The Moderator Test Station at the Spallation Neutron Source

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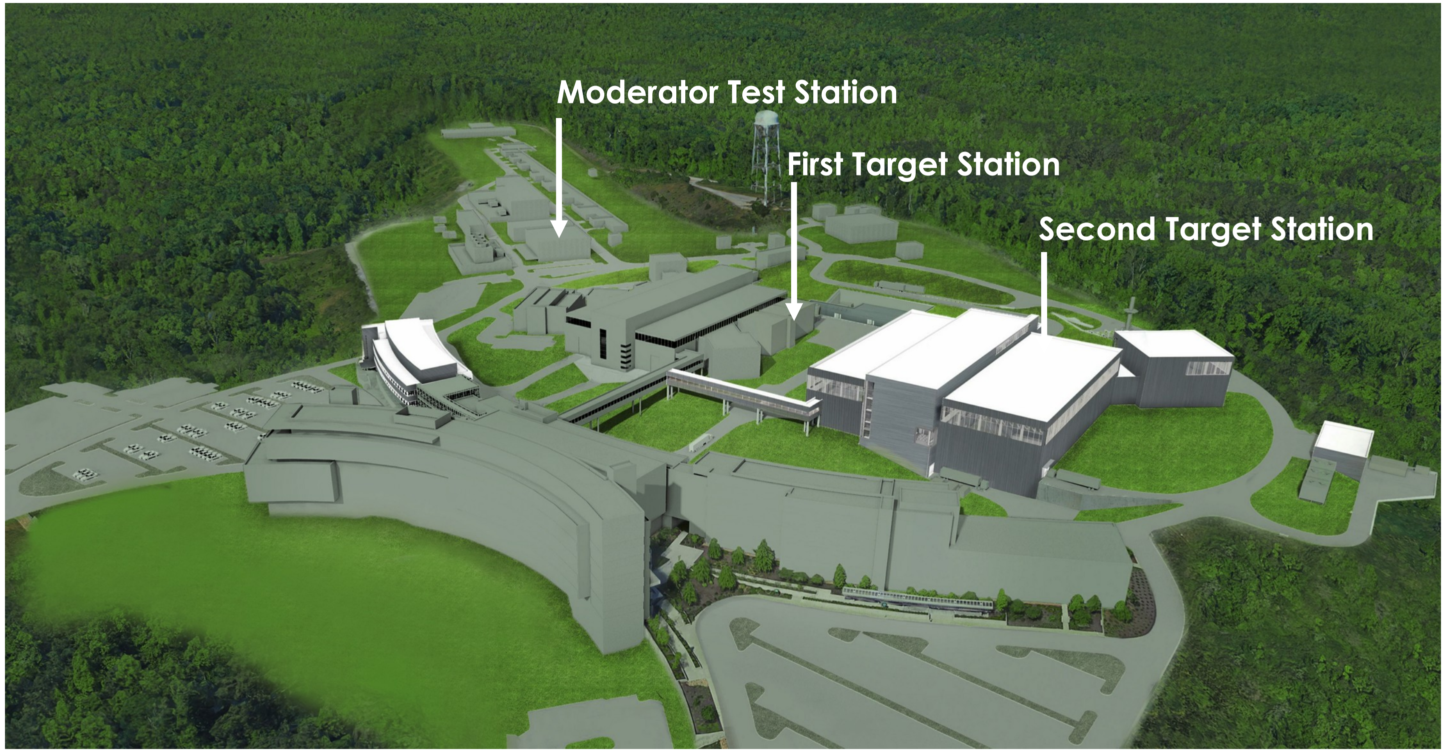
Outline

- Moderator Test Station concept
- Moderator Test Station project
- General description
- Target Development
- Analyzer Development
- Science Case highlights
- Operational Plan



ORNL Moderator Test Station Concept

- MTS concept developed to take advantage of the SNS Beam Test Facility and optimize a neutron source to the sole purpose of testing moderator systems and materials, while enabling any moderator testing we ever had trouble performing
- SNS RFQ test station (the BTF - 10.1016/j.nima.2019.162826)
  - 2.5 MeV negative hydrogen ions, up to 50 mA peak, up to 60 Hz, up to 1 ms; all fixed
- Use a LEBT-style proton chopper; choose from 0.5 to 10 μs proton pulse
- Add a target; 3E10 n/s at 75 W from p(^{7}Li,n), low primary energy, large beam spot
- Provide a large volume space for test moderator
  - Can't do 10 cm high by 16 cm diameter elsewhere, or reflector-filters, or long tubes, or ...
  - Wing configuration is prototypical and allows small view of high brightness configurations
- Provide for rigorous reproducibility in moderator positioning and orientation
- Optimize the facility solely for moderator characterization

MTS Science Case

- We have identified 8-10 moderator concepts for testing
  - Intermediate temperature moderators (80-240 K) like ammonia, ethane, propane
  - Directionally-enhanced moderators (10.1016/j.nima.2014.04.047)
  - Pelletized moderators (10.1016/j.nimb.2013.12.006)
  - Slush moderators (methane, hydrogen)
  - Moving moderators (10.1016/j.nima.2020.163562)
  - High brightness moderators (10.1063/5.0095900)
  - Very cold neutron source moderators (10.1088/1742-6596/1021/1/012083)
- Additionally, there are a wide variety of materials to be tested in conventional monolithic configurations overlapping with some of these concepts

ORNL Moderator Test Station Project

- ORNL is developing the Moderator Test Station as an Accelerator Improvement Project, as specific class of DOE project in which funding is taken completely from a single year's operating budget, so there is a hard cap to the total project cost, but it is all committed from the beginning
- Funded for 9M$, with initial contingency >20%
- Conceptual Design Review completed 1 April 2024
- Preliminary Design Review completed 11 February 2025
- Final Design Review scheduled 6 May 2026
- Installation expected to begin April 2027
- Commissioning expected to begin January 2028

