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The importance of W cross sections in spherical tokamaks

IAEA FENDL meeting 30th Oct – 2nd Nov 2023

By T. Eade

Overview

1. Conventional and spherical tokamaks
2. The inboard build of spherical tokamaks
3. Possible shielding materials
4. Comparisons of W cross section
5. Overview of benchmark plans

Conventional and Spherical Tokamaks

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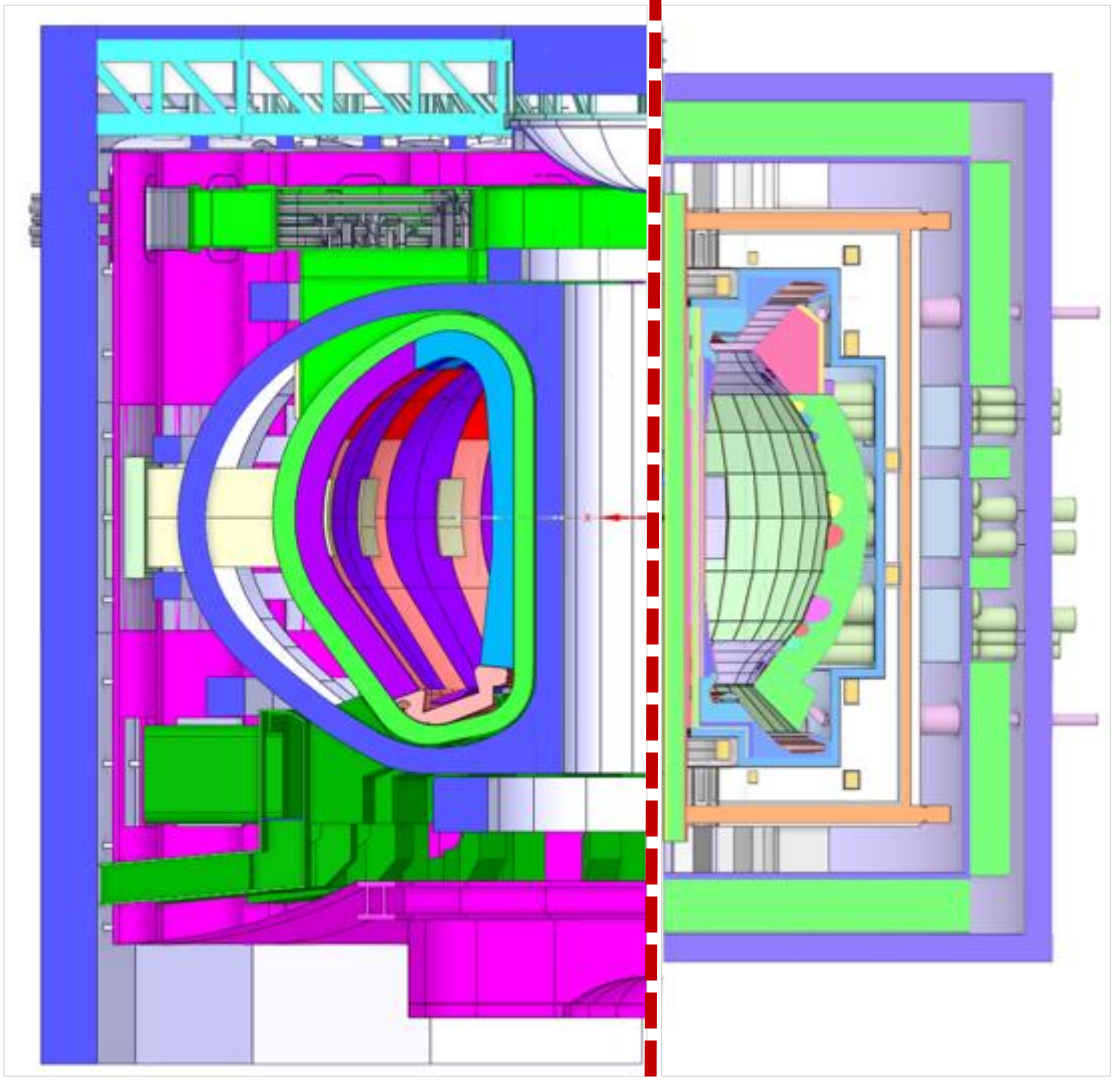
Conventional



