OAK RIDGE National Laboratory

Core Vessel Shielding Preliminary Design Neutronics Analysis

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U.S. DEPARTMENT OF ENERGY

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STS Neutronics Perspective

Rotating W target

1.3 GeV 700kW proton beam (<1 μs)

Spallation neutrons moderated in coupled low-dimensional (flat) cylindrical and tube moderators designed for high brightness

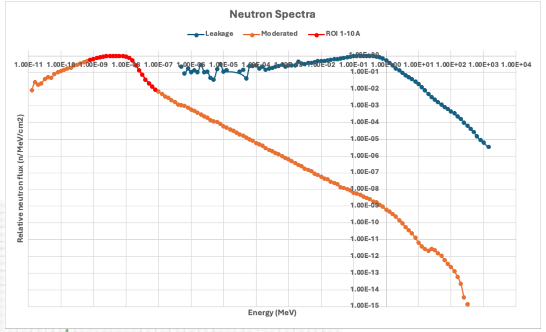
Para-hydrogen at 20 K

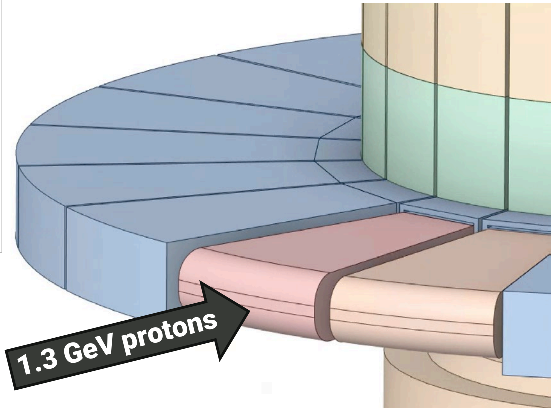
Water premoderator, Be reflector

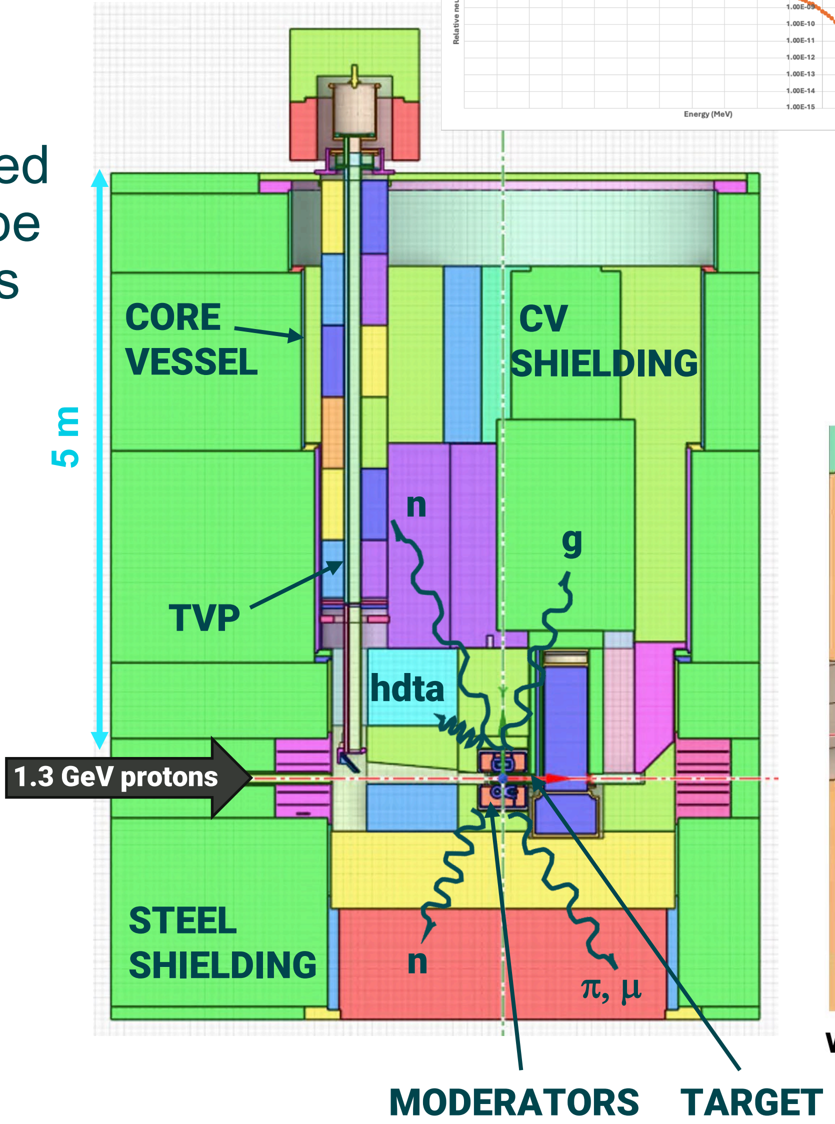
Tightly coupled with the target

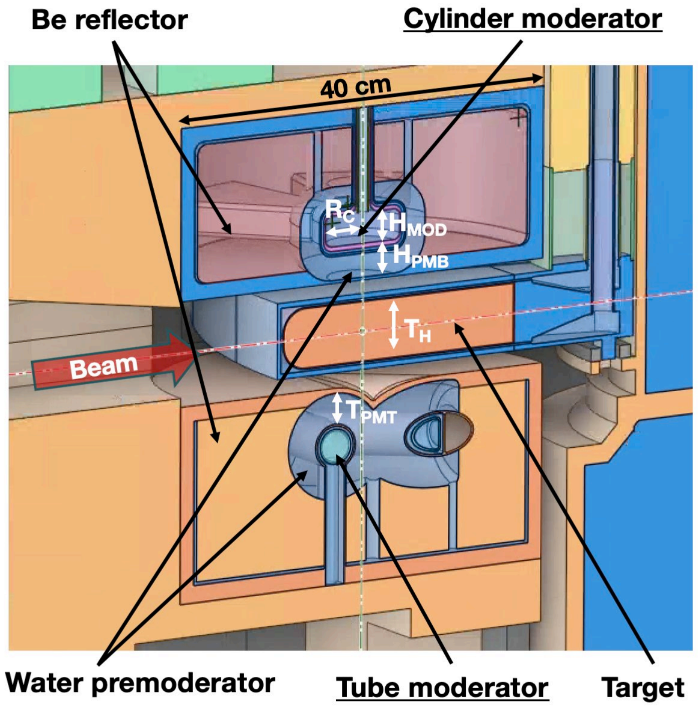
Neutronics support:

Neutron brightness, lifetime due to radiation damage (dpa), energy deposition, prompt and activation dose rates, radiation shielding design









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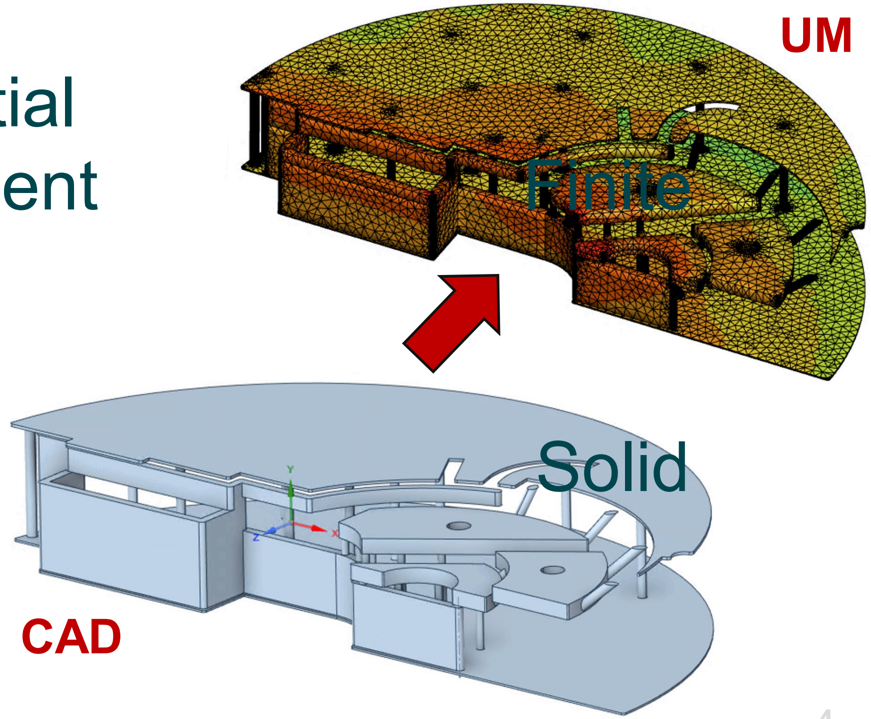
CVS Preliminary Design Neutronics Analysis

- The goal is to perform MCNP radiation transport (neutronics) calculations to support the Core Vessel (CV) and CV Shielding (CVS) preliminary design analysis
- These calculations include:
  - **Energy deposition** from the beam-on operations to provide input for the subsequent structural stress and thermal analyses, mainly to design efficient cooling and maintain structural integrity throughout the service life-time
  - **Radiation damage** to determine the service life-time
  - **Prompt radiation dose** rate from the beam-on operations to guide the effective radiation shielding design
  - **Shutdown radiation dose** rates related to the end-of-the-life operations

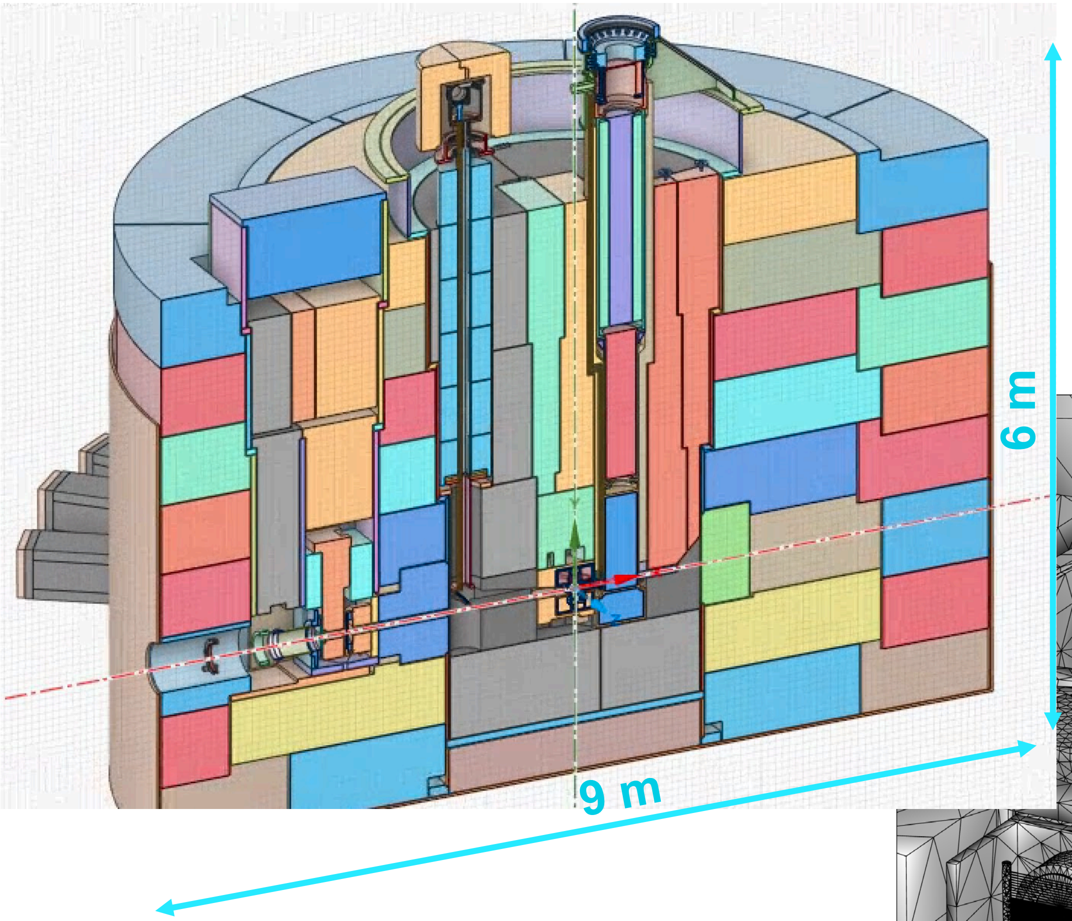
Unstructured Mesh (UM) Geometry (UMG) Application