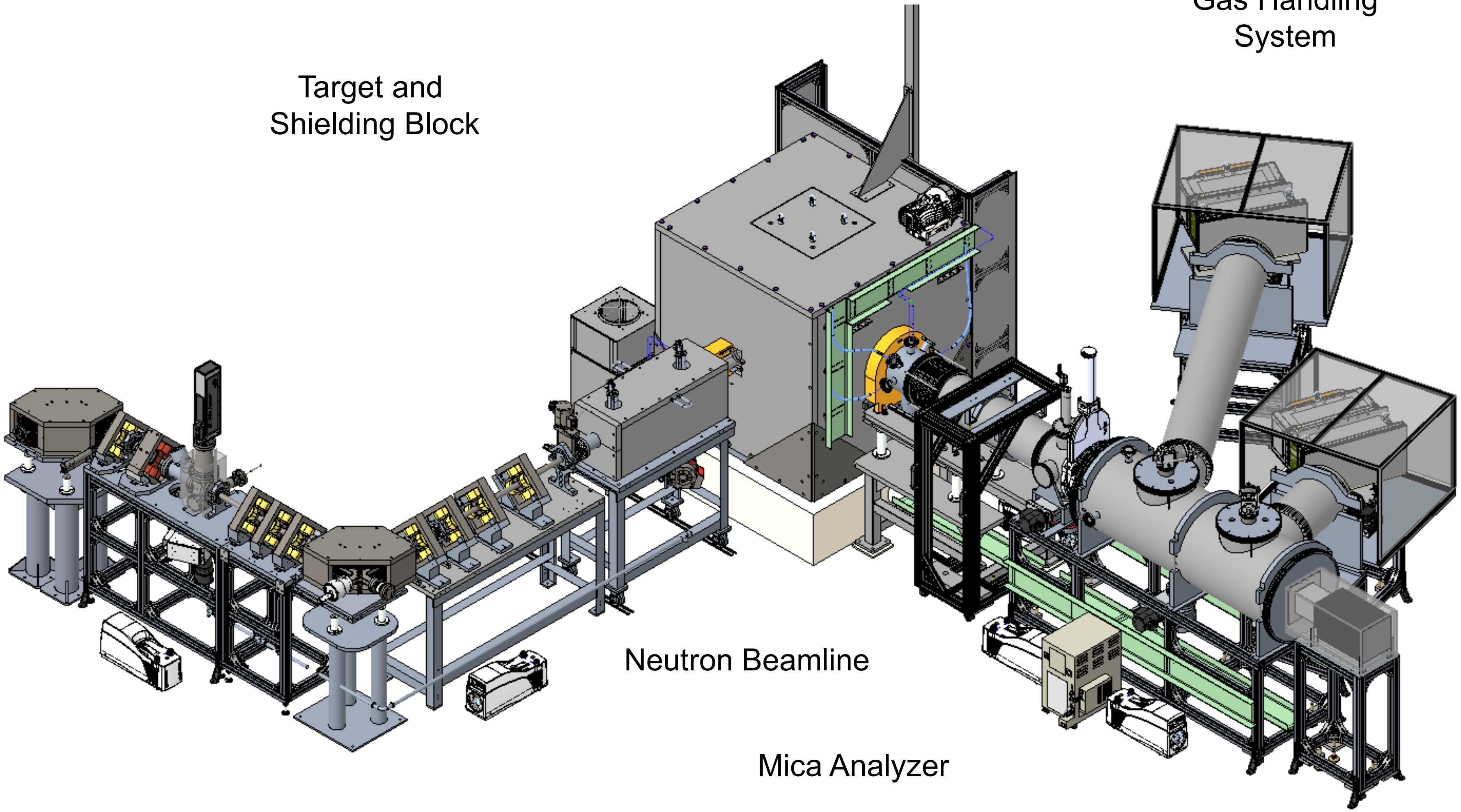
MTS Science Case - Specifics

- Hydrogen moderator performance on SNS FTS doesn’t scale well, losing 20% of the benefit of higher power per MW on proton beam power – we don’t know yet whether this is due to flow maldistribution, entrained gas, stagnation zones, orthohydrogen, or ….
- New facilities plan to leverage high-brightness advanced parahydrogen moderator designs
  - Validating these designs will let us push boundaries a little harder, and know just how well we have to catalyze the hydrogen system to support the desired performance
- New Moderator Development
  - New poisoning / decoupling strategies may extend the lifetime of our inner reflector plug while reducing the penalty arising from burn-up
  - Intermediate temperature moderators like liquid ammonia or ethane might be a better fit to instruments on the current water moderator, or new instruments in a three-source future
  - Directionally-enhanced moderators have already been demonstrated to increase brightness into a specific direction (e.g., a guide) by factors, more efficiently using the neutrons we produce
  - Pelletized moderators offer access to colder materials with higher hydrogen density, better serving high resolution long-wavelength instruments, while minimizing challenges from radiation damage

MTS Typical Moderator Characterization

- Energy spectrum; <0.1 meV to >10 eV
  - Simple time-of-flight measurement, both low-efficiency and high-efficiency in-beam detectors, possibly eventually including single-pulse spectral measurements
  - Flight path length of ~2.5 m or greater required, short pulse required
  - Key Performance Parameter: 1E4 n/ster/eV/(Ws) at 2 W required, 6E4 and 75 objective
- Energy-dependent brightness across moderator; 1 meV to 1 eV
  - Pinhole collimation with area detector
- Energy-dependent emission time distribution; 0.3 meV to 3 eV
  - Time-focused crystal analyzers; 0.3 meV to ~3 eV requires two separate analyzer arms, but also makes it practical to check resolution effects
  - Flight path lengths of ~6 m total, short pulse required
  - 1-5 Angstrom required, 0.3 to 18 Angstrom objective

MTS and Proton Beamline Extension



Gas Handling System

Area Detector

Target and Shielding Block

Area Detector

Area Detector

Neutron Beamline

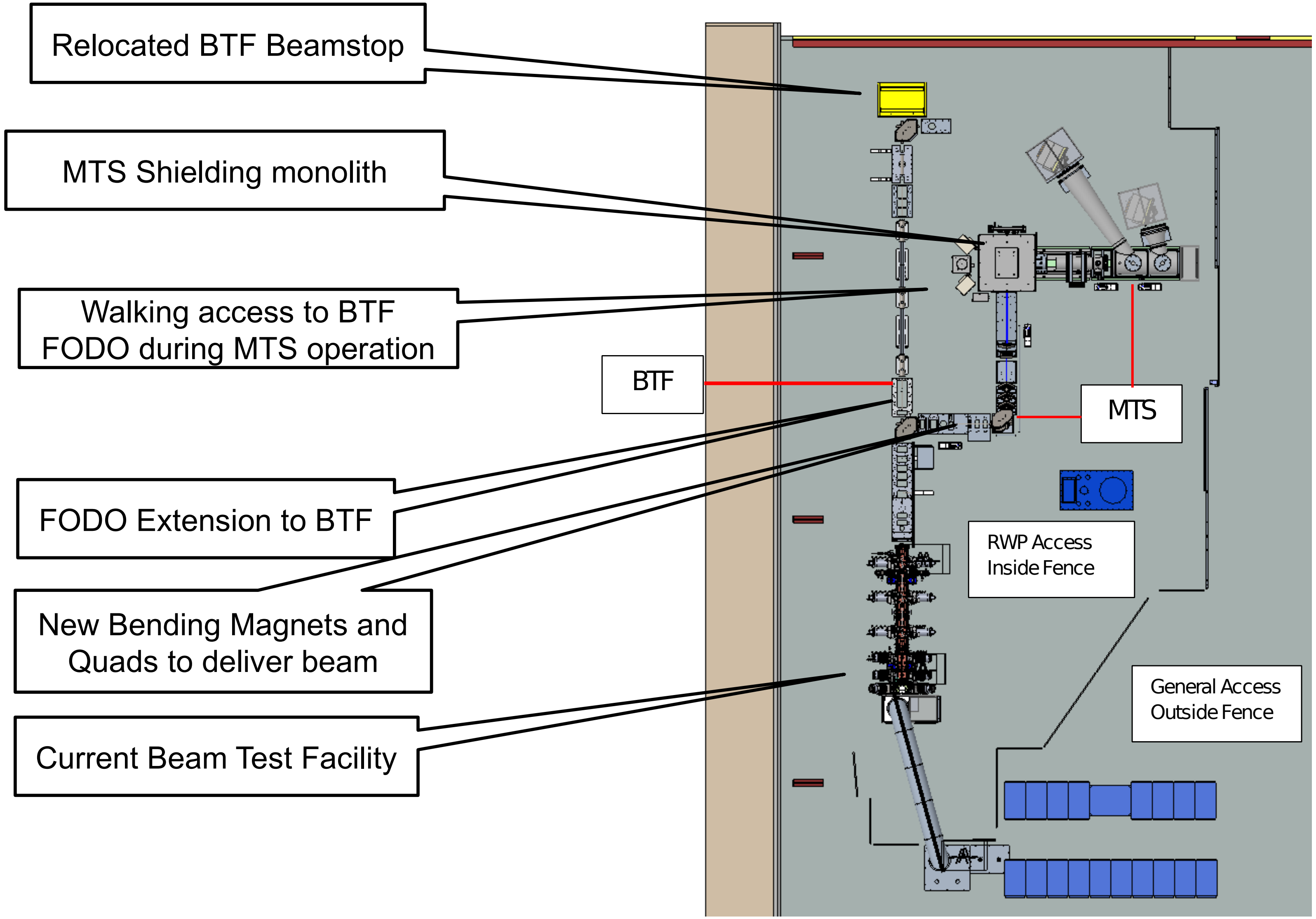
Beam Stop Shielding

Mica Analyzer

Proton Beamline

Copper Analyzer (Future)

