EUROfusion

Use of Mesh based Variance Reduction Technique for Shielding Calculations of the Stellarator Power Reactor HELIAS

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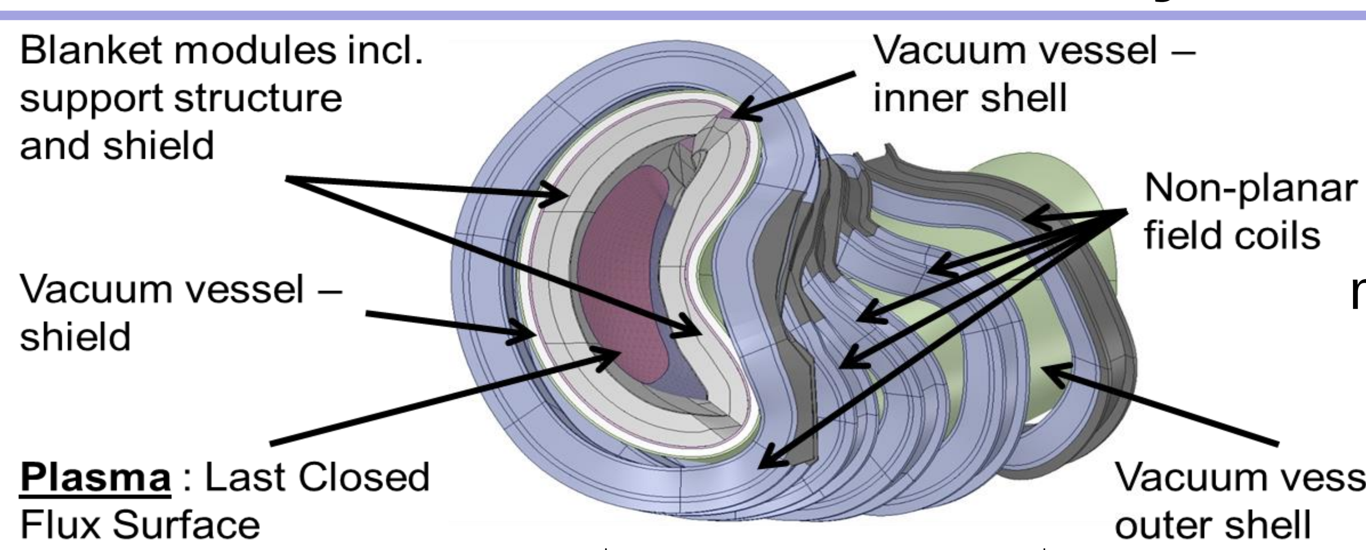
Motivation and Objective

- Helical-Axis Advanced Stellarator (HELIAS) is a demonstration power reactor with 3000 MW D-T fusion power.
- First thorough neutronic investigation of HELIAS with DAG-MCNP (DAG = Direct Accelerated Geometry) approach.
- Shielding capability needs to be assessed for the stellarator by applying mesh based weight window variance reduction method.
- Nuclear responses in a critical area: high neutron wall load (~1.4 MW/m²) and reduced material thickness (~103 cm).
- Evaluation of the obtained results according to the EU DEMO tokamak recommended radiation design limits.

