





August 2026 | Target and MRA FDR

# Target Drive Room Beam-on Dose Rates

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STS Neutronics



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**Charge Question 2: Has the design been shown to meet the requirements?**

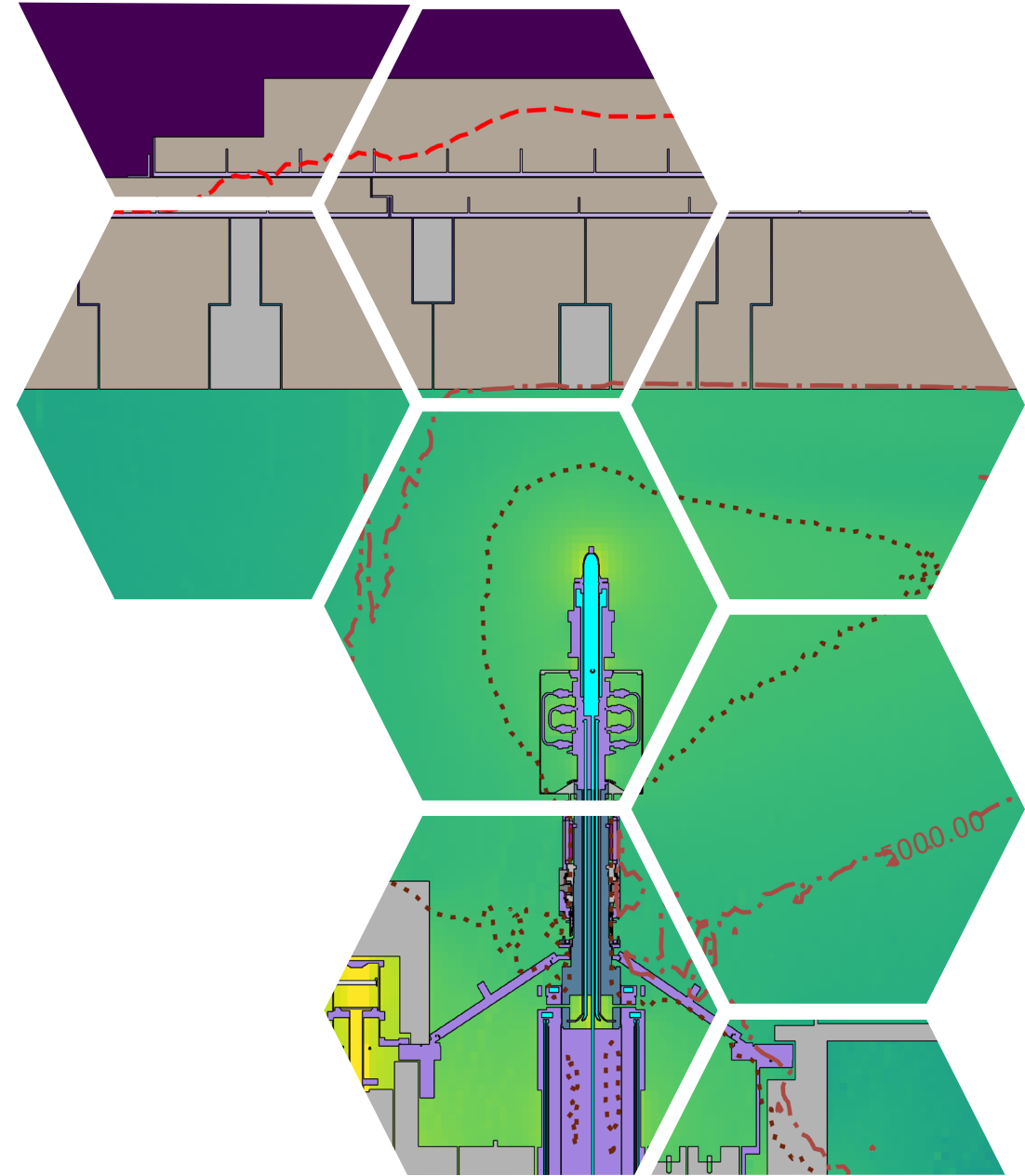
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**Charge Question 3: Do DACs and other supporting documentation adequately support the final design?**

**Charge Question 5: Is the design sufficiently mature to proceed with finalizing the procurement package?**

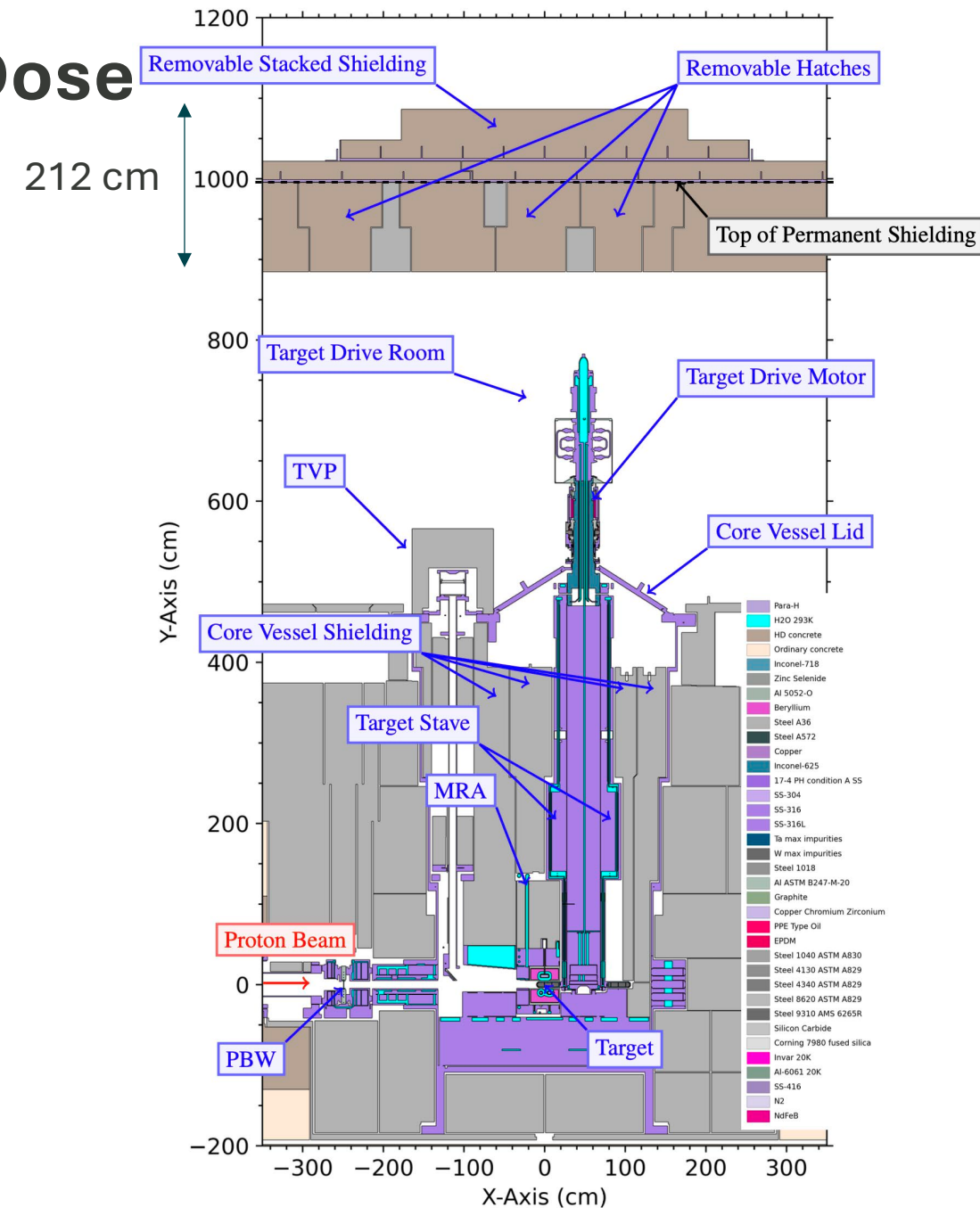
# Topics

- Overview
- Proton Source Description
- Water Source Description
- Methodology
- Results
- Conclusions



