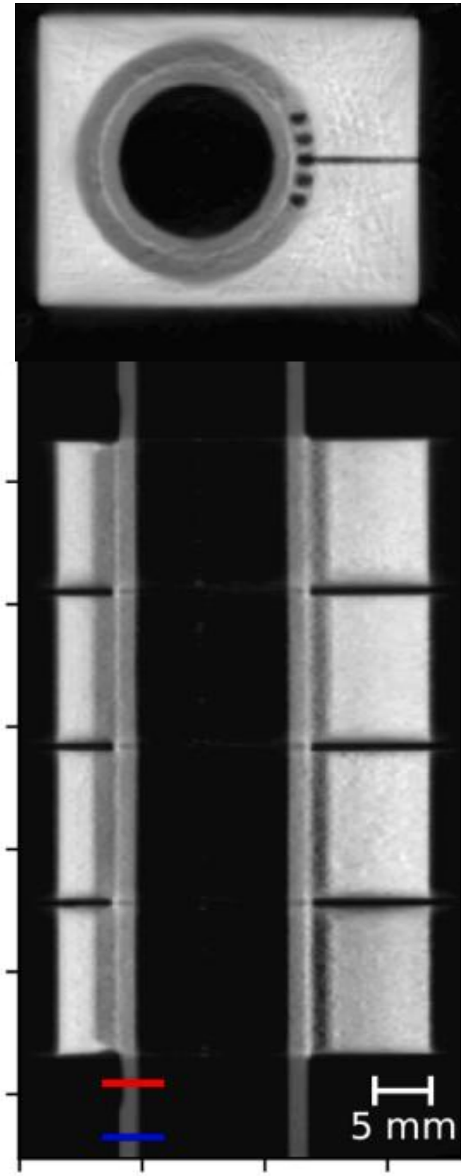
Up to 100 με strain resolution
Up to 100 μm resolution
Up to 28×28 mm FoV

Structural integrity of divertor monoblock assembly



https://doi.org/10.1016/j.fusengdes.2008.05.022

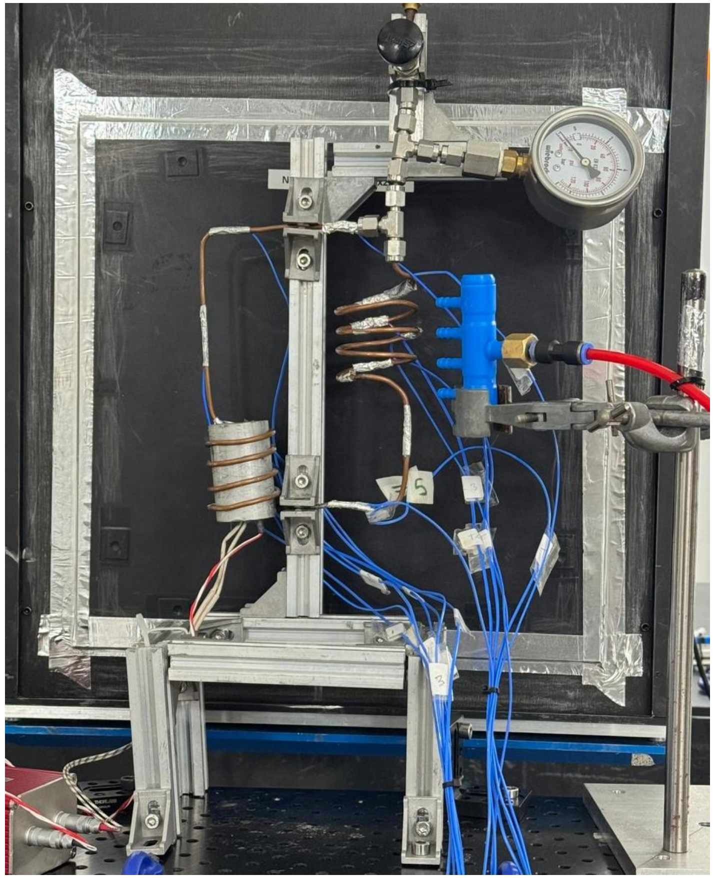




Neutron tomography penetrated through tungsten and revealed defects on the monoblock assembly

