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# UKAEA LIBRTI

# The objectives and science basis of the LIBRTI test facility

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# Outline

- Motivation for a test facility: the LIBRTI programme
- (Digital) Science objectives within LIBRTI R&D
- Simulations to test scientific feasibility
  - Modular solid-breeder mock-up design
  - Tritium production rates
  - “Ability to measure” assessment
- LIBRTI status

 

# Fusion fuel cycle challenge

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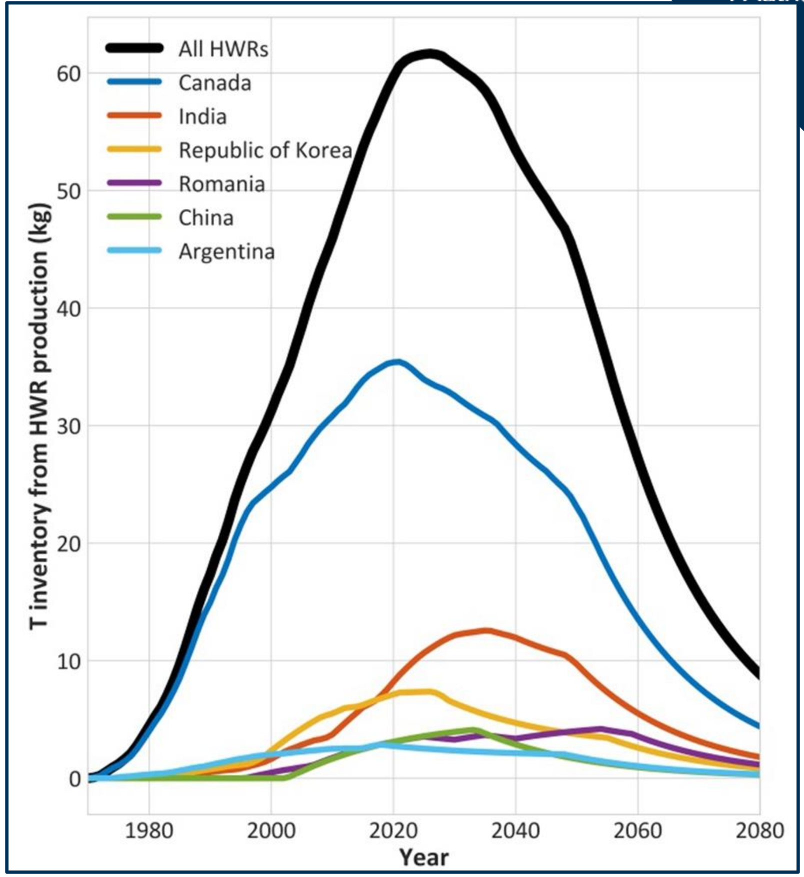
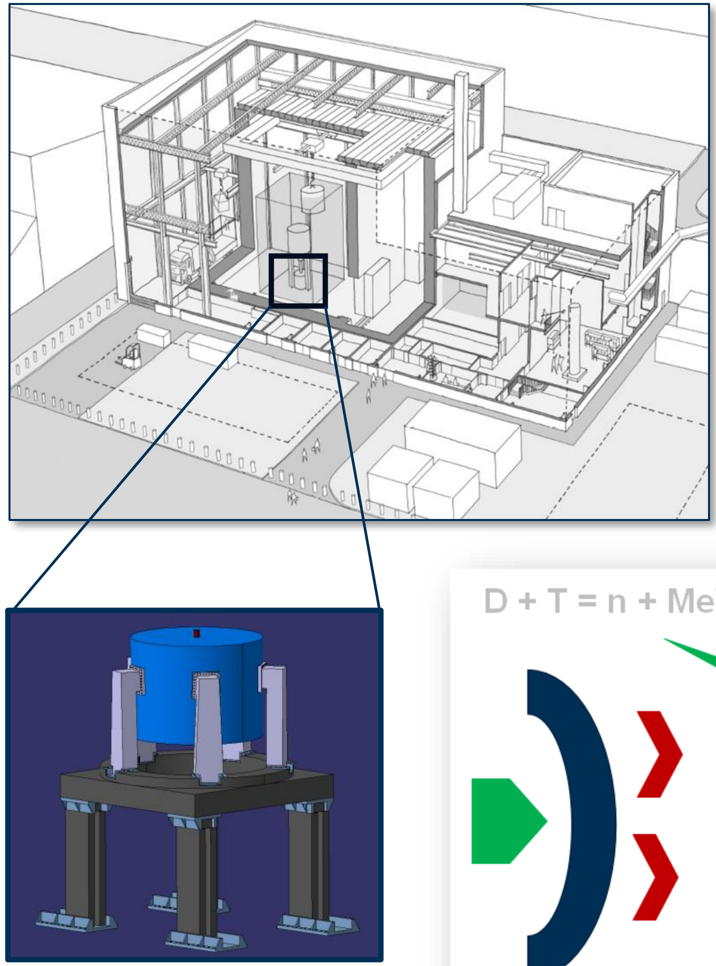
- Tritium $^3H$ supplies are very limited, and each GW of deuterium-tritium fusion power will burn ~ 50 kg per year
- Thus, a viable fusion power plant must be tritium self-sufficient
- Developing technologies that will enable a plant to produce at least 1 $^3H$ atom for each D-T reaction is a critical challenge for fusion
- This development needs to be accelerated …

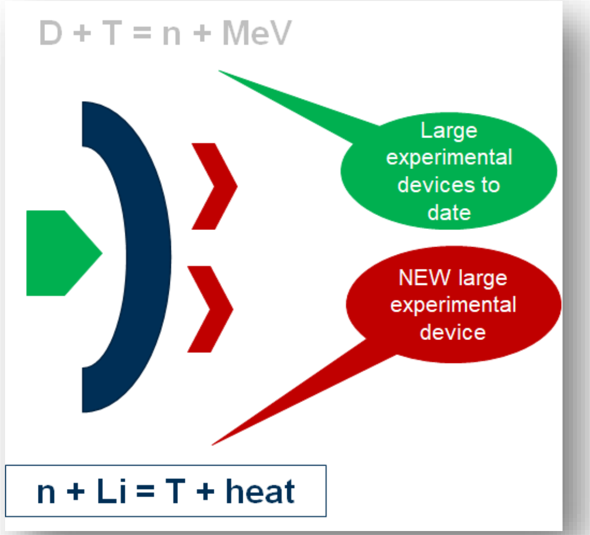



Estimates of tritium availability from fission sources (neglecting any use)
Kovari et al. Nuclear Fusion 2017

# LIBRTI: ~£200m Fusion Fuel Capability



## LIBRTI – LIthium BReeding Tritium Innovation




- ✓ Predict and reproducibly achieve Tritium production
- ✓ Known quantity of tritium out for known quantity of neutrons
- ✓ Science Simulation underpinned by experiments
- ✓ Learn by doing – Develop Skills
- ✓ Moving Science towards Engineering

**A globally unique testbed for benefit to the fusion powerplant design and construction**

# Science and engineering goals for LIBRTI

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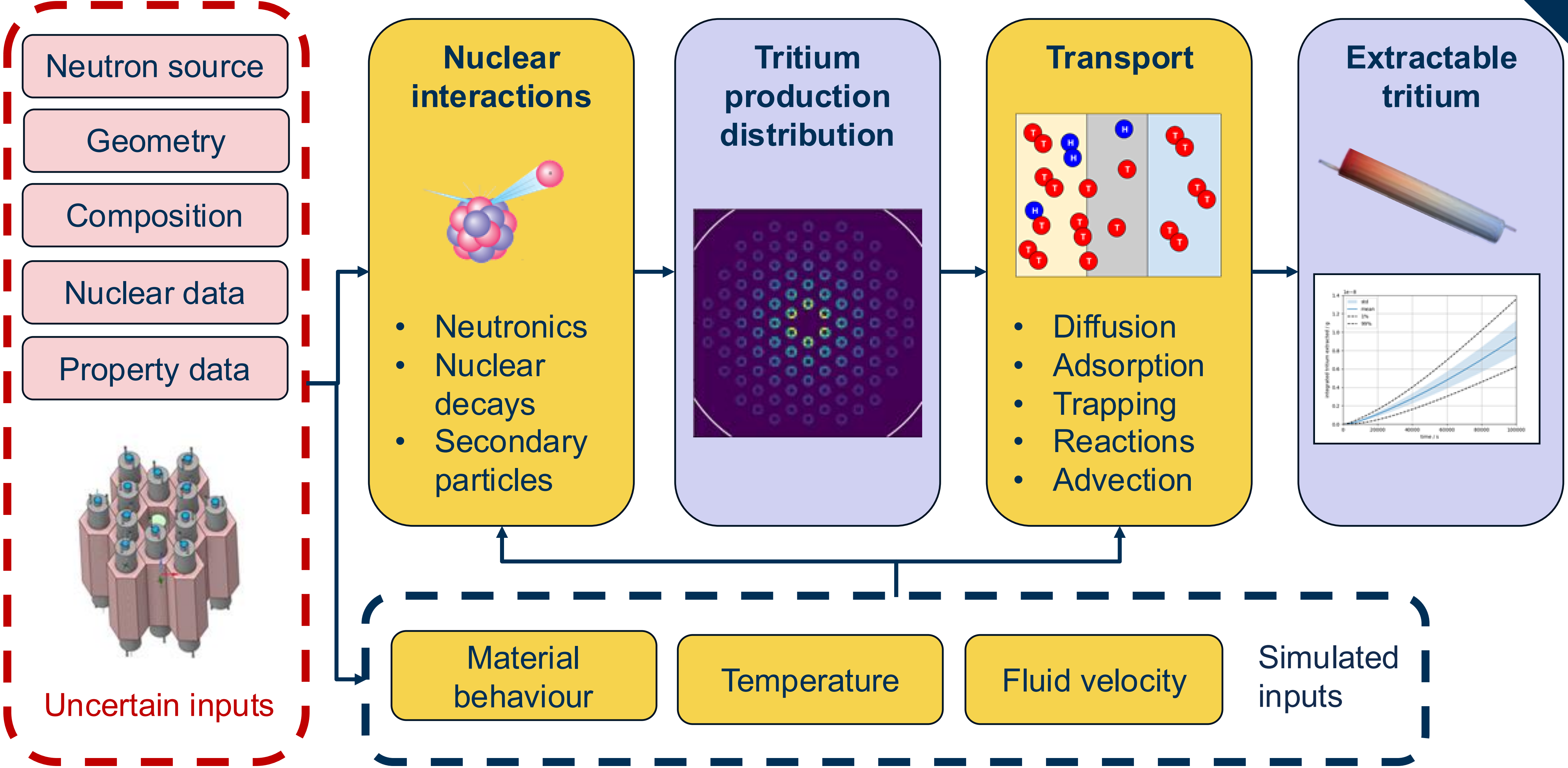
- Deliver a facility capable of testing engineering scale (~ $m^3$) mock-ups of tritium breeding concepts
  - Built around a neutron source producing DT fusion neutrons and sufficient flux to go beyond the current state-of-the-art (typically static) breeding tests
- Experimental programme(s) to design, test and manufacture mock-ups of breeding blanket concepts
  - Final goals are integrated engineering scale mock-ups tested at the LIBRTI neutron source

