Characterization of SHINE's High-Flux DT Neutron Source

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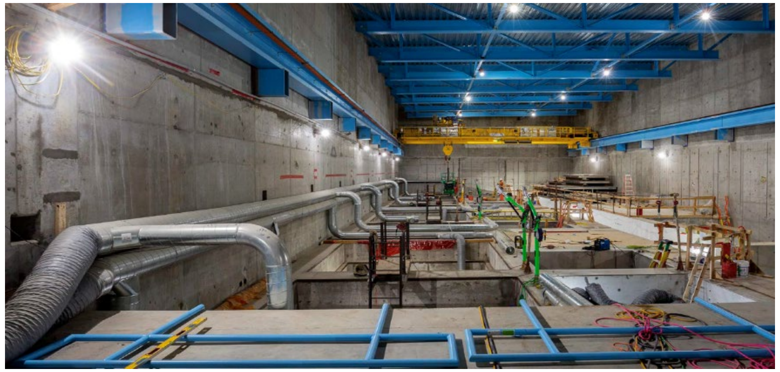
Intro: SHINE's Pathway To Fusion Energy

PHASED APPROACH WITH GROWING CAPABILITY

- Delivering low-yield fusion systems (DD and DT) for 10+ years
  - Years of licensing facilities with activation, tritium, rad waste disposal, etc.
  - Expanding into tritium system and rad hard electronic system builds since the SHINE/Phoenix merger
- Commissioning Mo-99 facility with 8 fusion systems, fission subcritical assemblies, and liquid U/FP processing
  - Significant experience gained in nuclear construction, licensing, rad waste mitigation/handling, and decommissioning planning
- Early R&D activities looking at applying painful lessons learned for next-phase fusion systems and UNF recycling/transmutation facility
- **Looking for opportunities to apply our hard-gained experience and expertise to support the broader fusion community**