MTS Overview: Layout at extended BTF



Relocated BTF Beamstop

MTS Shielding monolith

Walking access to BTF FODO during MTS operation

BTF

MTS

FODO Extension to BTF

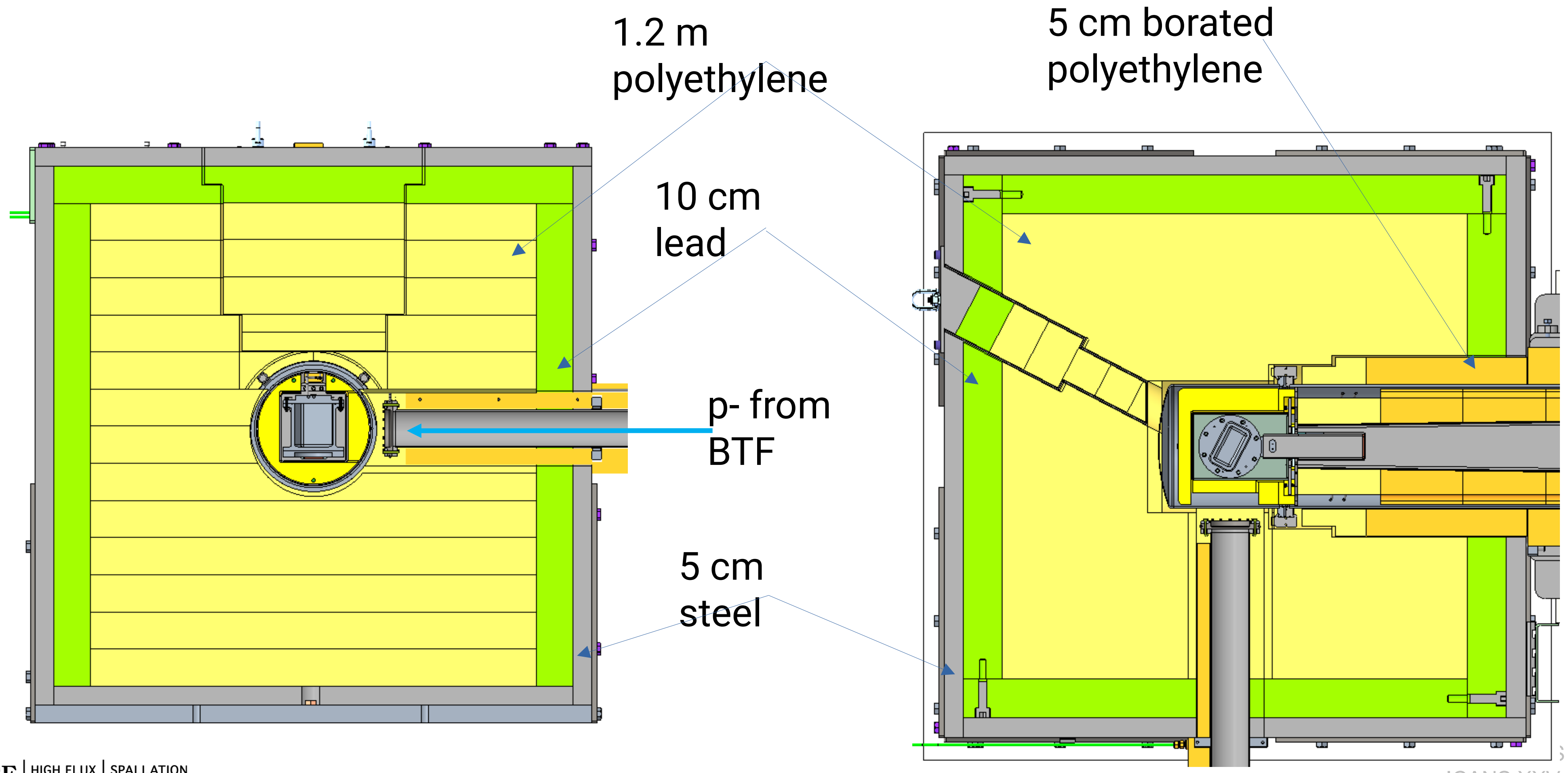
RWP Access Inside Fence

New Bending Magnets and Quads to deliver beam

General Access Outside Fence

Current Beam Test Facility

MTS Shielding, Moderator, and Neutron Beamline



1.2 m polyethylene

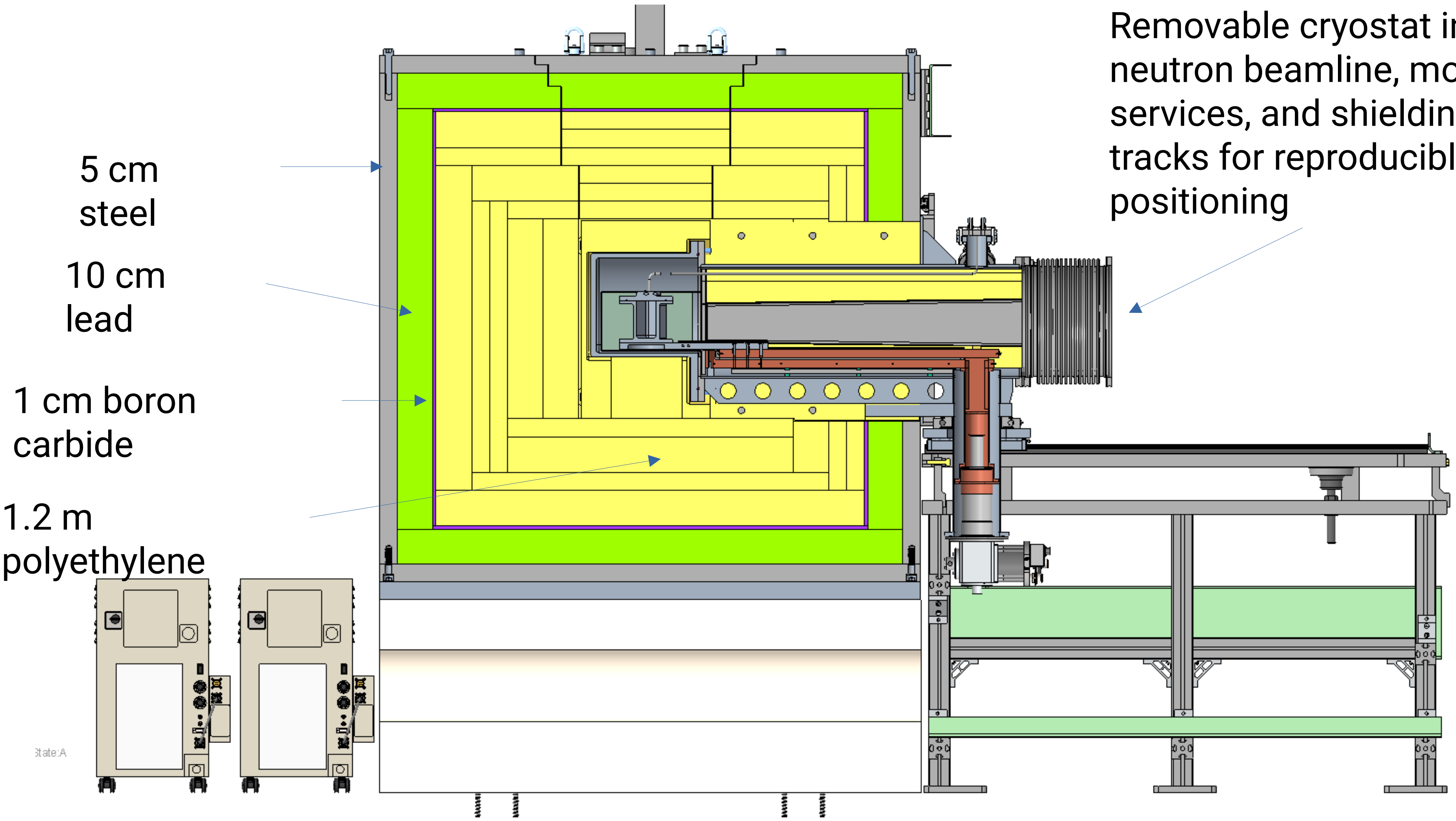