HELIAS Geometry

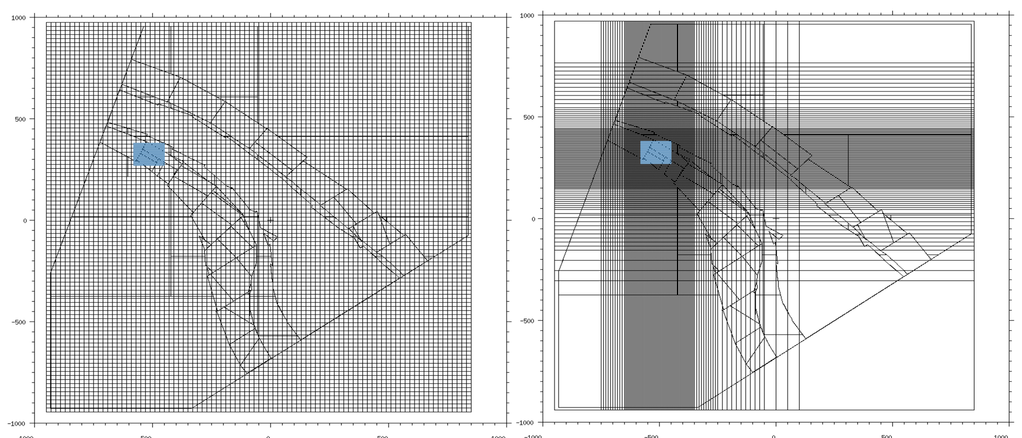


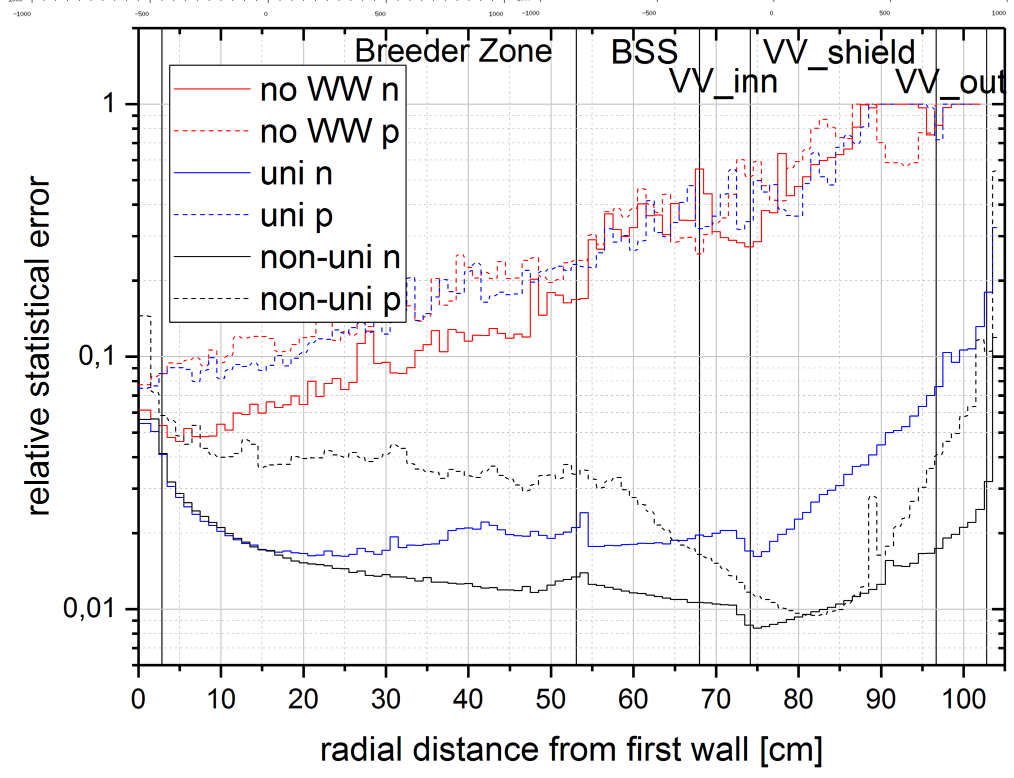
HELIAS CAD model including material layers and plasma distribution

Radial Structure	Thickness [cm]	Material Composition
Tungsten Armor	0.2	100% Tungsten
First Wall	2.5	70% Eurofer, 30% Helium
Breeder Zone	50	HCPB with 60% Li-6 enrichment
Back Support Structure (BSS)	~10 – 40	75% Eurofer, 25% Helium
Vacuum Vessel (VV) inner shell	6	100% Steel (SS-316)
VV shield	20	60% Steel (SS-316), 40% Water
VV outer shell	6	100% Steel (SS-316)