10.1016/j.fusengdes.2021.112661

Passive heat exchanger for spent fuel cooling system



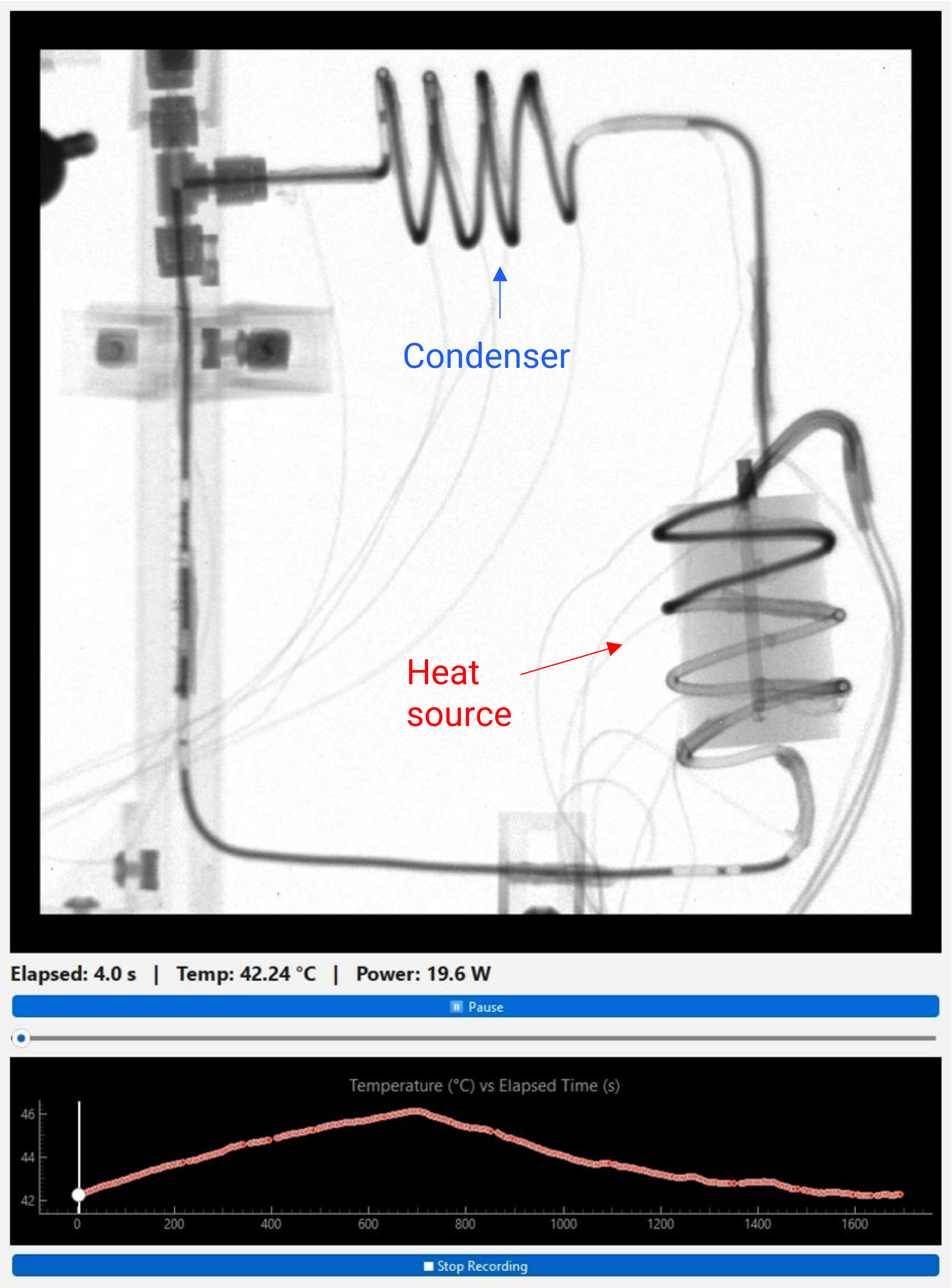
Heat-pipe-based passive cooling system for nuclear fuel