5 cm borated polyethylene

10 cm lead

p- from BTF

5 cm steel

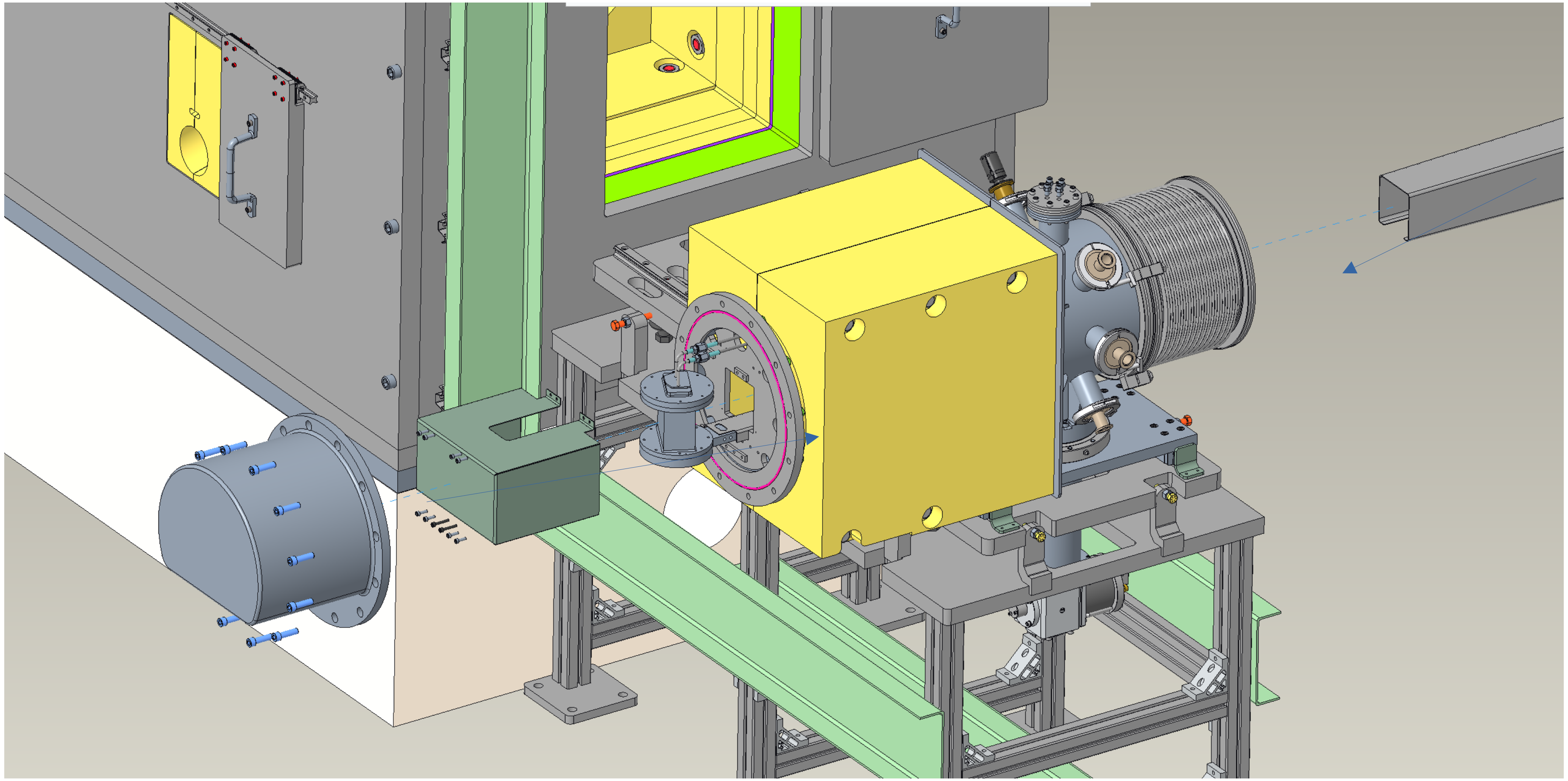
MTS Shielding, Moderator, and Neutron Beamline



Removable cryostat including neutron beamline, moderator services, and shielding, on tracks for reproducible positioning

n

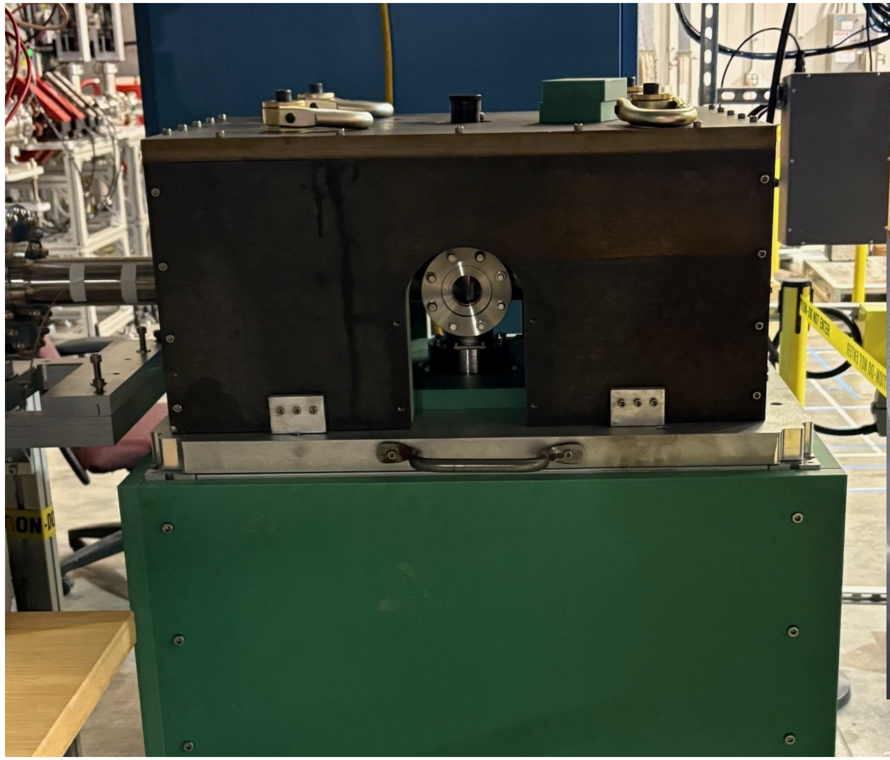
MTS Cryostat

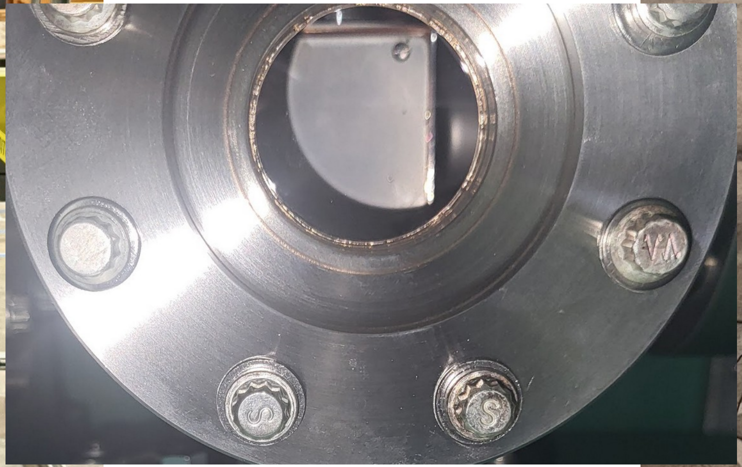


Removable cryostat in withdrawn position allowing direct access to test moderator