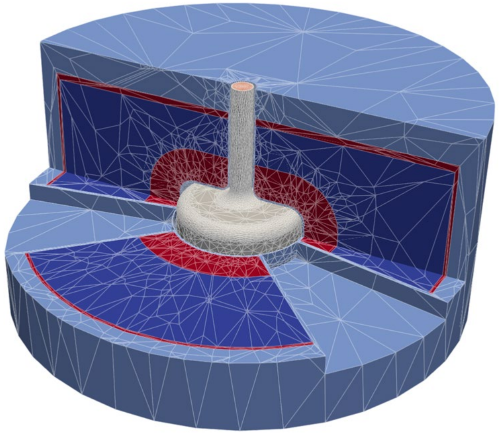
- The analysis relies heavily on the recently developed UMG capability of MCNP6.2 and Attila4MC' volumetric mesh generator
- UM enables conversion of the solid CAD models directly for MCNP, which significantly improves both the efficiency and quality of the neutronics models' generation
- Volumetric (3D) UM provides data with high spatial resolution that can be used as input for subsequent Element Analyses (FEA)
- The use of UM has been thoroughly validated against the traditional MCNP's Constructive Geometry (CSG) modeling

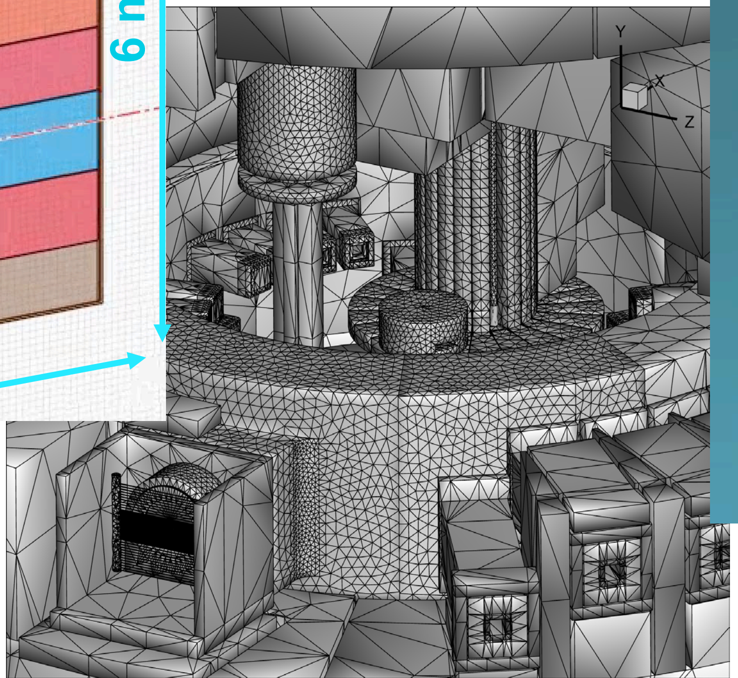


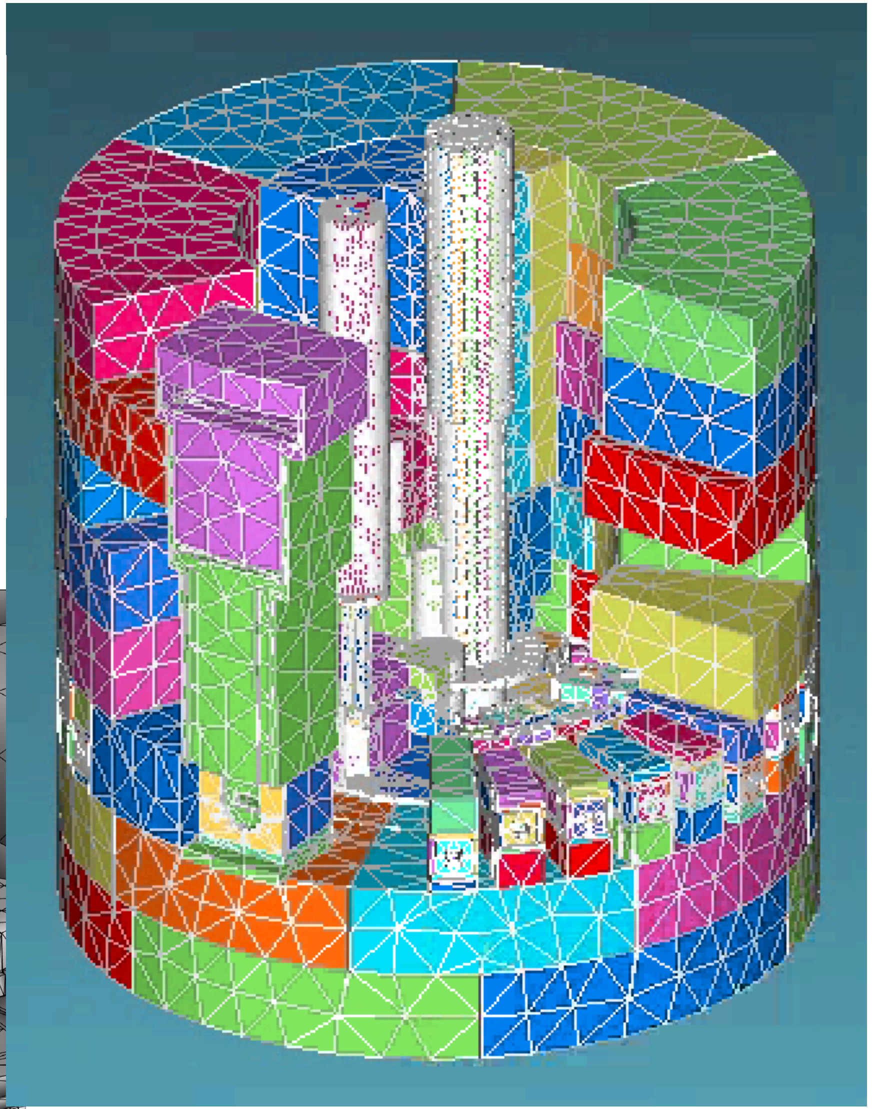
Extensive use of Unstructured Mesh (UM) at the STS