Spherical

Conventional Tokamak

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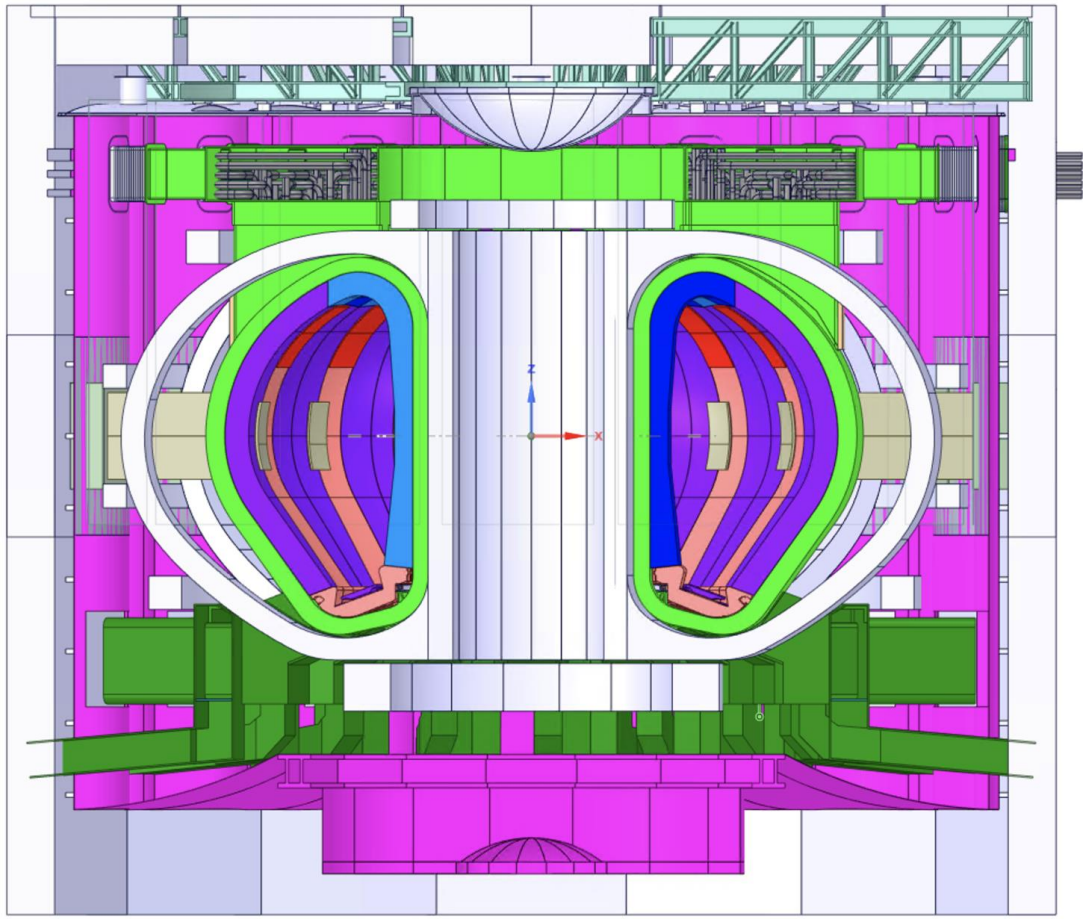
- ITER/DEMO like tokamaks
- Large aspect ratio (a = R/r > 3)
- Reasonably well understood plasma physics
- Generally large inboard region
- Results in large devices



Spherical tokamak

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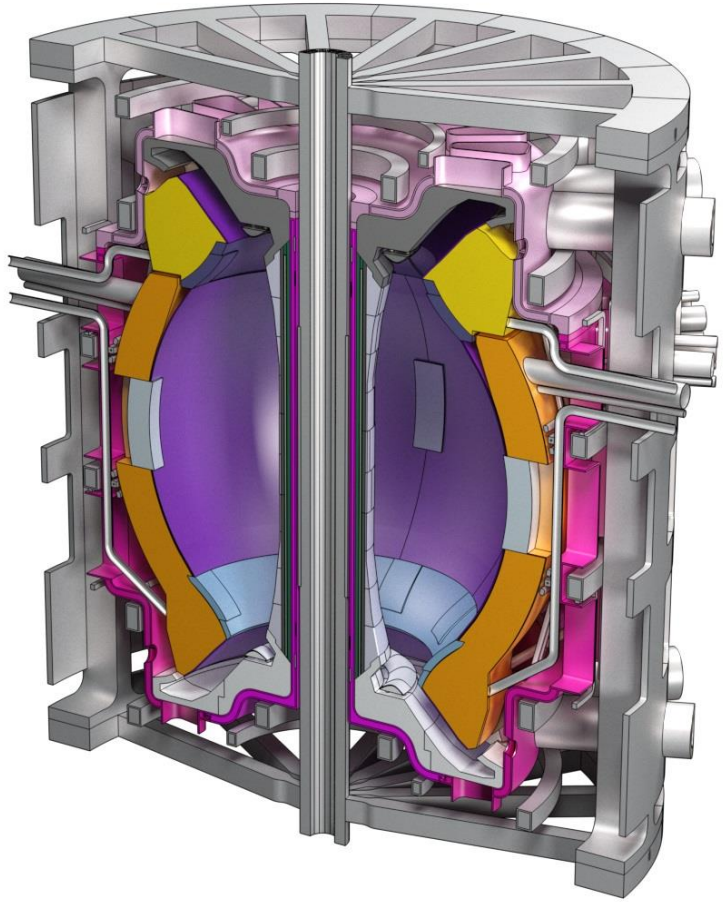
- Tokamaks with smaller aspect ratios (a = R/r <2)
- Large plasma volume in a small space
- Lower magnetic field needed to contain plasma
- Better plasma stability
- Could lead to cheaper reactors
- Higher neutron and heat loading
- Small inboard region