MTS Target Testing at BTF Performed in November

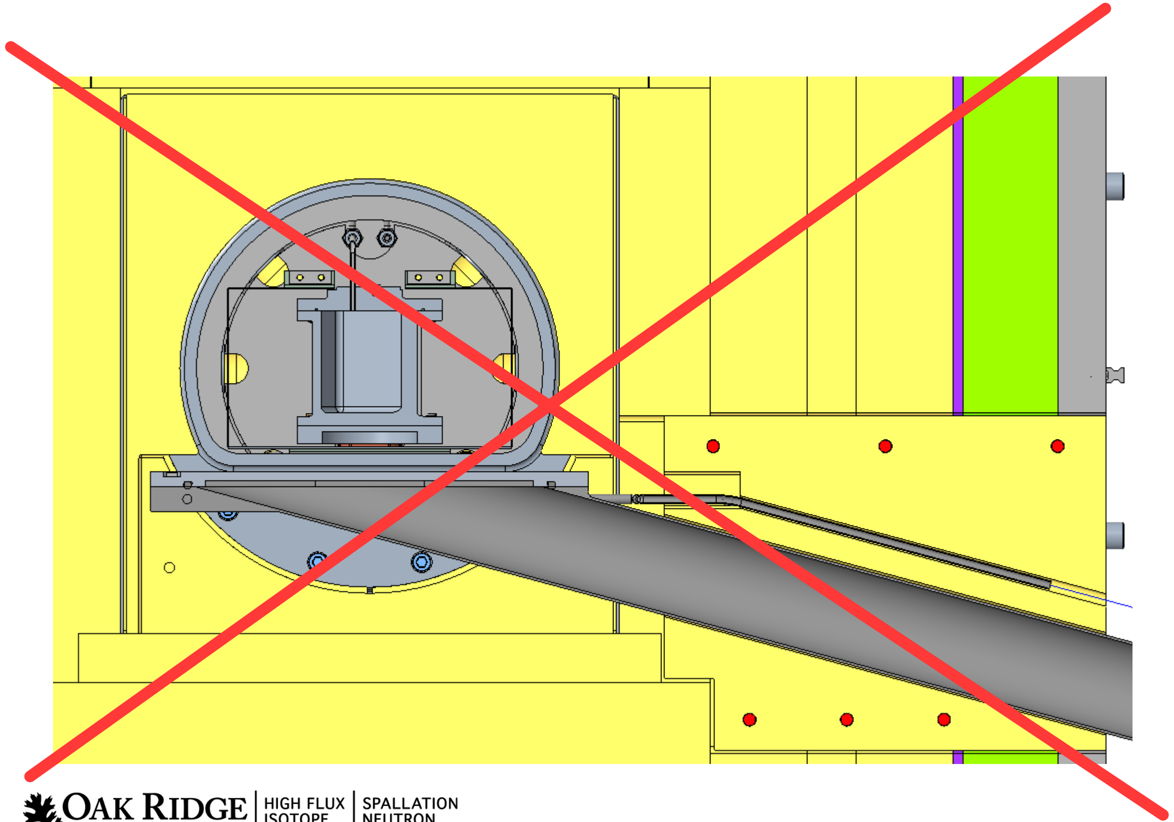
- Original concept specified inclined target to spread beam
- Low energy elastic scattering at design angle hypothesized to impact target performance – tested at BTF
- Same target, inclined at different angles, did show effect. Design orientation lost >50% of neutron intensity

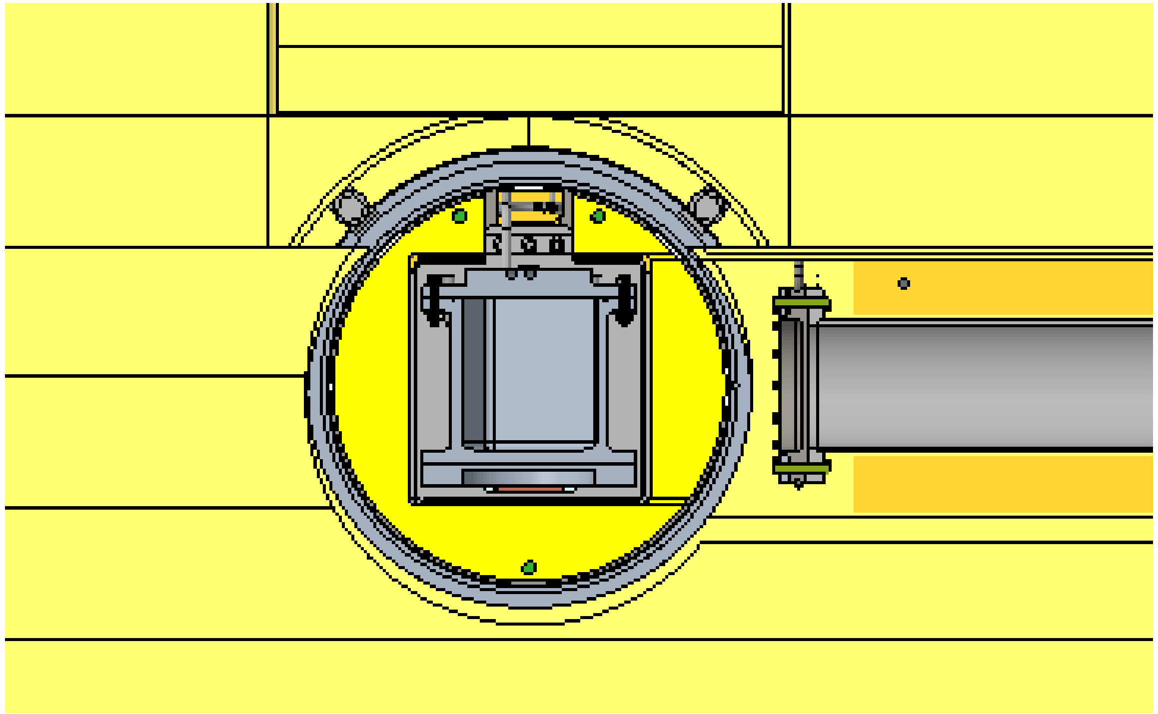




Inclined Targets for Low Energy Ions Suffer Losses

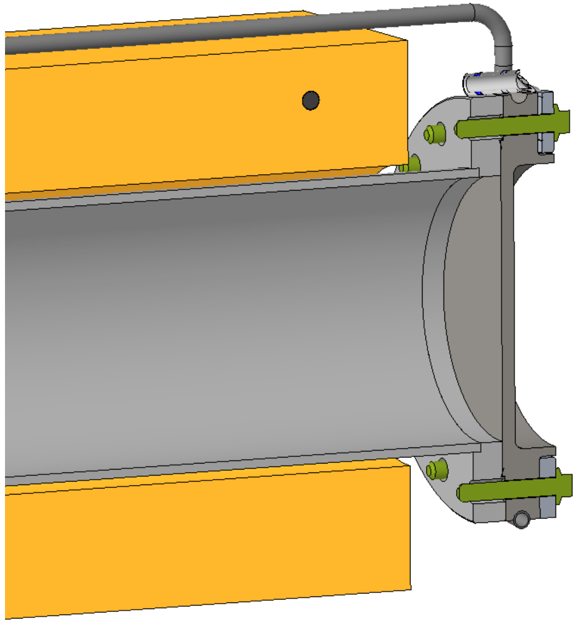
- Original concept specified inclined target to spread beam, intended to reduce heating and make a more “prototypical” illumination (i.e., from a stopping length heavy metal target)
- Low energy elastic scattering at design angle DOES impact target performance – 2x loss
- Target configuration changed to normal incidence, results in additional 3x better coupling
- Six times the intensity for an easier proton beam layout and a 70% reduction in target size!