Neutron radiography reveals working fluid dynamics inside copper tube

Up to 60 microns spatial resolution

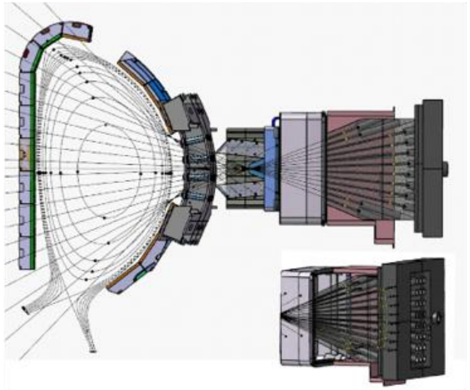
Up to 200×200 mm FoV

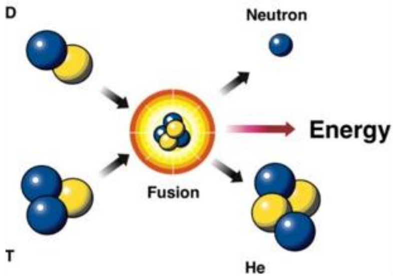
Up to 1 fps time resolution (2D)



Applications: Role of NILE for nuclear fusion technology

Fusion Plasma Diagnostics: testing of detectors



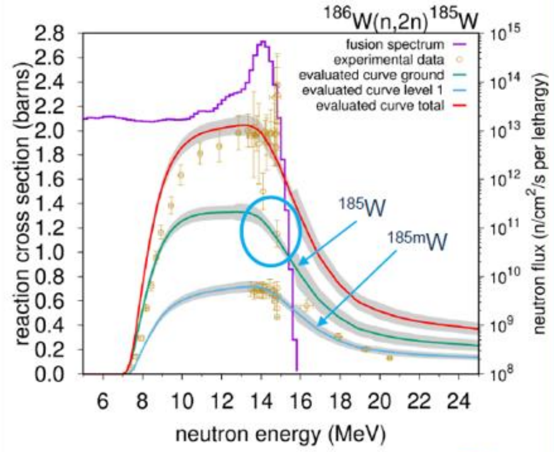


In particular, neutron diagnostics for the physics Q >> 1 tokamaks. E.g. Diamond detectors

Nuclear data validation

1) Validation of cross sections. E.g. Lack of cross section measurements for (n,2n) reactions on 186W(and other W isotopes)

2) Validation of shielding calculations for radioprotection (radiation transport codes)

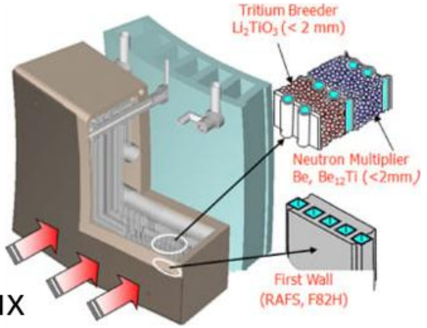


Important for both fission and fusion research.

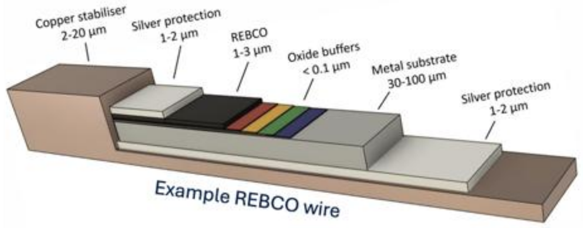
Tritium breeding tests

First tests of materials/technology for tritium breeding blankets.

Good for validation, but not enough flux to produce T at scale. To note £ 200M investment of UKAEA in LIBRTI facility. LIBRTI will do engineering-scale tritium breeder blankets.



Material studies



DEMO/ STEP

10-100dpa

Flux too low for most material damage studies... But, useful for some specific material testing: e.g. testing of high-temperature superconductors.

Summary

- Neutron-based characterisation techniques offer unique capabilities for nuclear energy research
- Beyond characterisation: Irradiation, and many more