The inboard build

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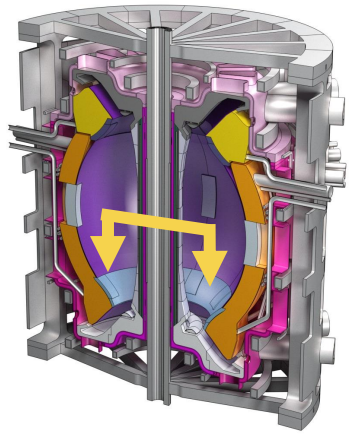
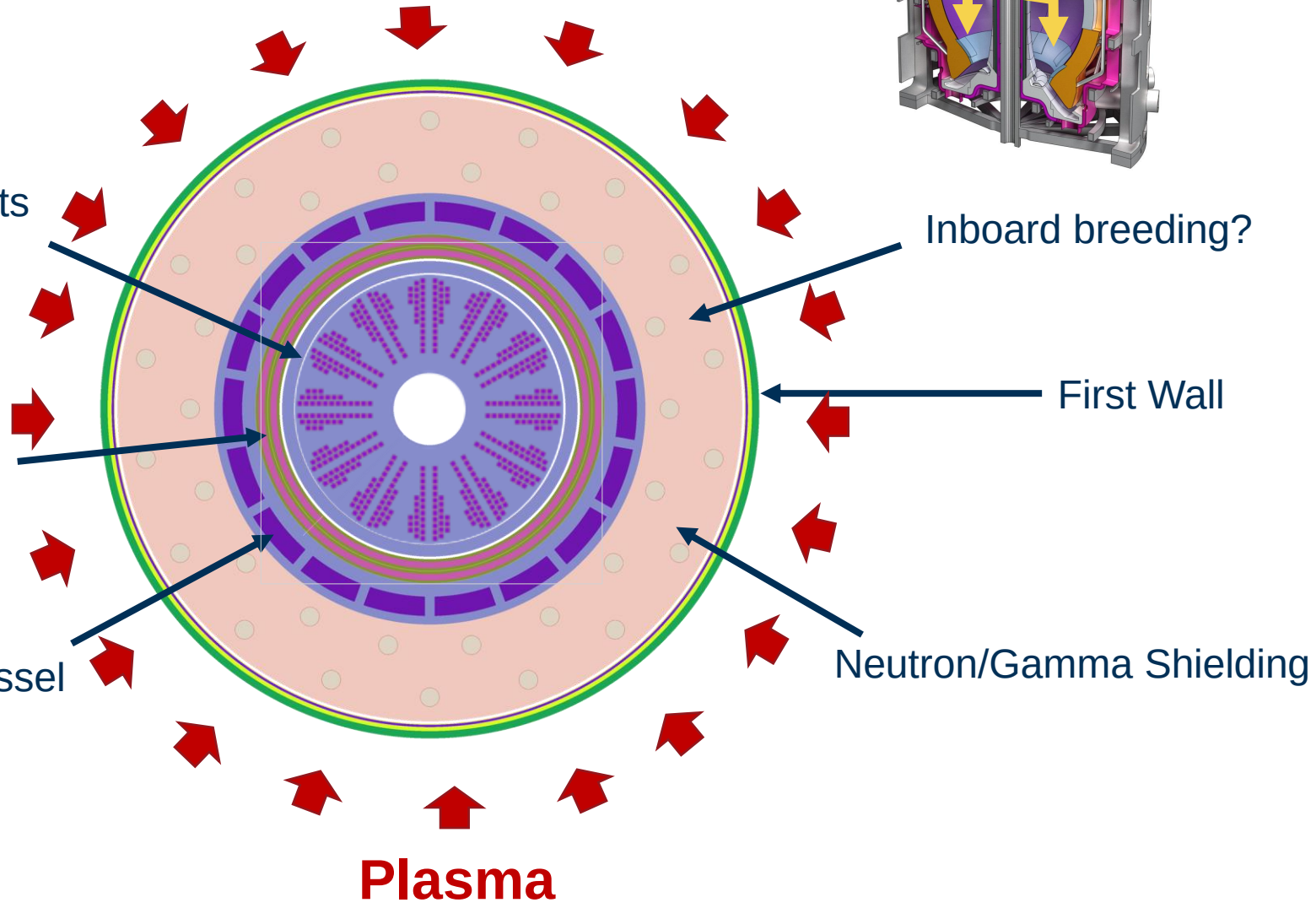
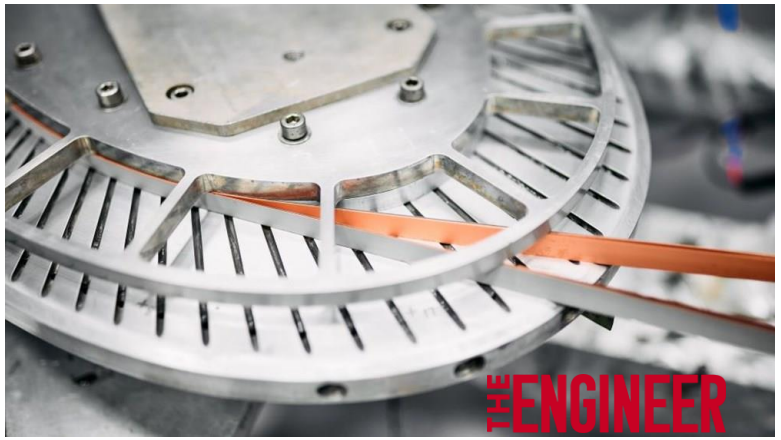
Horizontal Cut through the inboard column