MTS Target Concept Development

- Lithium coated directly onto copper flange, edge cooled by water
- Titanium encapsulated target allows handling in air.
- Layers are applied using physical vapor deposition
- Collaborative effort with Energy Storage and Conversion group at ORNL

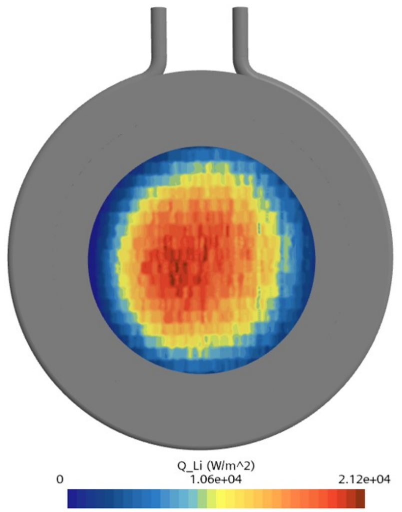


Copper plate (5 mm)
Lithium target (70 um)
Titanium overcoat (50 nm)

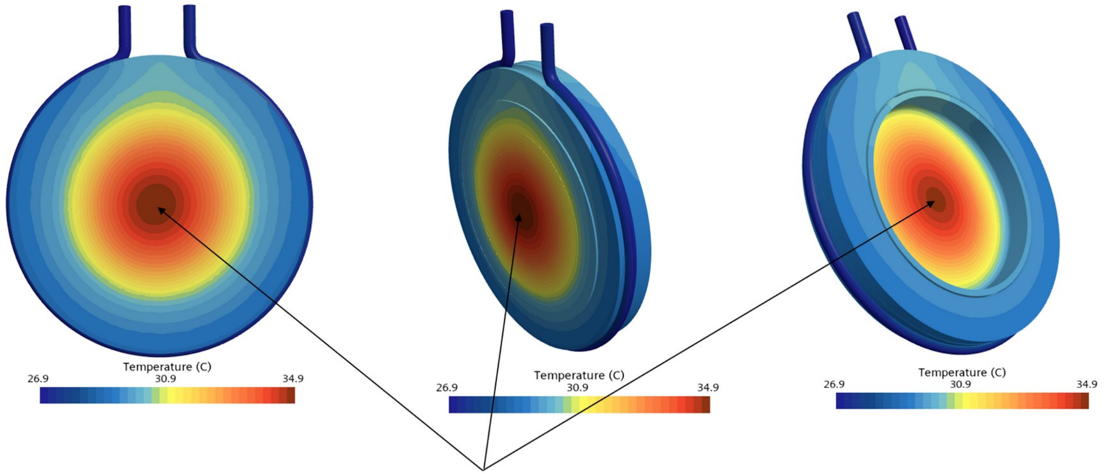
Courtesy: Katie Browning

MTS Target Cooling

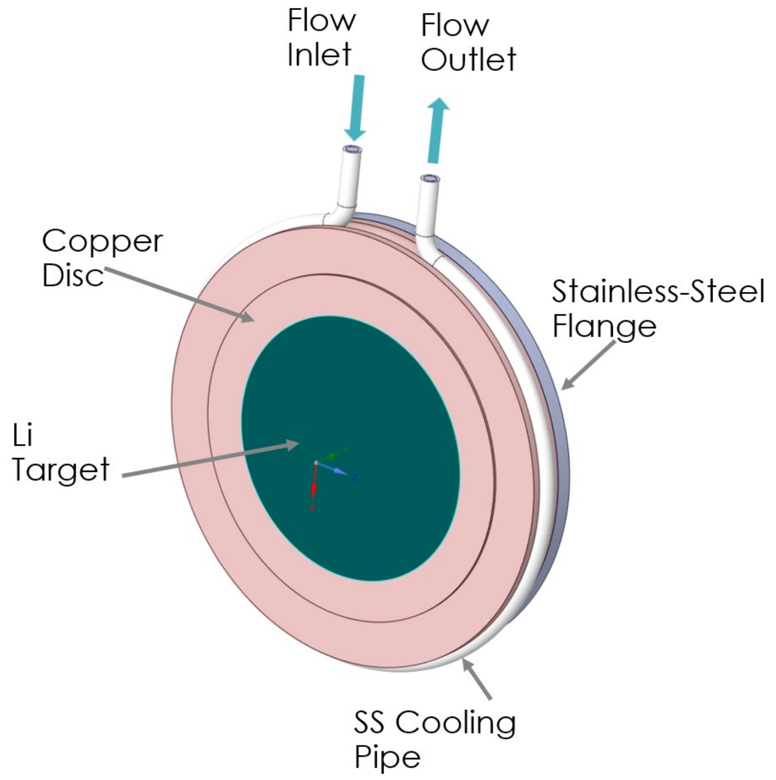
Mapped power profile in Li target

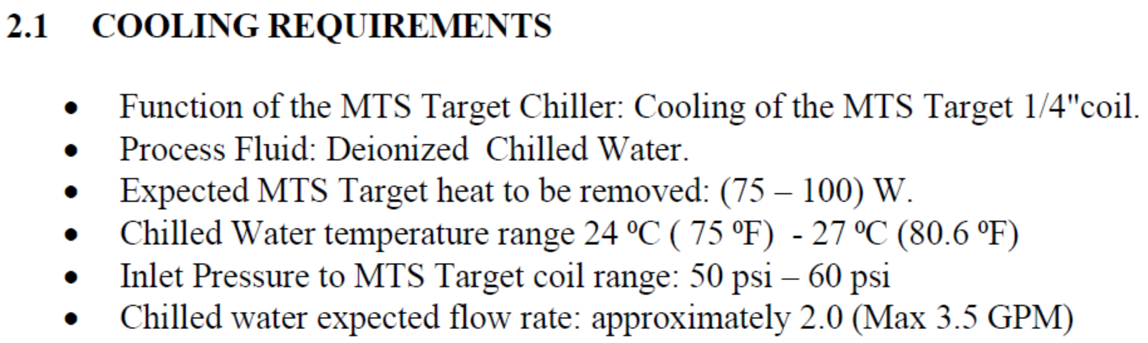


Total Integrated Power =72.2 Watts



Max Temp = 35 C

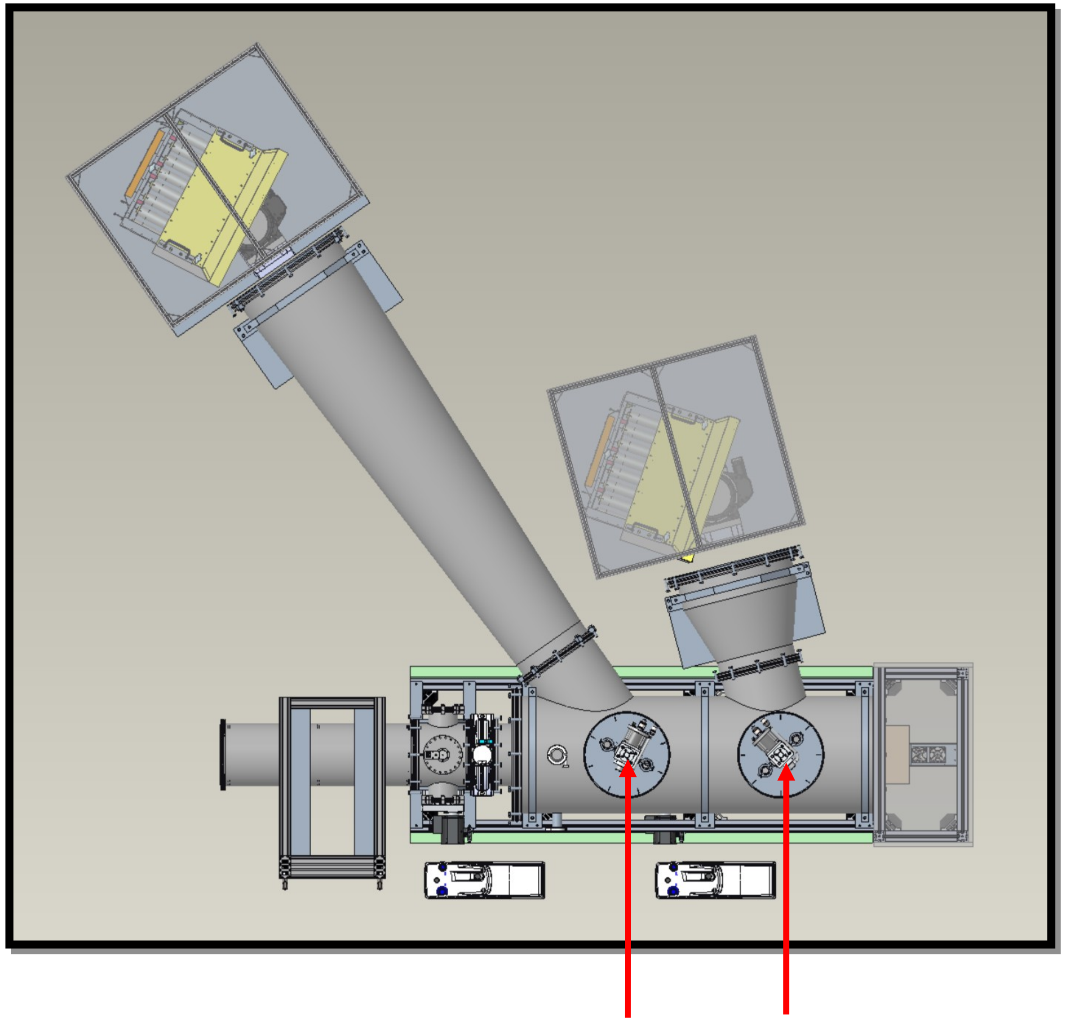




2.1 COOLING REQUIREMENTS

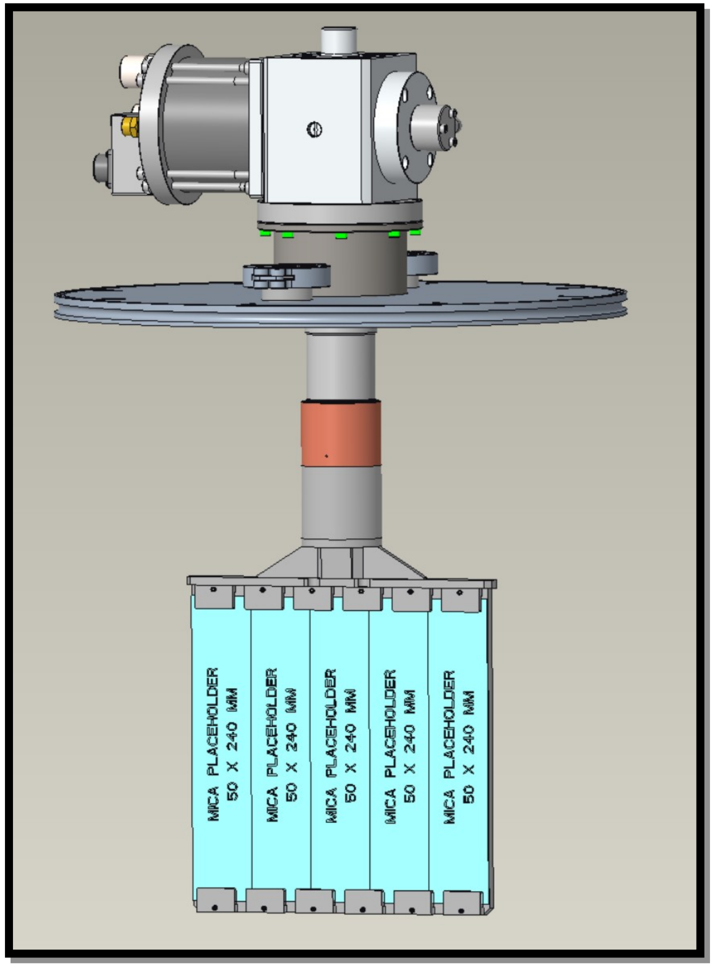
- Function of the MTS Target Chiller: Cooling of the MTS Target 1/4"coil.
- Process Fluid: Deionized Chilled Water.