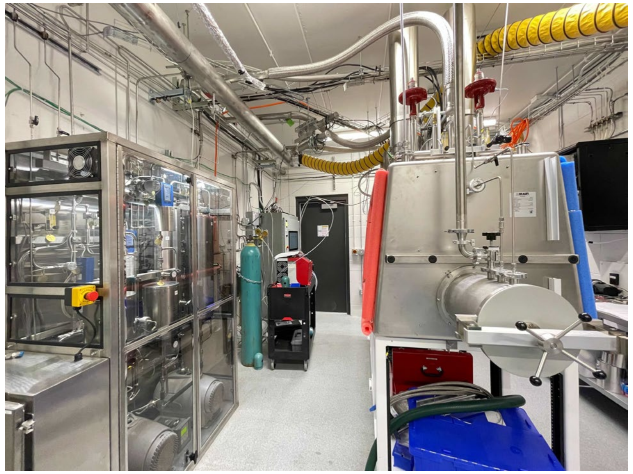
FLARE Facility

DT NEUTRON TEST FACILITY

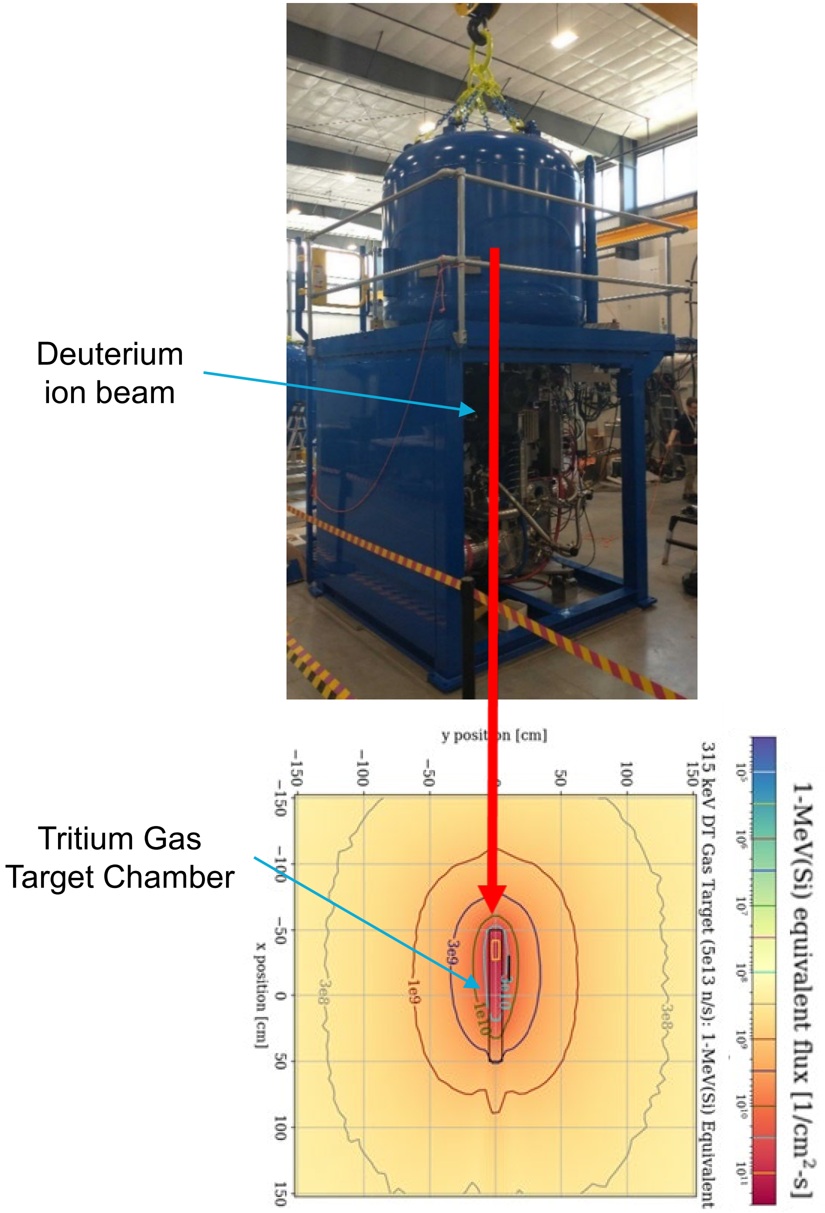
- Steady-state neutron generator
  - Operating production prototype to gain performance and reliability data over the past 4 years (DD and DT operations)
  - 2 units constructed, 2 in commissioning, 4 in assembly
- Tritium Purification System
  - Continuously supplies, purifies, and recovers tritium gas

Concept of Operation

1. Microwave ion source creates plasma
2. DC accelerator extracts ion beam (300kV)
3. Magnetic field focuses ion beam
4. Differential pumping system maintains target pressure while keeping accelerator pressure low
5. Beam strikes tritium gas and generates neutrons
   - Up to **$5x10^{13}$ n/s** measured output

