UKAEA involvement in SINBAD benchmarks

Alex Valentine, Bethany Colling, Ross Worrall, Steven Bradnam, Andrew Davis, Tim Eade Jonathan Naish, Chantal Nobs, Lee Packer, Jonathan Shimwell, Thomas Stainer
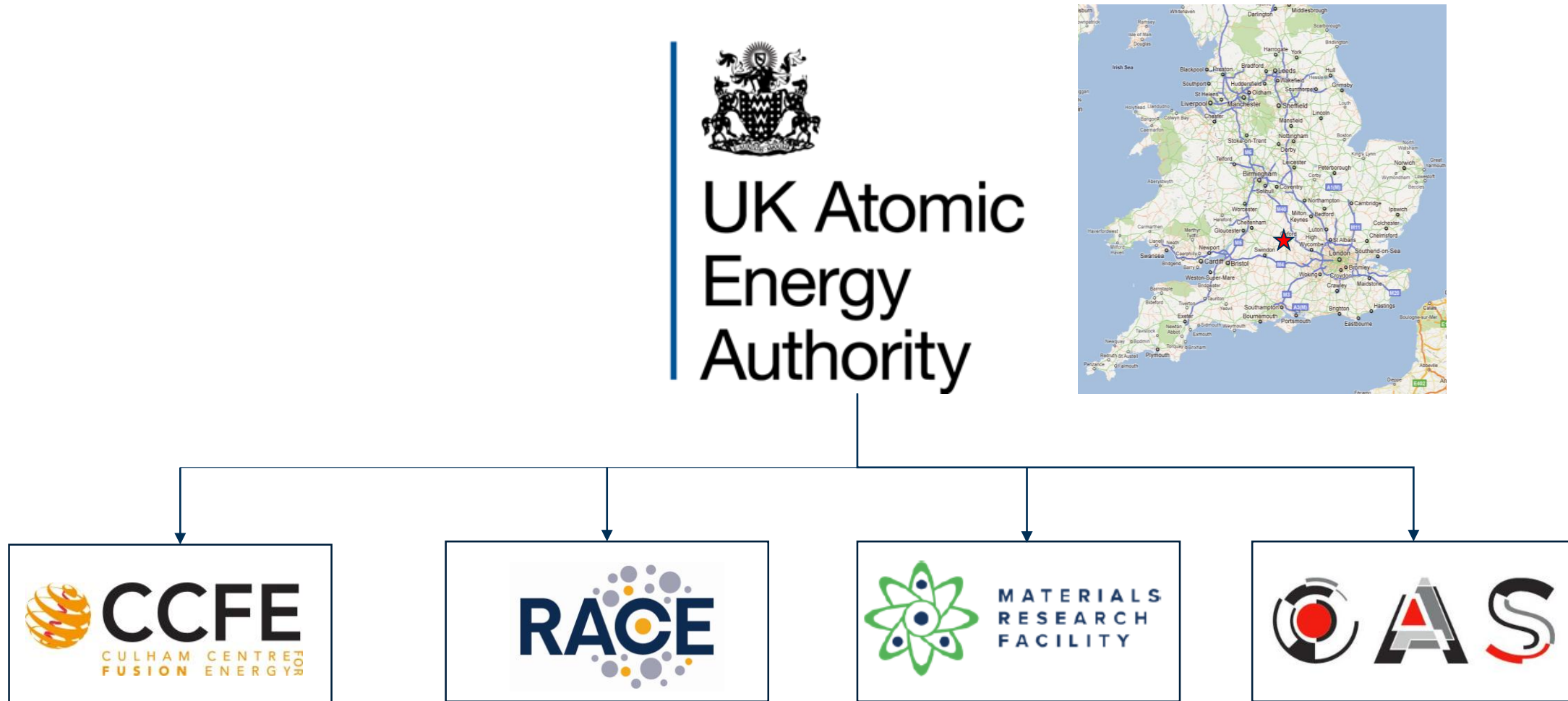
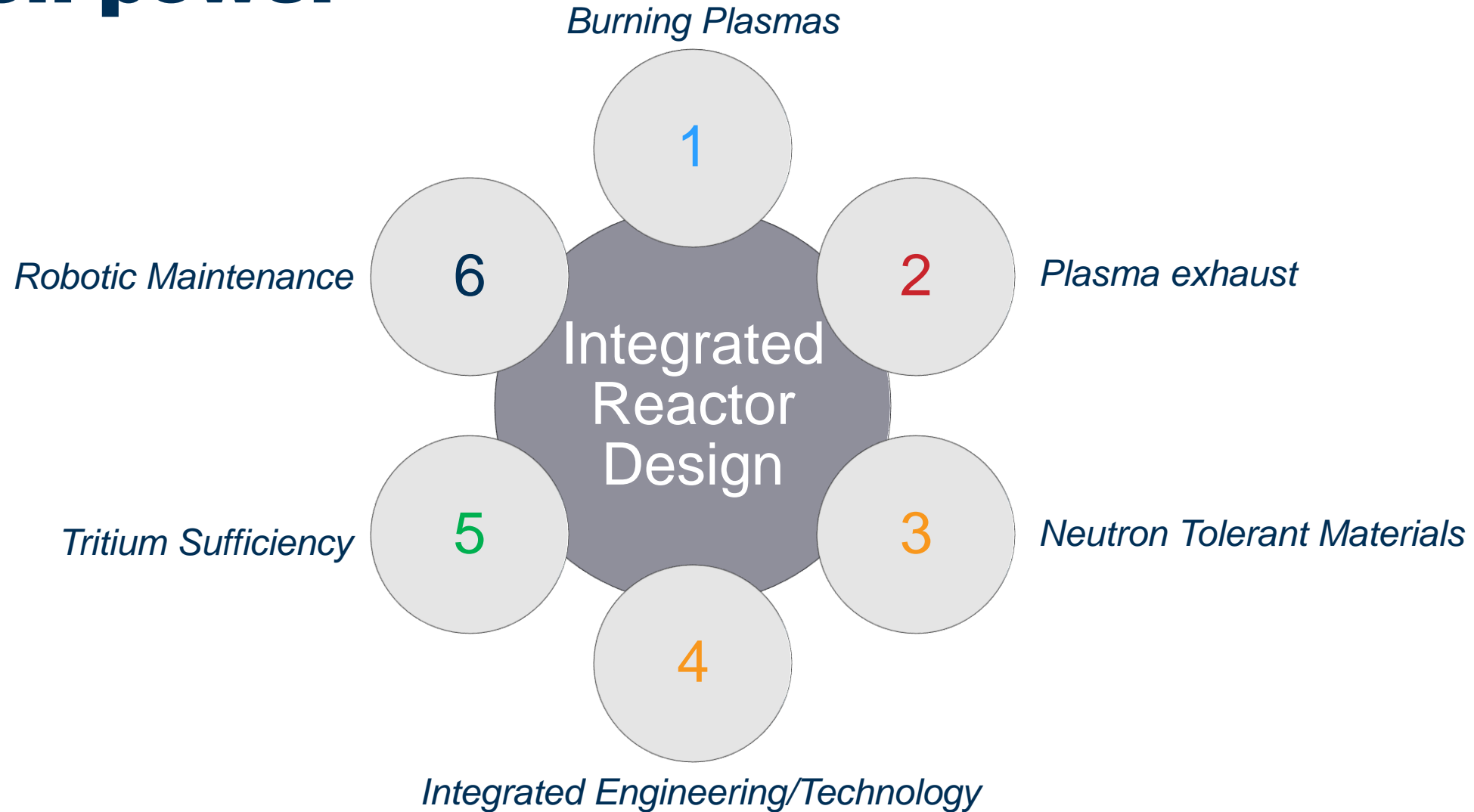31st WPEC Meeting, Subgroup 47, 24/06/2019