- CAD to MCNP conversion and variance reduction on UM with Attila4MC

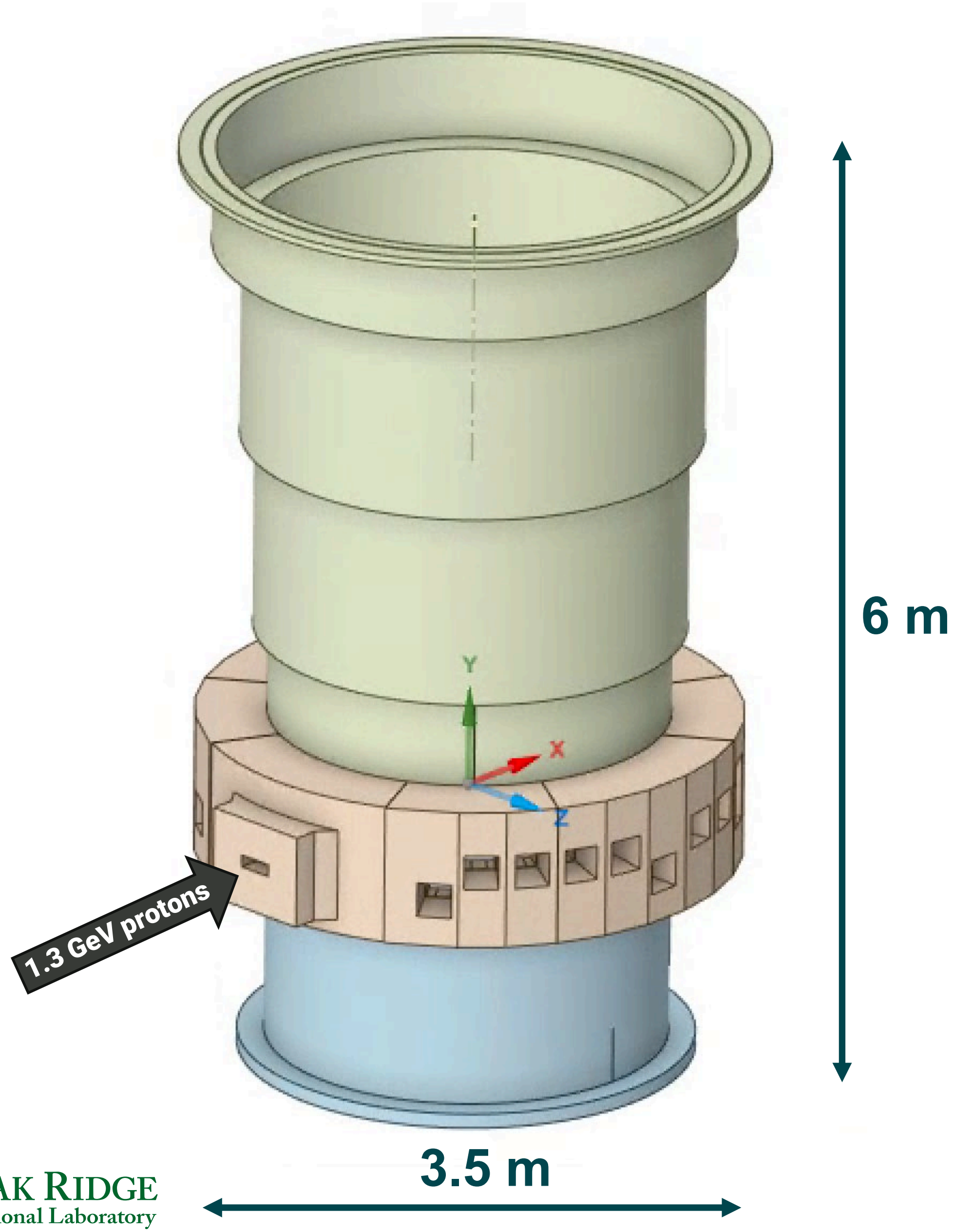


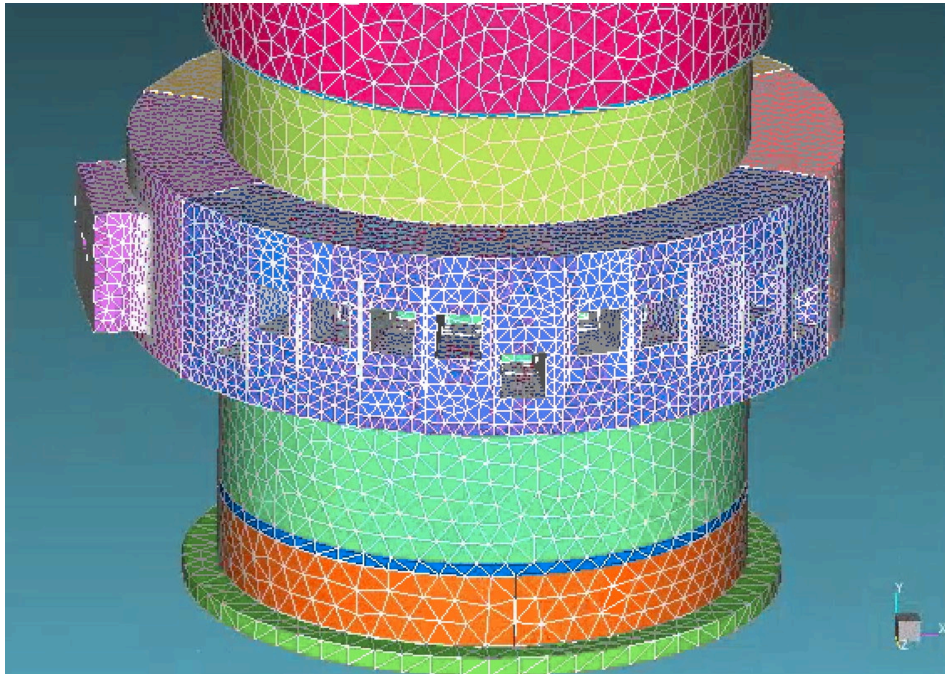




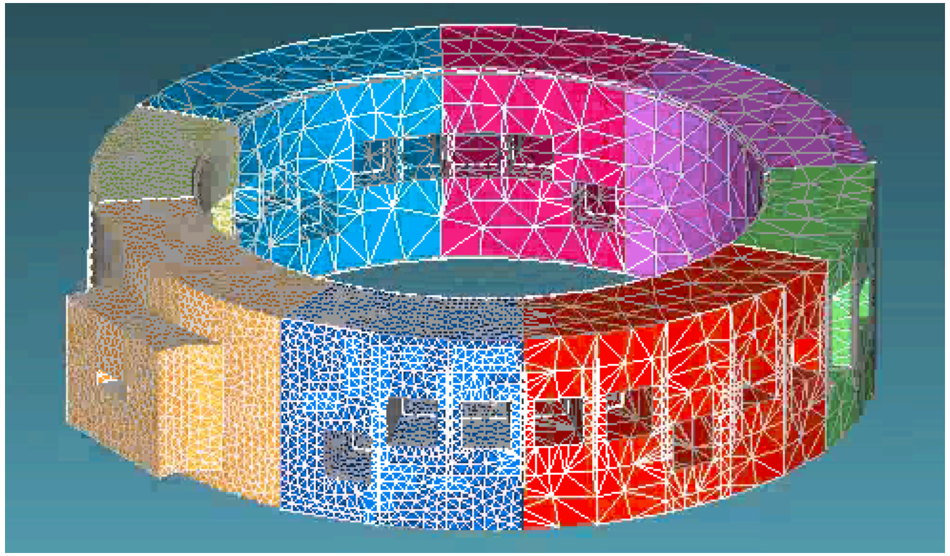


CV UM model for MCNP

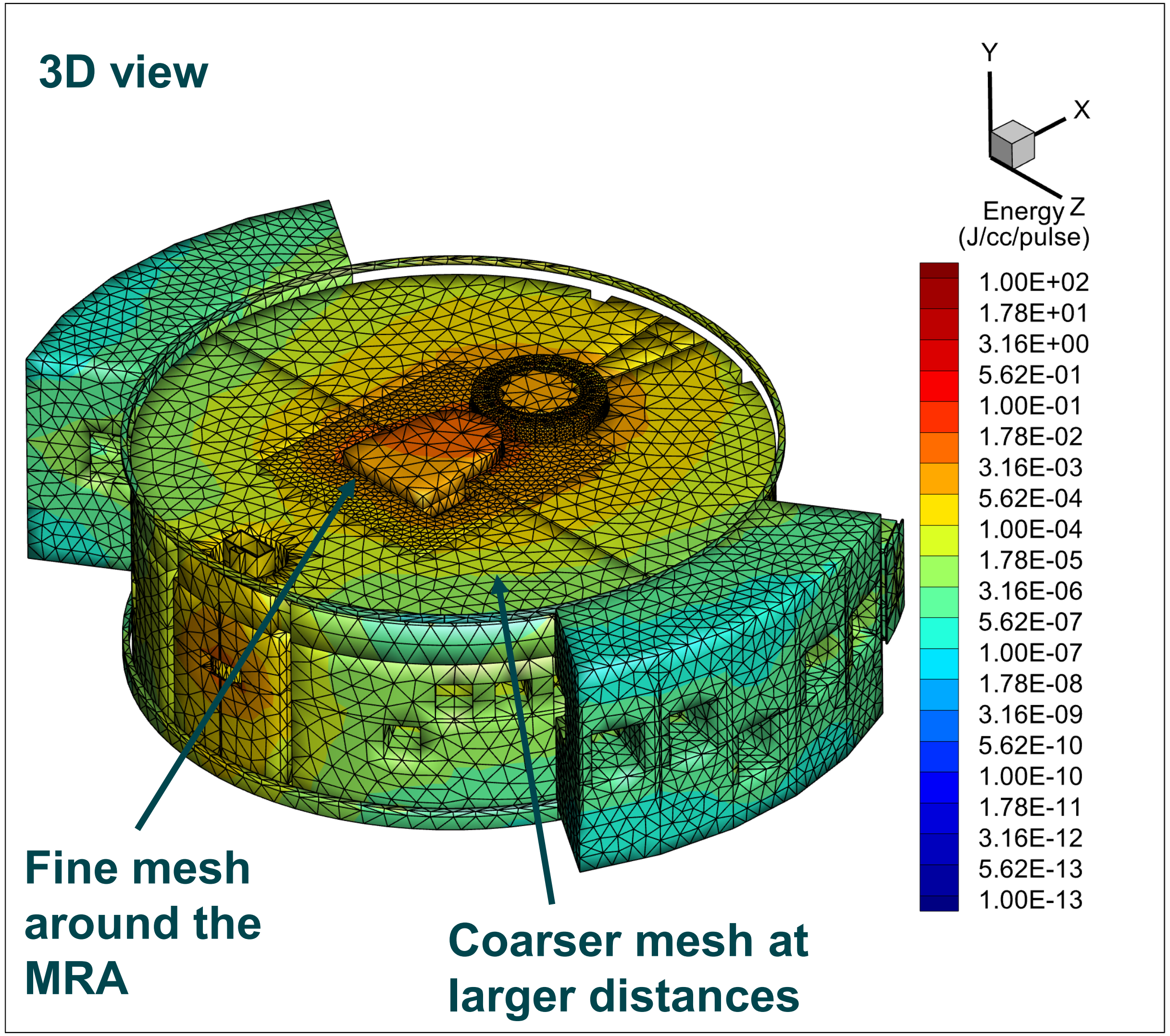




CV belt line

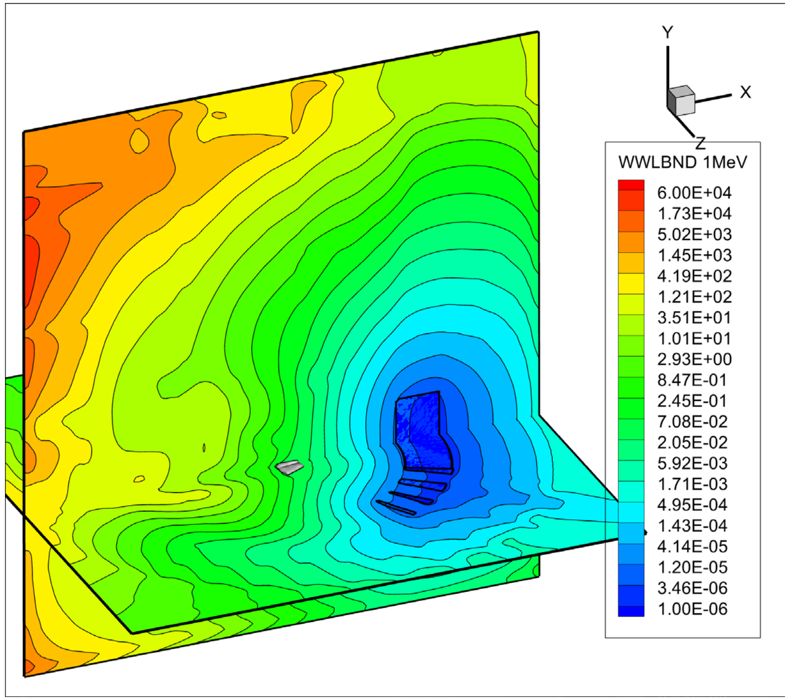


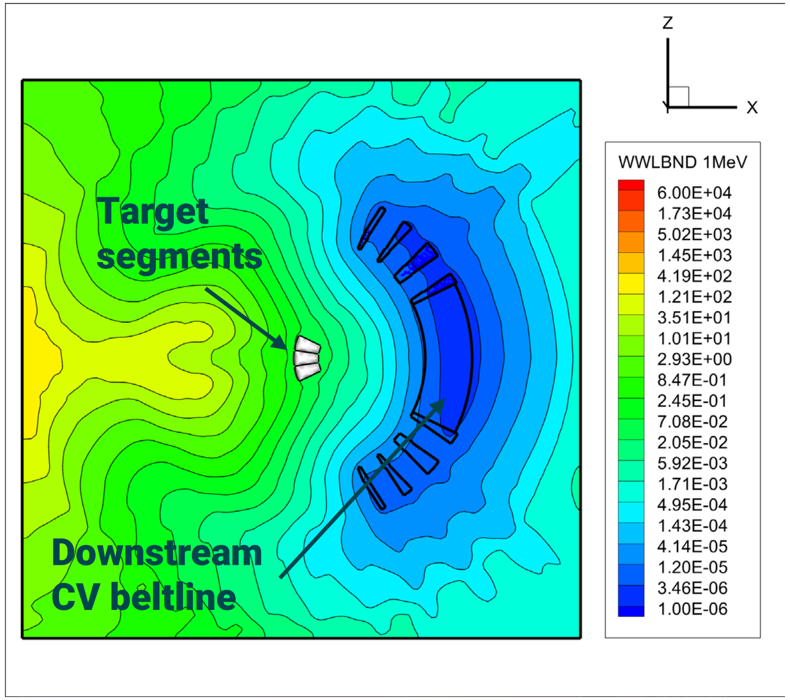
CVS UM model for MCNP



CVS Neutronics Analysis

- Deterministic energy-dependent n/p weight windows necessary for faster MCNP convergence calculated with Attila4MC/Cottonwood
- FW-CADIS starting with a secondary neutron source in the target
- HILO2K materials library used for neutrons up to 1.3 GeV