- Expected MTS Target heat to be removed: (75 – 100) W.
- Chilled Water temperature range 24 ºC (75 ºF) - 27 ºC (80.6 ºF)
- Inlet Pressure to MTS Target coil range: 50 psi – 60 psi
- Chilled water expected flow rate: approximately 2.0 (Max 3.5 GPM)

MTS Analyzer Arrays



Symmetric Crystal (Mica) Analyzer Array

Asymmetric Crystal (Copper) Analyzer Array (Future upgrade)



Mica Permanent frame

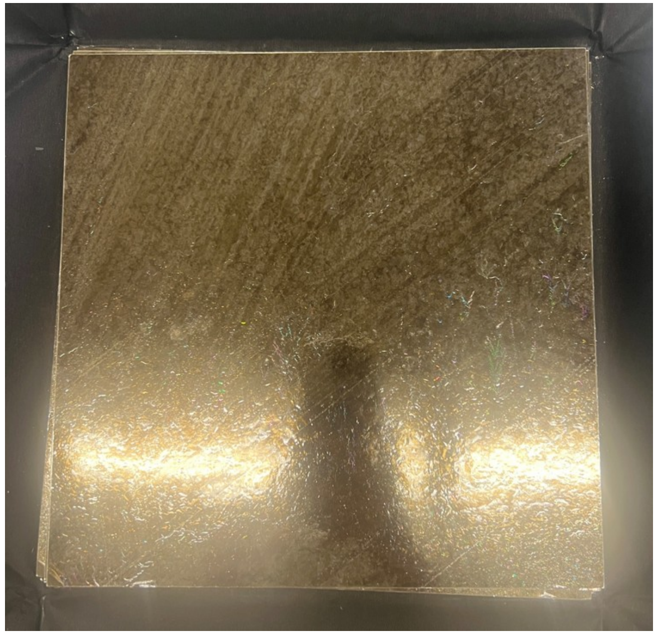
- Mica will be cooled to 80 degrees Kelvin

MTS Mica Analyzer

- Mica procured from three vendors
- Natural phlogopite
- Compared to fluorophlogopite, phlogopite has significantly larger mosaic and reflectivity

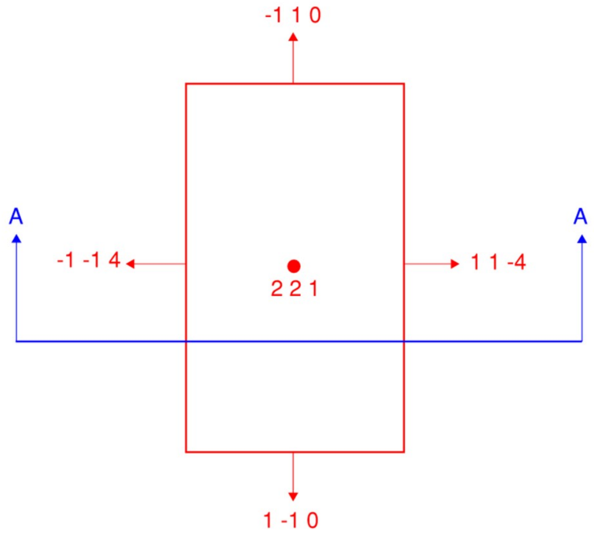
Asheville Mica Energy Solutions
Mica size: 242 mm x
(varies from 102mm to 127mm)

SPI Supplies
Mica size: 240 mm x 50 mm

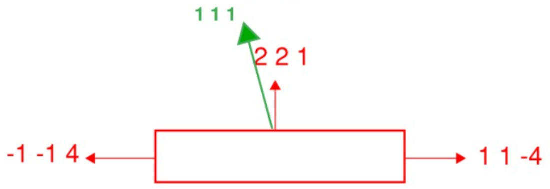


USA Mica
Mica size: 240 mm x 240 mm

MTS Copper Analyzer (Upgrade)