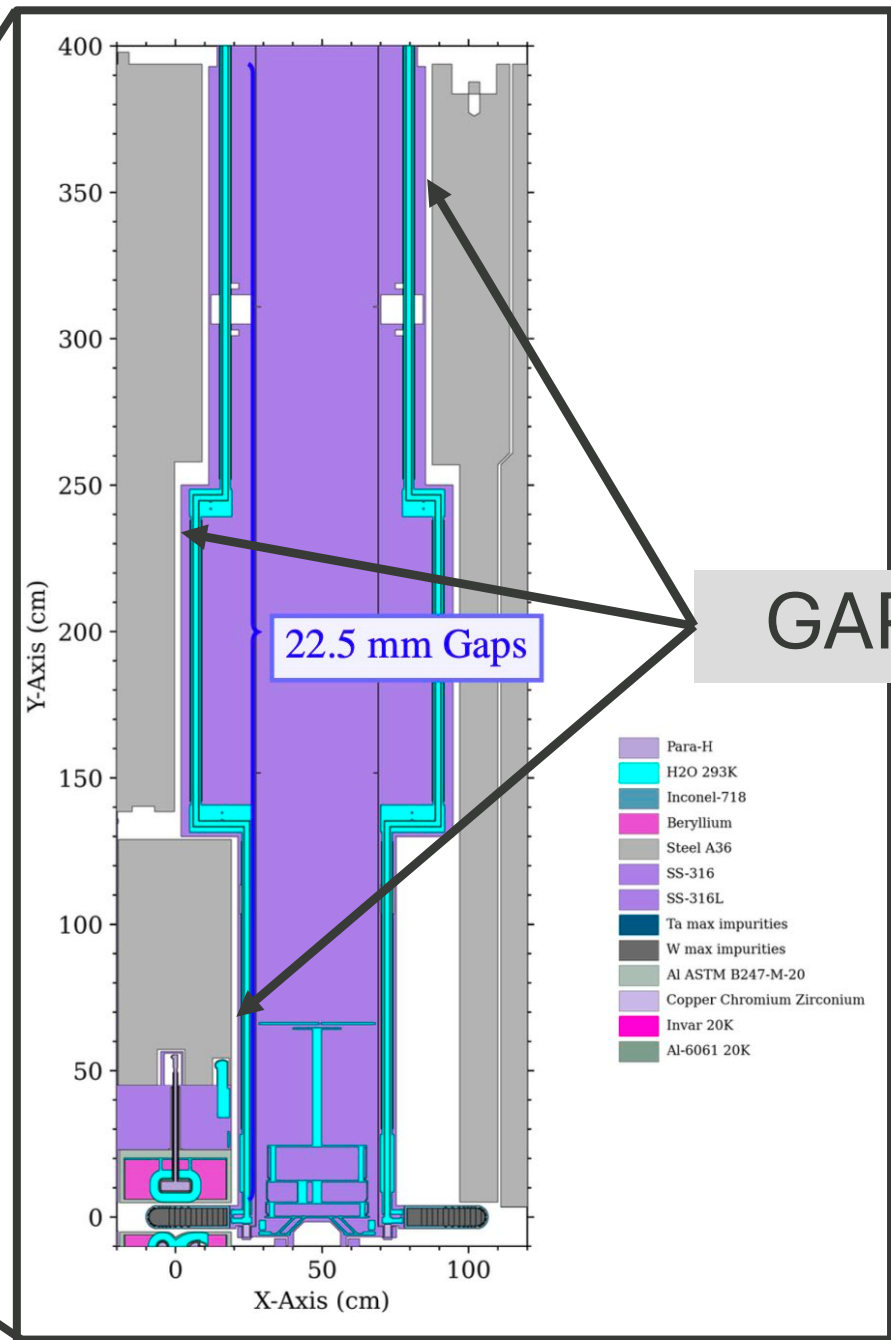
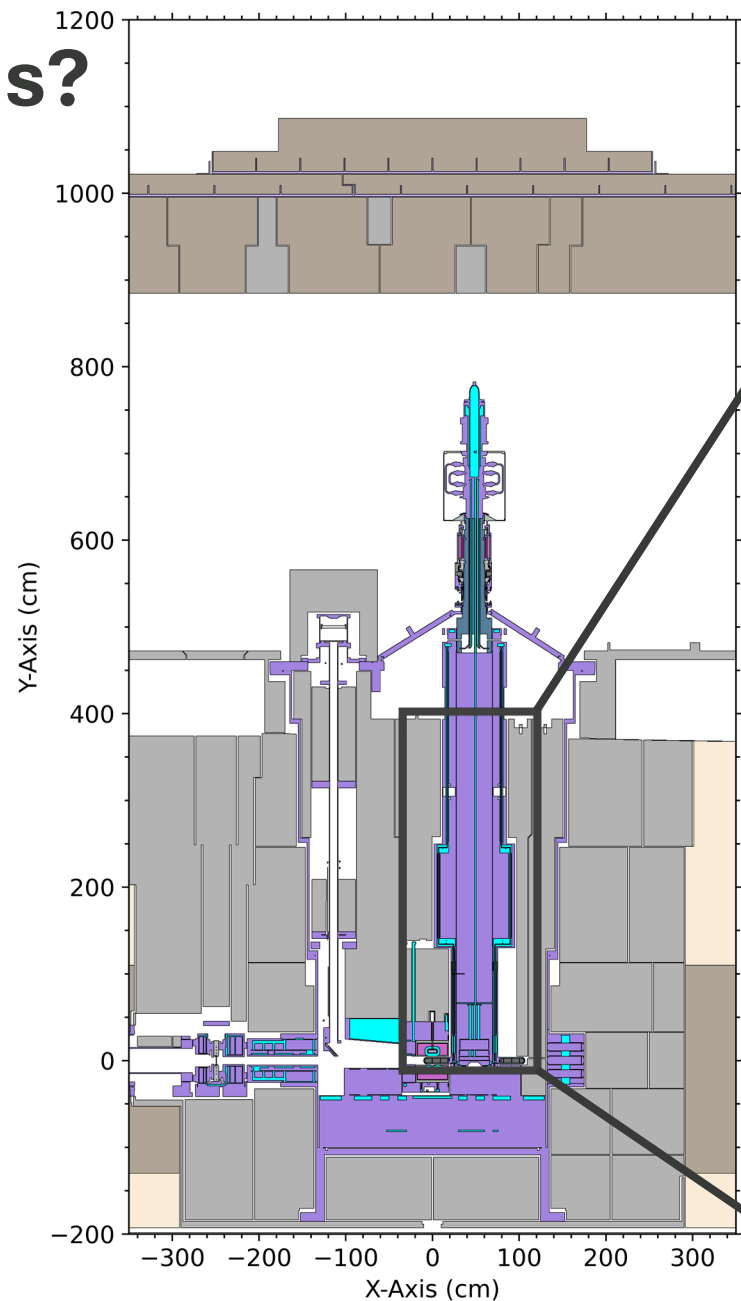
# Beam-on Target Drive Room (TDR) Dose

- Goal of Study:
  - Find the maximum allowable gap around the target assembly and minimum TDR roof thickness that does not violate the 0.25 mrem/hr high-bay dose limit, and calculate material doses to target drive and crown components.
- Key Takeaway:
  - Gaps no larger than 22.5 mm with 212 cm of HD concrete will achieve 0.25 mrem/hr on the high-bay floor during operation, and all materials meet dose requirements.
- Radiation Sources:
  - Proton Beam on Target
  - Activated Target Water (Photons and Neutrons)