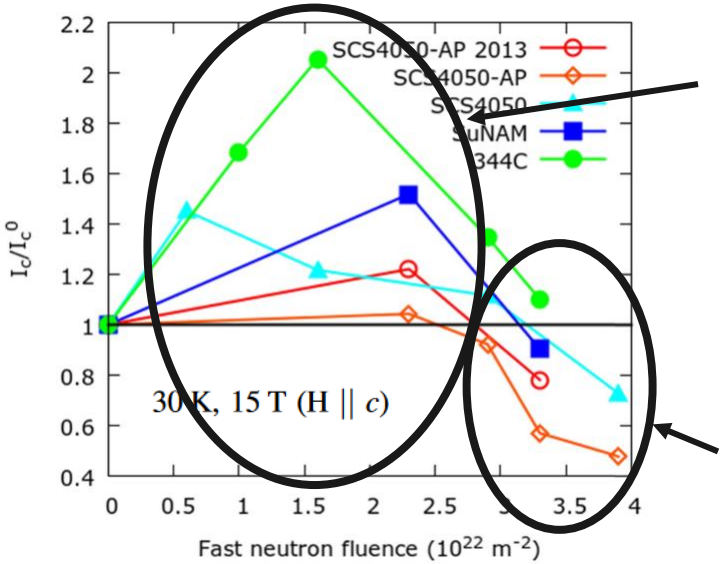




Inboard Magnets

- High Temperature Superconducting (HTS) tapes are often used
- Performance can be degraded by neutron irradiation
  - DPA (fast fluence)
  - Transmutation
  - Nuclear heating

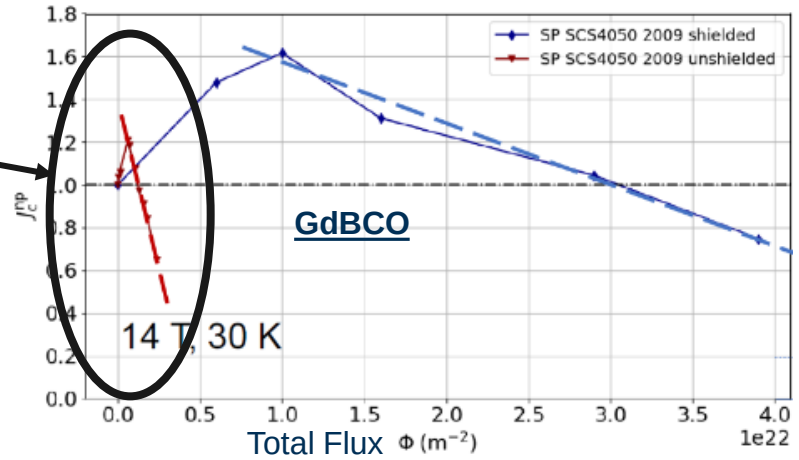




Critical current goes up with irradiation

Critical current goes down with further irradiation

Capture cross section in Gd leads to transmutation



D. X. Fischer, R. Prokopec, J. Emhofer, and M. Eisterer, "The effect of fast neutron irradiation on the superconducting properties of REBCO coated conductors with and without artificial pinning centers," *Supercond Sci Technol*, vol. 31, no. 4, p. 44006, 2018, doi: 10.1088/1361-6668/aaadf2.

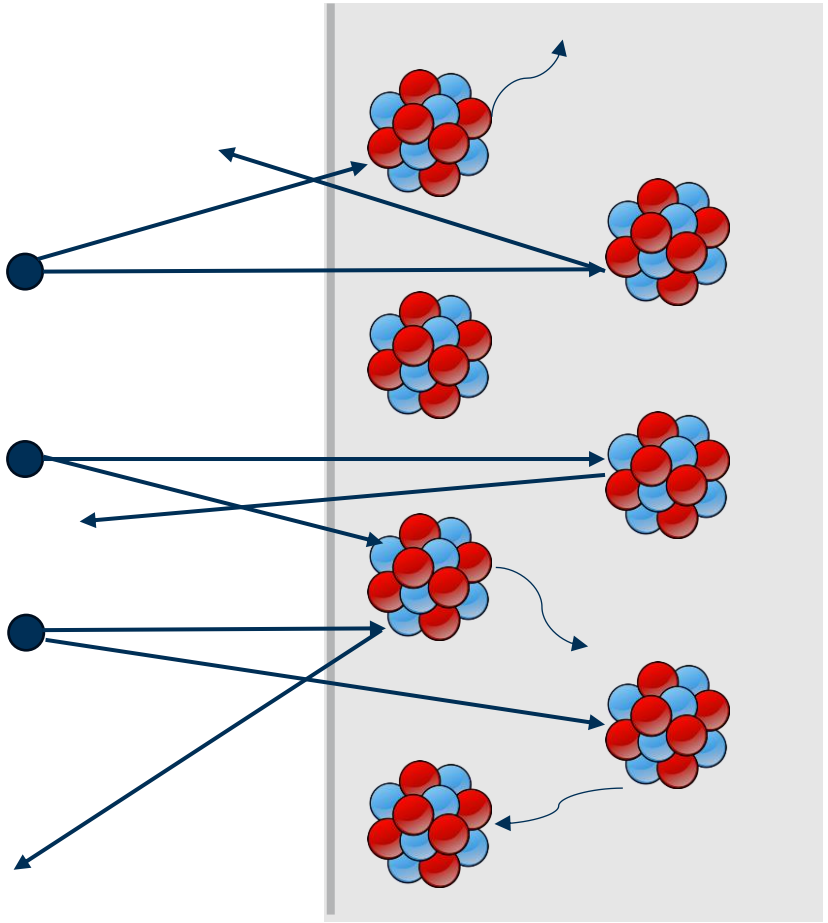
Data for a SuperPower SCS4050 CC manufactured in 2009 presented by R. Unterrainer at Informal Workshop on the Irradiation of Superconductor in May 2023.