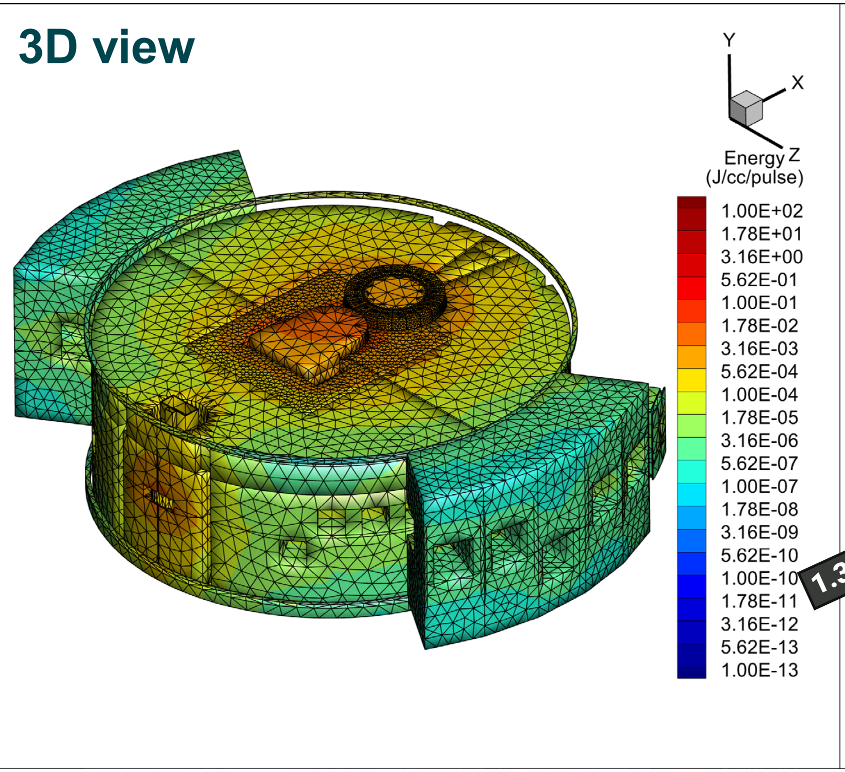
Weight windows for 1 MeV neutrons with the FW-CADIS motivating tally in the downstream CV beltline

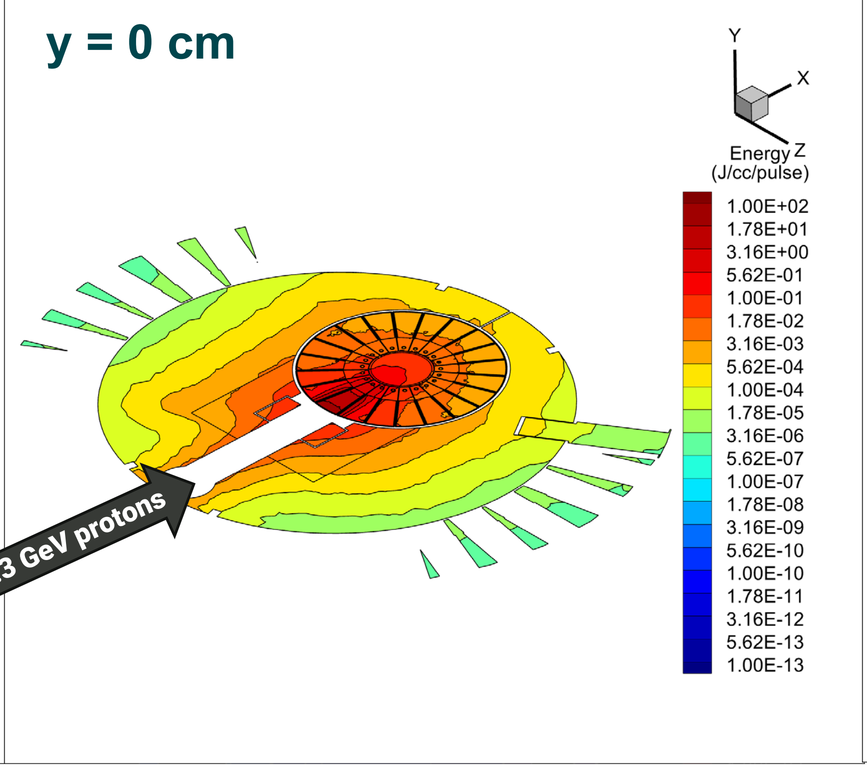
CVS Energy Deposition

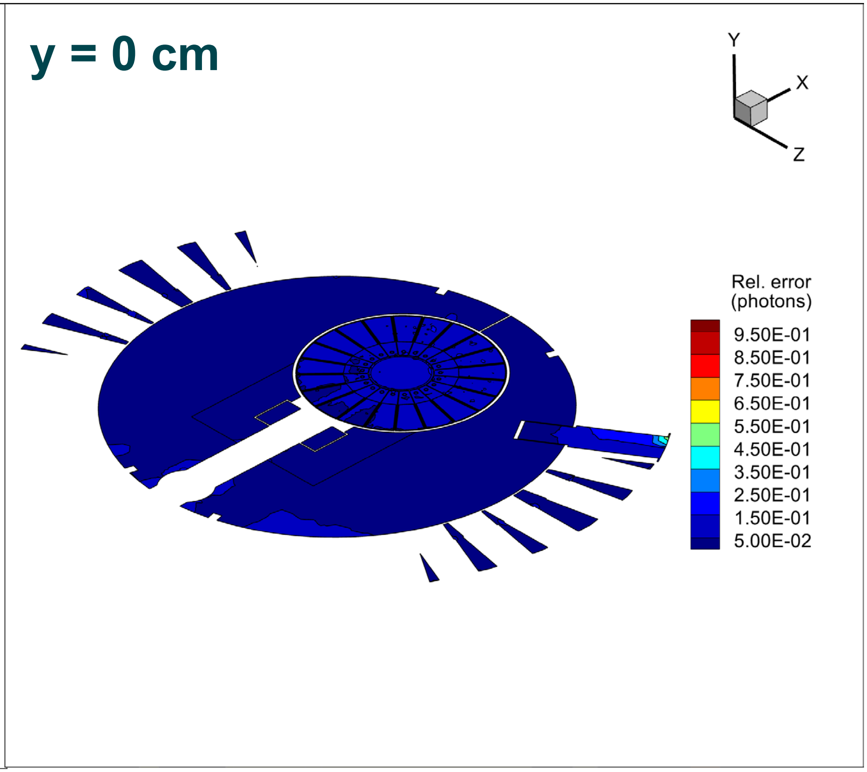
- In the first iteration, energy deposition calculated for a homogenized mixture of SS316L (90%) and water (10%) for cooled blocks
- Based on this data, cooling channels designed for “warmest” blocks #4 & 5 around the target, and a new analysis was carried out (slide #13)
- Initial analysis performed with monolithic target block design (21 segments) and 90 cm^2 proton beam profile (more conservative); subsequent analyses ran with lasagna target design (20 segments) and 62.5 cm^2 beam profile

CVS Energy Deposition

- Central CVS blocks and a cut through the proton beam level (y=0)