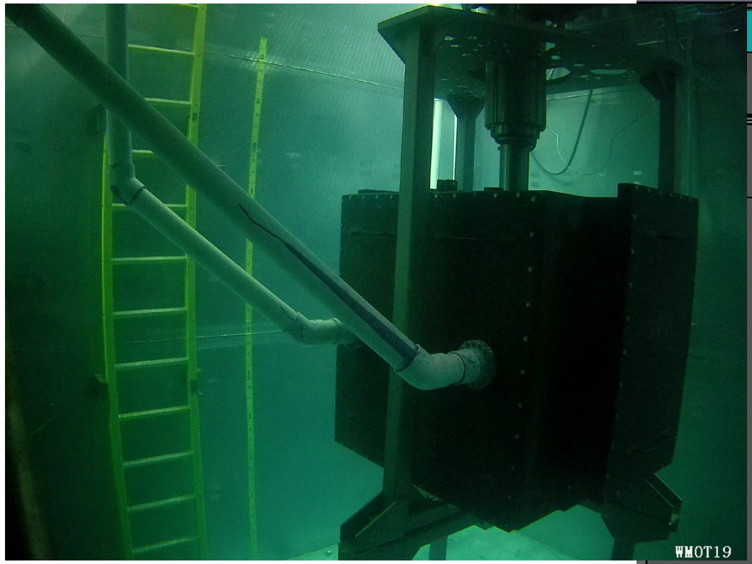


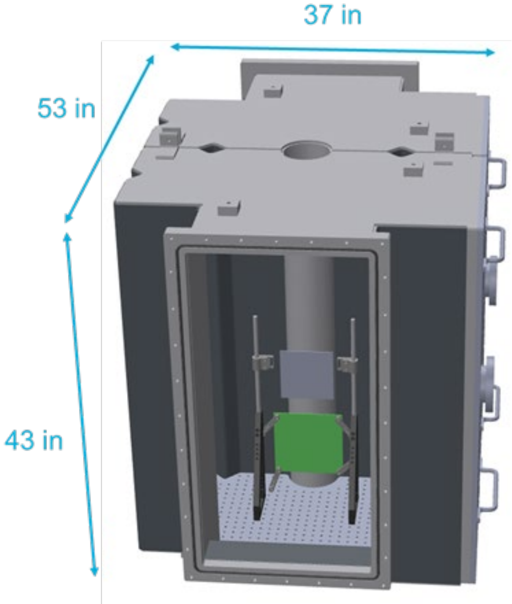
Tritium Lab at SHINE's FLARE facility

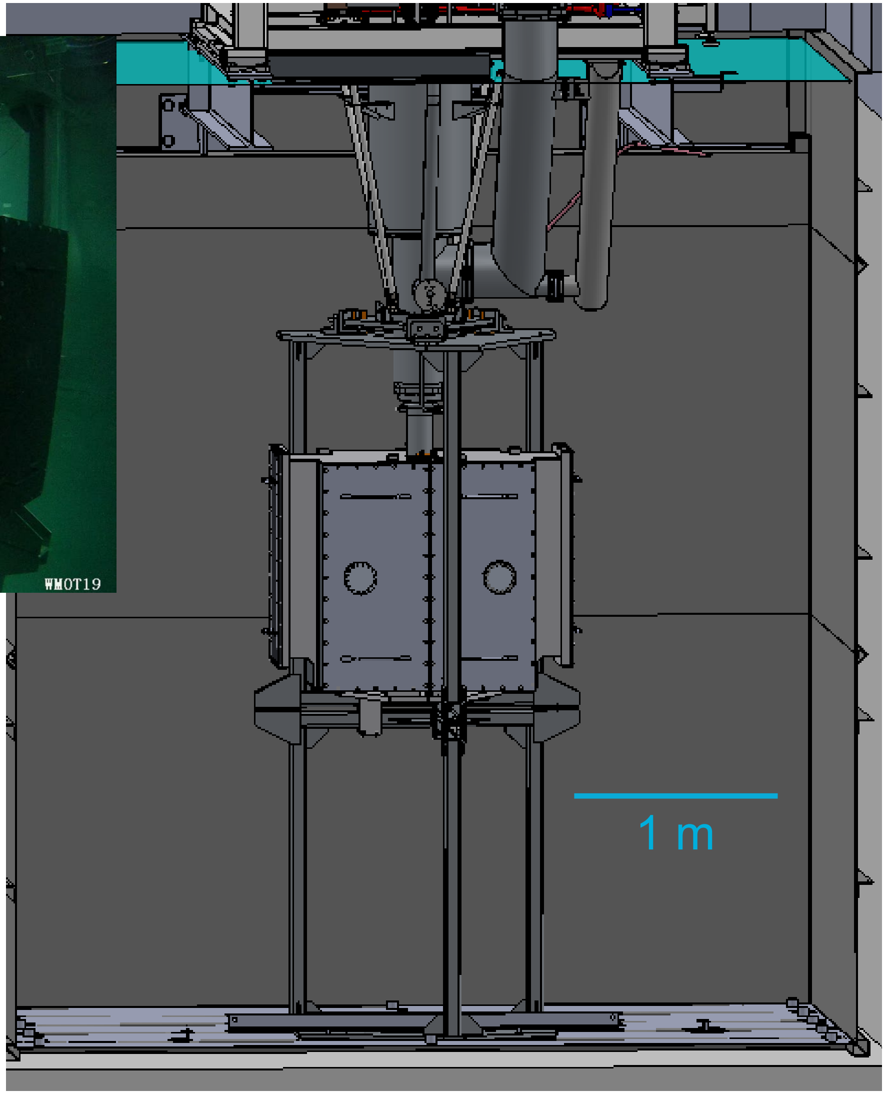


DT Neutron Irradiation Services Available Today

- Continuous operation from 8-132 hours, depending on customer need
- Irradiation cavity surrounds DT source
    - Keeps out water
    - Reduces moderation of neutrons
    - Low activation aluminum walls
    - Large enough for multiple devices
    - Good uniformity due to line source of neutrons
- Upgrading in Q2 2024
    - Installing two ducts that will allow test articles to be loaded without emptying the pool