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Organisation overview

Challenges to the development of fusion power

Burning Plasmas

Plasma exhaust

Neutron Tolerant Materials

Integrated Engineering/Technology

Tritium Sufficiency

Robotic Maintenance

1
2
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Integrated Reactor Design

JET: Hosted at UKAEA on behalf of its European partners. Fundamental to the successful operation of the next generation of magnetic confinement tokamaks.
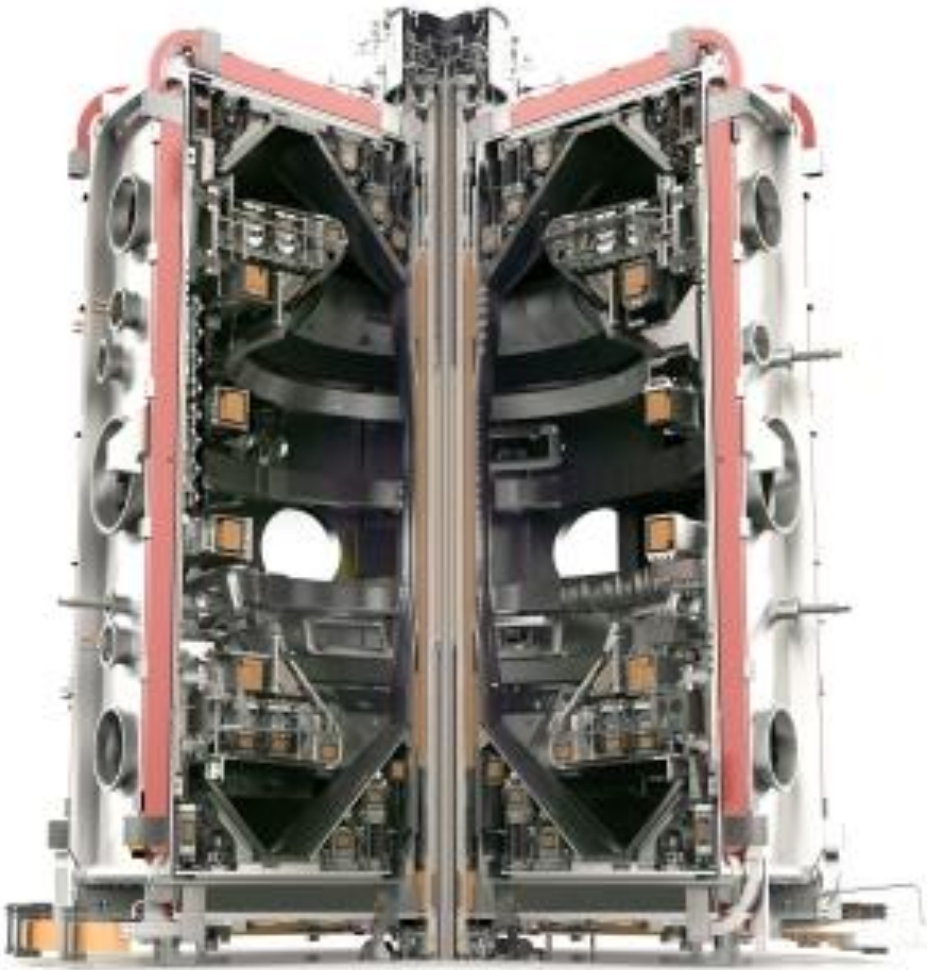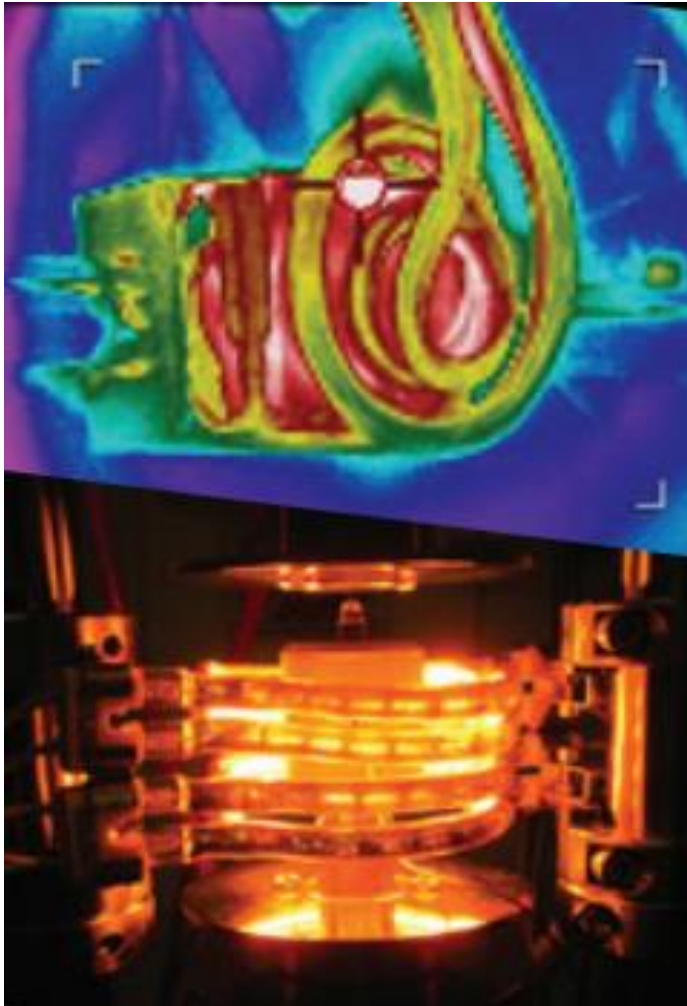
MAST-U : The UK's flagship spherical tokamak fusion reactor. Recently undergone £20 million upgrade.