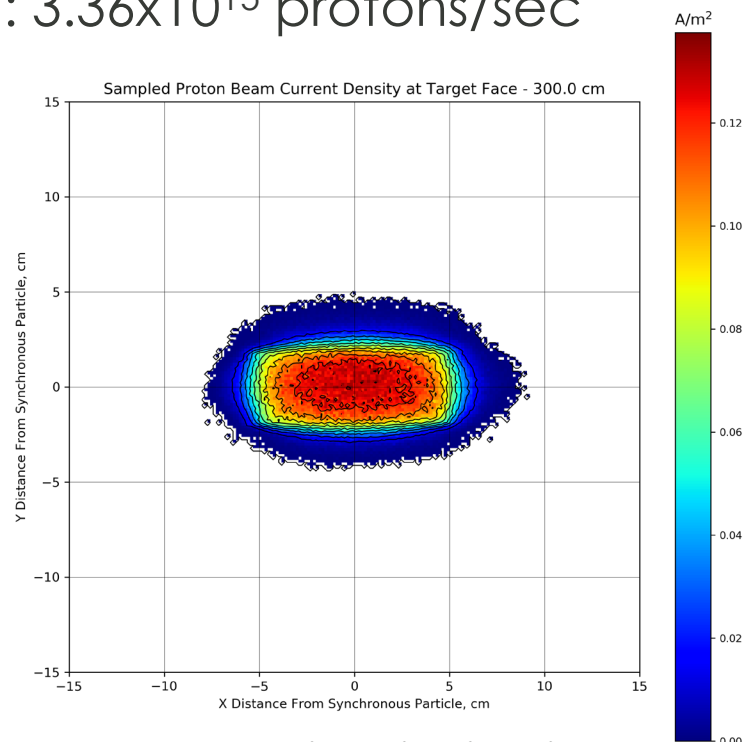
Target Systems Geometries

# Which gaps?

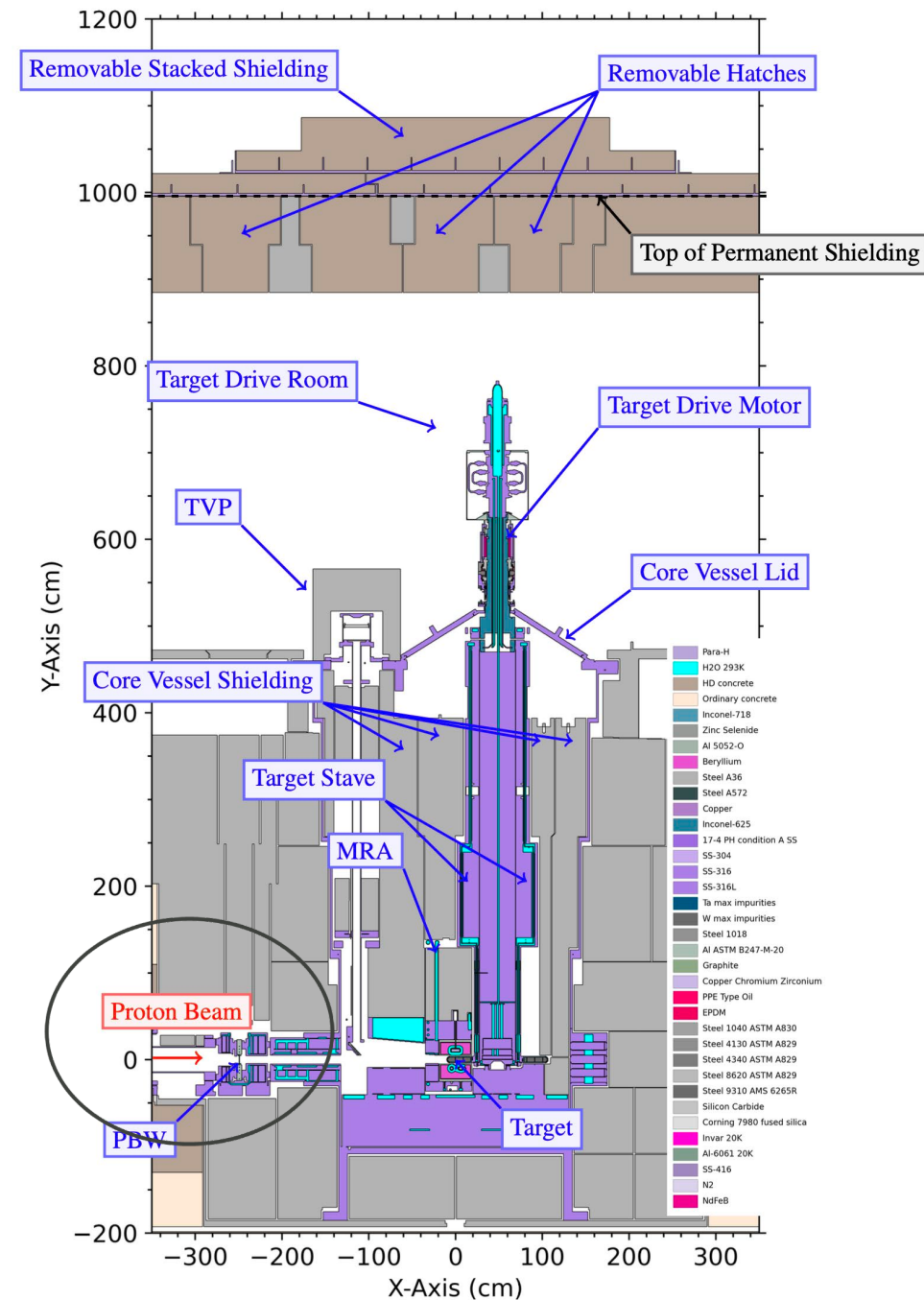


# Proton Source

- Energy: 1.3 GeV
- Power: 0.7 MW
- Repetition Rate: 15 Hz
- Beam Area: 95% of beam within 60 cm<sup>2</sup>
- Normalization:  $3.36 \times 10^{15}$  protons/sec

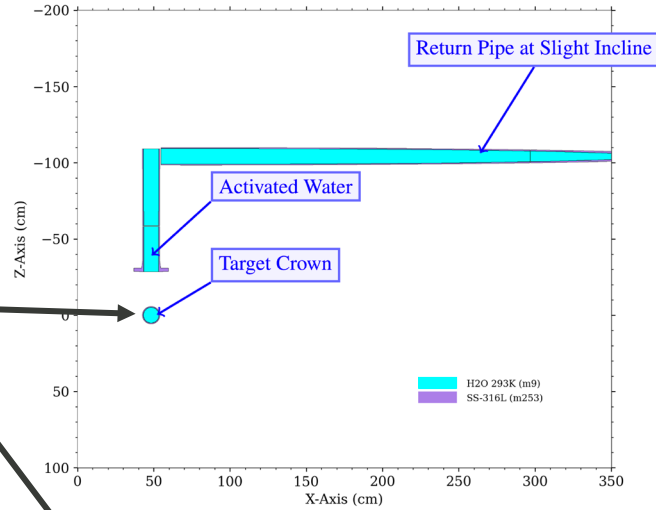
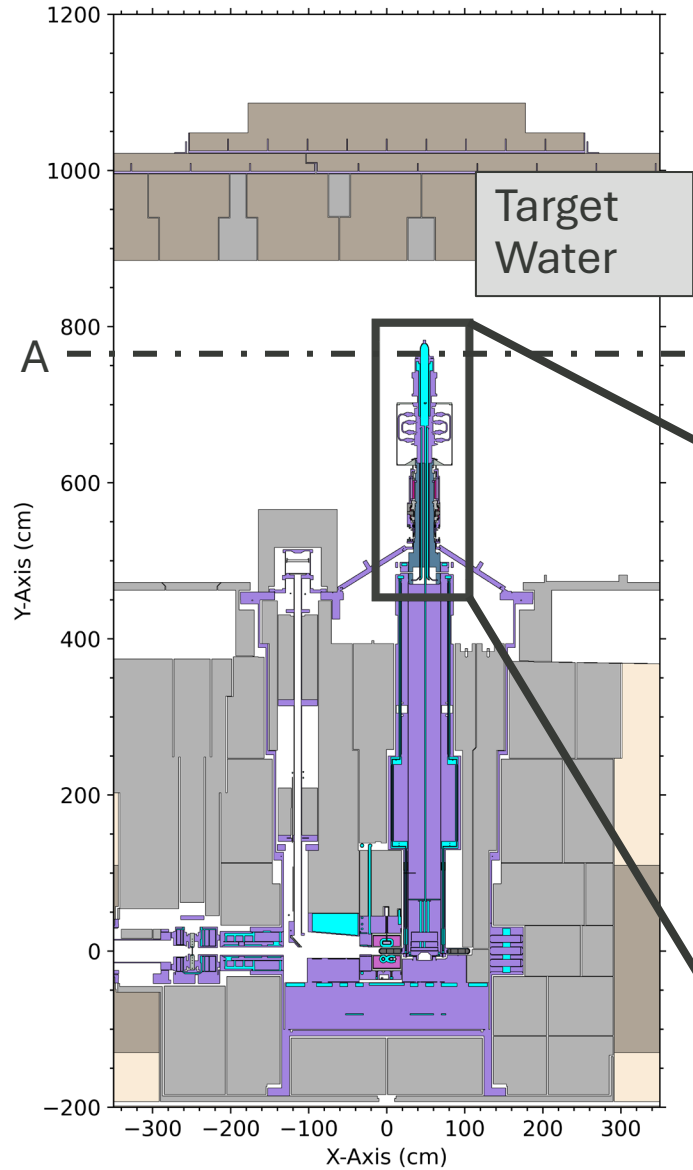