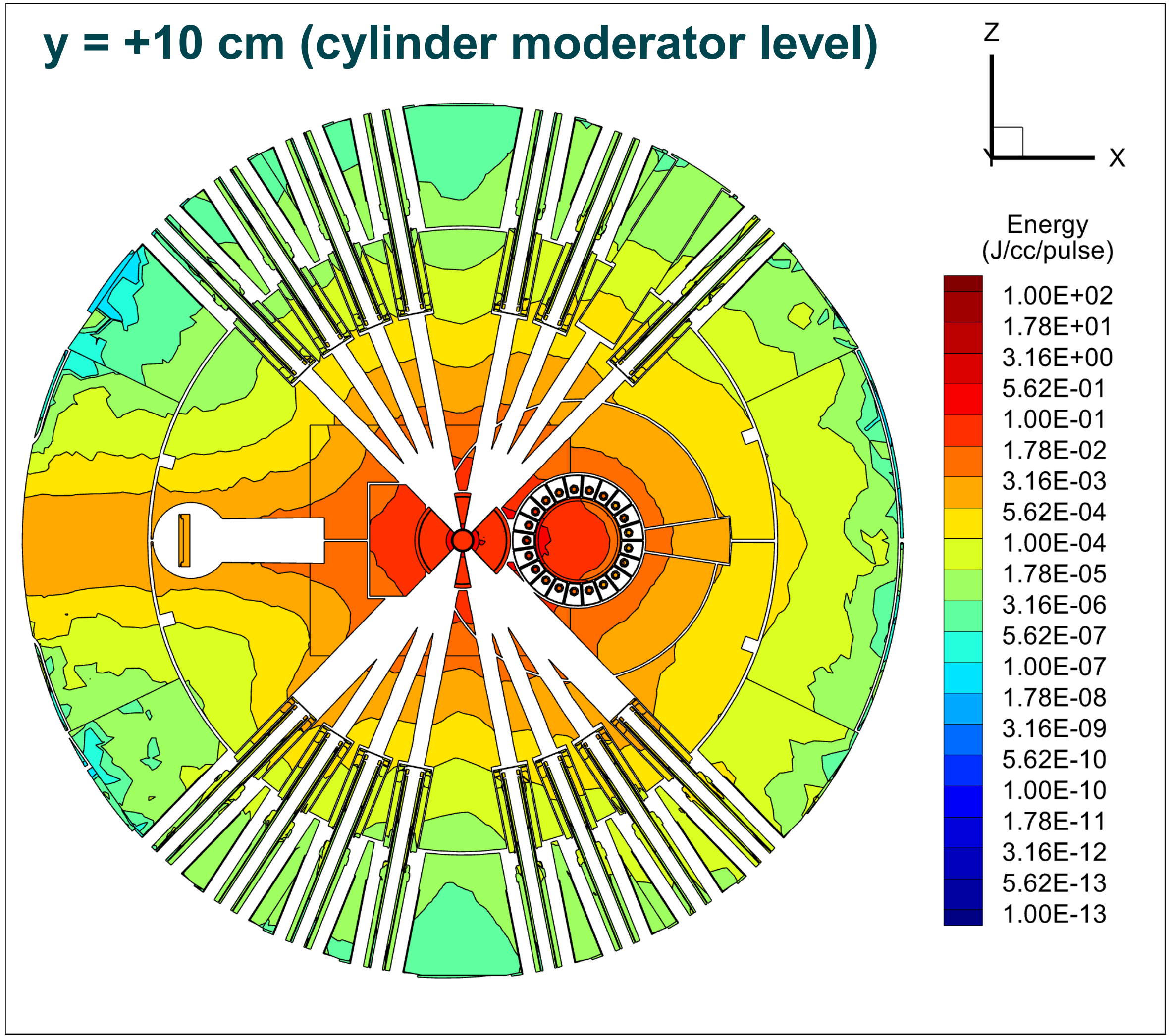


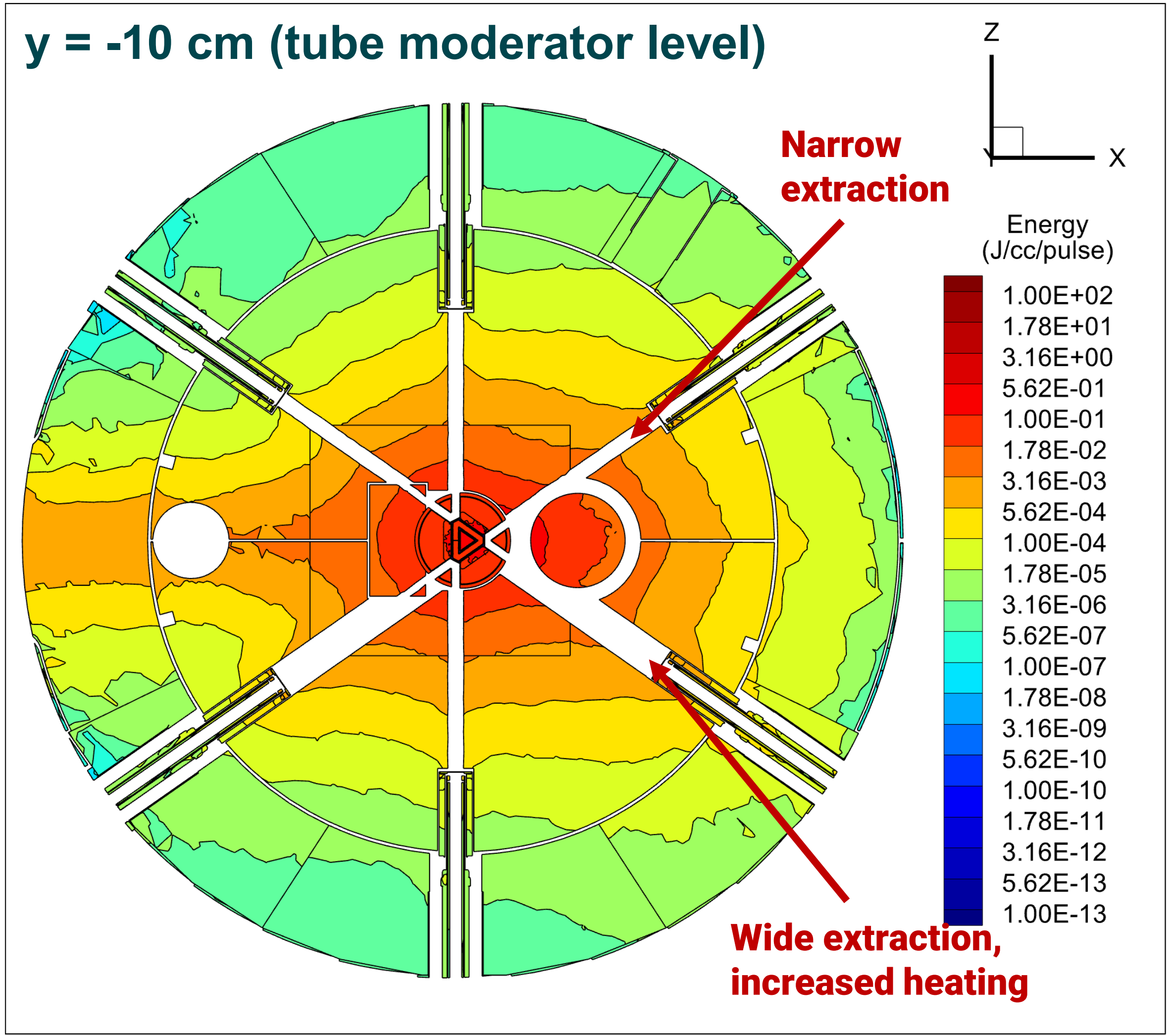




CVS Energy Deposition

- Cut through the neutron beam levels, with narrow and wide extractions



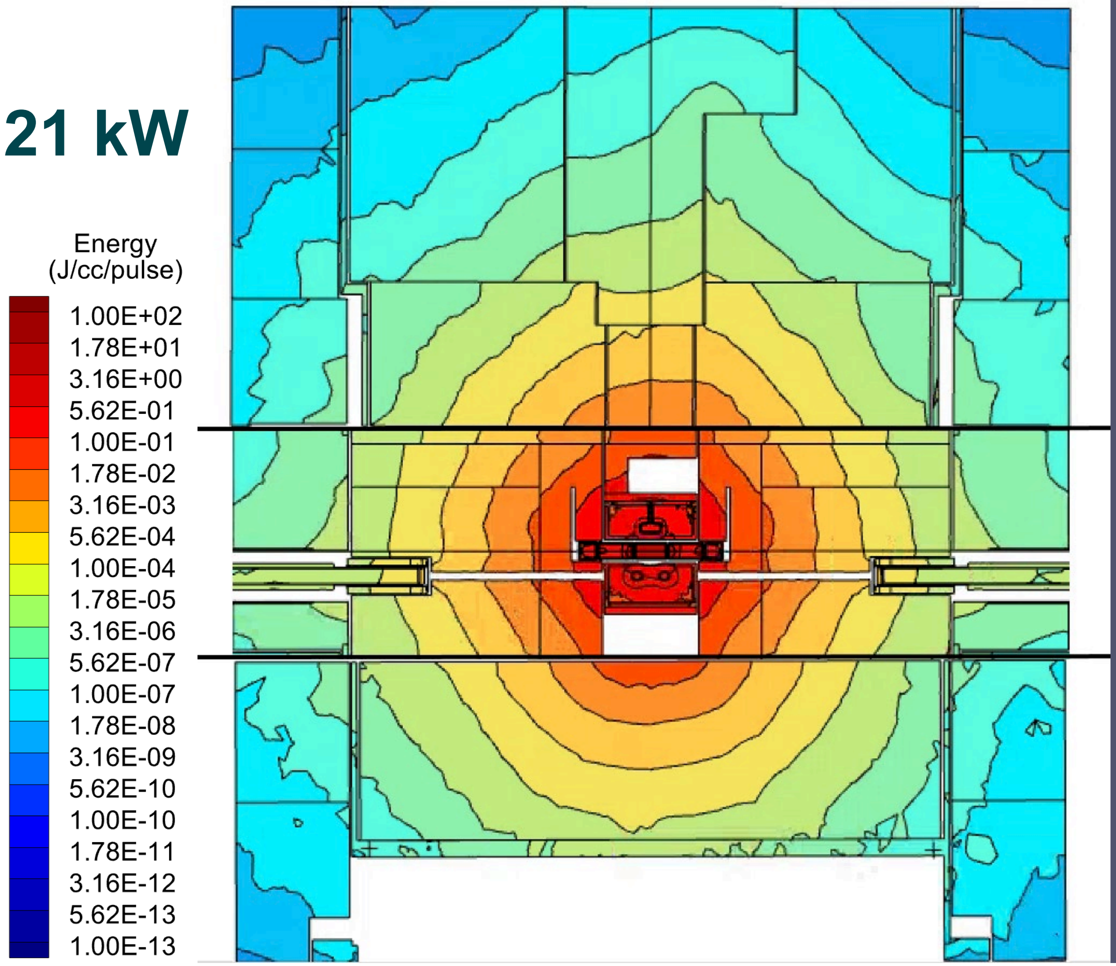


CV and CVS Total Heating

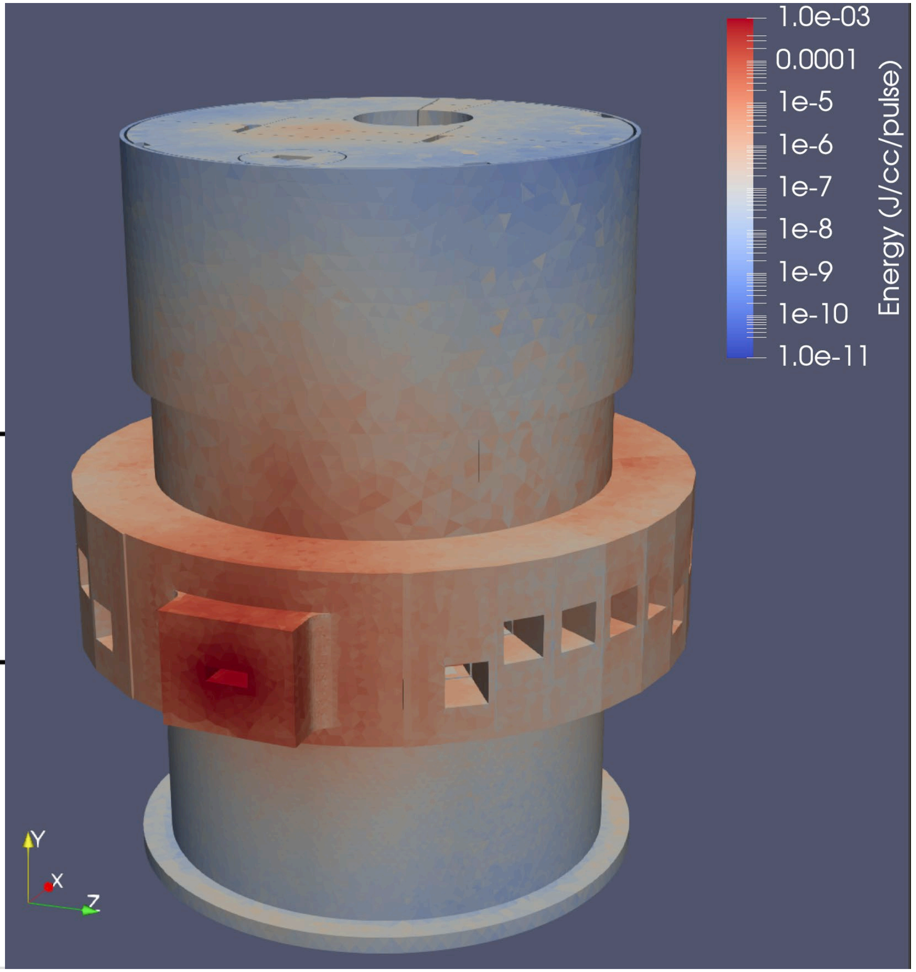
CV: 4 kW

CV shielding: 121 kW

Elevation plot through X=0

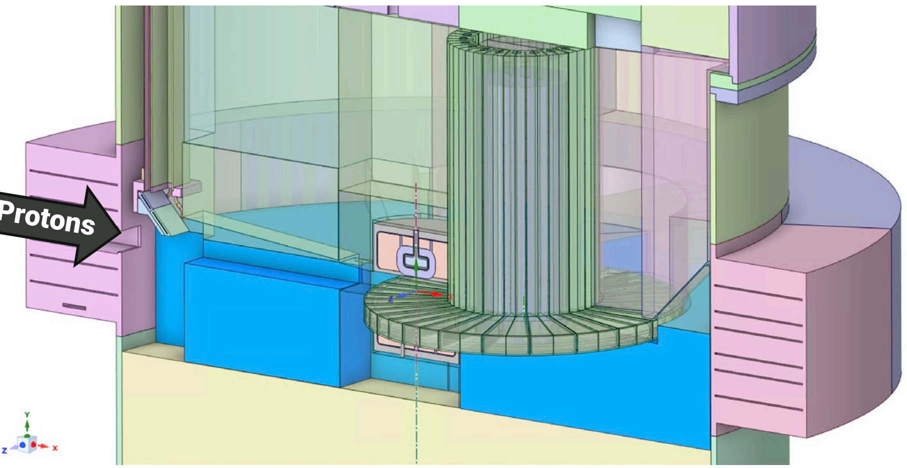


3D view

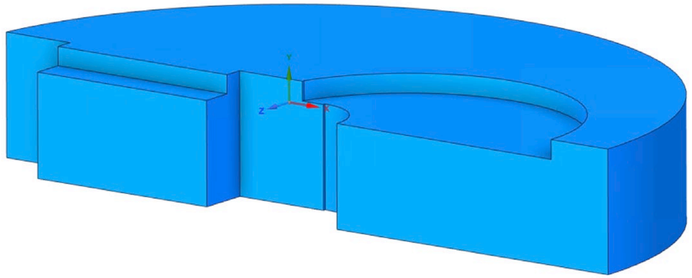


Detailed Energy Deposition in Block #4

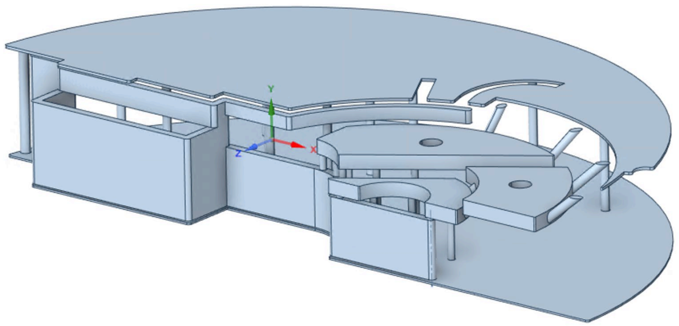
- High-fidelity energy deposition calculated for the shielding block surrounding the target with the designed water cooling channels