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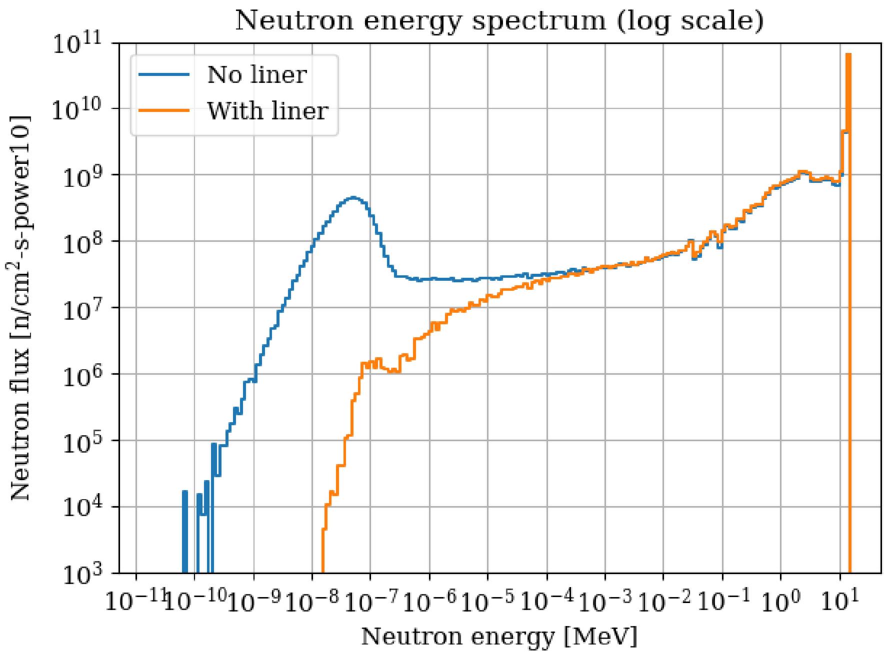
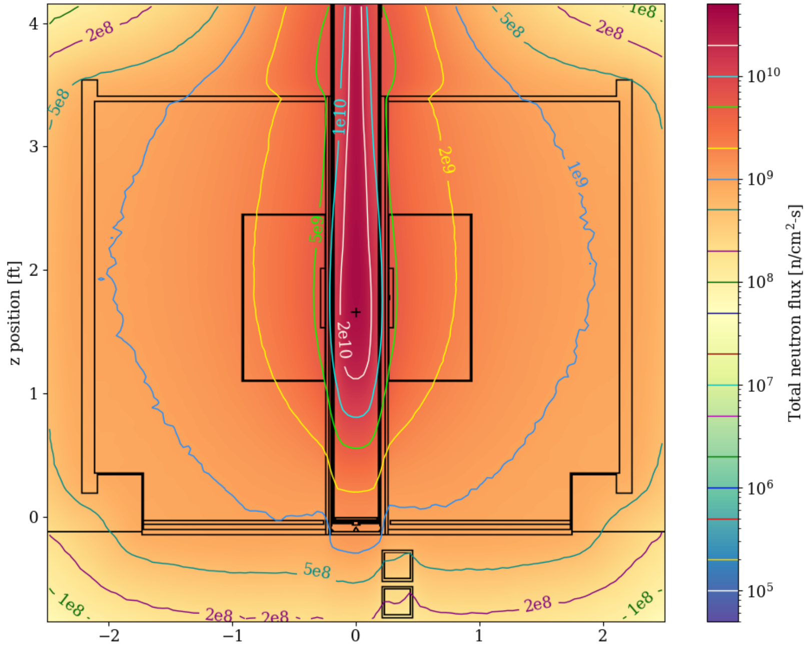
Available Neutron Flux Today