## Why?

1. To improve understanding of the factors that determine tritium recovery rates
2. **To develop new models and theory for an integrated multiphysics platform**
3. **To test, validate and verify the integrated models using LIBRTI measurements**
4. *Use those V&V models to design breeding solutions for fusion devices (including supporting the finalization of the UK-STEP blanket)*

# Modelling Tritium Lifecycle

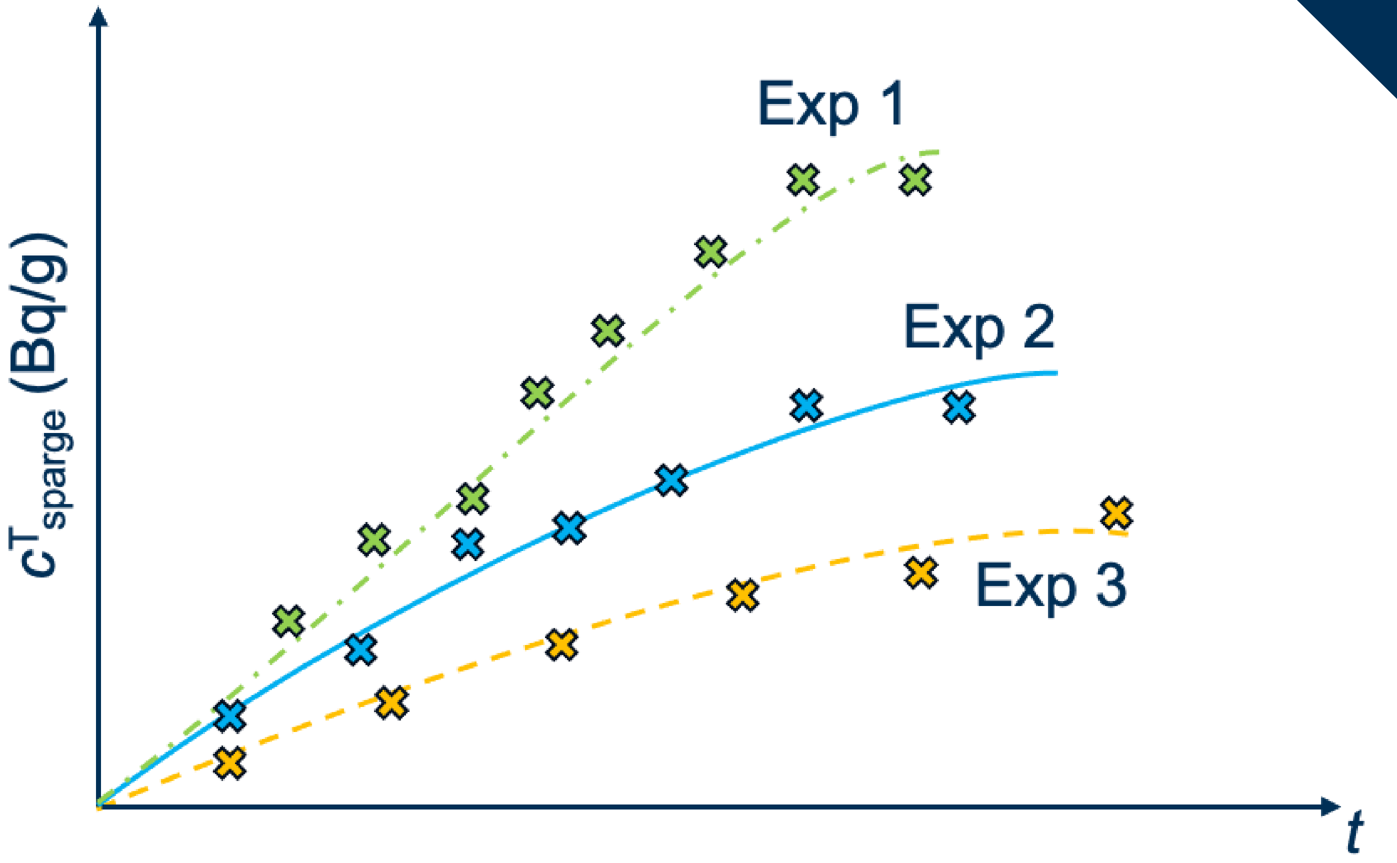



H. Brooks 2025

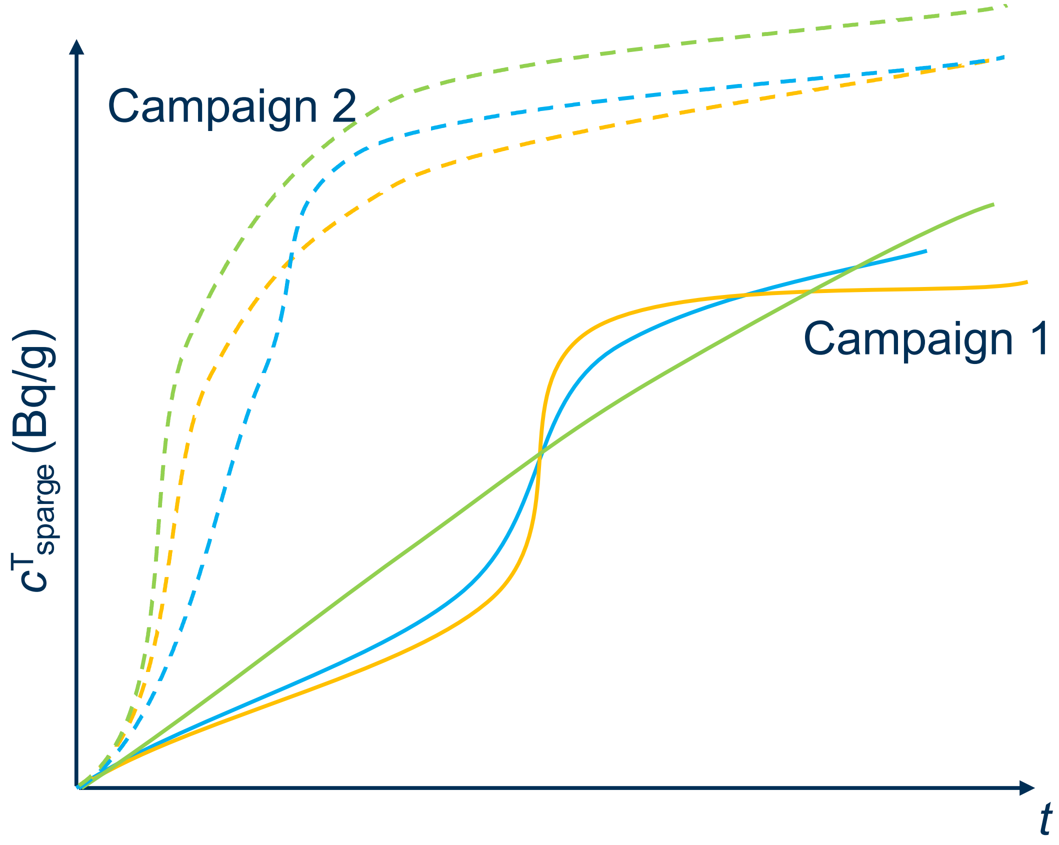
# How

- Repeated experiments on a mock-up, varying single parameters and measuring the change in the response curve
→ e.g., of tritium concentration in a sparge gas as a function of time
- Testing the models to confirm their ability to simulate the change impacts
  - Developing new models/theory as needed
- But to achieve the objective of a qualified Multiphysics platform we will need UQ…



# UQ requirements

- Repetition is also needed because a single response curve for one set of parameters (single set-up of an experiment) won't be sufficient
  - **Measurement uncertainty**
  - a series of repeated experiments to confirm response
  - campaigns of experiments



