UK Atomic Energy Authority

UKAEA

Modelling the Transport of Activated Fluids and Corrosion Products in Cooling Environments

C.R. Shand, T.A. Berry, R. Worrall, A. Dubas,
L. Humphrey, C.L. Grove, T. Kokalova Wheldon

UK Atomic Energy Authority

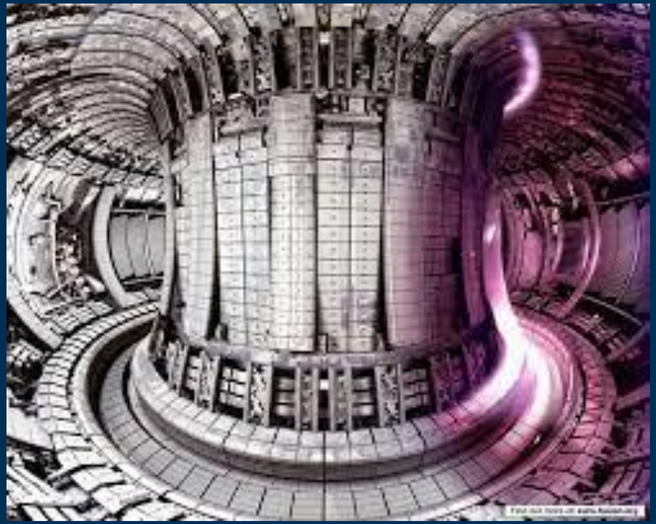
UK Atomic Energy Authority

5 divisions:

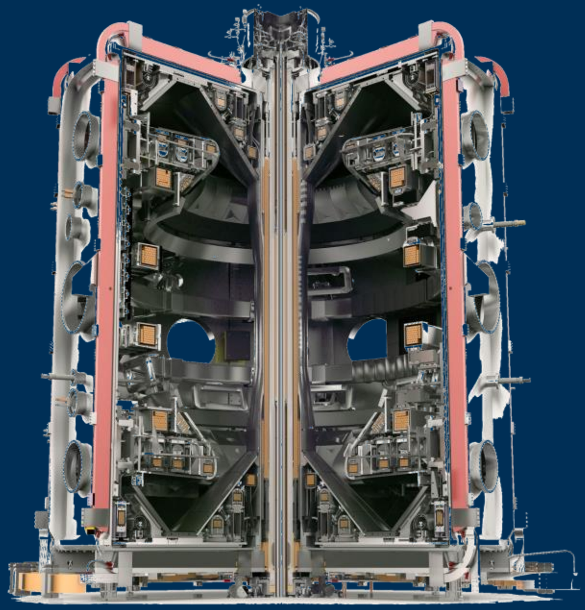
- **Plasma Science**
- **Fusion Technology**
- **H3AT**
- **Advanced Computing**
- **Materials Science**

UK Industrial Fusion Solutions Ltd (UKIFS)
Will deliver the STEP Programme, aiming to generate net electricity from fusion.

JET
Operated on behalf of EUROfusion and holds the world-record for fusion power



EUROfusion



MAST-Upgrade
A spherical tokamak primarily focused on plasma exhaust

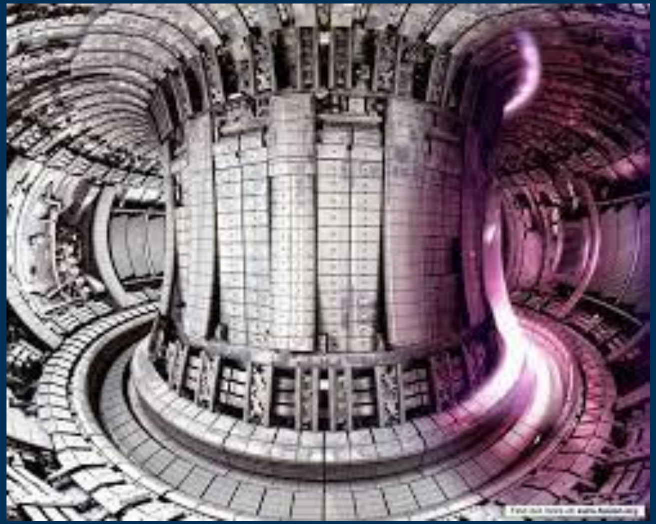
UK Atomic Energy Authority

UK Atomic Energy Authority

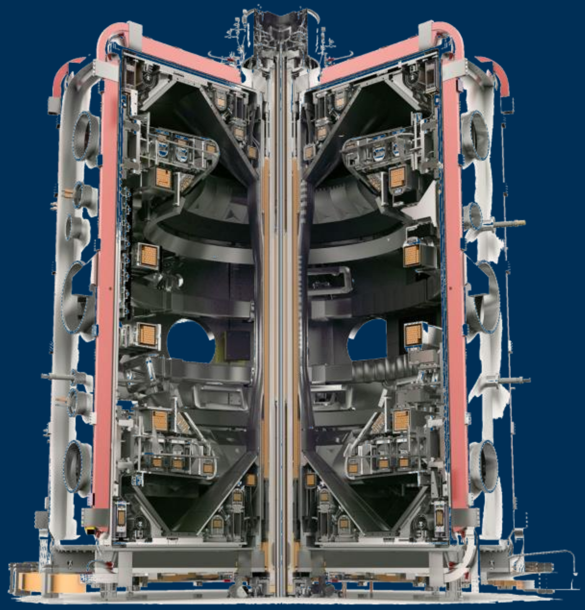
5 divisions:

- **Plasma Science**
- **Fusion Technology**
- **H3AT**
- **Advanced Computing**
- **Materials Science**

JET
Operated on behalf of EUROfusion and holds the world-record for fusion power



EUROfusion



MAST-Upgrade
A spherical tokamak primarily focused on plasma exhaust

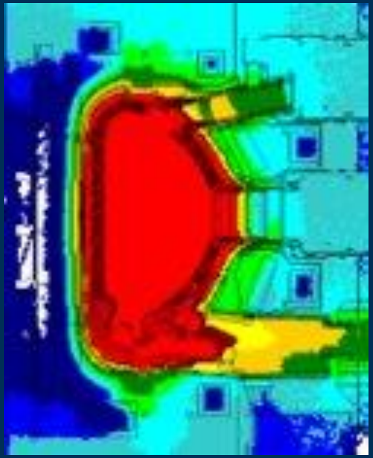
UK Industrial Fusion Solutions Ltd (UKIFS)
Will deliver the STEP Programme, aiming to generate net electricity from fusion.

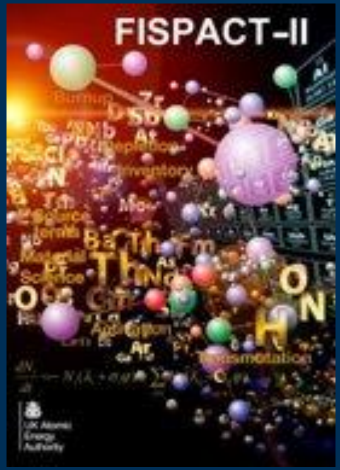
Applied Radiation Technology Group

UK Atomic Energy Authority

Neutronics Calculations:

- High resolution neutron/photon flux maps
- Material dose/DPA rates
- Gas production (e.g., He)
- Nuclear heating
- Tritium production





Activation Calculations:

- Nuclide inventory
- Radioactive waste
- Shutdown dose rates

Benchmarking and diagnostic development:

- High resolution gamma spectroscopy
- Low-background and Compton Suppression
- Radiation tolerant neutron diagnostics for real-time feedback
- Modern neutron spectrum unfolding techniques

2019 Water Activation Benchmark

The uncertainty in the calculation of radiation maps due to activated water are dominated by the modelling (approx. 200%) and the nuclear data.

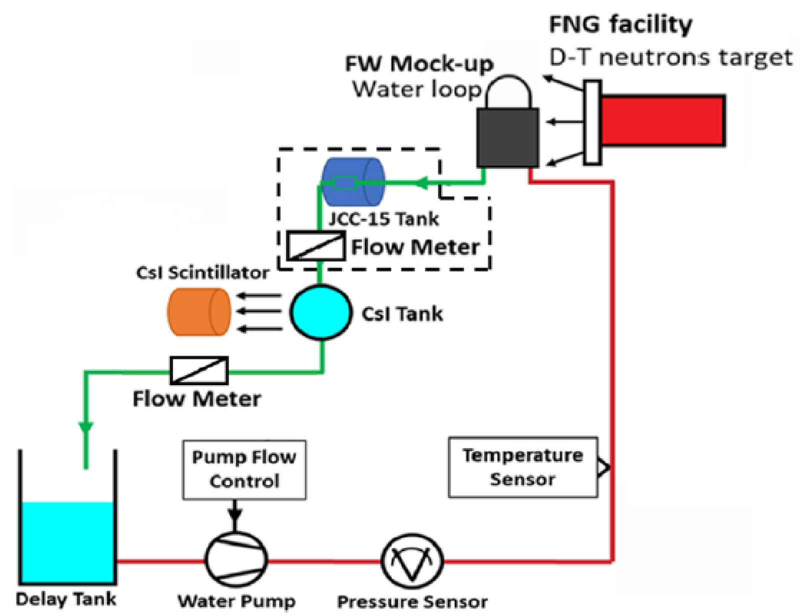
Safety factors between 8.2 and 4.7 [1,2] are applied. The motivation of this experiment is to validate the methodology and provide scientific justification to reduce these safety factors.