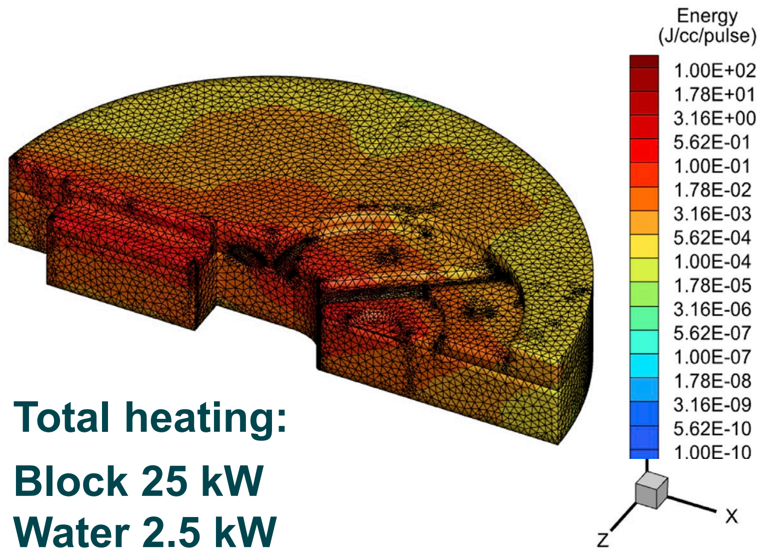


Block



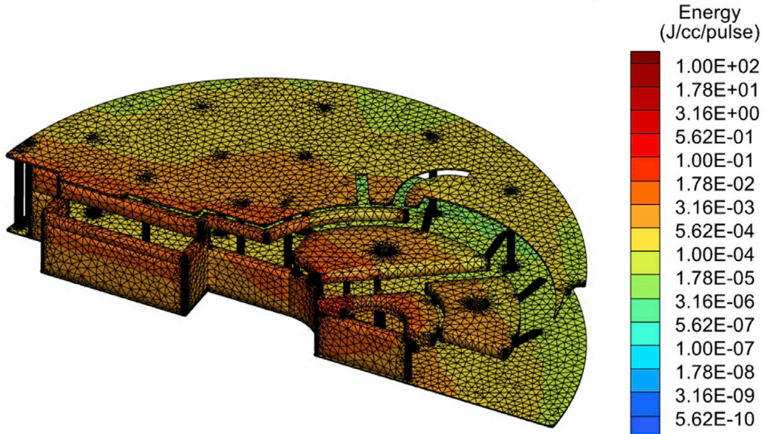
Cooling water





Total heating:

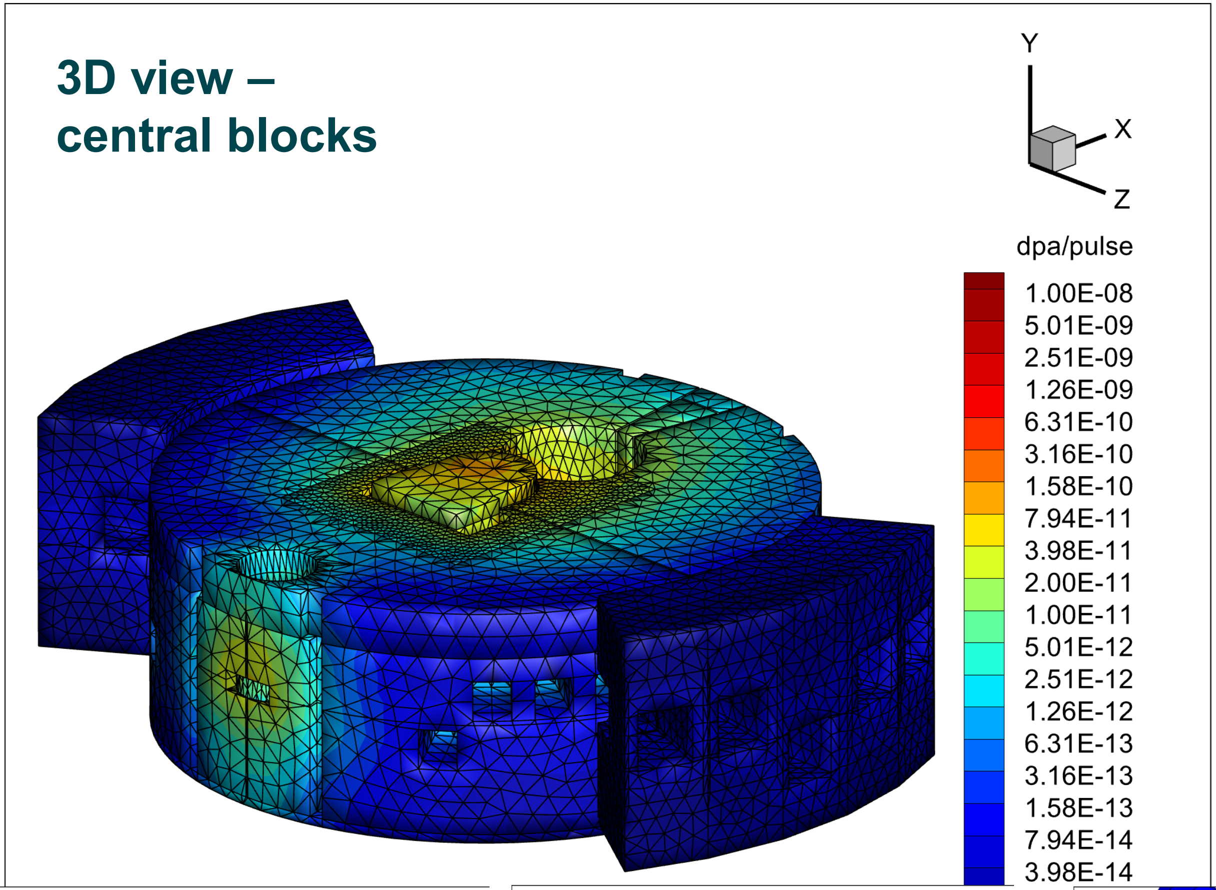
Block 25 kW
Water 2.5 kW

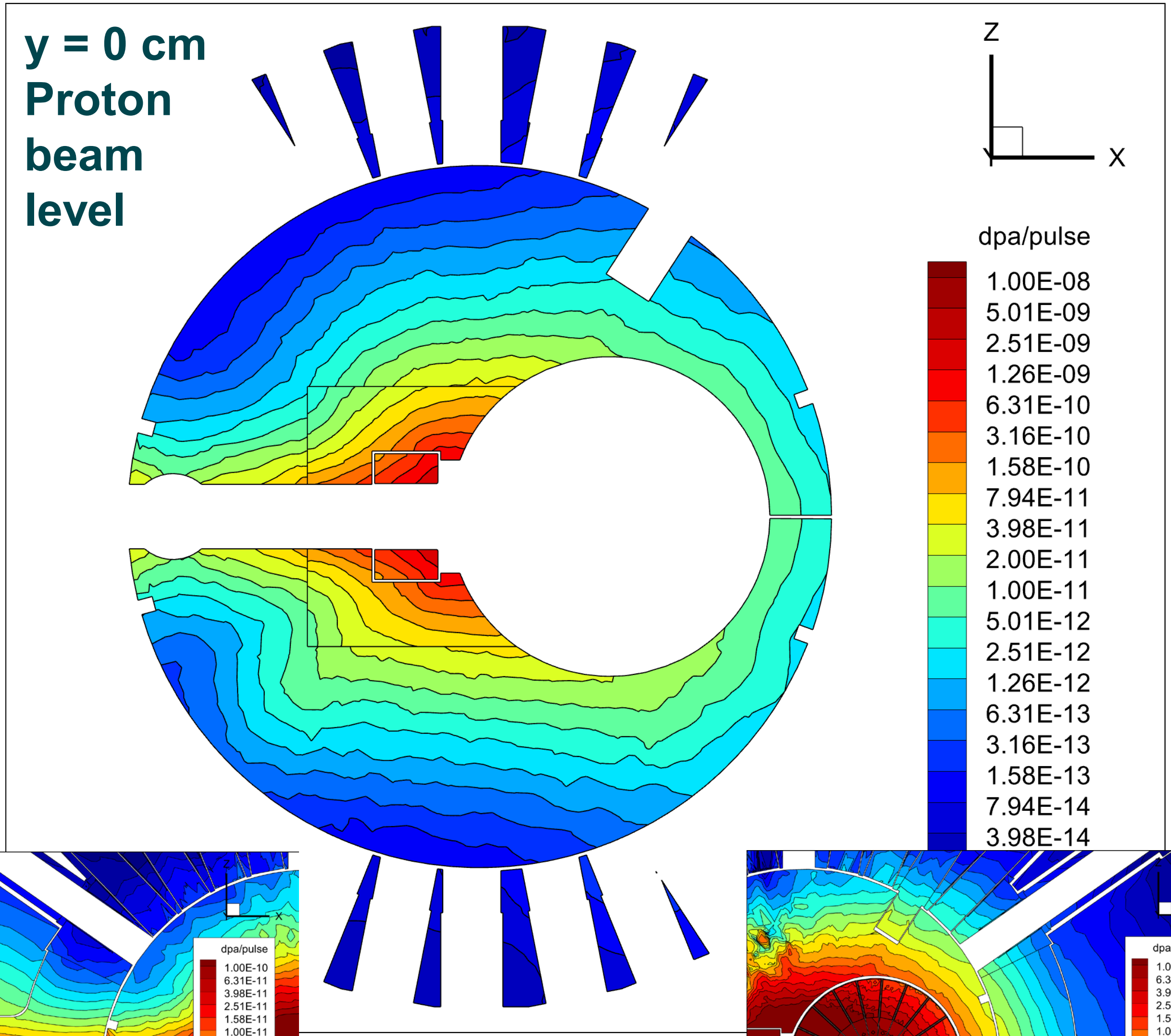


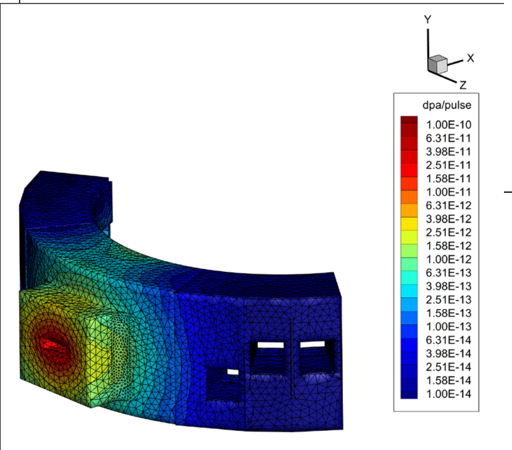
Radiation Damage

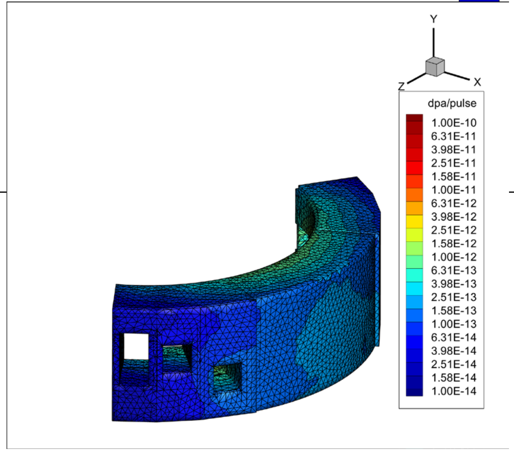
- Radiation damage in terms of displacement per atom (dpa) calculated for SS316L using cross sections from W. LU, et al., “A reevaluation of radiation damage cross section”, Journal of Nuclear Materials 431, 33, (2012).