Proton Beam Spatial Distribution courtesy of Wouter de Wet

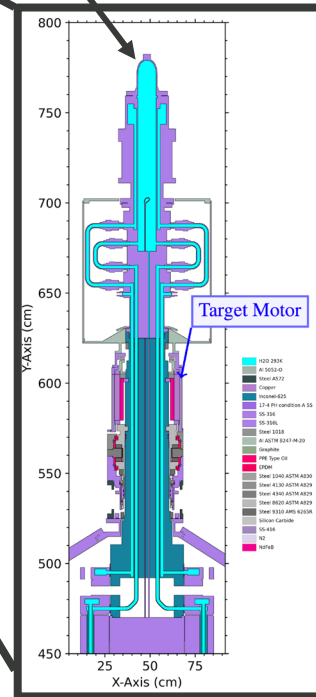


Target Systems Geometries

# Water Photon Source



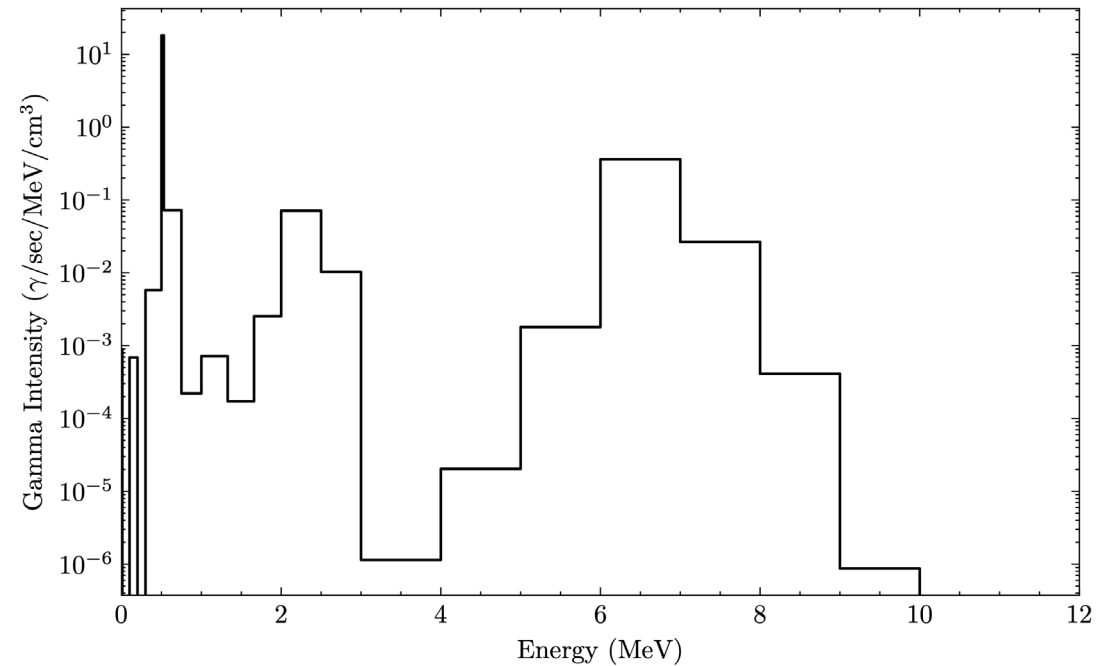
## Plan View at A-A (765 cm)



# Target Crown

- Intensity:  $2.12 \times 10^7$   $\gamma$ /sec/cm<sup>3</sup>
- Irradiation Time: 0.60 seconds
- Decay Time: 8.19 seconds
- Primarily driven by <sup>16</sup>N
  - ~6.2 MeV gamma
  - Half Life: 7.13 seconds

### Target Water Decay Gamma Energy Spectrum



# Water Neutron Source

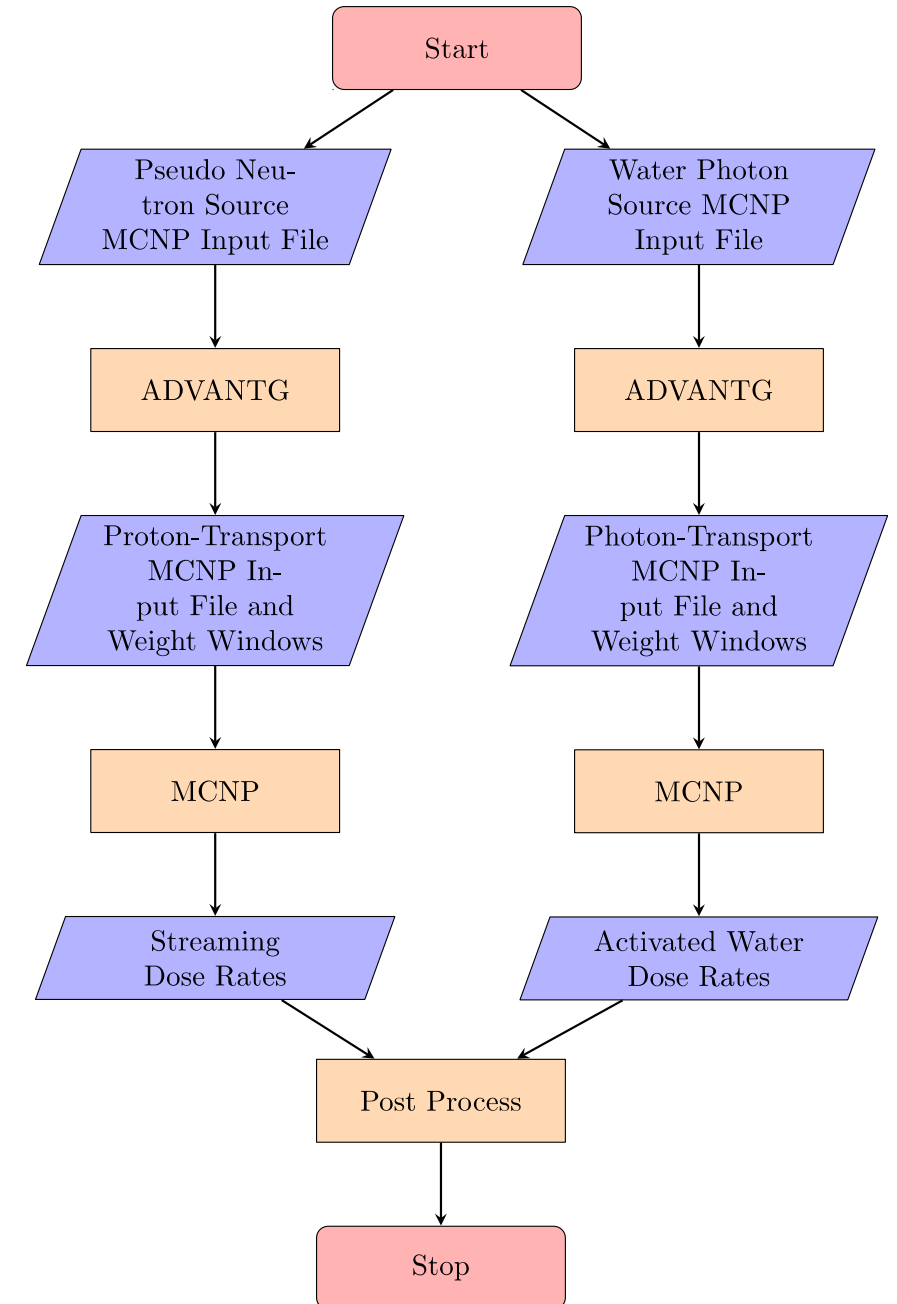
- Intensity:  $1.85 \times 10^4$  n/sec/cm<sup>3</sup>
- Irradiation Time: 0.60 seconds
- Decay Time: 8.19 seconds
- Primarily driven by <sup>17</sup>N
  - Half Life: 4.17 seconds