3 Neutron Tolerant Materials

Materials Research Facility: Bridging the gap in the UK to handle and process intermediate level nuclear waste

Fusion Technologies Facility (FTF): New facility under construction for thermal hydraulic, electromagnetic and novel materials testing under fusion irradiation conditions
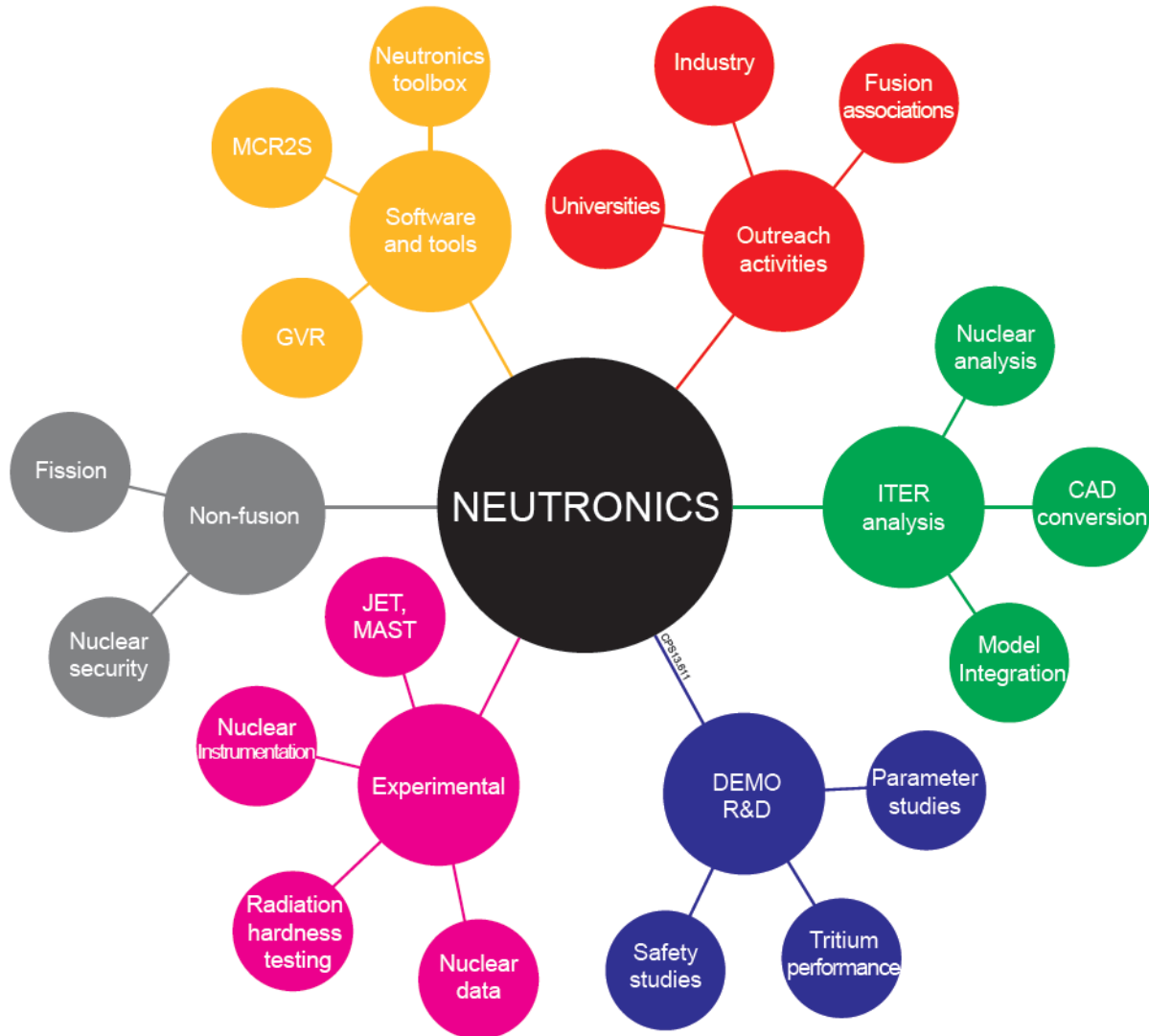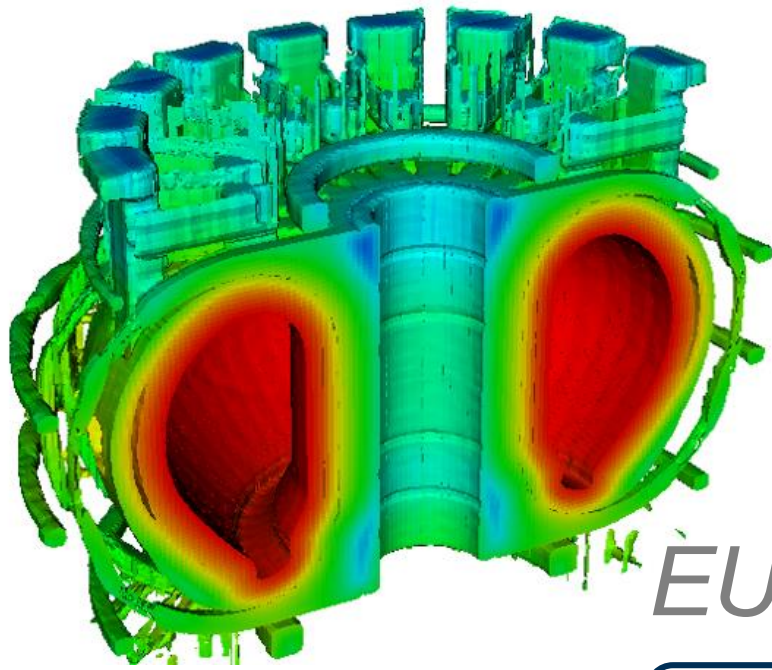
Hydrogen-3 Advanced Technology (H3AT): New facility providing infrastructure for feeding, recovering, storing and recycling tritium.
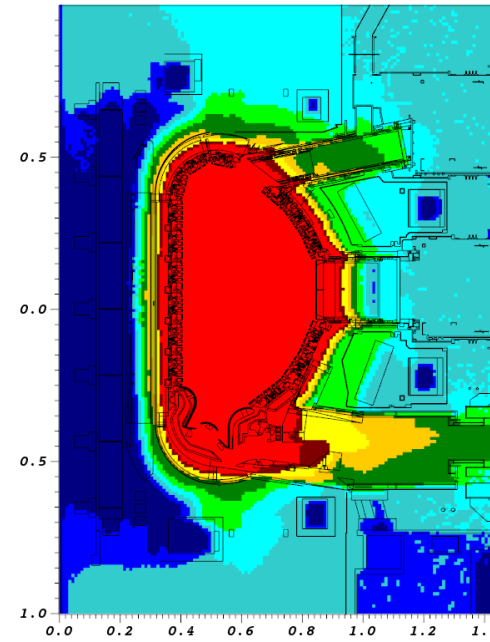
UK Atomic
Energy
Authority

Remote Applications in Challenging Environments (RACE): World leader in developing remotely operated systems for nuclear environments.