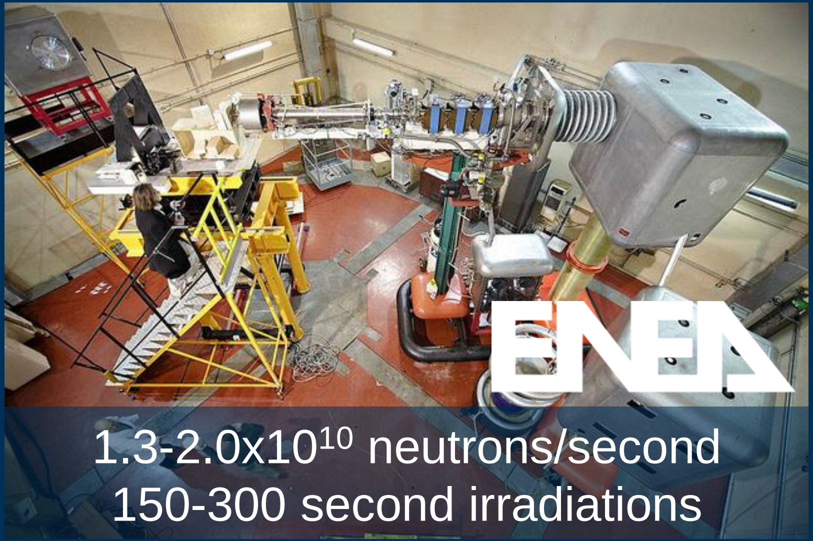
$$^{16}\mathrm{O}(n,p)^{16}\mathrm{N} \rightarrow \; ^{16}\mathrm{N}\;(\beta) \rightarrow \; ^{16}\mathrm{O} + \gamma,$$

$$^{17}\mathrm{O}(n,p)^{17}\mathrm{N} \rightarrow \; ^{17}\mathrm{N}\;(\beta^{-}\mathrm{n}) \rightarrow \; ^{17}\mathrm{O} \rightarrow \; ^{16}\mathrm{O} + \mathrm{n},$$

Challenges:

- Calibration – measuring 6.1 MeV and 7.1 MeV gammas and 0.4 MeV neutrons

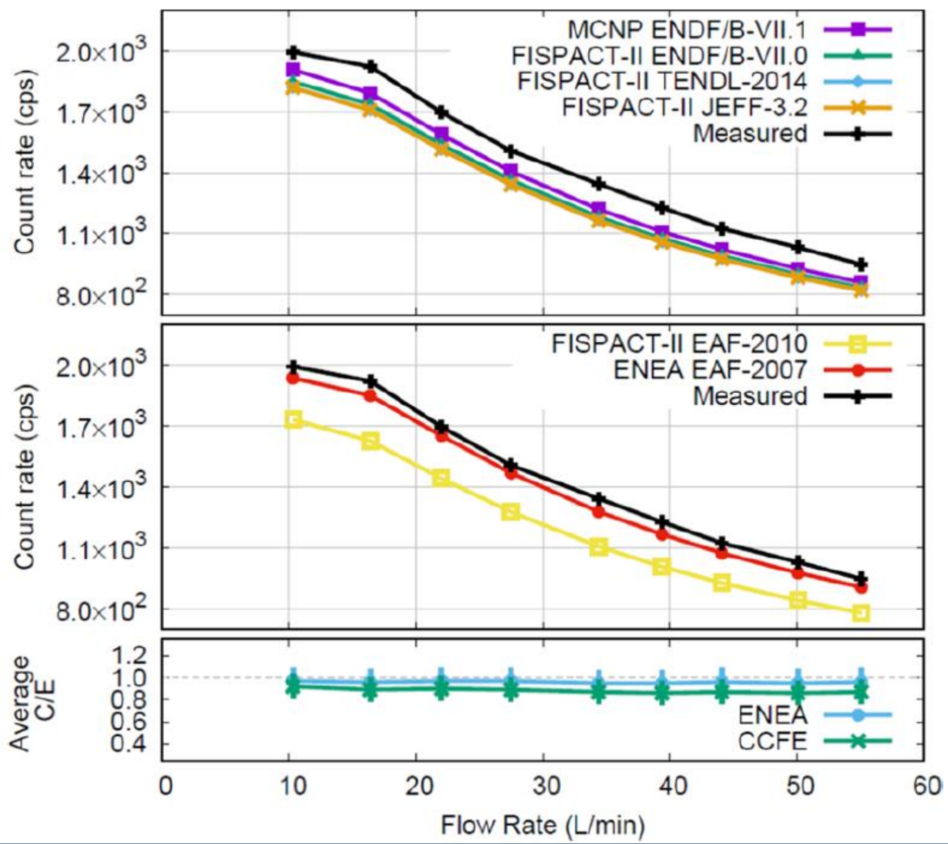




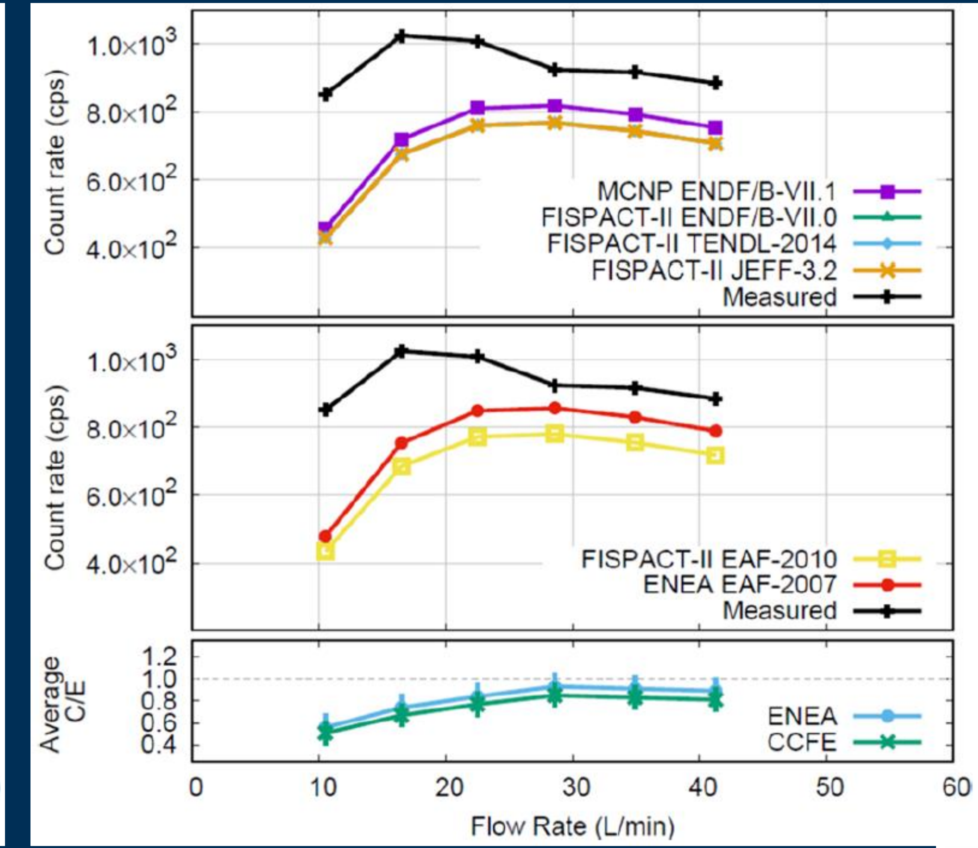
[1] S. Jakhar, et al., Calculation of activation water radiation maps in ITER, Neutronics Challenges of Fusion Facilities-II, Transactions of the American Nuclear Society 116 (2017).
[2] Nuclear Analysis of 16N and 17N radiation fields from TCWS activated water, IDM Number: ITER_D_QZ7BEK_v2.1, 16/11/2016.