| Energy (MeV) | Probability |
|--------------|-------------|
| 0.383        | 0.366       |
| 0.884        | 0.006       |
| 1.17         | 0.554       |
| 1.7          | 0.074       |

Discrete Neutron Energy Emission Spectrum

# Particle Transport Methodology

- ADVANTG 3.2.0 Calculations:
  - Purpose:
    - Generate Weight Window Variance Reduction Parameters
    - Encourage particles up gaps and penetrate target drive room ceiling
  - Discrete Ordinates Transport
  - HILO-2K multi-group cross sections
- MCNP Version 6.2.0 Calculations:
  - Purpose:
    - Transport source to desired location and calculate dose rates
  - Monte Carlo Transport
  - ENDF/B-VII.1 Cross Sections



# Beam On Total Dose Rates

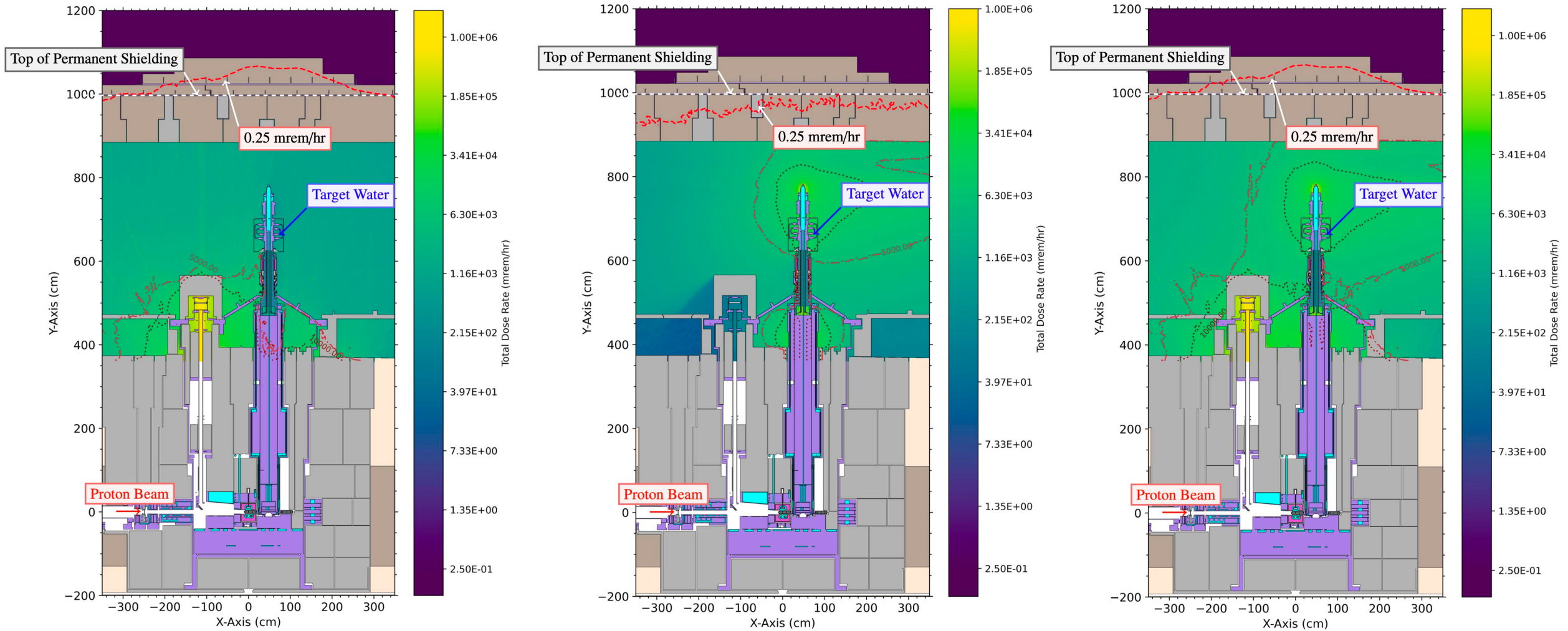
Proton Source Dose Rates



Activated Water Source Dose Rates

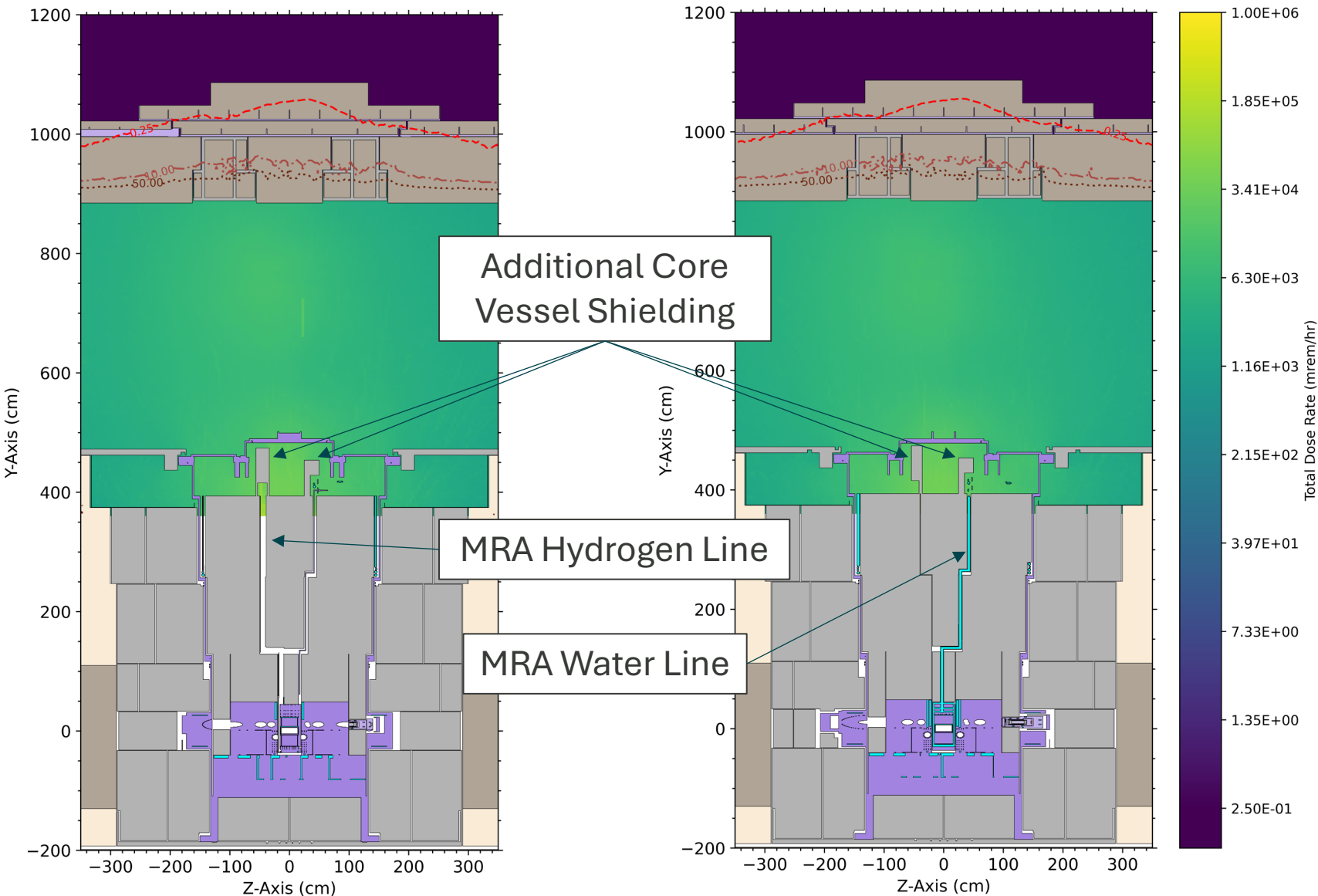


Total Beam On Dose Rates



# Streaming up MRA Water and Hydrogen Lines

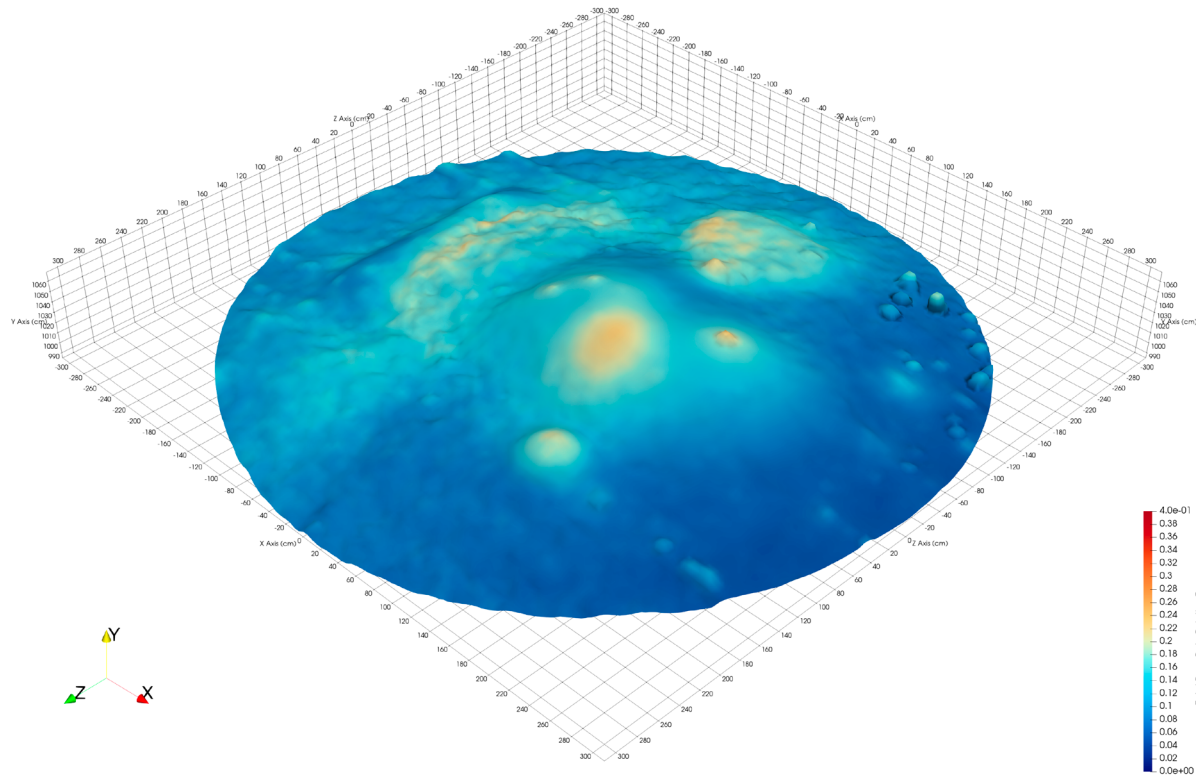
Radiation streaming up hydrogen and water lines are mitigated by core vessel shielding



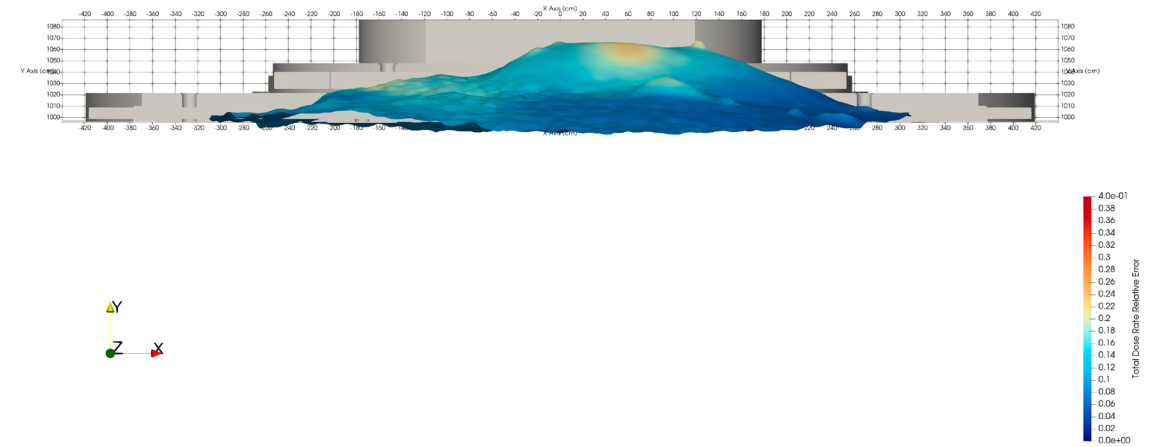
Cross Section through MRA Hydrogen Line

Cross Section through MRA Water Lines

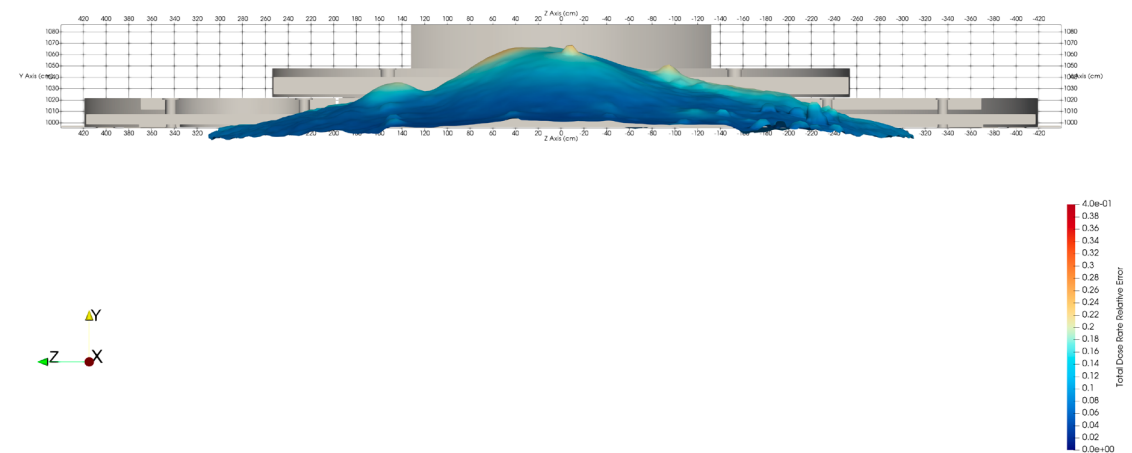
# 0.25 mrem/hr contour is fully contained in TDR roof