Weight Window Generation

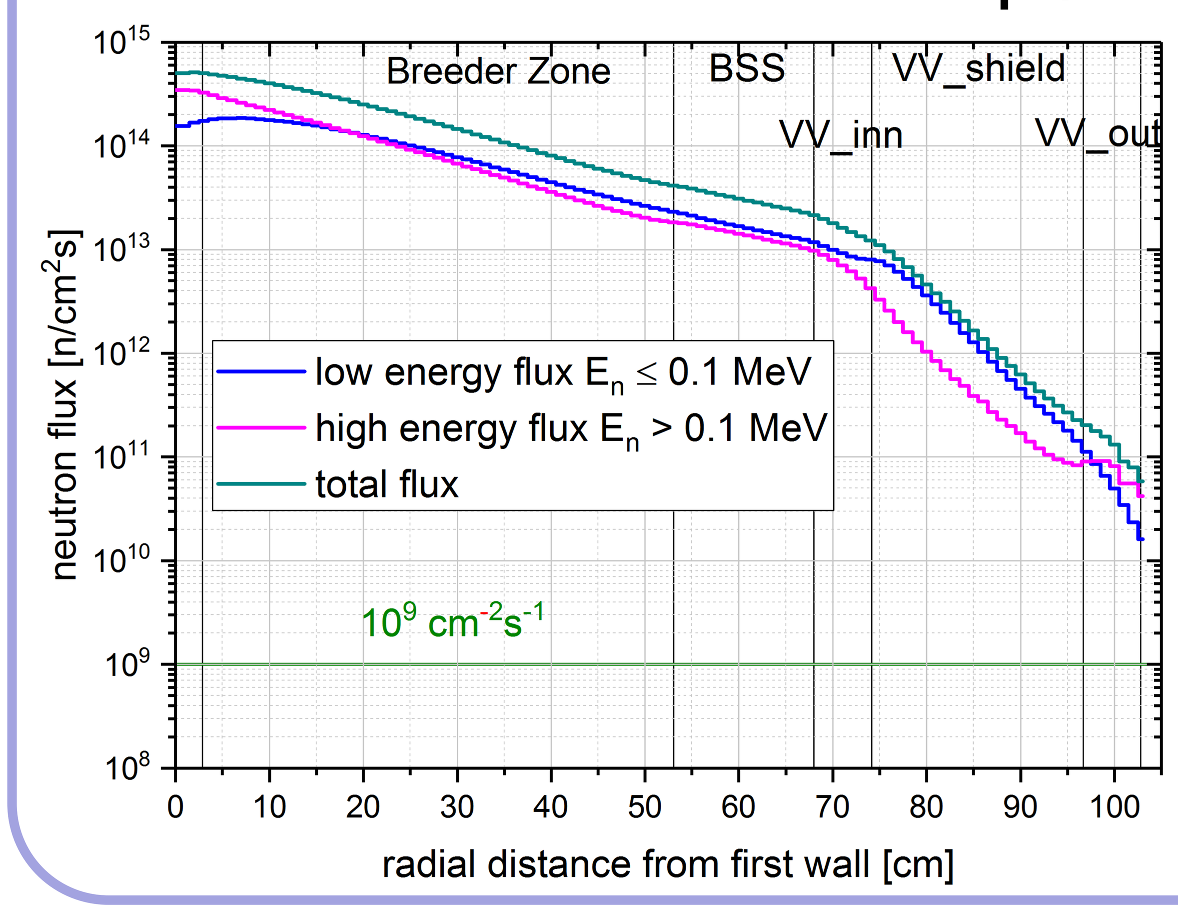
- Mesh based weight window generation with ADVANTG (ORNL).
- Two different mesh set-ups: uniform with 20x20x20 cm³ (optimized for neutrons) and non-uniform with 5x5x5 cm³ (optimized for neutrons and photons) in target region (blue box).
- Relative statistical error determined inside the target region, with a mesh tally, for neutrons and photons.
- Statistical error is significantly decreased → non-uniform WW mesh is used.