# UQ requirements (2)

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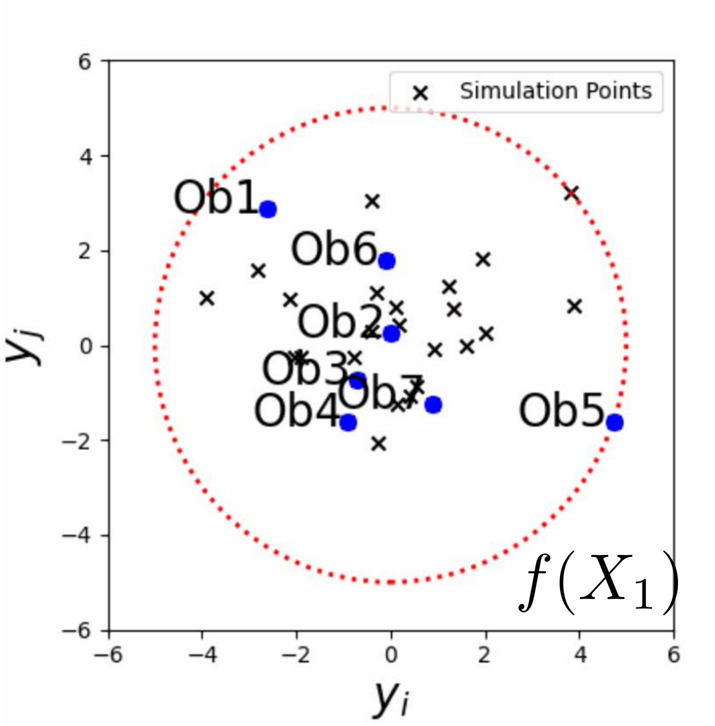
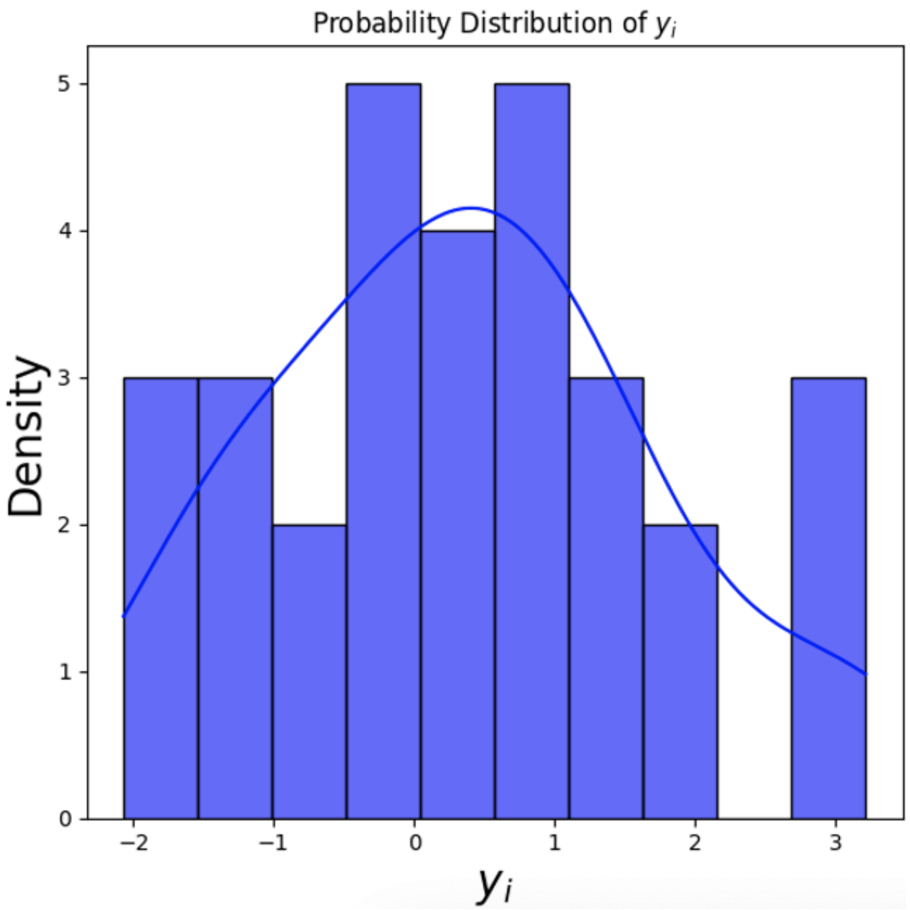
- For a fixed experimental set-up, a LIBRTI simulation will have a distribution of initial conditions and produce a distribution of simulation outcomes
  - and the equivalent set of experimental observations will also vary
- **Simulation uncertainty**

$$X_i = (\mathbf{x}_i, \sigma_\mathbf{i}(e), \phi_{is}(e), M_i(\mathbf{x}), \ldots)$$

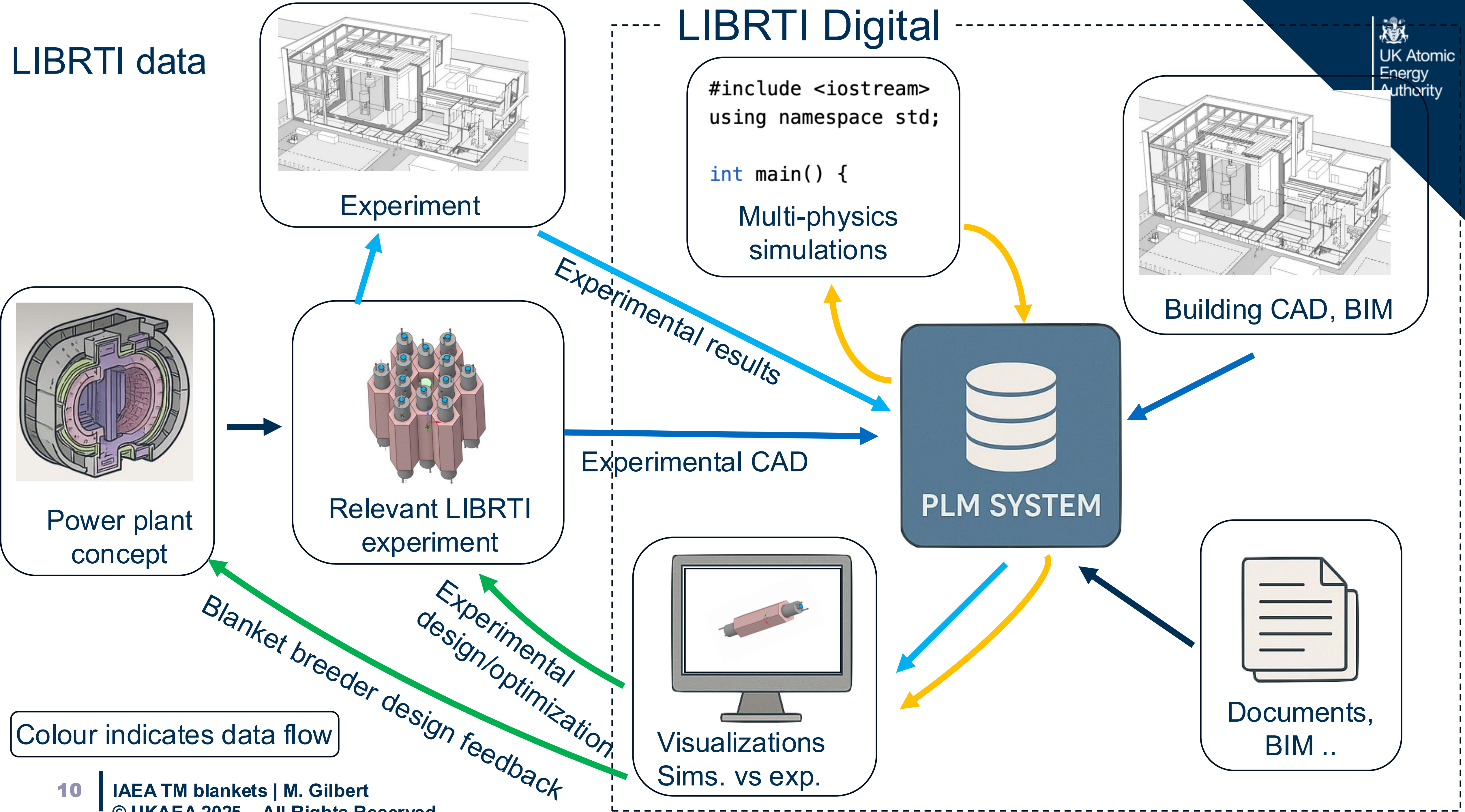
$$\vec{y} = f(\vec{X})$$

We are developing the infrastructure to enable the desired digital outcomes including UQ



# LIBRTI data



LIBRTI Digital
Experiment
#include <iostream>
using namespace std;
int main() {
Multi-physics simulations
Building CAD, BIM
Experimental results
Experimental CAD
PLM SYSTEM
Power plant concept
Relevant LIBRTI experiment
Experimental design/optimization
Blanket breeder design feedback
Visualizations Sims. vs exp.
Documents, BIM ..
Colour indicates data flow

# Validation of science basis

# Feasibility questions

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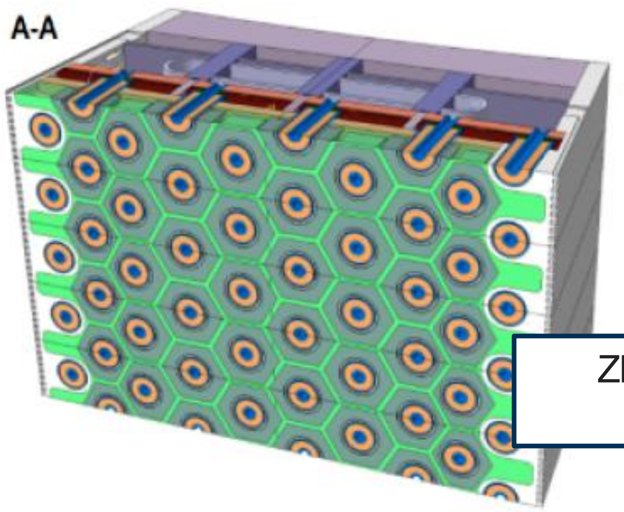
- Are the performance characteristics of the intended LIBRTI facility and the neutron source sufficient to meet the experiments objectives?
- Will measurable levels of tritium be produced?
- Will a DT based neutron source interfere with tritium measurements in an experiment?