Isometric view of the total dose 0.25 mrem/hr contour in the TDR roof shaded by Monte Carlo relative error

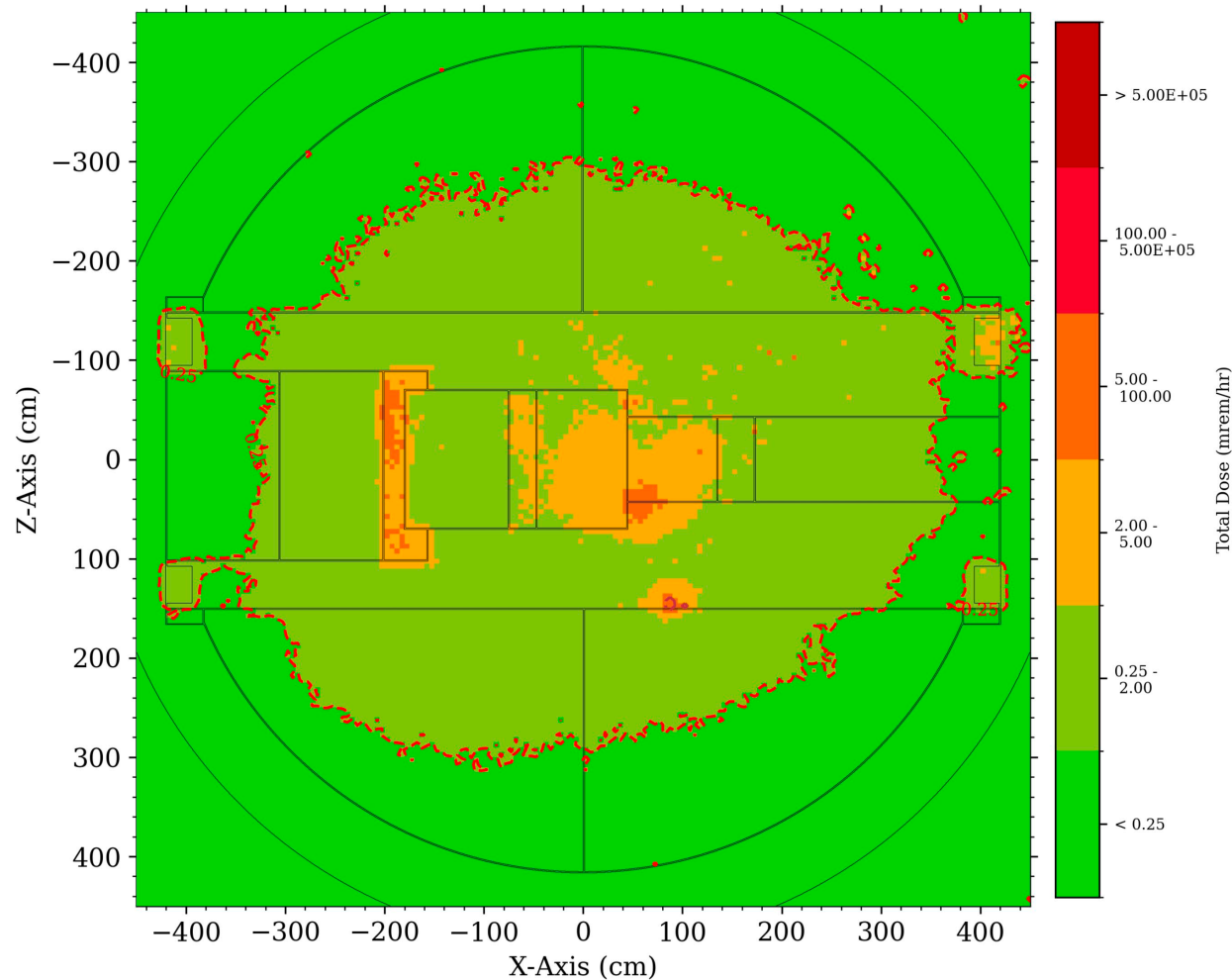


Elevation view perpendicular to the proton beam



Elevation view along the proton beam

# Plan View of the High Bay Floor Elevation



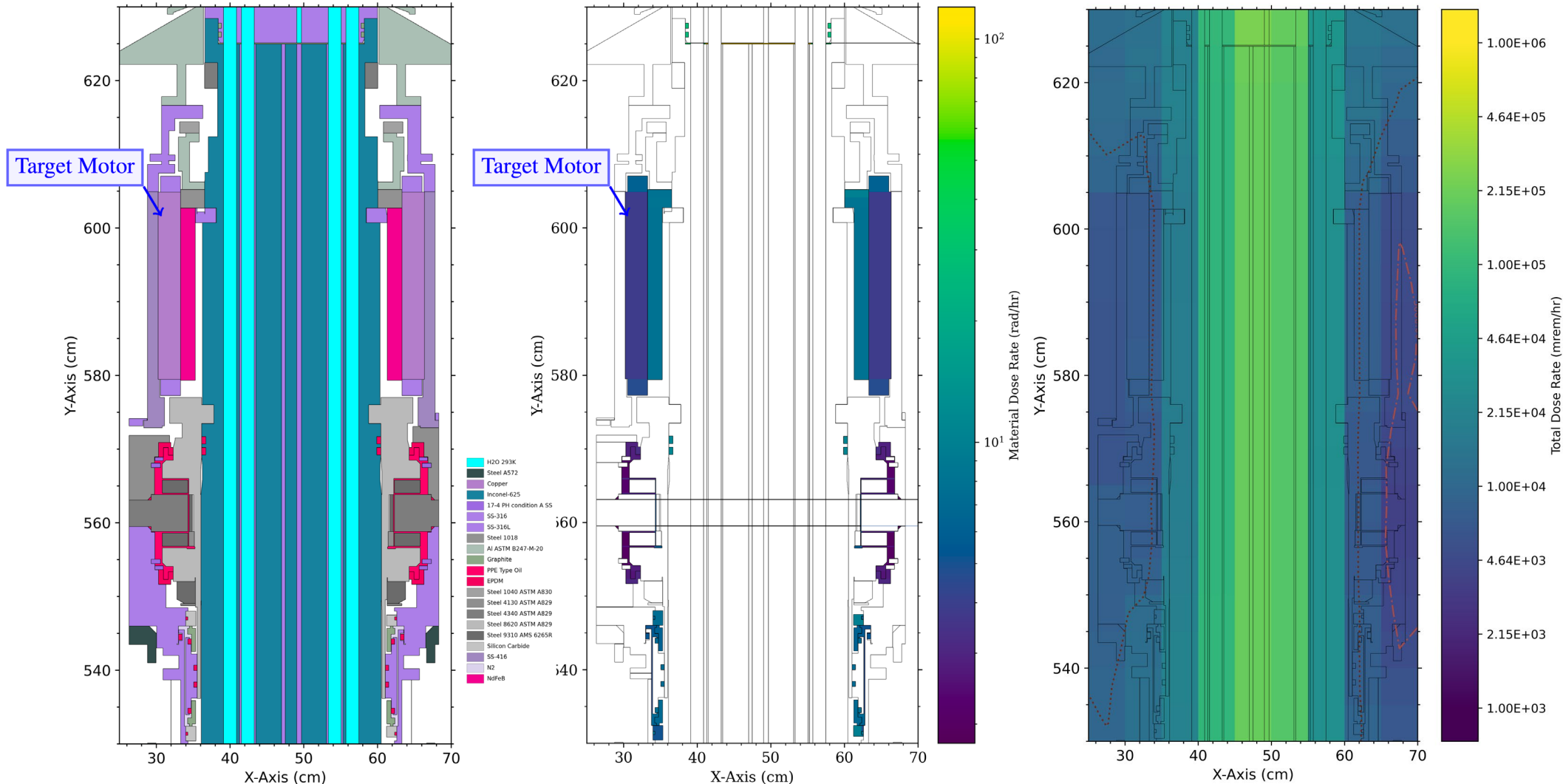
- Supplemental shielding was designed to:
  - Reduce background to instruments
  - Meet goal of  $< 0.25$  mrem/hr in high bay
  - Be easily removed for remote handling operations
- If supplemental shielding on the TDR roof was not installed, the localized regions of elevated dose could be roped off