2019 Water Activation Benchmark

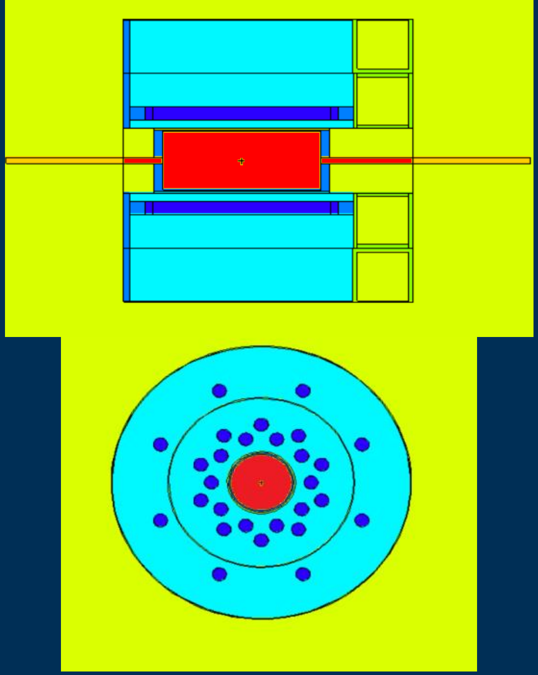
UK Atomic Energy Authority

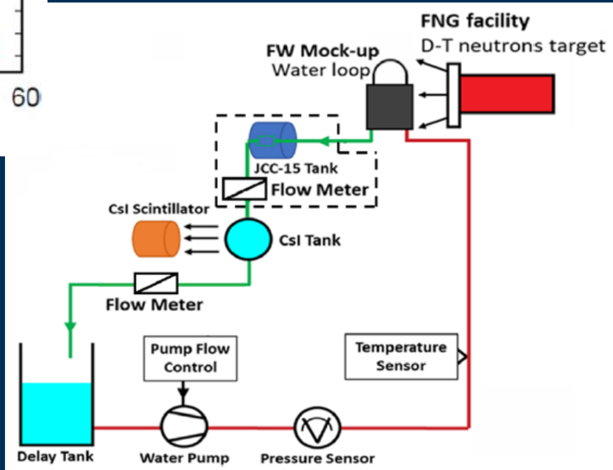


Count rate calculated for N-16 for circuit #1



Count rate calculated for N-16 for circuit #2





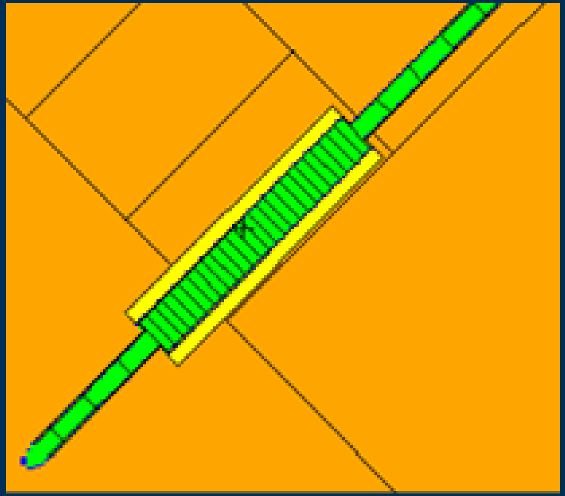
ENEA

FUSION FOR ENERGY

UKAEA Fluid Activation Codes

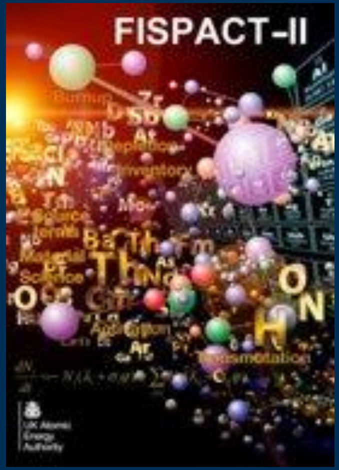
UK Atomic Energy Authority

Goal:
To develop a toolkit capable of tracking the activation and transport of fluids and corrosion products, with a focus on delivering fusion-relevant benchmark data.



GammaFlow
Uses pre-calculated reaction rates in cells to track the concentration of target isotopes in a system, optimised for simulating fluids where there are only a few reactions of interest.

Main benefits: Quick, simple, scalable.



ActiFlow
Uses the FISPACT-II API to calculate the activity and decay heat in voxels of a flux mesh tally for multiple isotopes simultaneously.

Main benefits: Handling complex fluids with many reactions.

G. Bailey, et al., The FISPACT-II User Manual, UKAEA-CCFE-RE(21)02 (2023)

Approach to CFD Calculations

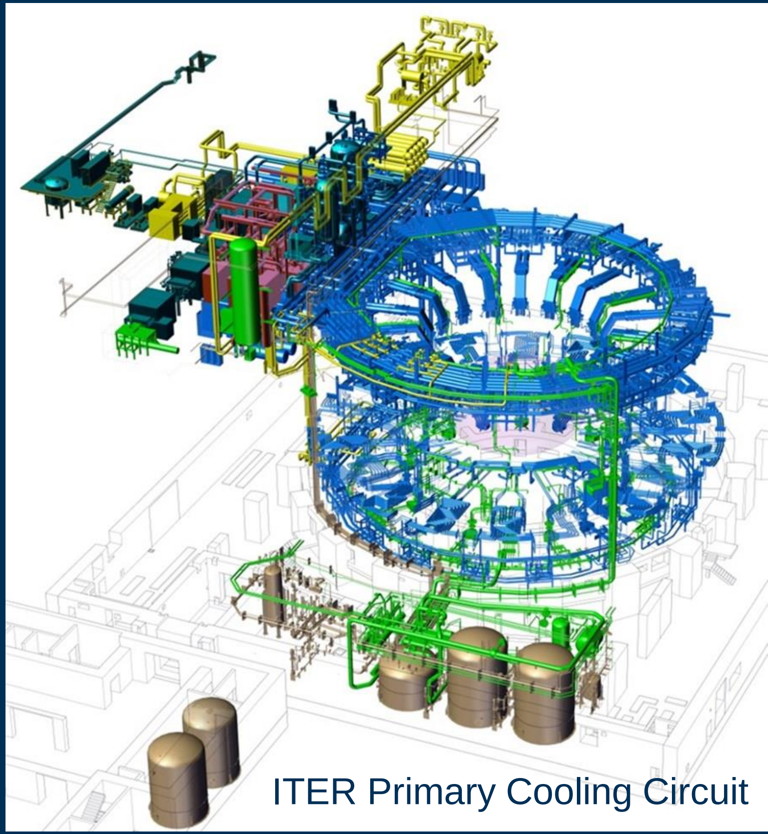
UK Atomic Energy Authority

Our approach assumes turbulent flow.

When the water flow is not in fully-developed turbulent conditions or when the geometry domain diverges from regular pipes, the uniform velocity methods can significantly miscalculate the activation of fluids.

