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

**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](image1)

**Weight Window Generation**

- Mesh based weight window generation with ADVANTG (ORNL).
- Two different mesh setups: 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 \(\Rightarrow\) 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” \(\Rightarrow\) target: \(10^{9}\) cm²s⁻¹ to coils.
  - “Peak nuclear heating in winding pack” \(\Rightarrow\) limit: \(50\) W/m² to coils.
  - “Lifetime criteria in order to ensure that the fracture toughness is reduced by no more than 30%” \(\Rightarrow\) limit: \(2.75\) dpa/lifetime to VV.
- Shielding requirements for superconducting magnets not met in critical area \(\Rightarrow\) shielding performance need to be improved.
- Displacement damage at VV\_inn: \(~0.11\) dpa/ky \(\Rightarrow\) 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.