RACE

Applied Radiation Technology

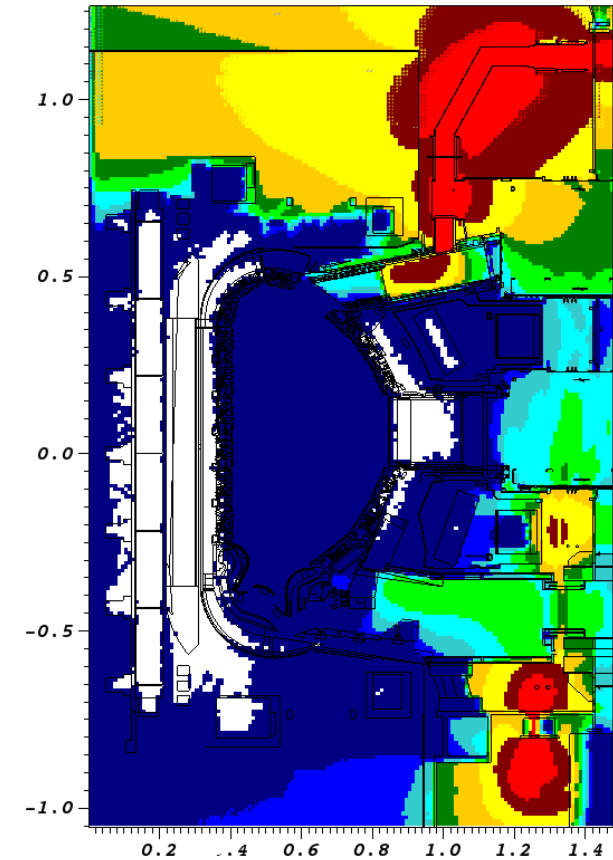Plasma Source

ITER

EU DEMO
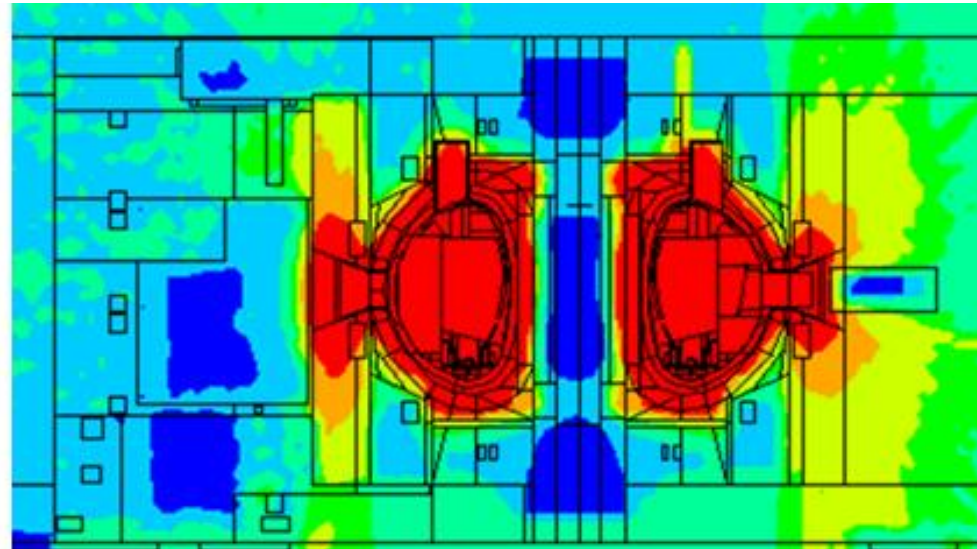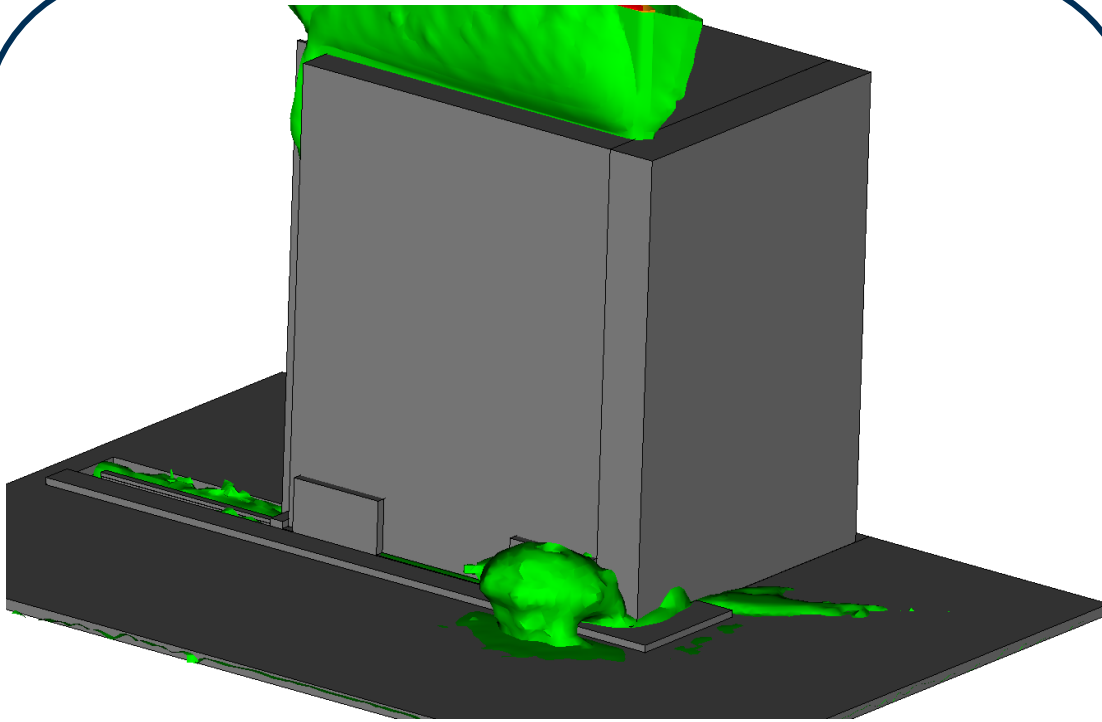
Radiation field mapping for fusion reactors