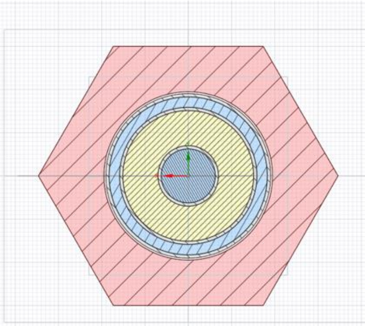
- The answers to these questions will inform further developments of the facility
- The answers have been investigated by preliminary simulations…

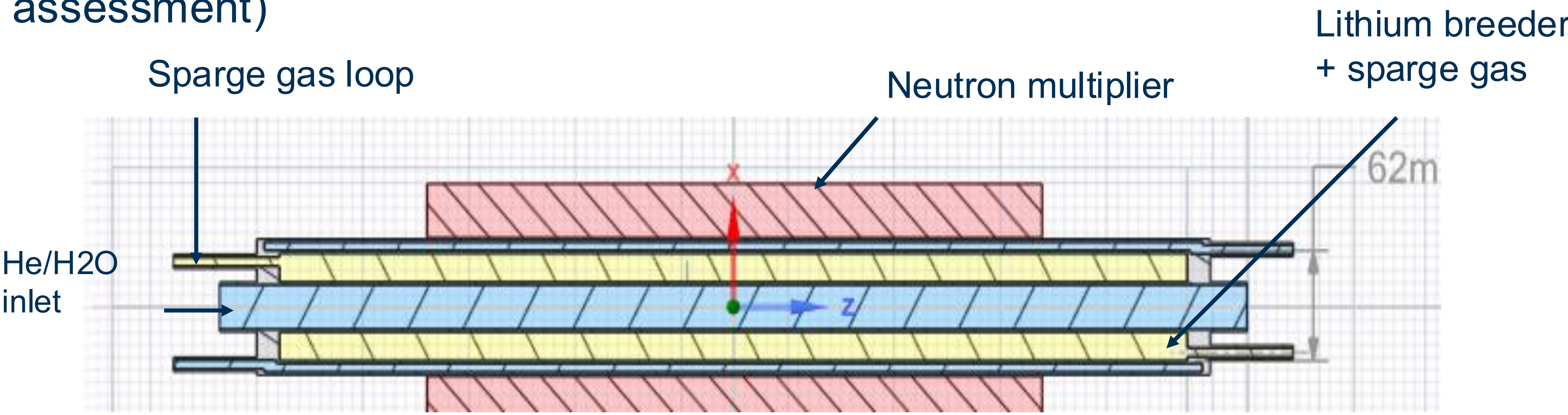
# Pincell design

- Modular system - Inspired by the DEMO HCPB design
- Motivated by providing a flexible, low-cost, design that can be used to test different breeder configurations in different neutron environments
  - Stainless steel (316) tubes
  - hexagonal cross section to enable pins to be integrated together
  - 2 cm multiplier layer (lead was assumed for the preliminary assessment)



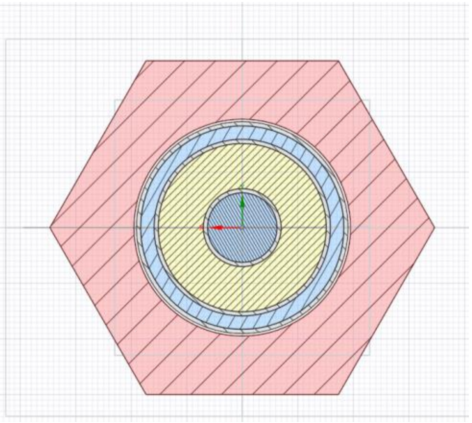

Zhou et al. *Appl. Sci.* **2023**

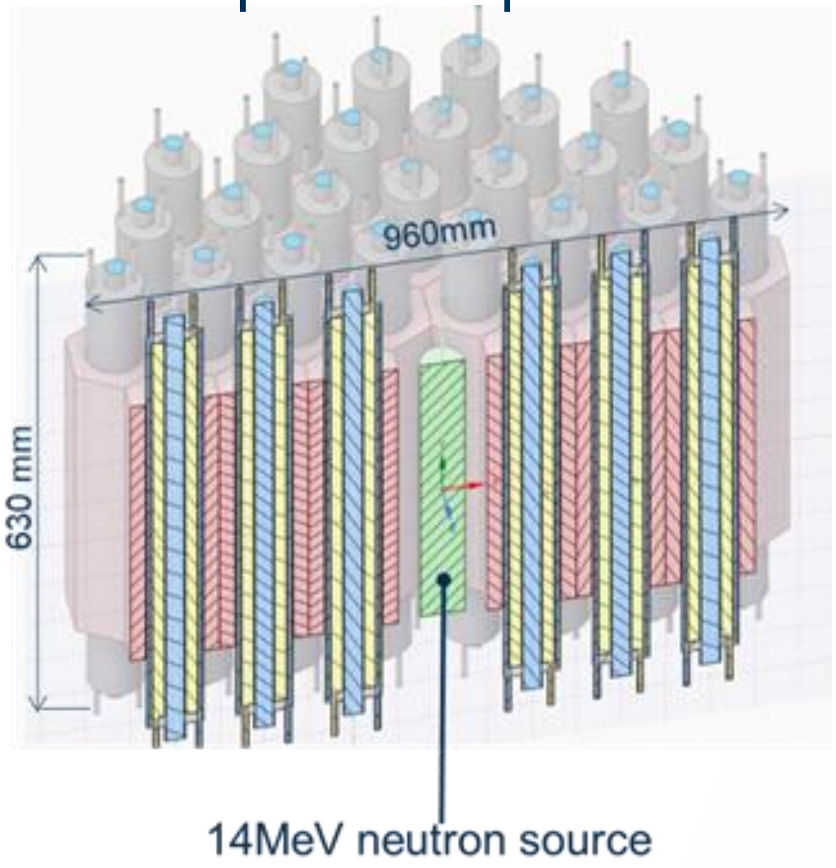


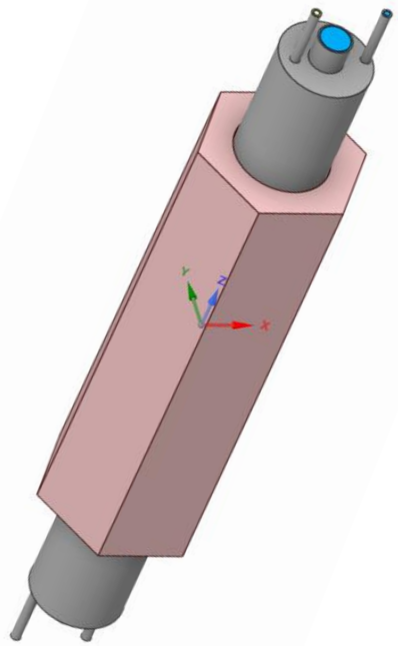


# Modular set-up

- Multiple pincells envisaged in a full-scale experiment
- For example: a 54 pincell arrangement:





- Potential opportunities from such a configuration:
  - $^{3}H$ output variations in different locations as a function of different experimental configurations (different materials, different geometry, etc.)
  - Each pincell can be a different experiment and can be rapidly changed, re-used and sent for post-experimental analysis (attractive for universities in particular)