Inboard shielding materials

- To effectively shield the inboard magnets we need to:
  - Reflect as many neutrons as possible (helps with TBR)
  - Then reduce the energy of the neutrons (and absorb)
- Shielding materials for MeV neutrons need to maximise Σ:

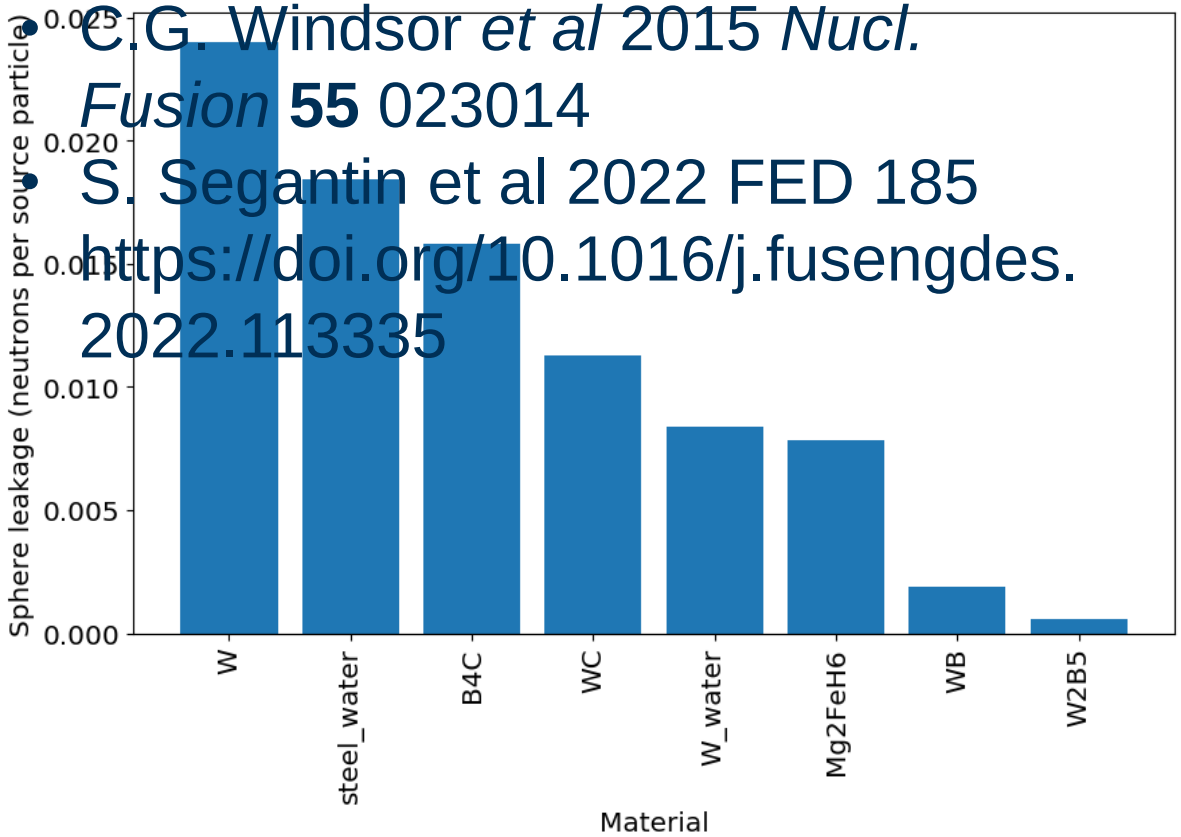
$$\Sigma = N_D \sigma$$

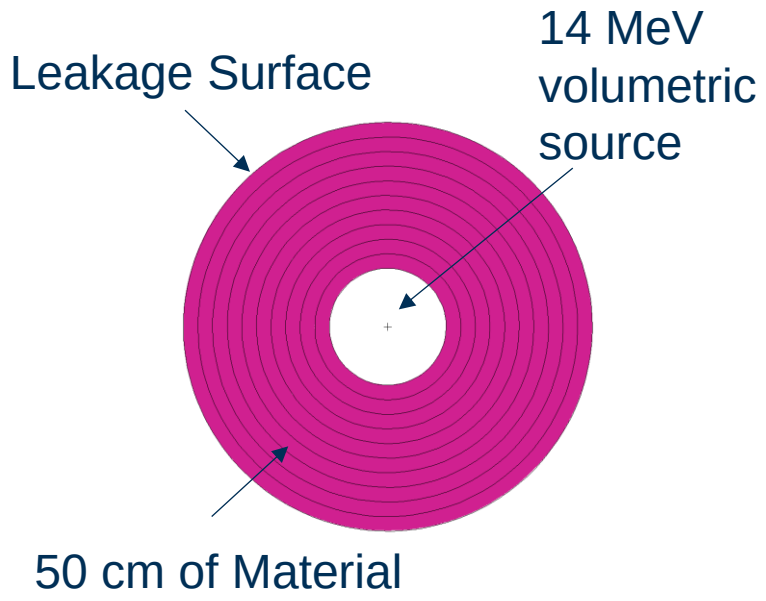
  - Some moderating material:
    - Low Z atoms

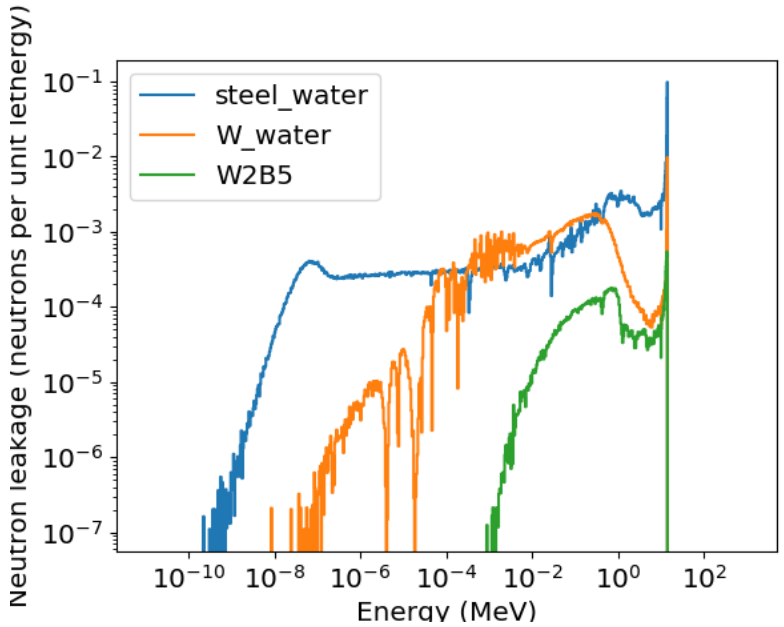


Inboard shielding materials

- Simple leakage sphere model
- Shown that W compounds/mixtures provide excellent high energy neutron shielding
- Also shown by others:
  - C.G. Windsor *et al* 2015 *Nucl. Fusion* **55** 023014
  - S. Segantin et al 2022 FED 185 https://doi.org/10.1016/j.fusengdes.2022.113335