JET

Cooling Water System Source

UK Atomic
Energy
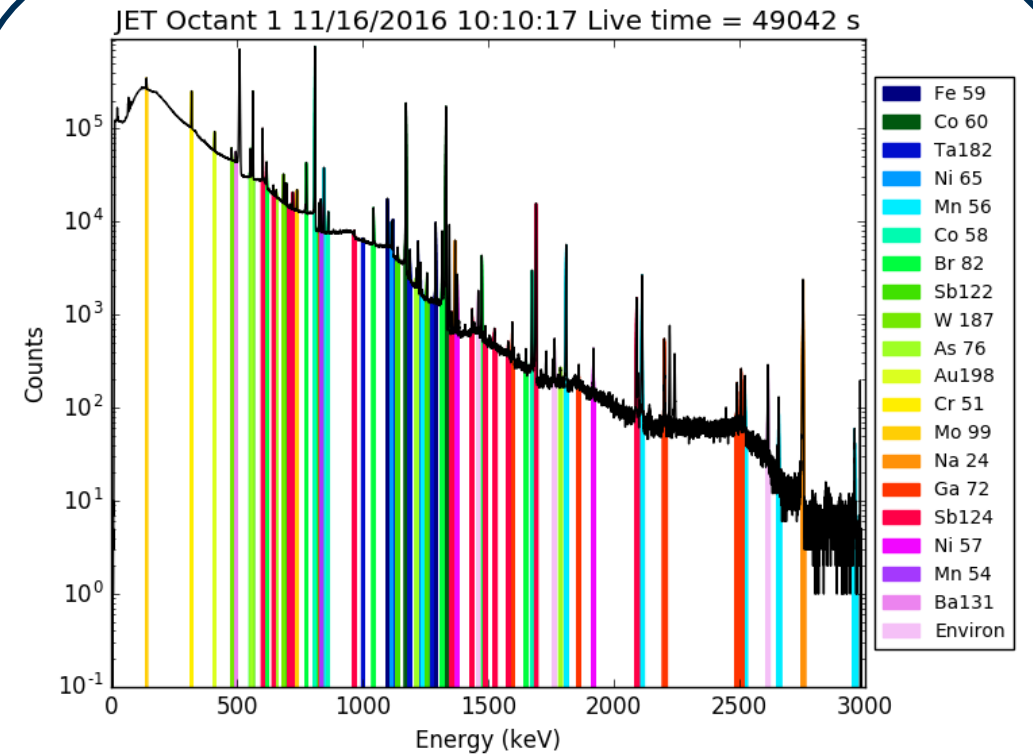Authority

Commissioning of Hot Cells: **Materials Research Facility (MRF)**

Gamma Spectroscopy: **Adriana Laboratory**
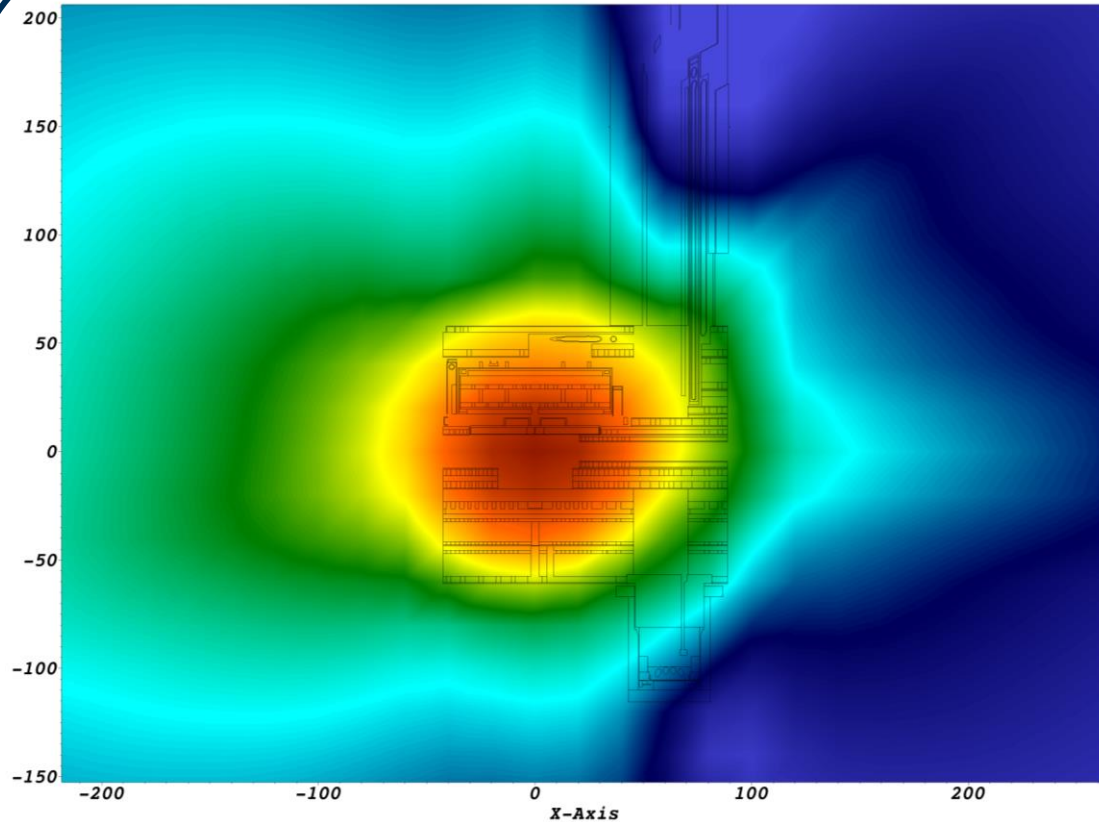
Radiation transport and shutdown dose field:
European Spallation Source
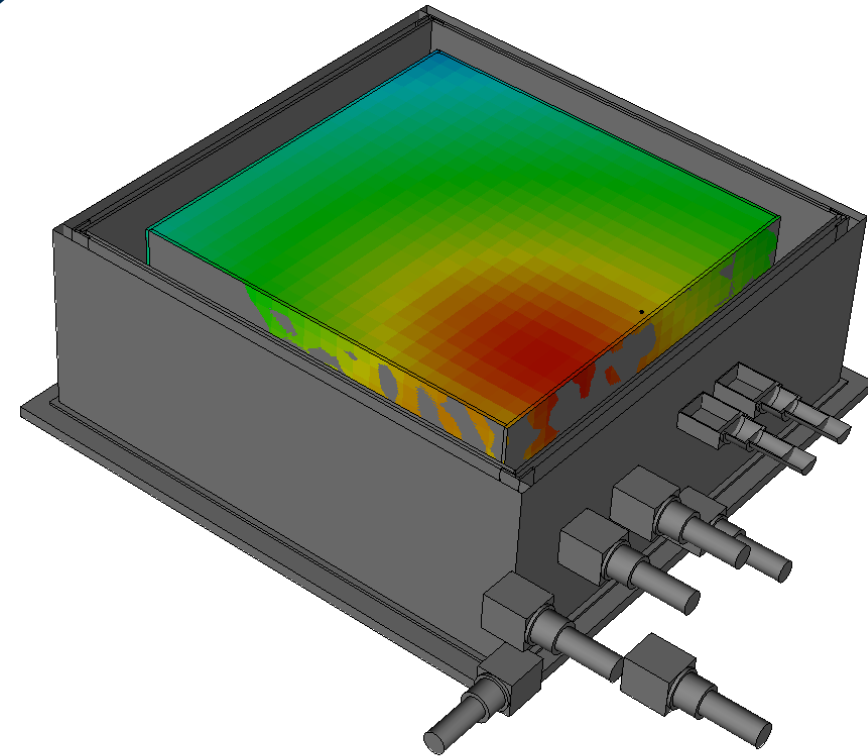
Time of Flight Measurements: **Lancaster University**