The FNG water activation benchmark showed up to a factor of two underestimation in the N-16 concentration due to the presence of recirculation within a component.

When we scale to the complexity of a circuit like the ITER primary cooling circuit, it's clear that work is needed to validate our approach.



ITER Primary Cooling Circuit

Development of FARBASE

OpenFOAM

UK Atomic Energy Authority

Fluid Activation Residence time dataBASE

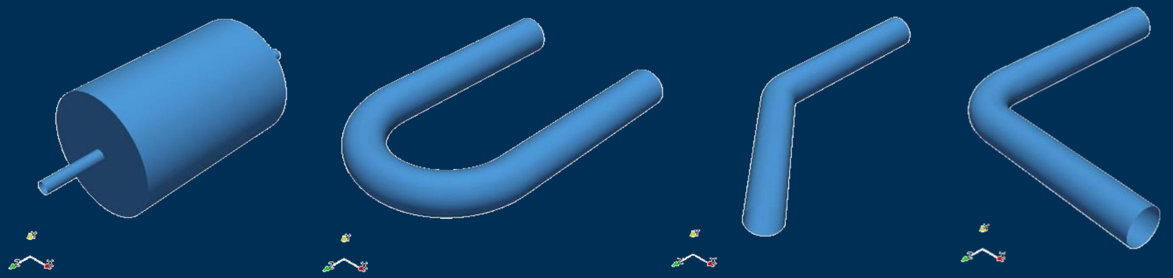
Motivation: to parametrically model large, complex water circuits with the ability recalculate quickly.

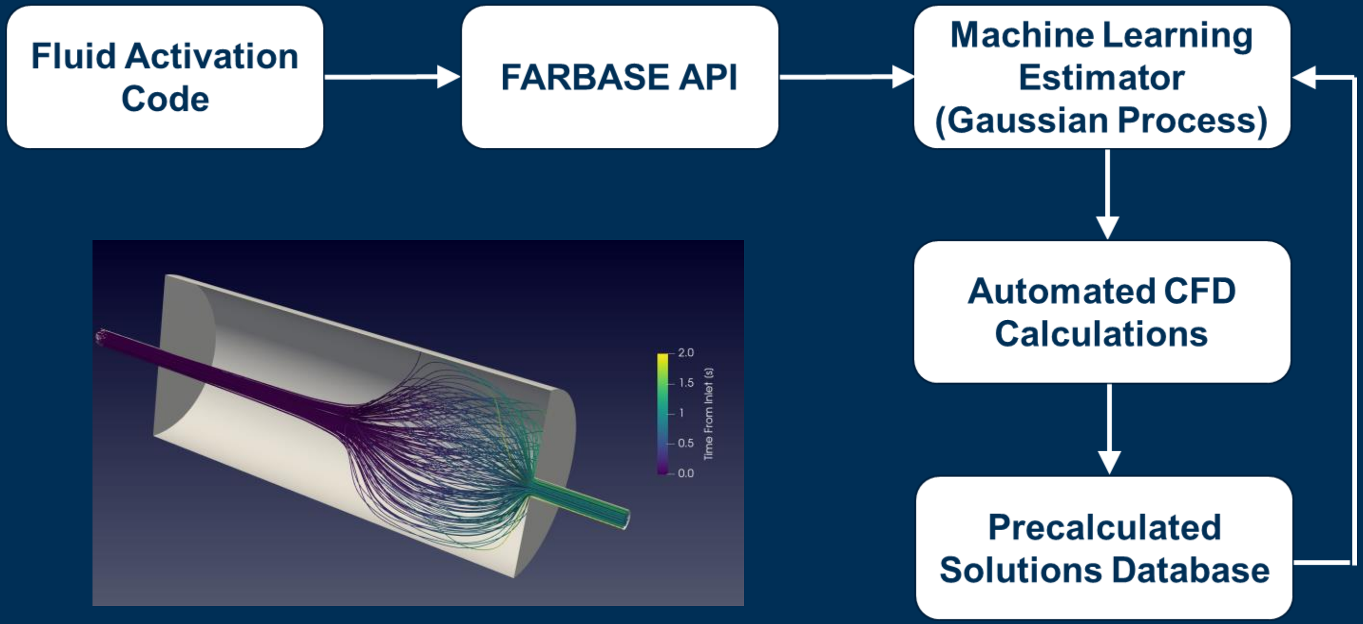
Components are generated using a parametric CAD library with meshing capabilities to generate input files for OpenFOAM.

The pre-calculated solutions database is populated by OpenFOAM for components with defined dimensions, flow rates, and density.

The machine learning estimator uses a Gaussian process to interpolate the residence time distributions for desired parameters.

If the error bands are too large, FARBASE automatically executes CFD calculations.