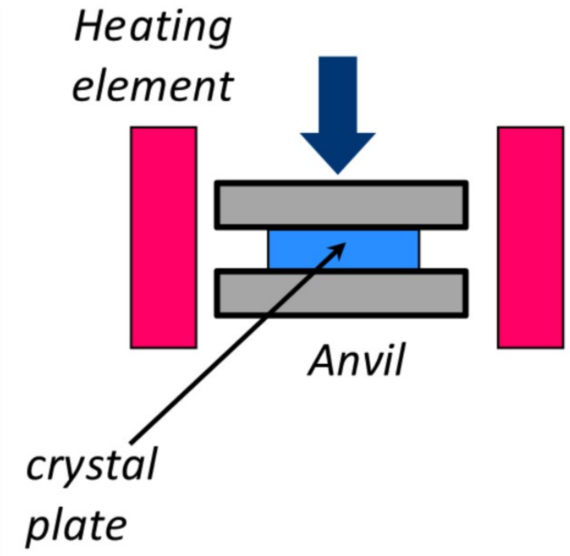


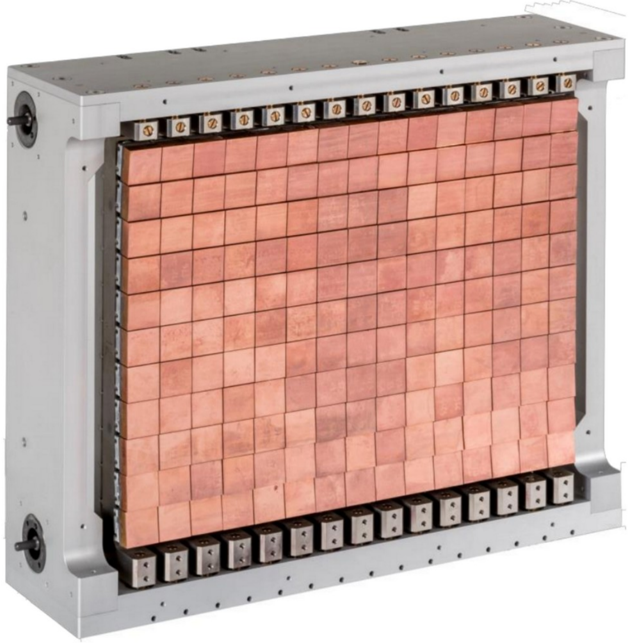
PLAN VIEW



A-A SECTION VIEW
NTS

F





Photos from Institut Laue-Langevin

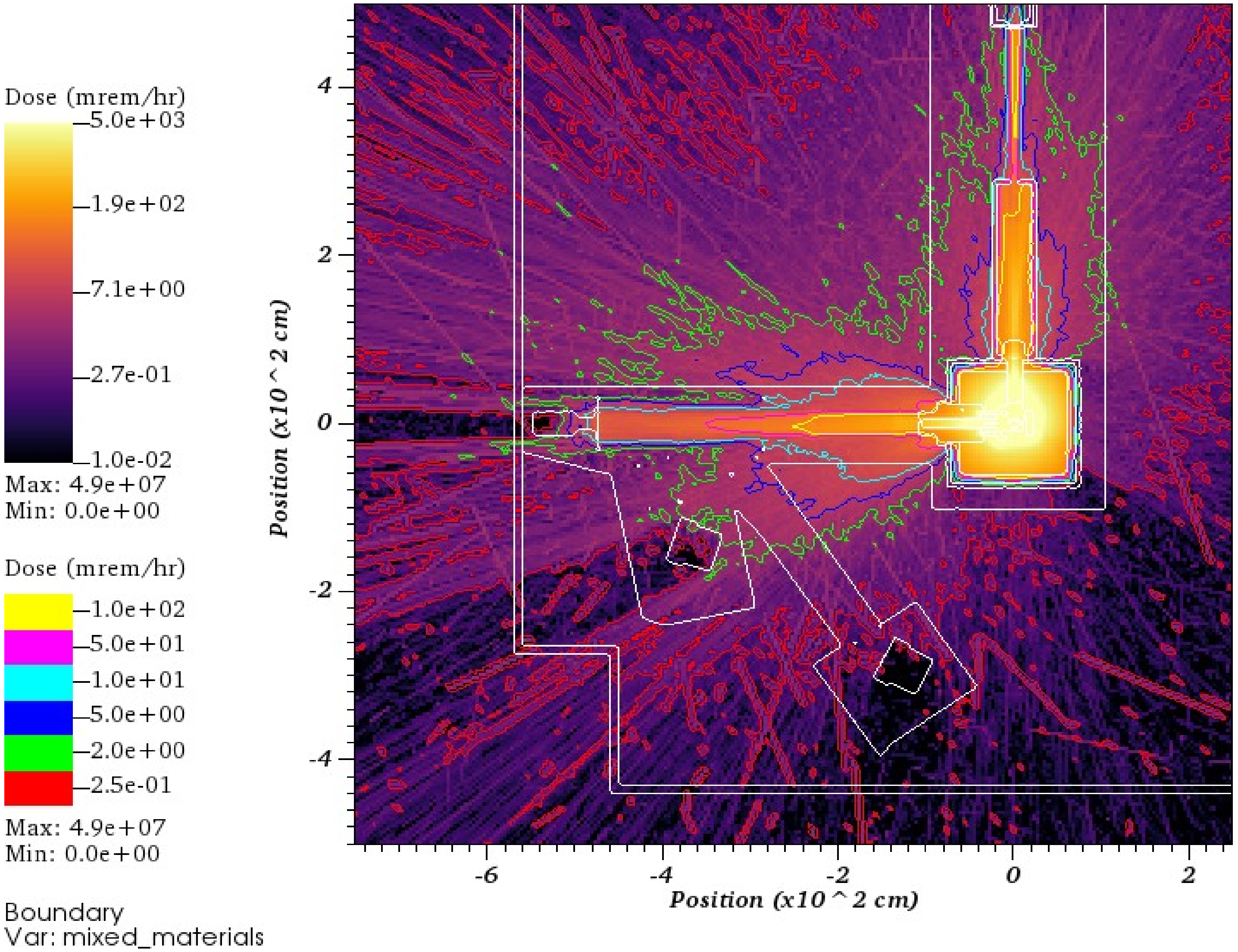
- On hold due to time / development needed to produce crystals
- Anticipate 50 mm by 50 mm by 2 mm 221 oriented copper with 2 degree mosaic

MTS Operational Plans

- The MTS will operate for as much as 20 – 25 weeks per year, typically in one- or two-week periods, for system development and moderator testing
- The MTS Science Case (ORNL/TM-2024/3583) outlines twelve different moderator concepts and an array of new materials for testing once operational – we will have ample tests to fill the time
- Operation of the MTS will require the beam from the BTF. We do not anticipate operating “both” at the same time, but we do anticipate having access to either while the other is running
- Running MTS will typically involve much more production level beam than BTF usually uses for accelerator physics and operations studies – 60 Hz continuous operation for several days at a time, totaling as much as 20 to 25 weeks per year
- There will be local control, but most accelerator control will be from the Central Control Room
- Local and CCR control for the neutron beamline and gas handling system

MTS Radiation Safety

- Shielding analysis performed on CAD geometry converted to MCNP using GEOUNED and GeomWriter
- The current shielding layout limits dose rates outside the fence to less than 2 mrem/hour except for some streaming around the in-beam detector, which will be blocked by the beamstop (not included in this particular calculation)
- Dose rates near the neutron beamline and the proton beamline will approach 10 mrem/hour, well within guidelines for the posted radiation area, but will generally not be accessed during operation
- BTF FODO line will be under 2 mrem/hour



Summary

- The SNS Moderator Test Station will permit characterization of a wide variety of moderator materials and concepts, in a prototypical wing configuration, supporting FTS improvements, the STS concept, and new moderator development
- Along the way we'll develop a capability to explore and characterize advanced moderator configurations that exceeds any facility currently available
- Targeted optimization will let us improve the measurement time to characterize a moderator at LENS with two orders of magnitude lower primary source intensity (and even lower shielding requirements)
- Improved characterization concepts will let us do so over a larger energy range, with more certain and better understood instrument characteristics