Nuclear Inventory Simulation

- FISPACT-II is a multi-physics platform for predicting the inventory changes in materials under both neutron and charged particle irradiations
  - Calculates the activation, burn-up, dpa, PKAs, gas production, etc.
- Can read data from the most up to date international nuclear data libraries including TENDL 2017, ENDF/B-VIII.0, JEFF 3.3, JENDL-4.0 etc…
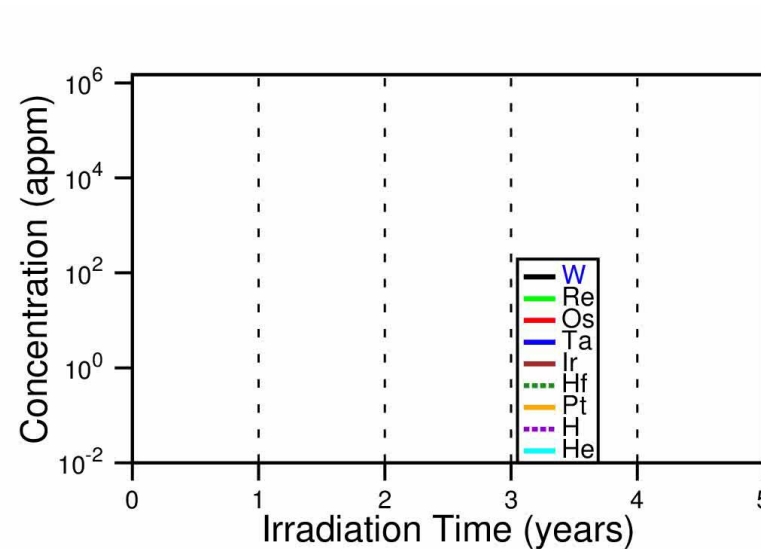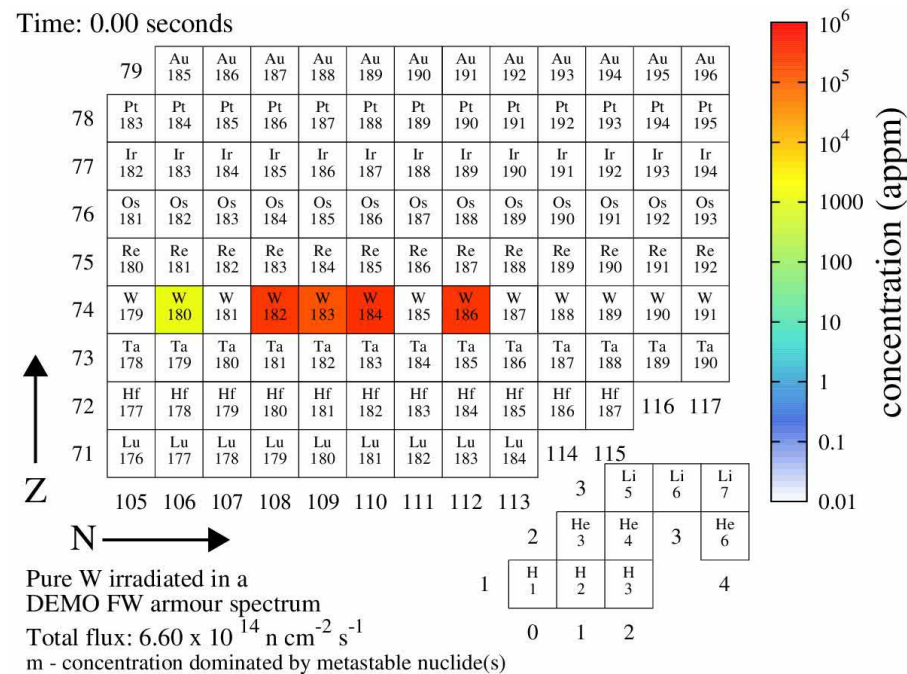
M. R. Gilbert et al., *Nucl. Sci. Eng* **171** (2014) 291-306
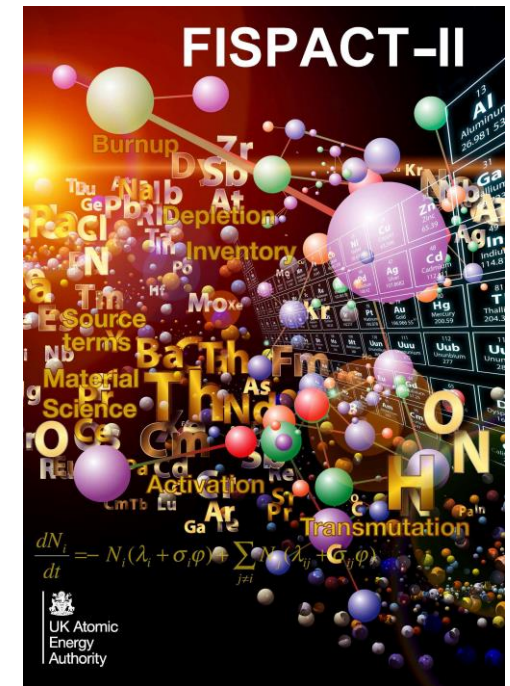
Nuclear Inventory Simulation