# Opportunity? Importance of angular scattering

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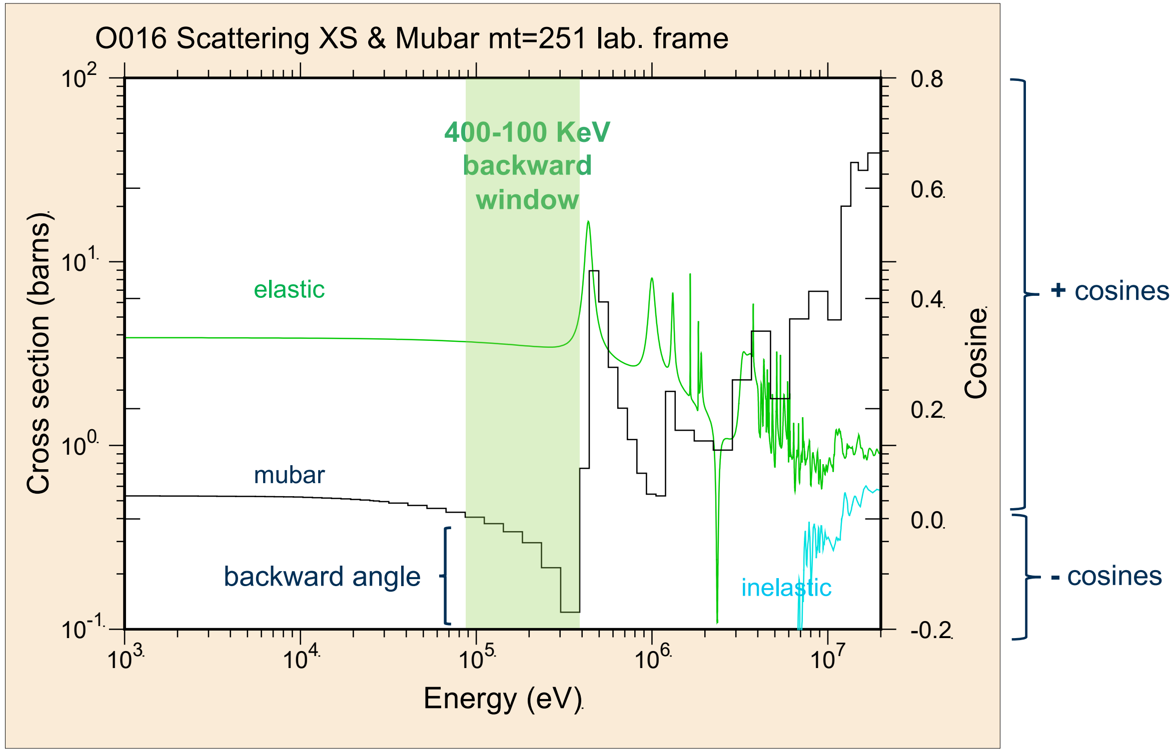
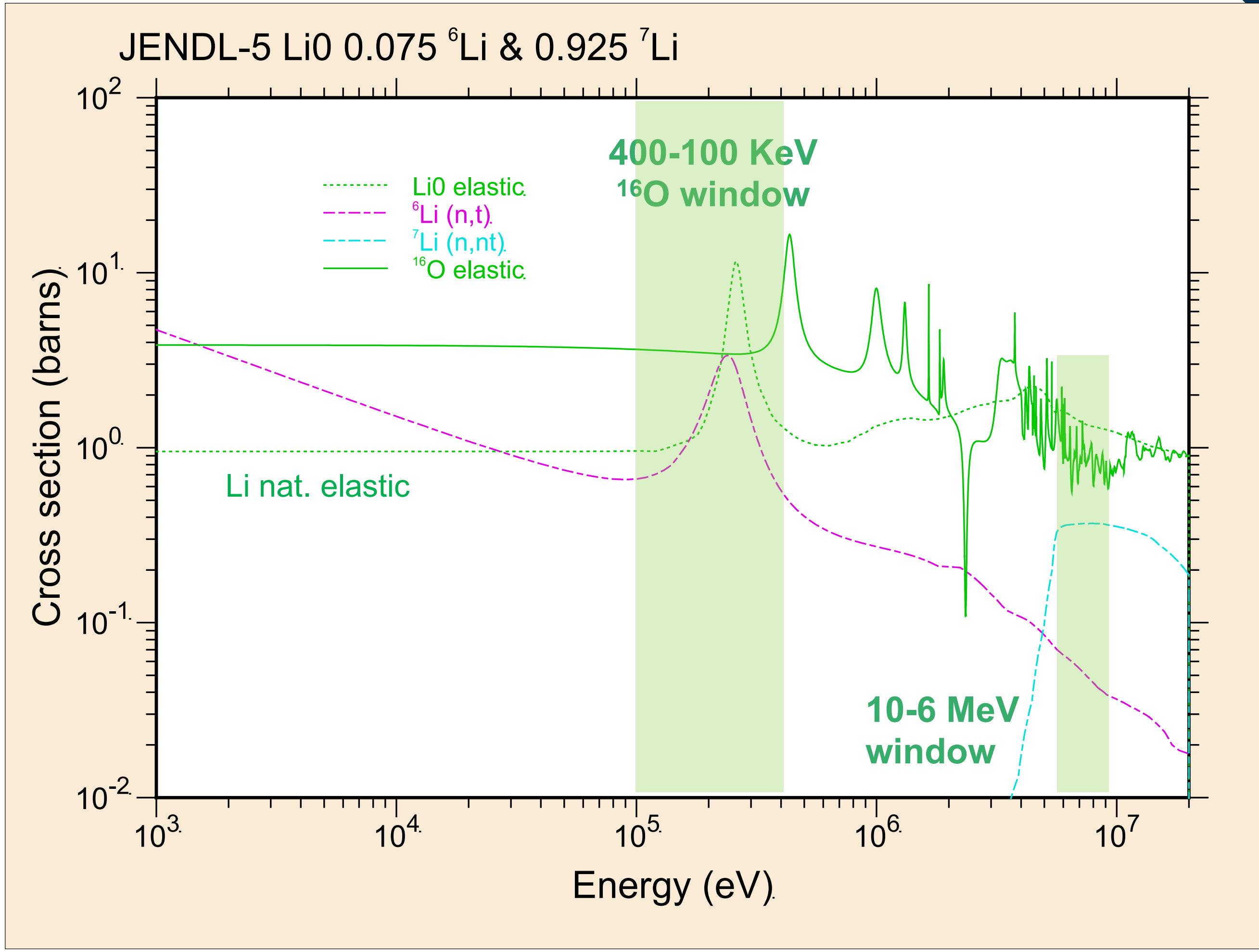


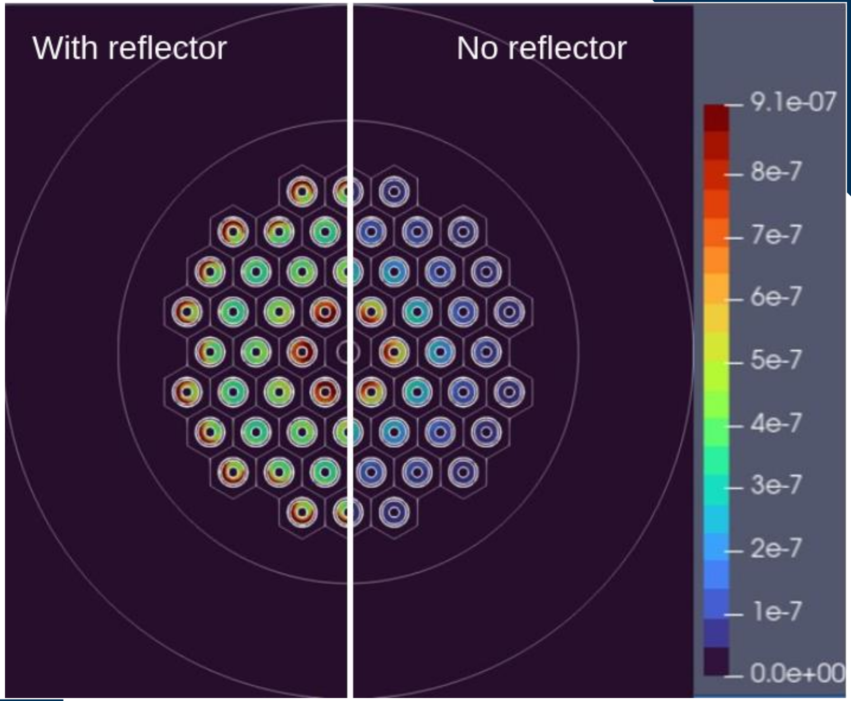

- tritium generation rate depends on neutron scattering through materials (including angular variation)
  in Li and other materials of breeder systems
- **$^{16}O$ 400-100 keV** negative mubar could **enhance** tritium production in the $Li^6$ 240 keV resonance region – needs design and testing (via pincells?)
- Relevant to breeder blanket designs that include O – such as $Li_4SiO_4$ ceramic

# Neutron transport and tritium production

- Early results assuming breeder material based on the mixed ortho-silicate and titanate lithium ceramic produced via the KALOS process at KIT

- Simulated estimates of tritium production rates:

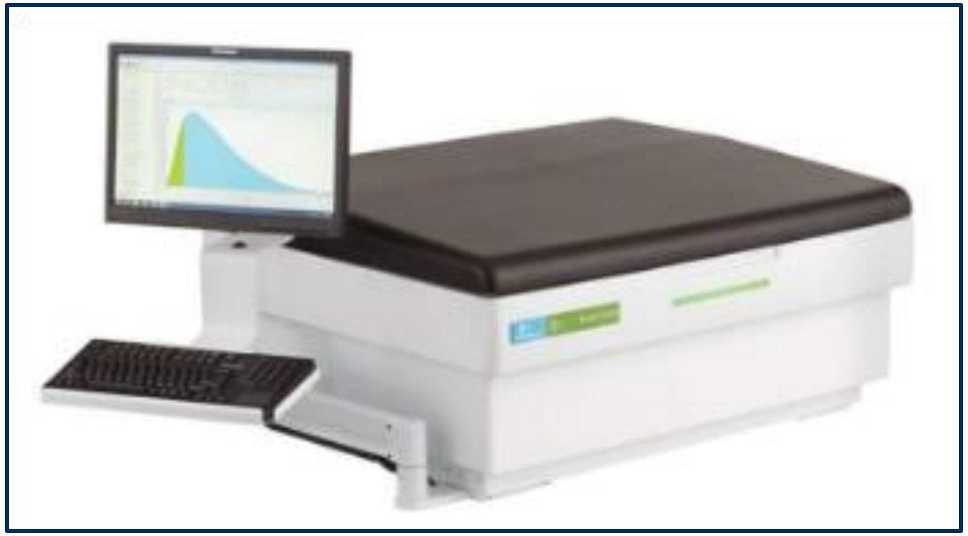
| | Without reflector | With reflector |
|---|---|---|
| Neutron source rate | $5 \times 10^{13}$ n/s | |
| Tritium production rate | $4.4 \times 10^{12}$ $^{3}$H/s | $2.5 \times 10^{13}$ $^{3}$H/s |
| Equivalent activity | ≈ 8 kBq/s | ≈ 45 kBq/s |




- Tritium production rate per source particle per cm$^3$ ($10^{15}$ source strength)
- Can also consider, for example, a graphite reflector surrounding the 54 pincells

# Measurement feasibility

- Liquid scintillation counting (LSC) is the current the best solution for high sensitivity measurements
- Sensitivities of 0.6 mBq/g can be achieved using coincidence correction and low background systems*
- Even accounting for delay of release from solid pebbles of KALOS the predicted tritium production rates will be readily detectable
  - For example: 1000 Bq/g/s release rates have been detected from 0.5 mm KALOS pebbles pre-loaded with $^{3}H$ at 600 °C (Kolb et al. JNM 2017 v. **489**)
  - More recently: Wu et al., in Int. J. Hydrogen Ene., **68**, (2024) 1393 found that complete tritium release from $LiTiO_3$ irradiated at HINEG-CAS was achieved within 4 hours at ~1000K



*Parker et al. Prog. Nucl. Ene 2023 v.**162**

# Signal vs. noise consideration

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- Will the signal from tritium generated in the experiment be lost in contamination from the tritium-based neutron source?