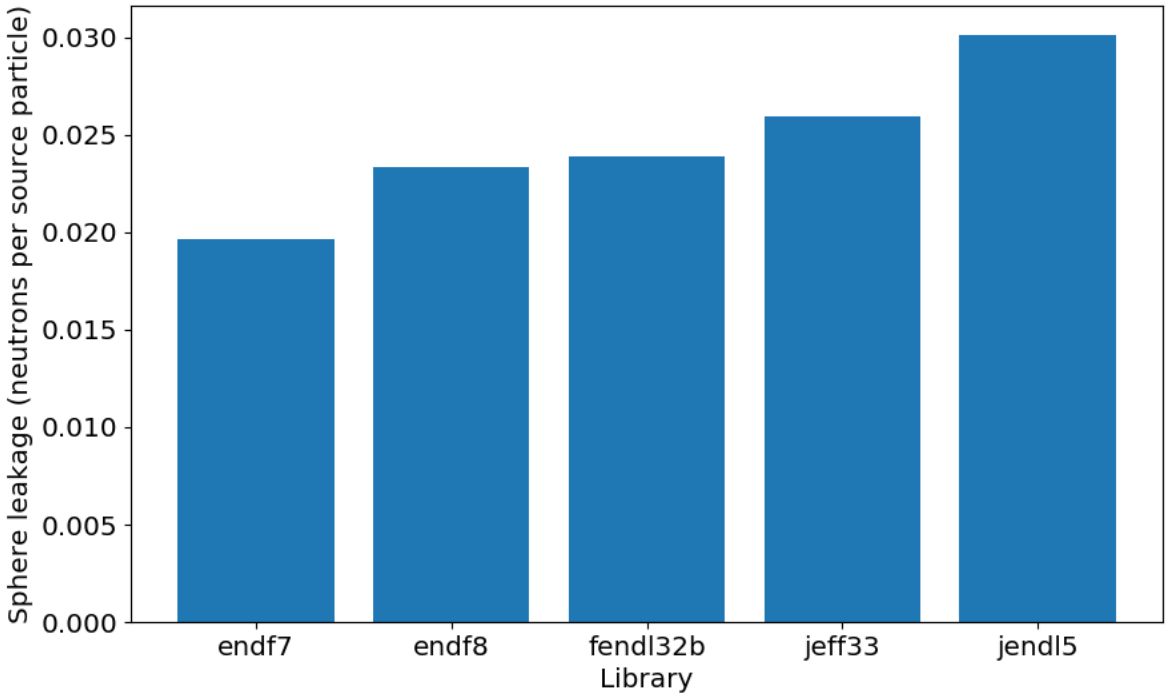


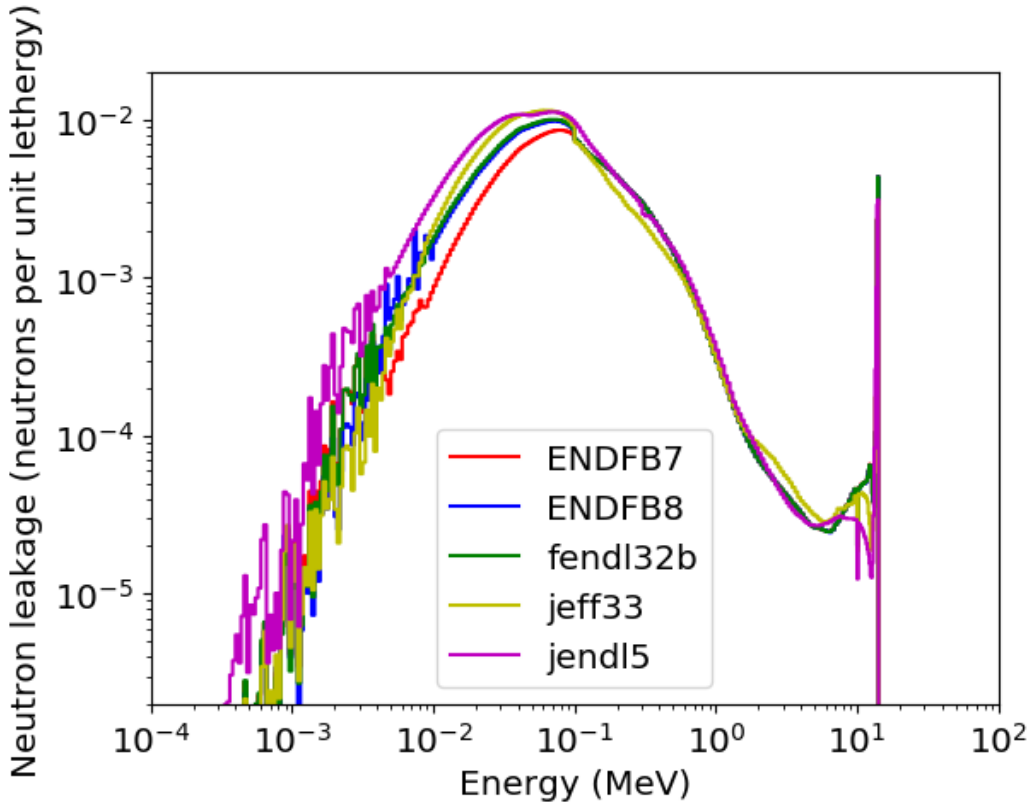


W cross sections comparison

- Using the same simple model and just W
- Sensitivity study to look at selection of various libraries
- Up to 50% difference in fast flux leakage

Fast Flux (>0.1 MeV)