- FISPACT-II version 4.0 was released in February 2018
- Available at the NEA databank
  - New JSON output format for easy parsing
  - New PYPACT utility for straightforward manipulation of output files
- Recent developments include a fully integrated API
- Extensive validation has been undertaken with this release of the code.
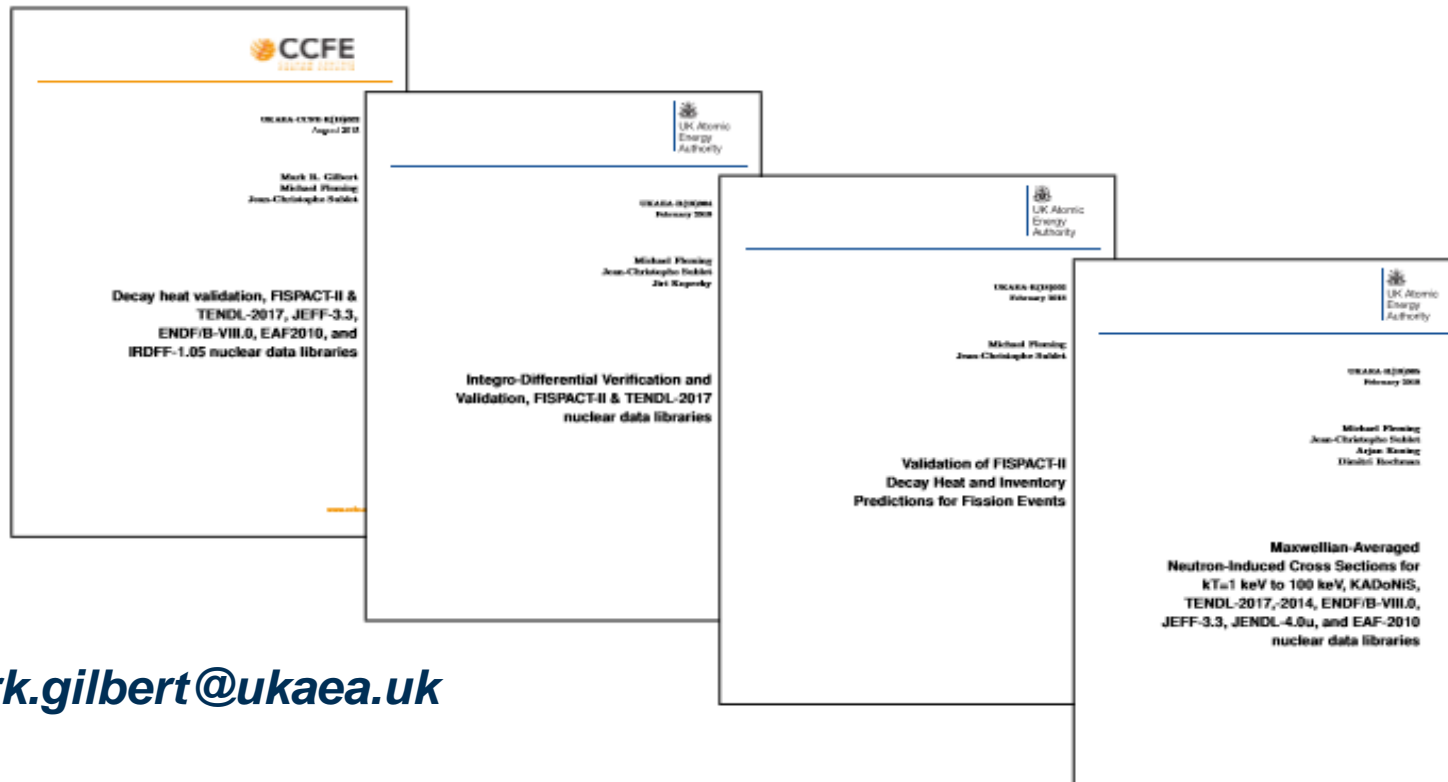
Contact: mark.gilbert@ukaea.uk
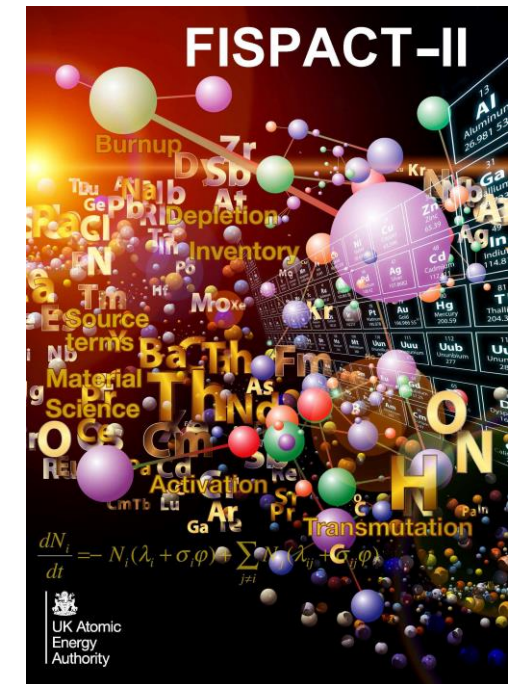
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EUROfusion Serpent benchmarking activities in 2018

- Comparisons between Serpent 2 results and MCNP and/or experimental values for **HCLL DEMO 2015 neutronics model** and **HCLL FNG blanket mock up experiment**.
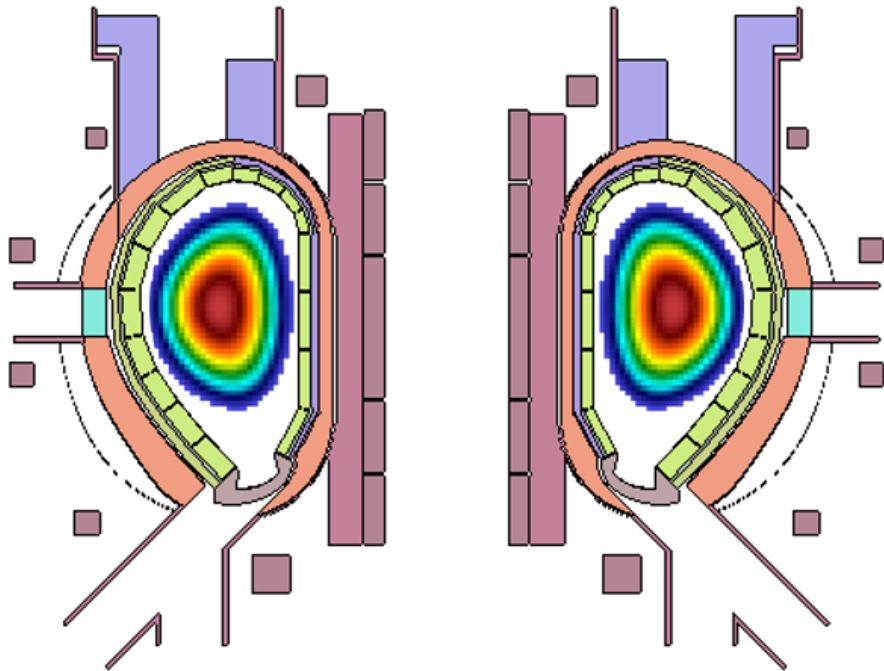
- Performed **DEMO** benchmarking, comparing Serpent 2 with MCNP results of flux, heating, tritium production etc.

- Good agreement in neutron and photon flux.

- Significant differences seen in nuclear heating results - later shown to be due to neutron heating results in tungsten (we see negative values in energy range 1-15 MeV with JEFF data libraries for a simple spherical model of W).

EUROfusion Serpent benchmarking activities in 2018

Attempts made to compare the dosimetry foil reaction rates and Li_2CO_3 pellet tritium production.

- **HCLL FNG** blanket mock up experiment not yet in SINBAD.

- Some confusion over which is the most suitable and validated model(s).

Dosimetry foil model

Tritium pellet foil model
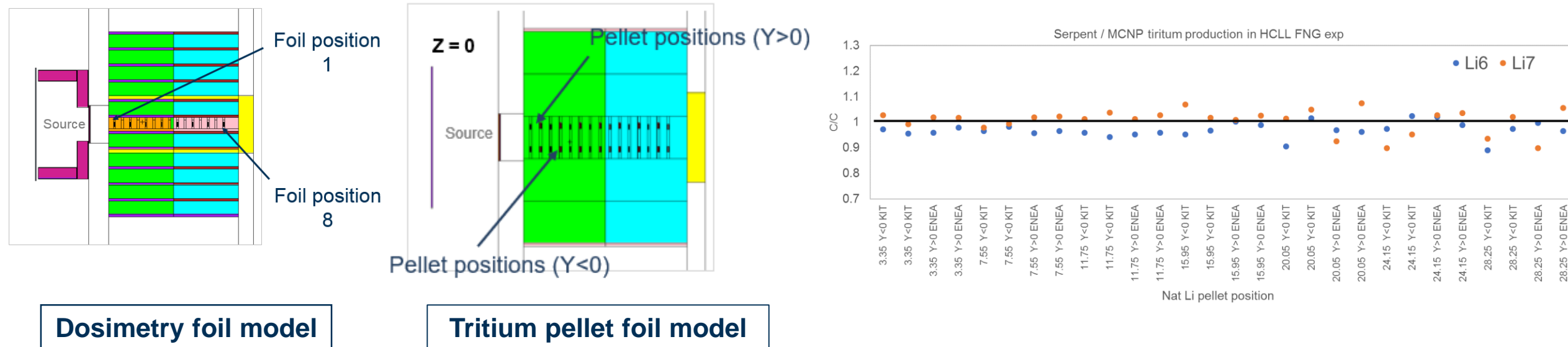
EUROfusion Serpent benchmarking activities in 2019