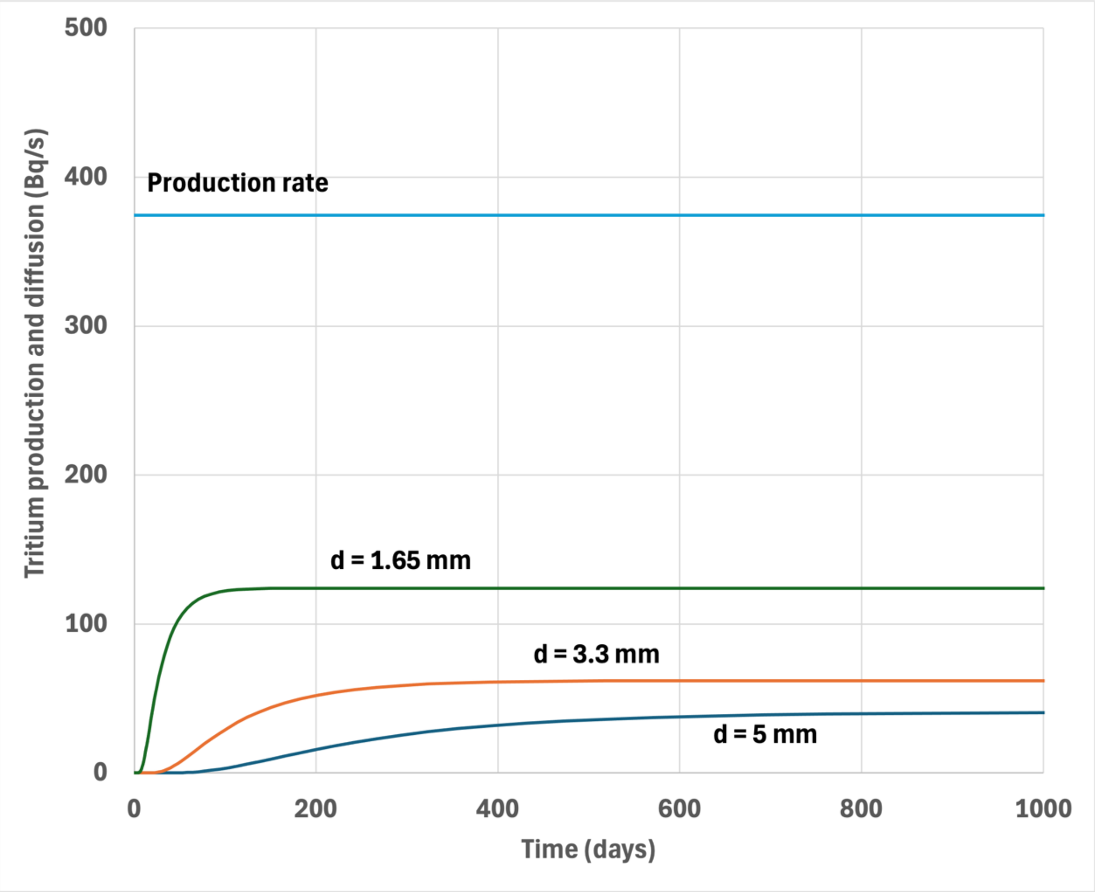
Early modelling of tritium transport from target chamber to an adjacent pincell:

- For a worst case upper bound: simple single wall of SS316 surrounding the tritium gas of the neutron source target chamber
- Estimate the rate of tritium diffusion out of the target chamber using change of concentration *C* solution via diffusion equation with diffusion constant *D*
- Compare to tritium production rate in the pins
- Consider different thicknesses (d) of steel …

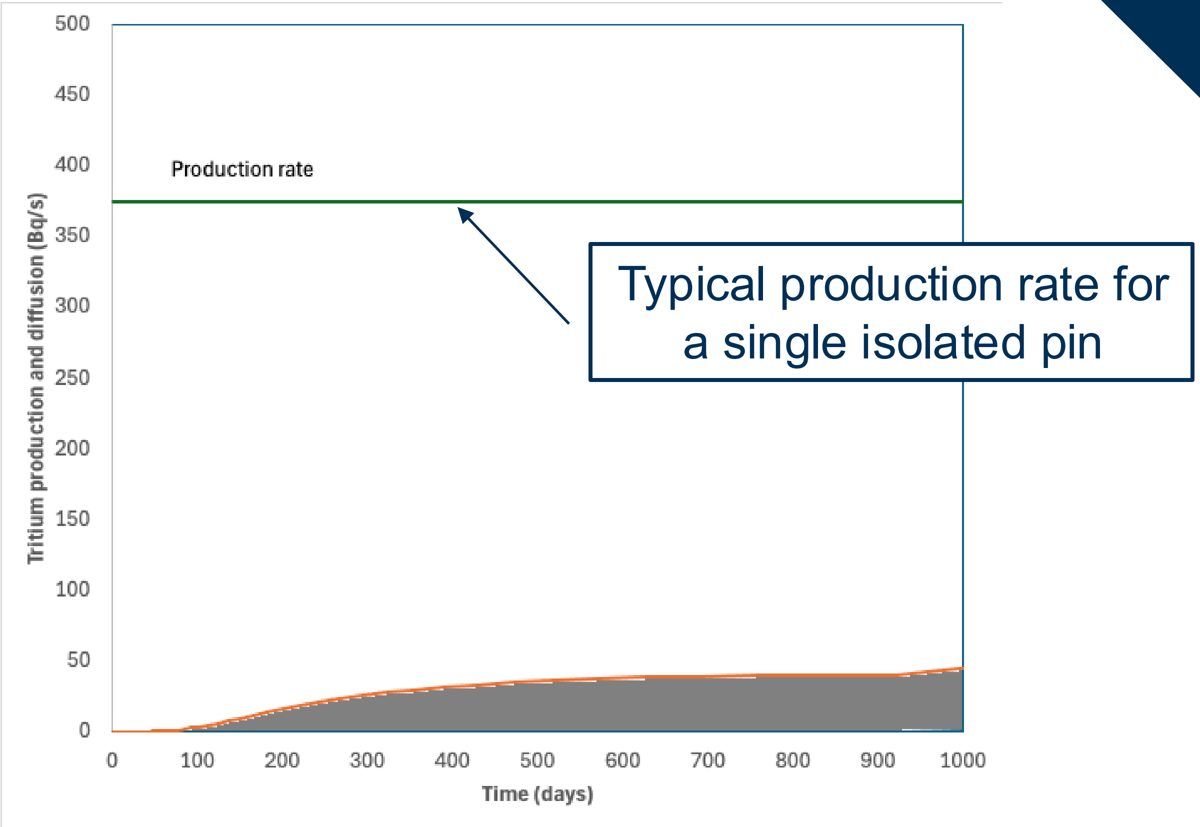
$$\frac{\partial C}{\partial t} = \nabla(D\nabla C)$$

# Probability of contamination




Tritium diffusion into pincell for different wall thicknesses. T = 100 °C (intended operation T)




Uncertainty estimate for d=5 mm associated with different grades of steel, which have different diffusion coefficient D and solubility S

*P* of $^3H$ in target ~ 40 torr

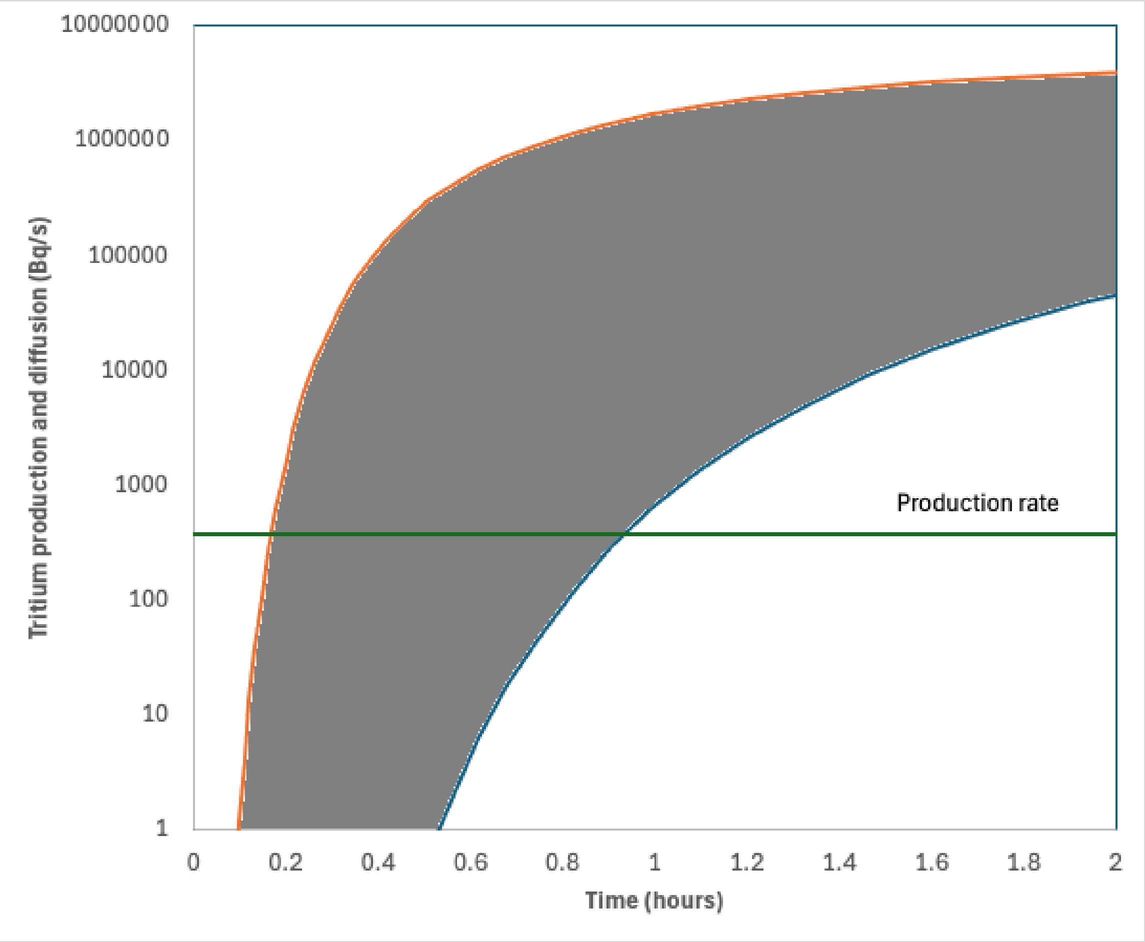
$$C = S\sqrt{P}$$

(Boundary condition)