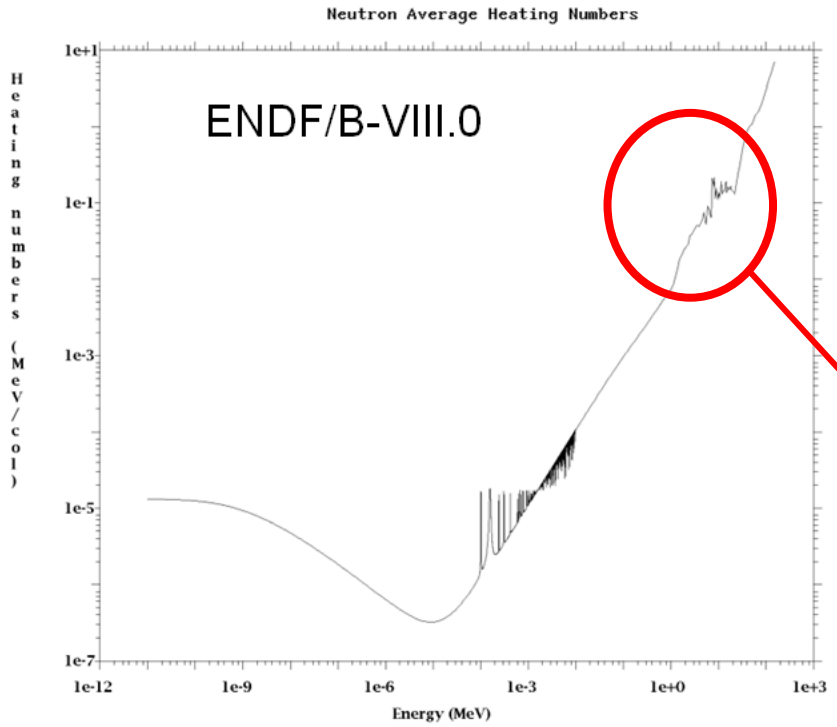


Note: statistical errors <1%

Nuclear heating values comparison

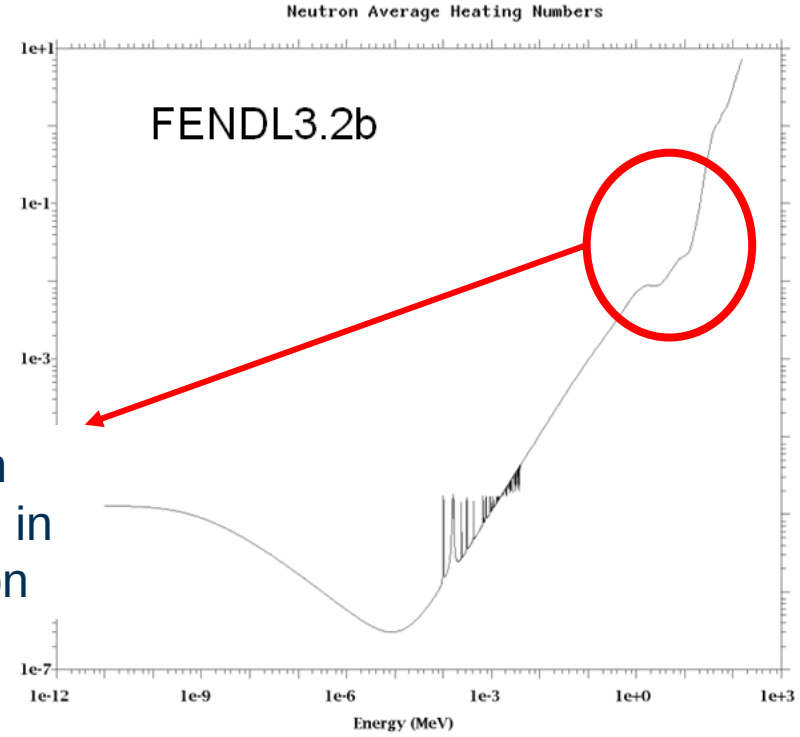
- Nuclear heating in W
- Photon heating within 3% of ENDF/B-VII
- Large difference in neutron heating
- Neutron heating up to 5% of total heating

Photon Heating



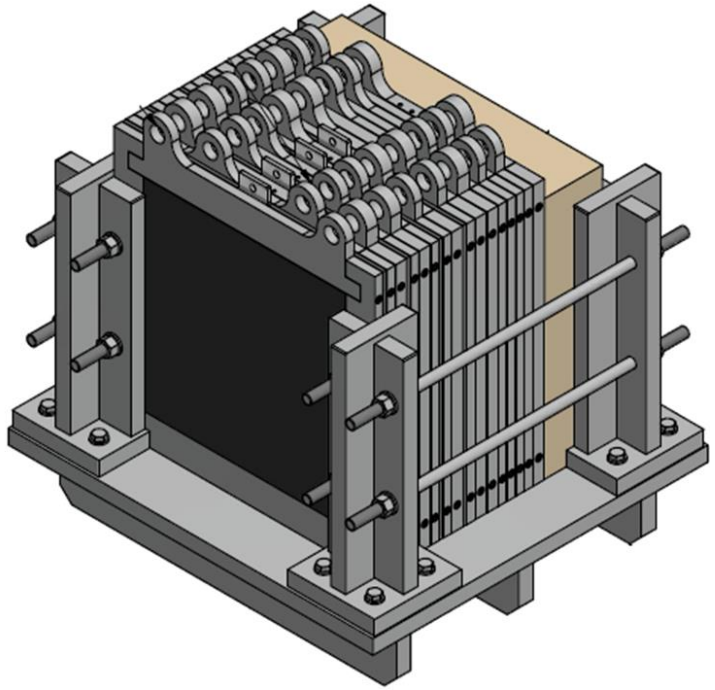
Difference in heating values in 10 MeV region

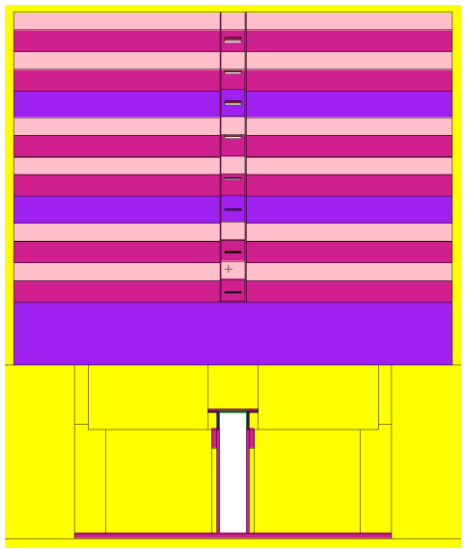
Neutron Heating



Benchmarks

- EUROfusion W benchmark carried out earlier in the year at FNG
- ‘Small’ scale WC and WB attenuation measurements
- STEP shielding benchmark experiment currently under design





Summary

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- Spherical tokamaks maybe a route to cheaper fusion energy
- The size of the inboard means that shielding is limited and therefore must be efficient
- W compounds have been demonstrated to have the best shielding performance
- Difference in leakage of up to 50% have been noted in a simple model with different nuclear data libraries
- Neutron heating varies significantly between nuclear data libraries
- Accurate W cross sections are vital in being able to accurately predict inboard magnet lifetime