- The activities in 2018 are continued into 2019. As well as the **FNG HCPB** benchmark (below), we will identify other suitable benchmarks from the SINBAD database

- Of most interest is neutron/ photon flux, nuclear heating and tritium production.
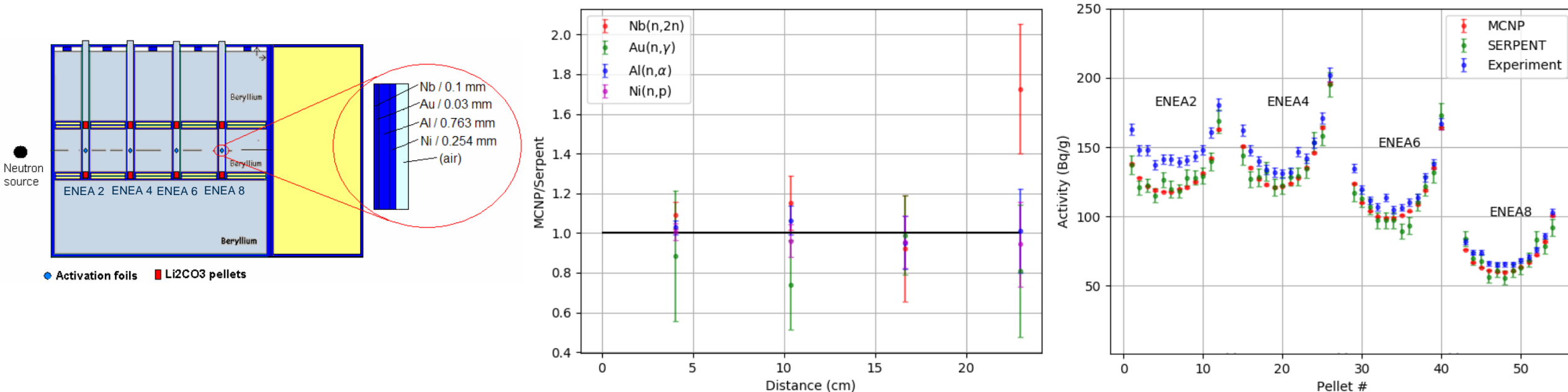
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General comments on SINBAD

Quality
- Quality control is relatively poor with current benchmarks. For example, several MCNP input decks are not valid and can not be ran without modification to input file.
- Some input decks / variance reduction methods in the distributed models may now be obsolete.

Repeatability
- All documentation is orientated towards journal publication. This leaves out certain details. In many cases, the origin of normalisations convolved with the calculational results is not clear. Reproduction of original calculational results is difficult
- HTML format is OK, however may benefit with additional report on the calculational model distributed with each benchmark

Availability
- Benchmarks available through NEA data bank and RSICC. We now have access to open source nuclear data as well as transport codes, can the distribution method of the benchmarks be revised?

Usability
- Certain inputs lack clear commenting/ comments require translation. Good practice, as with writing any code should be implemented and should be an integral part of the review stage

Completeness
- There is a lack of solely photon and photonuclear benchmarks
- Neutron and photon heating benchmarks are also of high relevance in fusion
- Should the benchmarks be distributed in other MC code formats as well as MCNP?
- Many of the older benchmarks are not distributed with MCNP models

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UKAEA Perspective: Future Benchmarks

- Recent government grant worth ~£20million given to UKAEA to conduct feasibility study for the design and construction of a spherical tokamak for energy production (STEP).

- This highly ambitious research program draws on the experience of industry and academia in the UK and aims to identify a pathway to supply net energy by the 2040s.

- STEP would greatly benefit from further specific shielding benchmarks, for example, a dedicated mock up of the inboard plasma facing components where extremely high heat density will necessitate strict optimisation of the design.

- Materials becoming more prominent in fusion reactor design, but not currently in SINBAD such as aluminium. There is also a revived interest in FliBe ($LiF-BeF_2$) as a coolant and breeder material. A benchmark dedicated to this material would be of value to the fusion community.

Fusion experiments: Measurement of ^{16}N during irradiation of First Wall mock-ups

- The collaboration aims to measure ^{16}N and ^{17}N production in water activated by DT neutrons and compare with calculations to reduce uncertainties in the calculation of radiation dose maps due to activated water.

- The main sources of uncertainty currently being due to modelling and nuclear data, and hence safety factors between 8.2 and 4.7 are applied.

^{16}O(n, p)^{16}N, ^{16}N (T$_{1/2}$=7.13s) $\rightarrow$ ^{16}O + γ (67% @ 6.13 MeV, 5% @ 7.12 MeV),

^{17}O(n, p)^{17}N, ^{17}N (T$_{1/2}$=4.17s) $\rightarrow$ ^{17}O $\rightarrow$ ^{16}O + n (37.7% @ 0.386 MeV, 0.6% @ 0.886 MeV, 49.8% @ 1.16 MeV, 6.9% @ 1.69 MeV), γ (3.7% @ 0.87 MeV).

- **Experiment scheduled 24th-28th June**
- **Project completion: 2nd August 2019**

External ring

Internal ring

Neutron detection

Gamma detection

This was!

ENEA

FUSION FOR ENERGY

Fusion experiments: Water Cooled Lithium Lead (WCLL) neutronics mock-up experiment

- The nuclear design and performance of breeder blankets fully rely on the results provided by neutronics calculations.

- An experimental campaign at ENEA is expected Nov/Dec 2019 aims to:
  - Provide a means to validate computational tools and nuclear data
  - Assess the prediction accuracy in providing fundamental data for the nuclear design, optimization and performance evaluation of DEMO, comprising safety, licensing, waste management and decommissioning issues.

- CCFE have been tasked with diagnostic activities to support the experiments, primarily dosimetry foils

- The foils will be embedded in the experimental region and used to monitor the local flux.

- Following irradiation at ENEA, spectroscopy measurements will be performed at ADRIANA – UKAEA Gamma Spectroscopy laboratory.

Trans-SPEC Portable HPGe detector

SAGe well detector

BEGe detector with NaI Compton suppression

190% RE coaxial HPGe detector

Activation foils can be placed in front of the bricks along the horizontal mid plane

Experimental region (detectors)

NNUF
National Nuclear User Facility
http://www.nnuf.ac.uk

EUROfusion   ENEA