# Higher temperatures

- However, if there are higher temperatures due to insufficient cooling or loss of coolant the contamination will be faster
- not expected for target chamber, which must be kept below 100 °C, but experimental mock-ups will be at higher temperatures
- Constrains experiments but not detrimentally

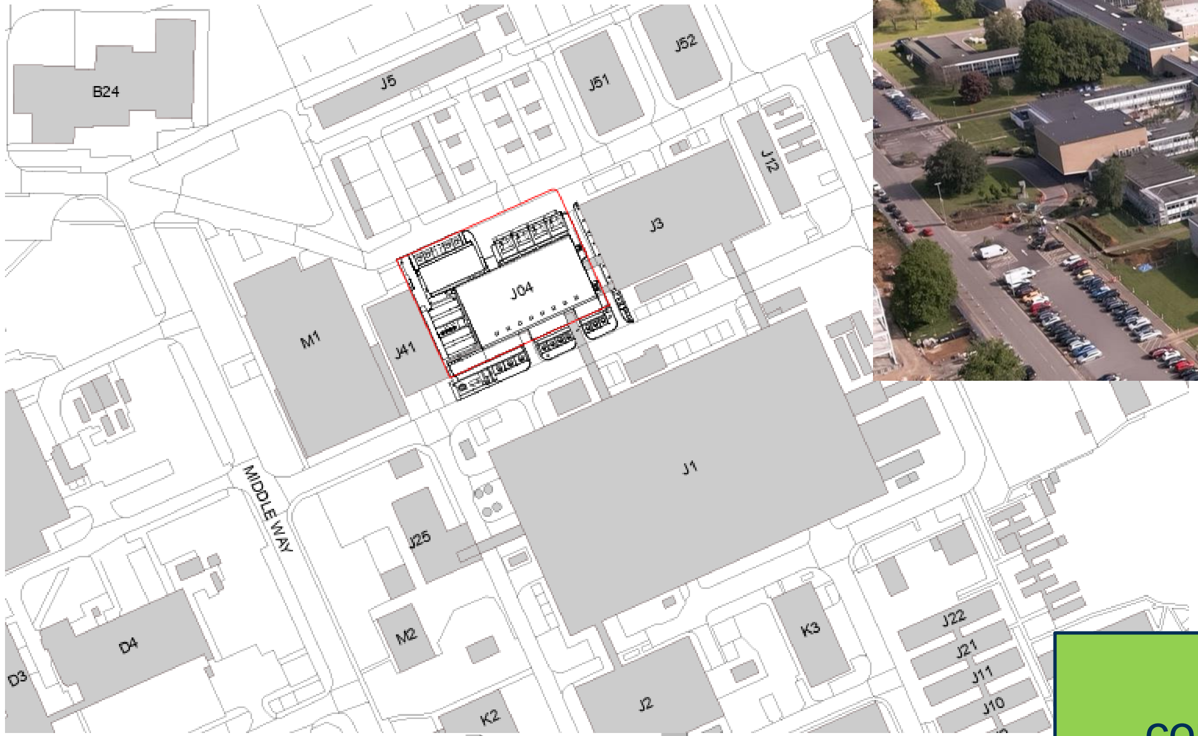


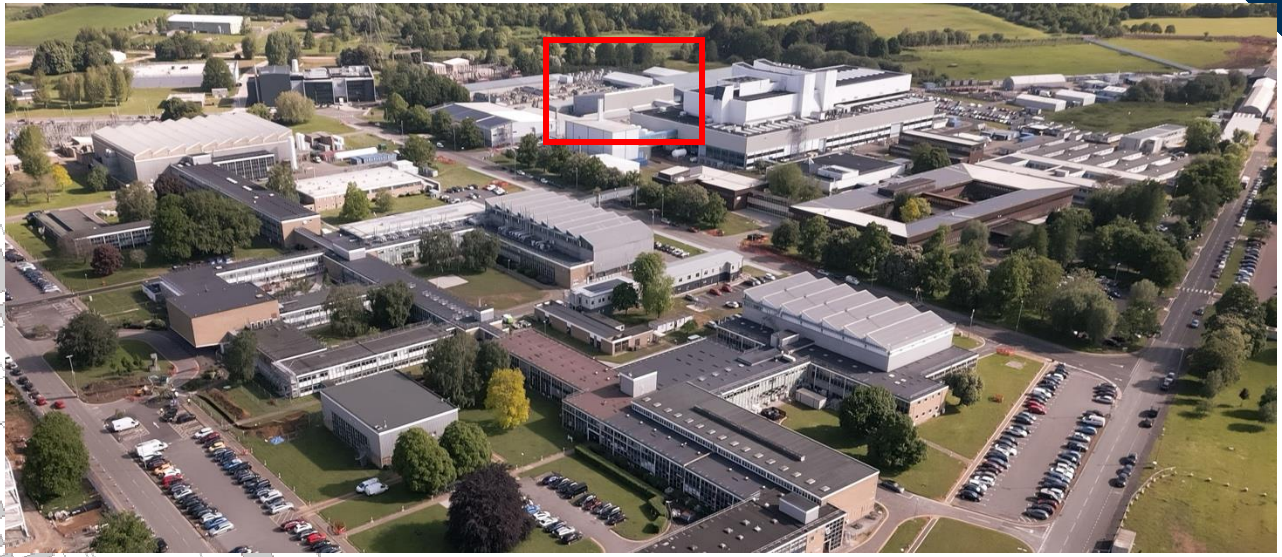

Tritium diffusion into pincell for a wall thickness d=5 mm. T = 600 °C

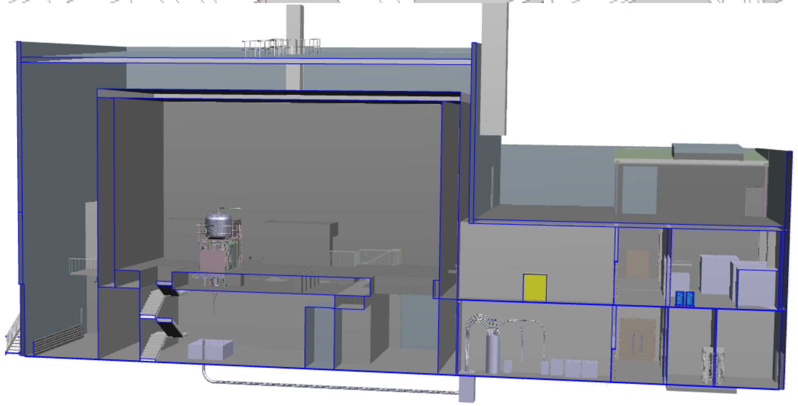
 

# LIBRTI status

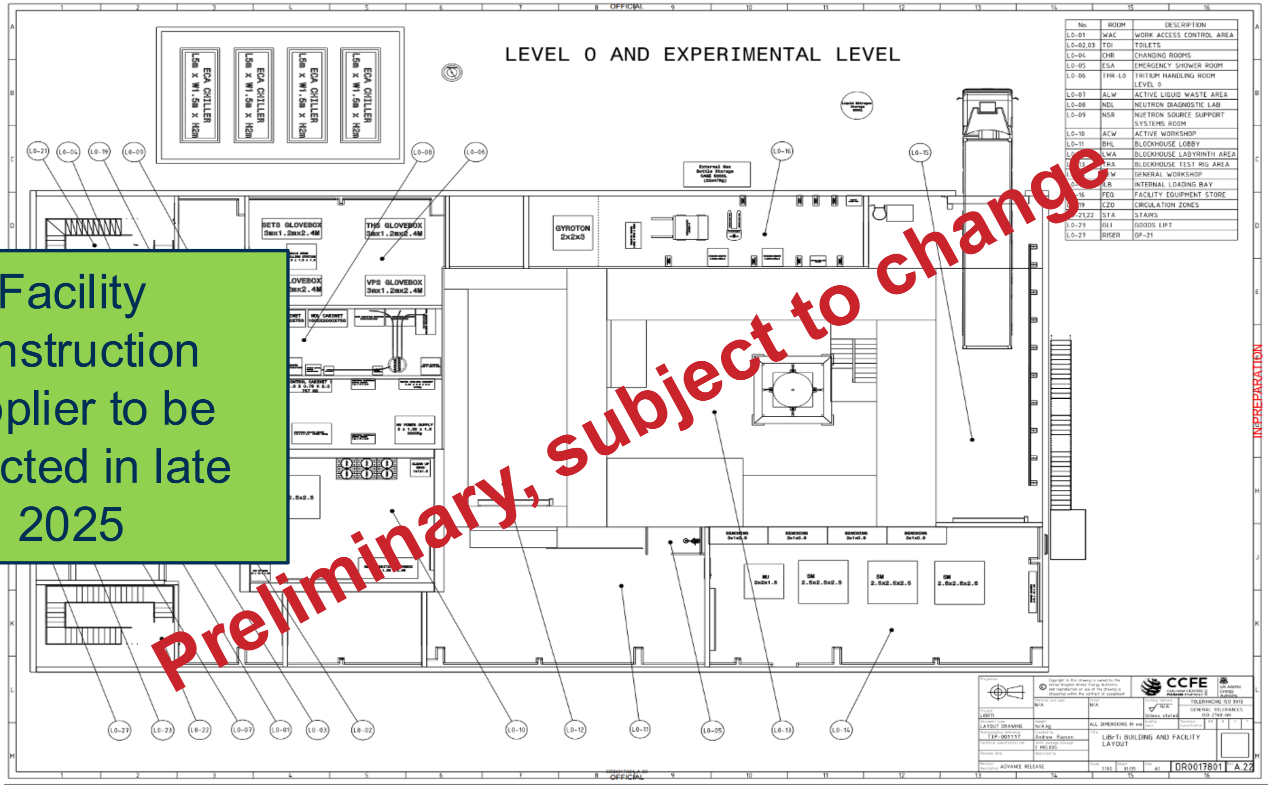
# Facility design





Facility construction supplier to be selected in late 2025



# Neutron source

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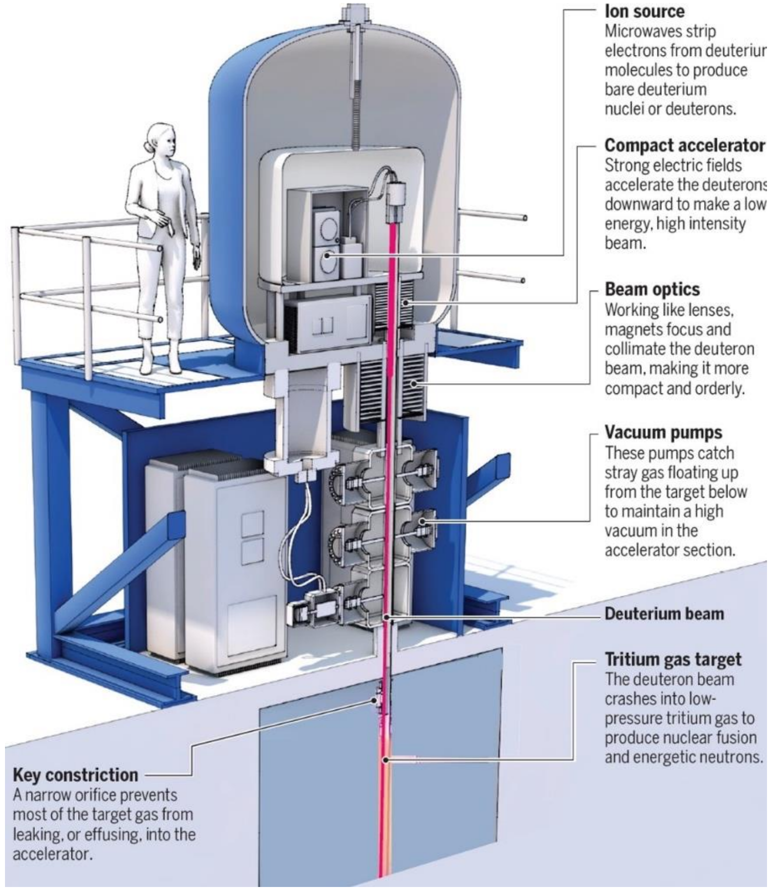
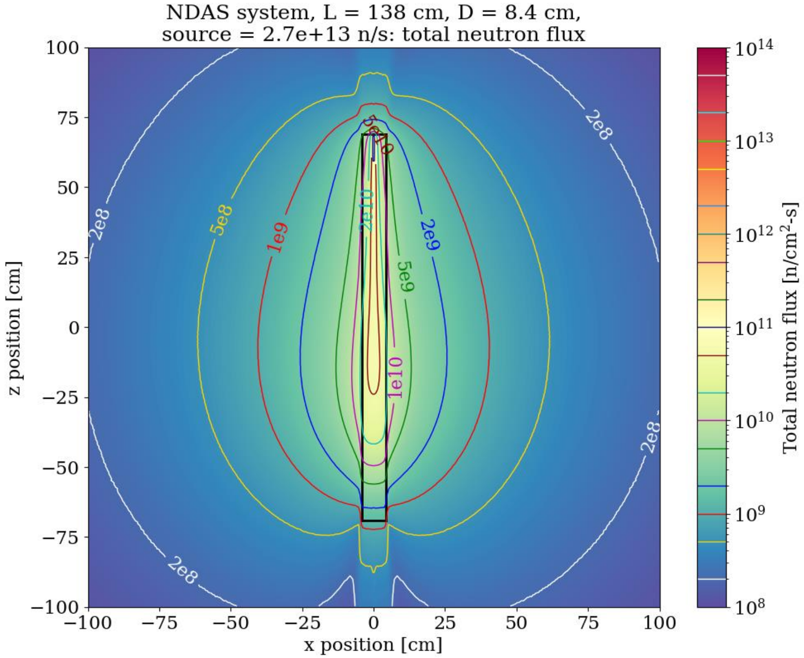



~7-8 m

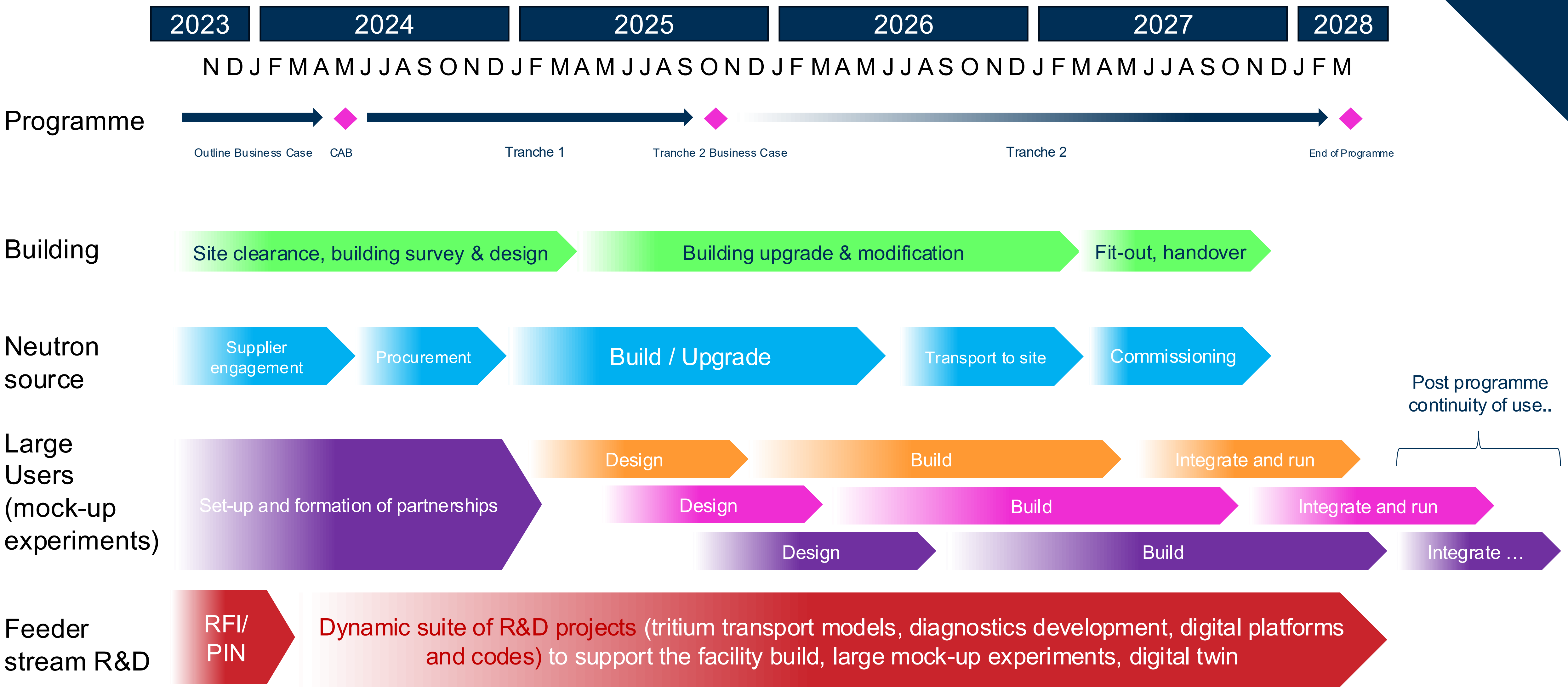
- Procured from SHINE (based in Wisconsin)
- 125 kW system
- 75 mA deuteron beam