Plan View of the Total Dose at the Current TDR Permanent Roof Elevation (995 cm above beam center)

# Beam On Total Dose Rates in Target Motor and Crown

## Key Takeaways:

- Peak dose rates are ~100 rad/hr
- Neutrons from activated water are negligible



Cross Section View of Target Motor and Crown Region

# Beam On Total Dose Rates in Target Motor and Crown

| Quantity                               | Calculated<br>at Lifetime                       | Limit                             | Margin<br>$\frac{\text{Limit}}{\text{Calculated}}$ |
|----------------------------------------|-------------------------------------------------|-----------------------------------|----------------------------------------------------|
| NdFeB Fast Neutron Fluence (> 0.1 MeV) | $(7.48 \pm 0.02) \times 10^{12} \text{ n/cm}^2$ | $1 \times 10^{13} \text{ n/cm}^2$ | $1.337 \pm 0.004$                                  |
| NdFeB Lifetime Dose                    | $4.72 \pm 0.04 \text{ kGy}$                     | 2.8 MGy                           | $593 \pm 5$                                        |
| PEEK Lifetime Dose                     | $4.2 \pm 0.2 \text{ kGy}$                       | 2 MGy                             | $480 \pm 20$                                       |
| Fluorine Rubber (Viton) Lifetime Dose  | $6.8 \pm 0.4 \text{ kGy}$                       | 20 kGy                            | $2.9 \pm 0.2$                                      |
| PPE Oil Lifetime Dose                  | $3.5 \pm 0.2 \text{ kGy}$                       | 0.2 MGy                           | $57 \pm 3$                                         |
| EPDM Lifetime Dose Limit               | $14.6 \pm 0.2 \text{ kGy}$                      | 80 kGy                            | $5.48 \pm 0.08$                                    |

## Target Crown Material Limit Comparison

Note: Radiation damage to metal components in the target crown is negligible

Conservative estimates for some non-modeled EPDM O-Rings were derived from tissue equivalent dose in water or picking a FMESH element:

- Rotary Union: 1034 rem/hr
- Segment Attachment: 660 rem/hr
- Jumper Fittings: 100 rem/hr

## Target Crown Material Particle Dose Rates

| Material                | Average<br>Absorbed<br>Dose<br>(rad/hr) | Neutron<br>Absorbed<br>Dose<br>(rad/hr) | Photon<br>Absorbed<br>Dose<br>(rad/hr) |
|-------------------------|-----------------------------------------|-----------------------------------------|----------------------------------------|
| Fluorine rubber (Viton) | $(9.7 \pm 0.3) \times 10^0$             | $(2.9 \pm 0.2) \times 10^{-2}$          | $(9.7 \pm 0.3) \times 10^0$            |
| PEEK                    | $(5.7 \pm 0.3) \times 10^0$             | $(1.28 \pm 0.05) \times 10^{-1}$        | $(5.6 \pm 0.3) \times 10^0$            |
| Reactor Grade Graphite  | $(1.305 \pm 0.008) \times 10^1$         | $(2.94 \pm 0.06) \times 10^{-2}$        | $(1.302 \pm 0.008) \times 10^1$        |
| PPE Oil                 | $(2.62 \pm 0.03) \times 10^0$           | $(9.93 \pm 0.09) \times 10^{-2}$        | $(2.52 \pm 0.03) \times 10^0$          |
| EPDM                    | $(5.01 \pm 0.04) \times 10^0$           | $(2.34 \pm 0.03) \times 10^{-1}$        | $(4.77 \pm 0.04) \times 10^0$          |
| Silicon Carbide         | $(6.89 \pm 0.09) \times 10^0$           | $(1.26 \pm 0.02) \times 10^{-2}$        | $(6.88 \pm 0.09) \times 10^0$          |
| NdFeB Magnet            | $(7.86 \pm 0.06) \times 10^0$           | $(1.325 \pm 0.005) \times 10^{-2}$      | $(7.85 \pm 0.06) \times 10^0$          |

# Conclusions and Discussion of Requirements

| Requirement Number | Description                                                                                                                                                                                                                                                                                                                                  | Pass/Fail |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| NA                 | Effective dose rates in the high bay above the TDR shall be less than 5 mrem/hr during beam-on-target operation                                                                                                                                                                                                                              | Pass      |
| S.03.02.02-10978   | The accumulated radiation dose (or damage) for each component and its constituent materials, evaluated at that component's end of life (i.e., at the planned replacement or retirement point), shall not exceed the applicable limits specified in the STS Materials Handbook or in manufacturer-published radiation tolerance data.         | Pass      |
| S.03.02.03-2301    | The accumulated radiation dose (or damage) for each segment component and its constituent materials, evaluated at that component's end of life (i.e., at the planned replacement or retirement point), shall not exceed the applicable limits specified in the STS Materials Handbook or in manufacturer-published radiation tolerance data. | Pass      |
| S.03.02-1454       | Target Assembly geometry and materials of construction must match those references in the calculations used to verify requirement #1017.                                                                                                                                                                                                     | Pass      |
| S.03.04-3593       | The MRA design shall support the Target Systems Monolith meeting the Target Systems Radiation Shielding Requirement.                                                                                                                                                                                                                         | Pass      |



# OAK RIDGE

## National Laboratory



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# Backup

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# Loop 1 Water Source Details

Parameters for Water Activation

| Parameter                          | Quantity | Unit            |
|------------------------------------|----------|-----------------|
| Total loop volume                  | 1470     | gallon          |
| Total loop flow rate               | 157.5    | gallon/minute   |
| Total loop time                    | 560      | second          |
| Target segments flow rate          | 150      | gallon/minute   |
| Target segments irradiation volume | 5666.48  | cm <sup>3</sup> |
| Target segments residence time     | 0.5989   | second          |
| Target shaft flow rate             | 7.5      | gallon/minute   |
| Target shaft irradiation volume    | 8798.56  | cm <sup>3</sup> |
| Target shaft residence time        | 18.593   | second          |

| Source Number | Irradiation Zone         | Target Segment Transient Time seconds | Target Shaft Transient Time seconds | Delta Transient Time seconds |
|---------------|--------------------------|---------------------------------------|-------------------------------------|------------------------------|
| 1             | Target Segment           | 0.0                                   | N/A                                 | 8.19                         |
| 2             | Target Segment           | 8.19                                  | N/A                                 | 1.30                         |
| 3             | Target Segment and Shaft | 9.486                                 | 3.2256                              | 1.0049                       |
| 4             | Target Shaft             | N/A                                   | 0.0                                 | 2.0516                       |
| 5             | Target Shaft             | N/A                                   | 2.0516                              | 1.174                        |
| 6             | Target Segment and Shaft | 560                                   | 560                                 | N/A                          |

Water activation source transient times

# Detail view of the total beam-on-target dose rates in the TDR