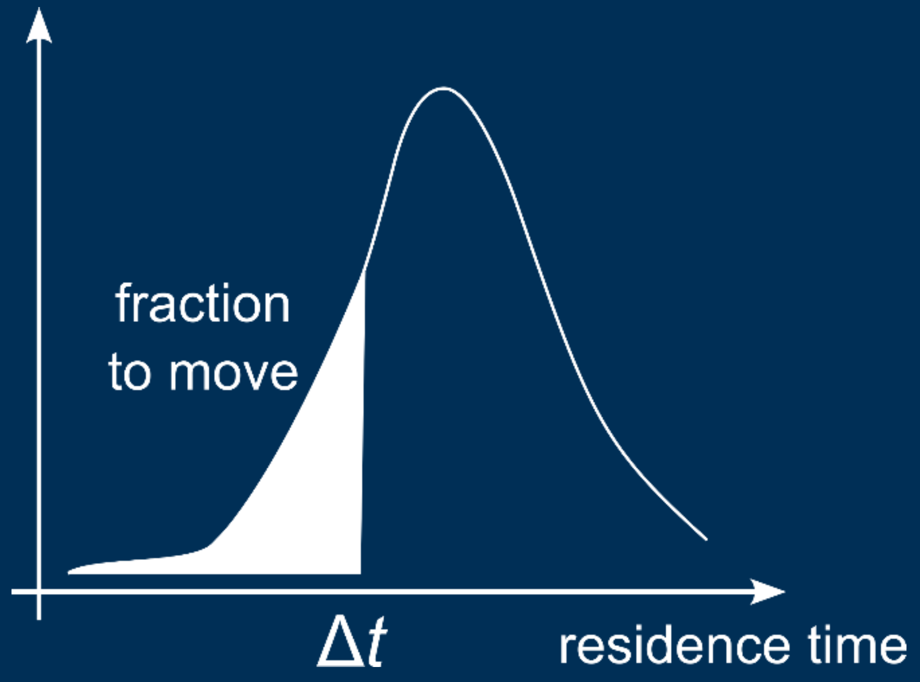


Integration of CFD into Fluid Codes

UK Atomic Energy Authority

FARBASE generates parameters which describe a probability density function (PDF) which can be used to reconstruct the residence time distributions for a given set of inputs.

Within ActiFlow and GammaFlow this can be implemented by defining how much fluid to move between cells for a given timestep.



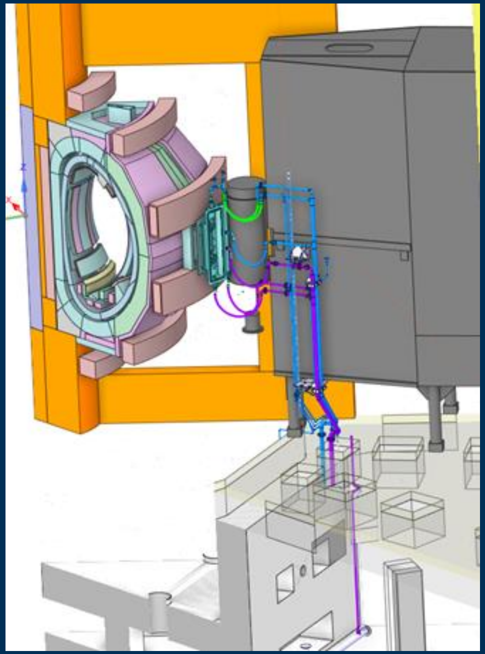
A key benefit of developing these codes at UKAEA has been to understand uncertainty, highlighting experimental benchmarks that would have the most significant impact.

2023 Water Activation in JET

CsI and BGO detectors placed in the basement of JET to monitor the decay gammas from N-16.

First test with a more complex irradiation schedule (pulses on the order seconds) and complex pipe network.

EUROfusion activity, the data will be available to EUROfusion participants to validate multiple codes.



2024 Water Benchmark at JSI TRIGA Reactor

Planned Benchmarking Experiments

Positron Emission Particle Tracking **(**PEPT) technique developed at the Positron Imaging Centre (PIC) at the University of Birmingham, in the UK.