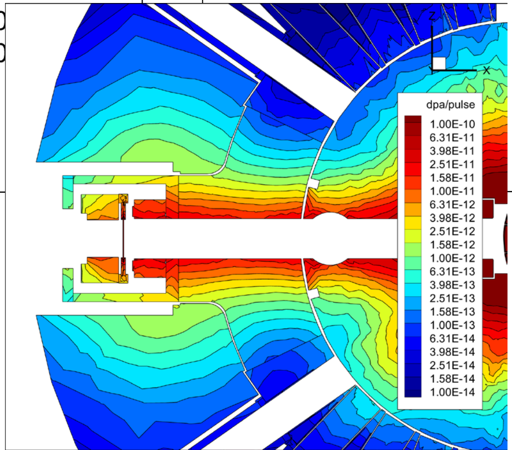
CV and CVS Radiation Damage

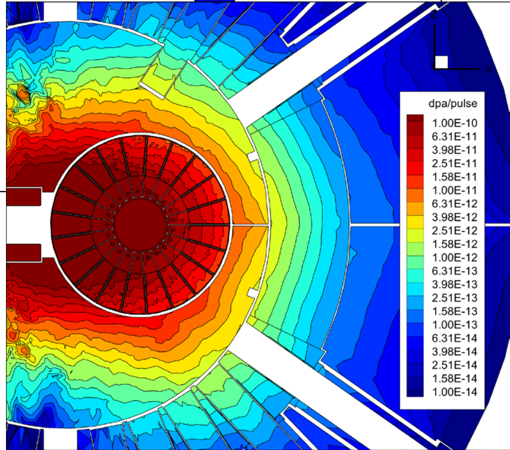




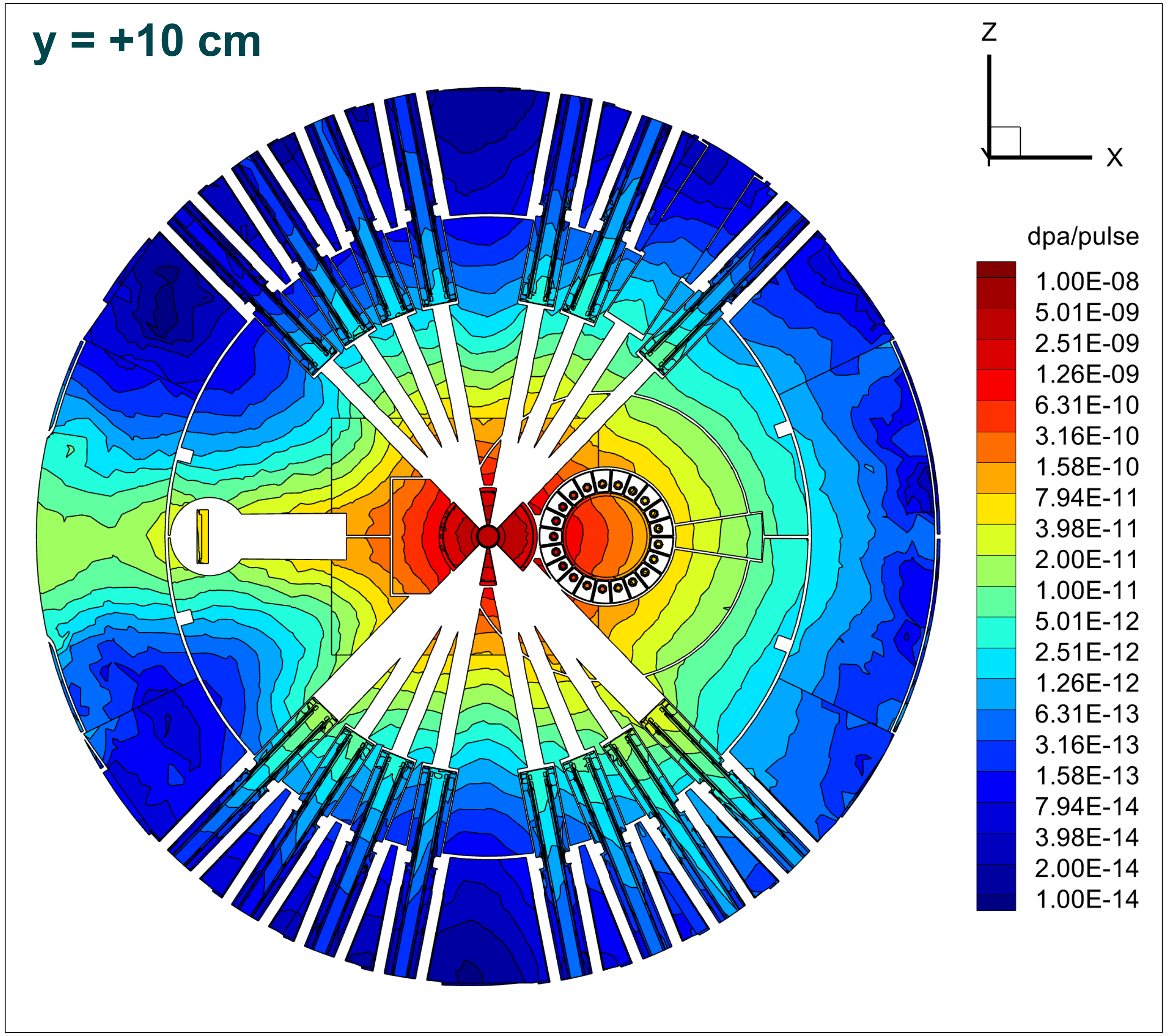


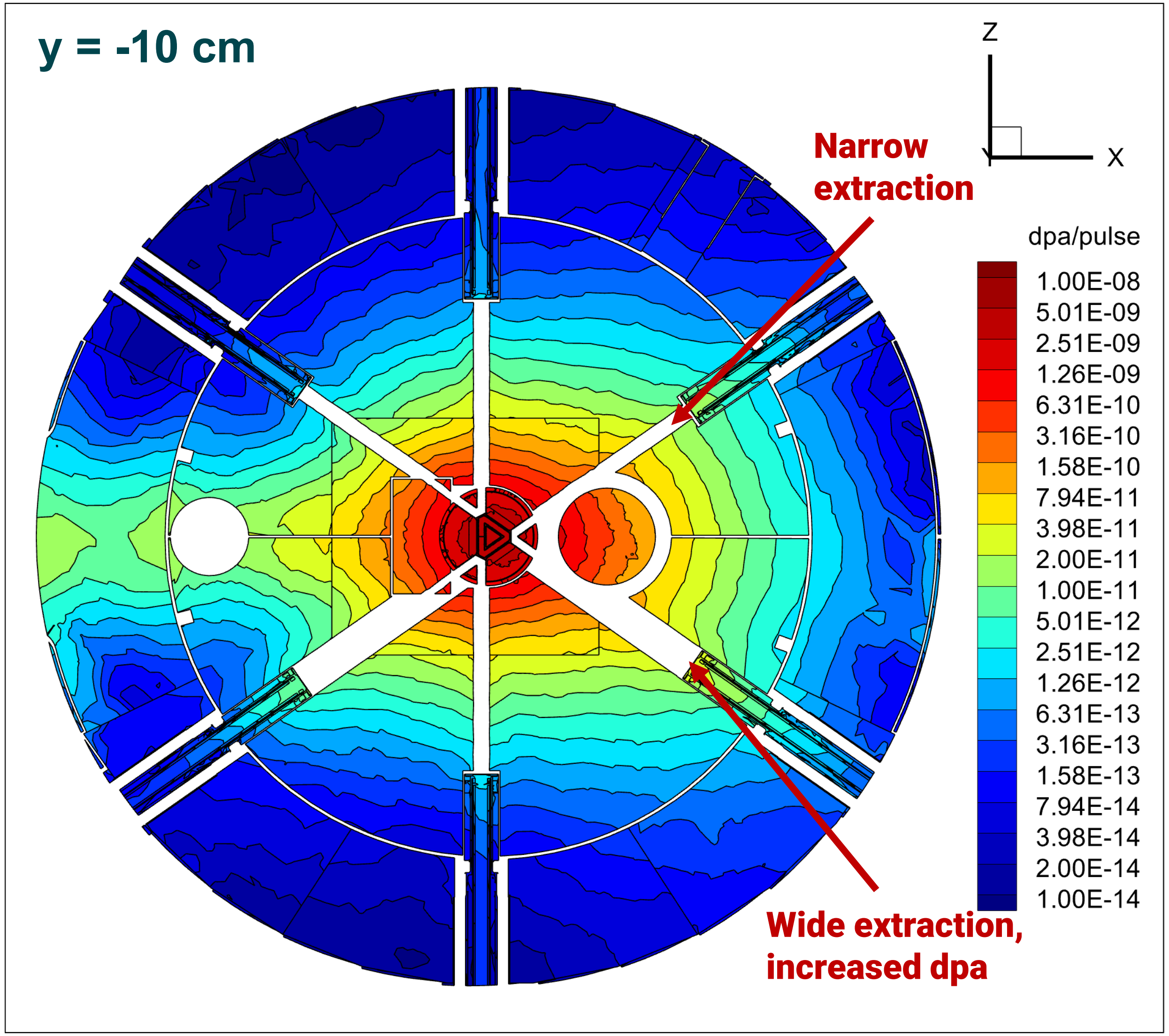






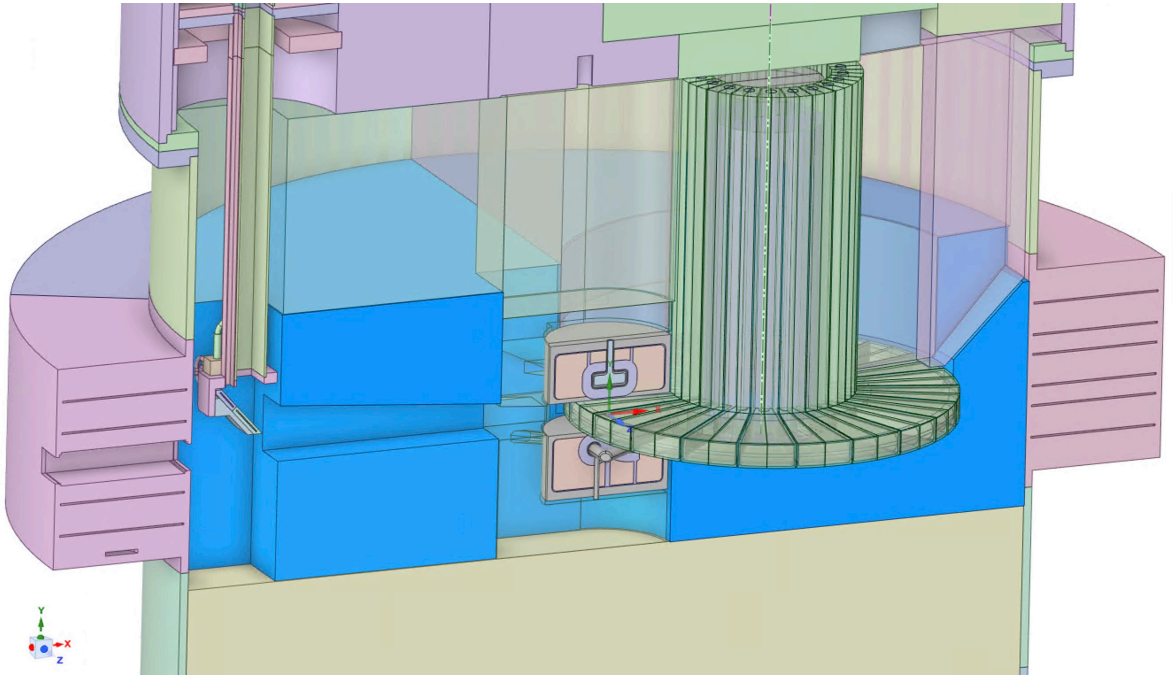
CV and CVS Radiation Damage (Neutron extraction levels)

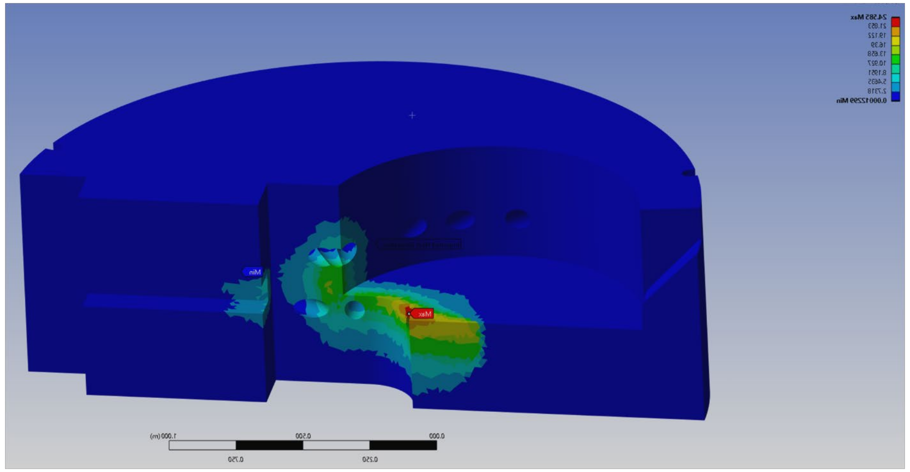




Radiation Damage

- Maximum radiation damage within 1 m from the proton beam level is 0.6 dpa/year or 25 dpa after 40 years of operation
- The minimum lifetime of the CVS is 100 years based on 60 dpa limit for SS316L and beam non intercepting components





Conclusion

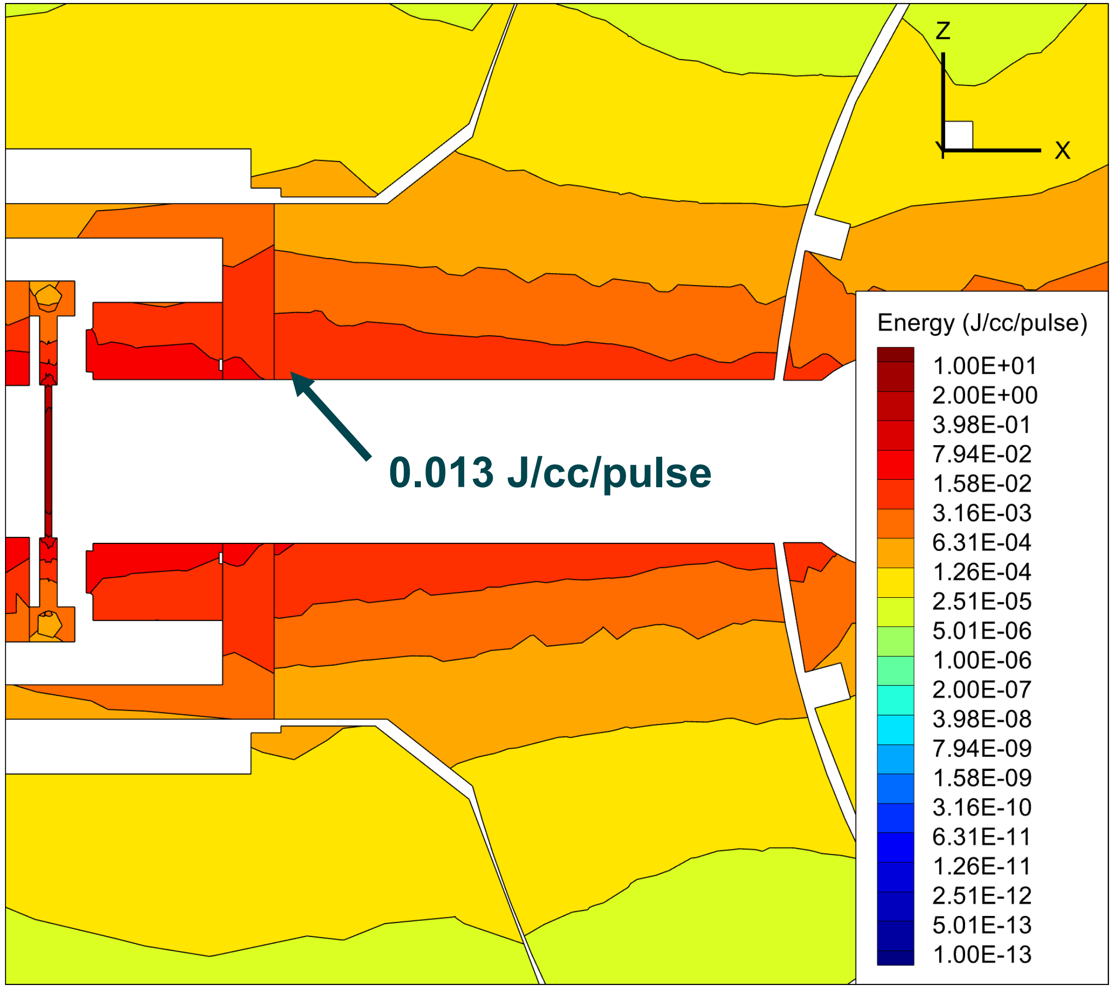