- ~300 keV deuterons into tritium gas target
- 2.7 $10^{13}$ n/s total DT-neutron output




- LIBRTI is also sponsoring research to upgrade the Shine source
  - containment upgrades
  - Ion beam refinement

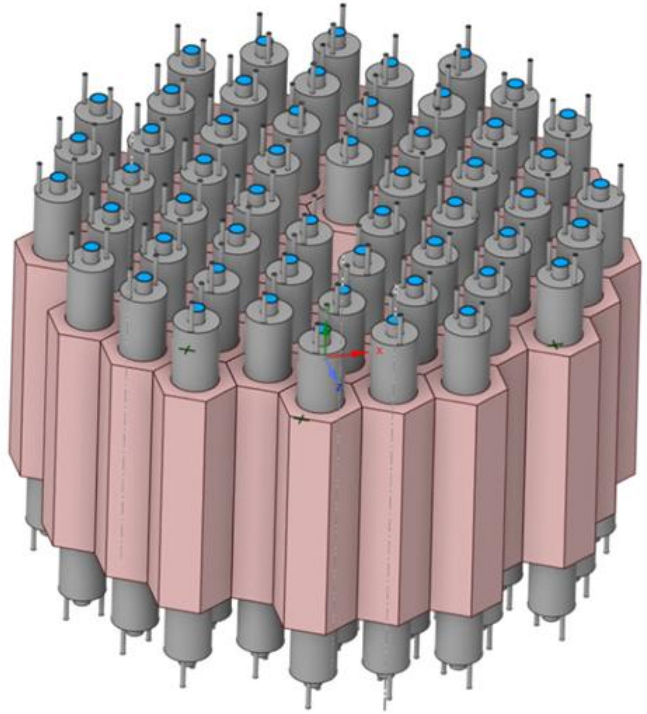
 

# LIBRTI – timeline



# Summary

- LIBRTI will provide a unique test facility for the advancement of understanding on tritium breeding within fusion systems
- Modelling is critical to the design of breeding solutions for fusion power plant → developing and validating a modelling platform is a primary goal
- Early analysis of the expected LIBRTI set-up and a potential modular test mock-up confirms that measuring tritium production is feasible (in principle)
- Understanding of the scientific basis for LIBRTI will evolve as the facility is developed (and even once experiments begin)



# Thank You

## LIBRTI welcomes contributions/collaborations on all aspects of the project.
## Please get in touch