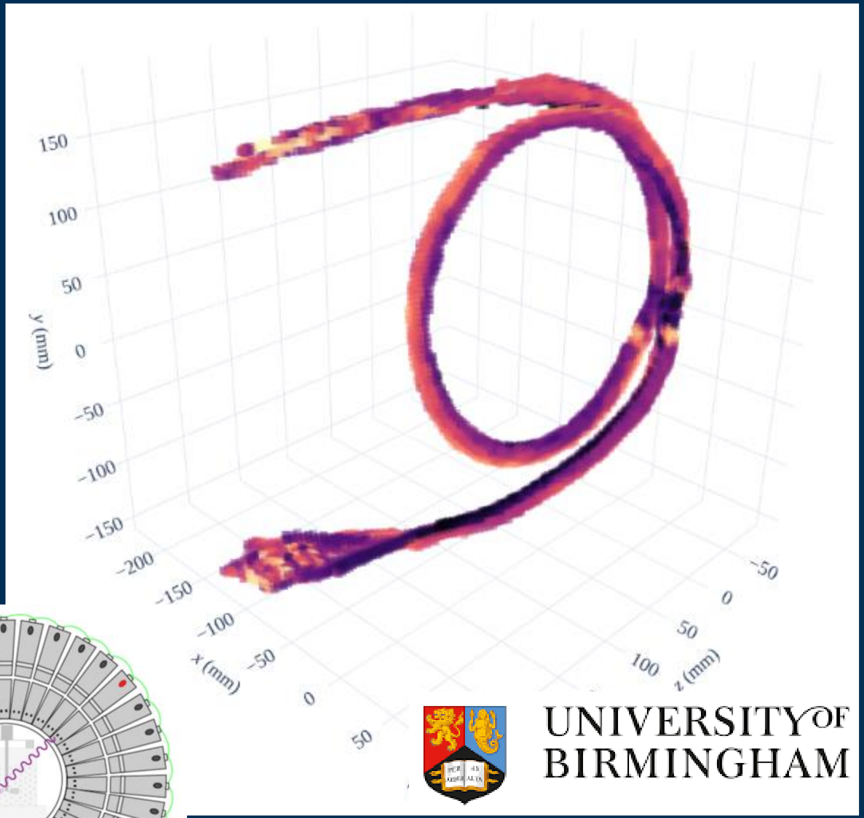
It uses the same diagnostics and positron annihilation phenomenon as used in Positron Emission Tomography (PET) technique, used in medicine.

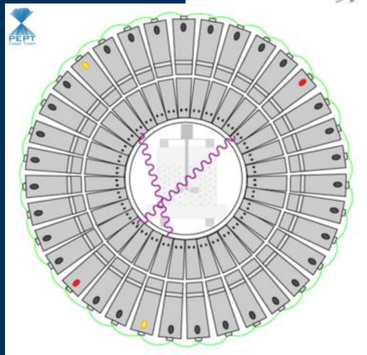
In PEPT a radioactive tracer particle is used to determine the location of individual particles accurately as it moves through a system.

At the University of Birmingham:

- Radioactive tracers can be produced using the cyclotron beam (MC40)
- It is possible to track multiple particles, so long as they remain at 2w.

Particle size: 50 µm – few mm
Spatial resolution (w): 6 mm





Experimental Benchmarking with Alternative Fluids

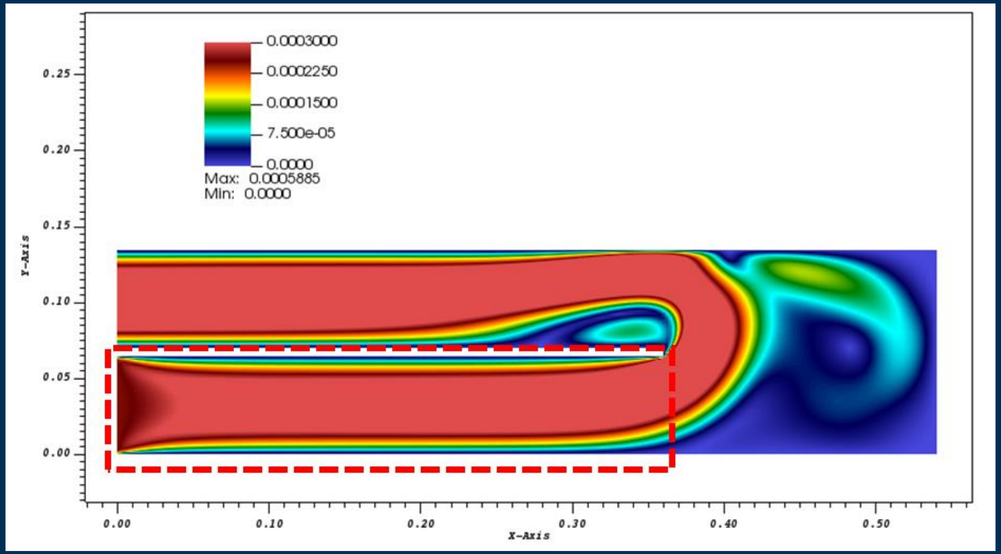
UK Atomic Energy Authority

Fusion-relevant benchmark data is limited. Work so far has focused on water activation and transport, to complement this there would be value in a benchmark for high-density fluids, e.g., LiPb.

Experiments using LiPb directly are challenging, alternative fluids with similar density and viscosity (density ~10 gcm^{-3} and viscosity 1E-3 Pa.s at 600^{o}C).

Sodium polytungstate (or sodium metatungstate)
$3Na_2WO_4 \cdot 9WO_3 \cdot xH_2O$
Density in solution: up to 3.1 gcm-3

Galinstan (gallium, indium, tin alloy) Density: up to 6.44 gcm-3



UK Atomic Energy Authority

Thank you for your attention

Dr Chantal Shand

chantal.shand@ukaea.uk