- Neutronics team provided support to help develop the preliminary design of the CV and CVS
- Calculated:
  - Energy deposition from the beam-on operations
  - Radiation damage
  - Prompt radiation dose rate from the beam-on operations
  - Shutdown radiation dose rates for target/MRA/TVP/PBW replacement
- Future work:
  - Repeat the analyses with the updated geometry for the final design review

Thank you

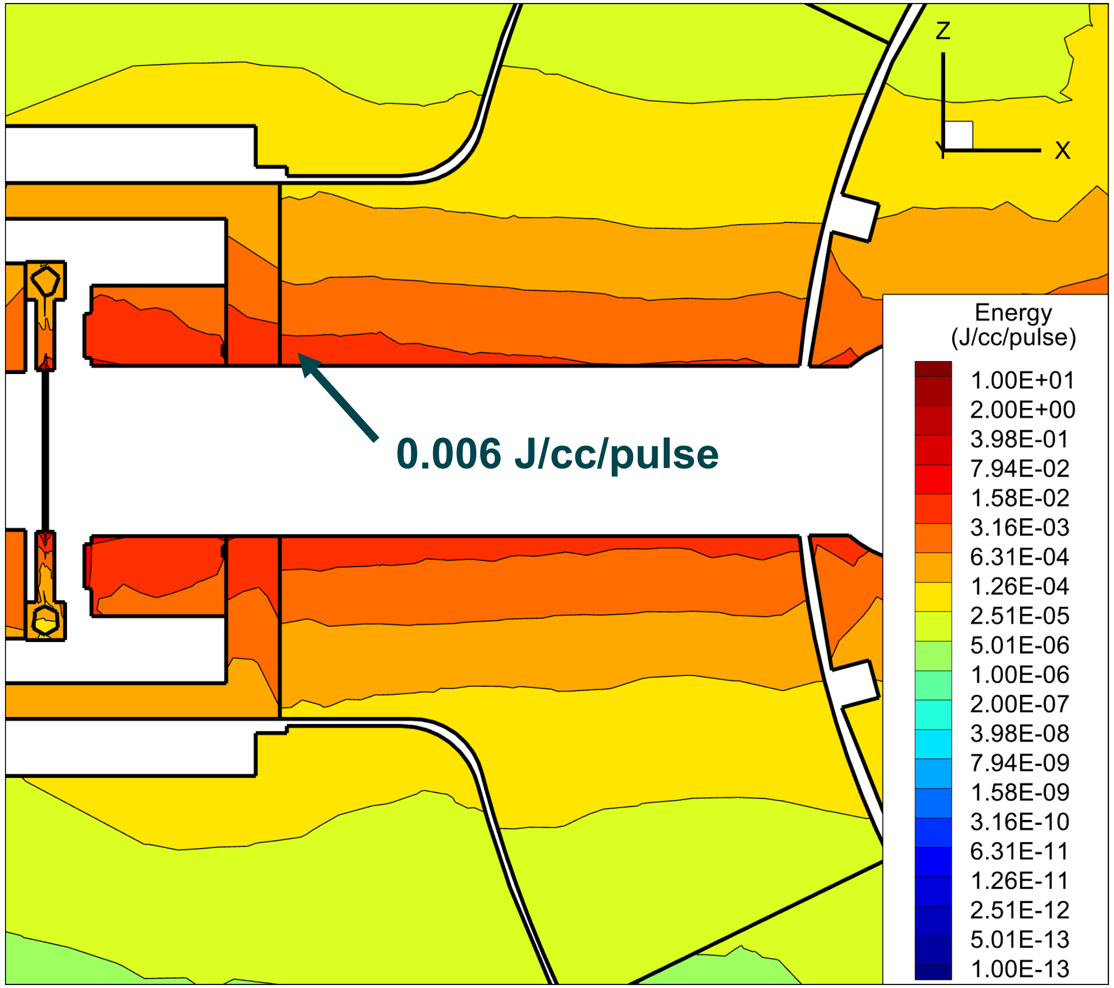
Backup slides

Studied impact of different beam profiles and PBW designs on CVS heating

10 mm PBW + Gaussian beam



5 mm PBW + Quadrupole beam



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