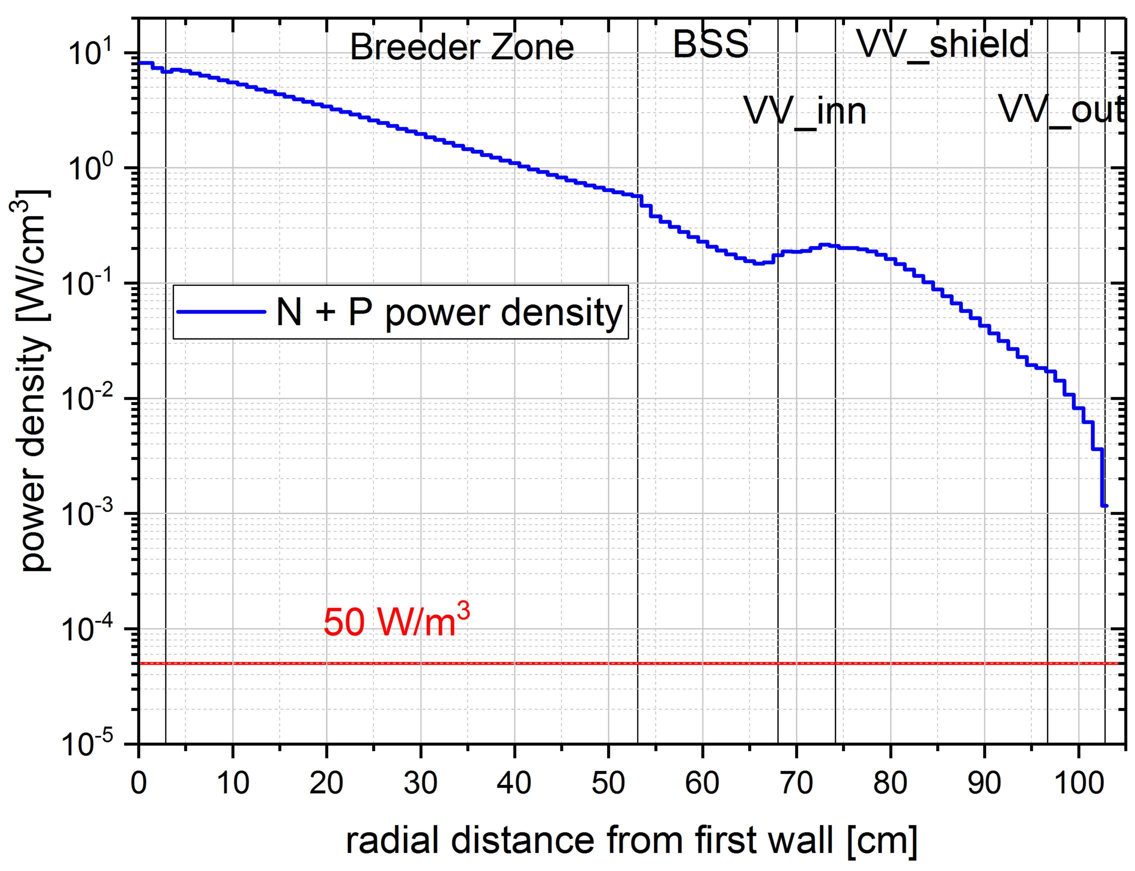


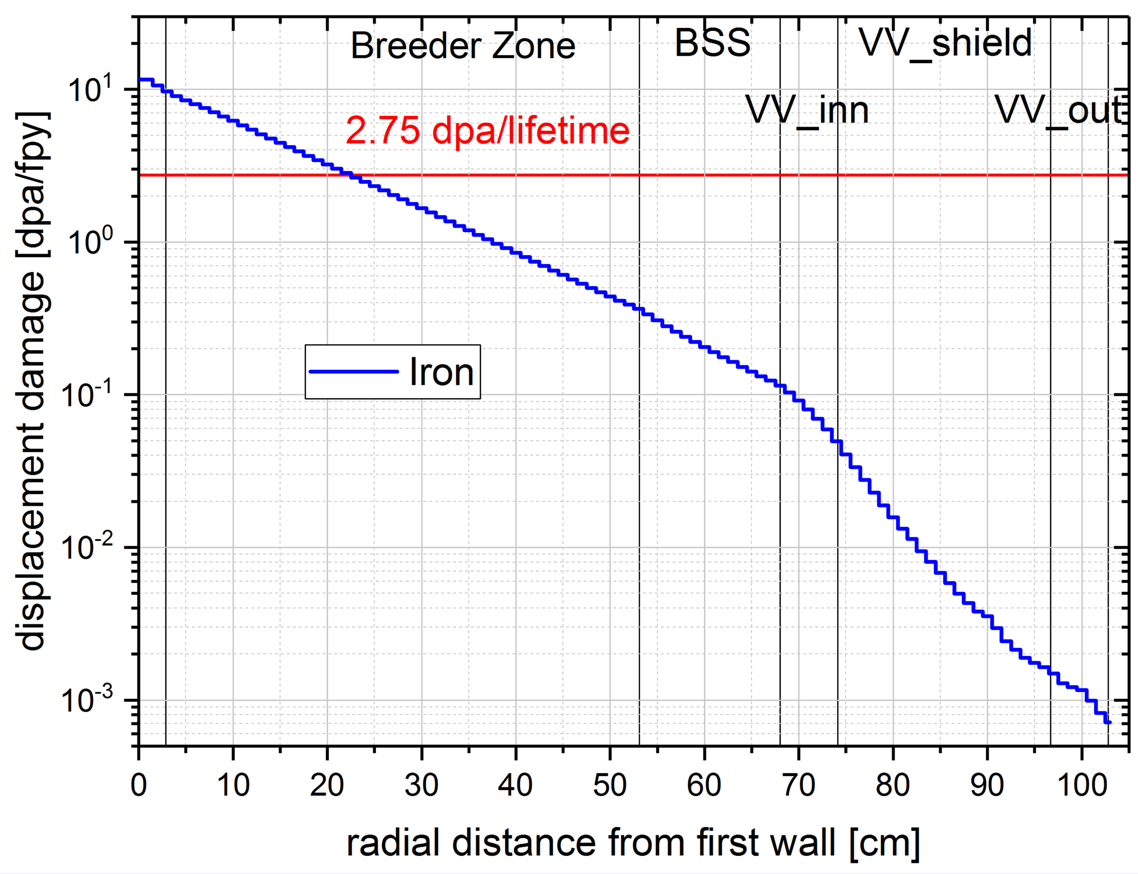


Computation and Results

- Radial profiles of nuclear responses in critical area, evaluated against radiation design requirements specified for EU DEMO tokamak.
- Nuclear responses of interest:
  - "Maximum neutron fluence to epoxy insulator" → target: $\mathbf{10^9\ cm^{-2}s^{-1}}$ to coils.
  - "Peak nuclear heating in winding pack" → limit: **50 W/m³** to coils.
  - "Lifetime criteria in order to ensure that the fracture toughness is reduced by no more than 30%" → limit: **2.75 dpa/lifetime** to VV.
- Shielding requirements for superconducting magnets not met in critical area → shielding performance need to be improved.
- Displacement damage at VV_inn: **~0.11 dpa/fpy** → lifetime of 25 years guaranteed to reach EU DEMO design limit.







Conclusion and Outlook

- *Variance reduction:* Mesh based weight window method suitable for HELIAS.
- *Calculations:* Statistical reliable radial profiles of relevant nuclear responses from first wall to magnetic field coil.
- *Shielding performance:* Requirements for superconducting magnets not fulfilled in critical area.
- *Recommended design improvements:* Larger shielding layer and/or more efficient shielding materials.

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