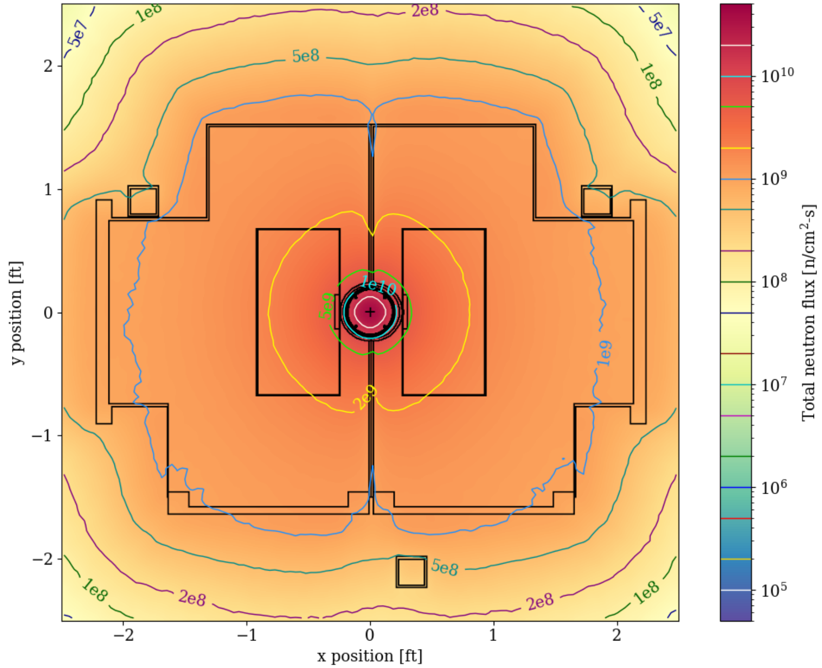
- Recently operating with source strength of 1.7e13 n/s
- Peak total flux = 7.2e9 n/cm^{2}s
- Fluence = 5.9e14 n/cm^2 (per day) or 3.2e15 n/cm^2 (per week)
- Large volume with flux averaging 2.5e9 n/cm^{2}s
- 72% of neutrons are >10 MeV at the highest flux locations
  - Thermal absorbers or reflectors can be inserted to modify the energy spectrum



Side View



Top View



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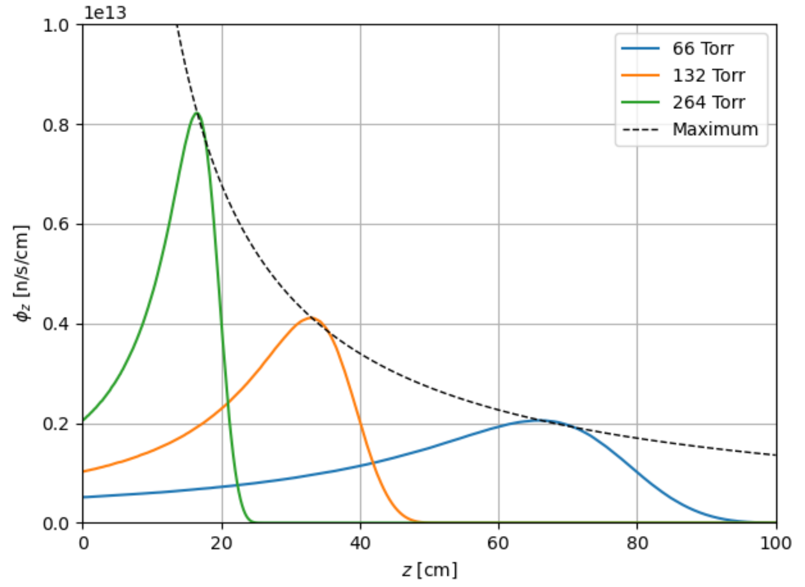
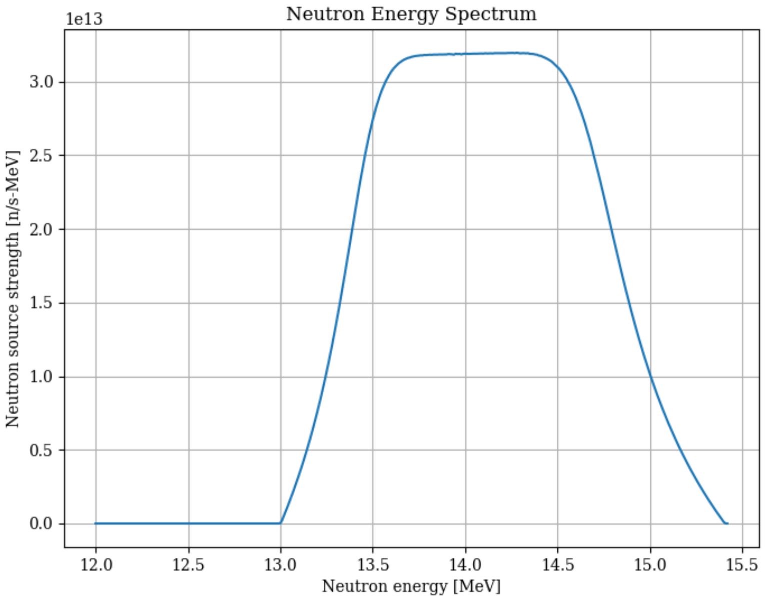
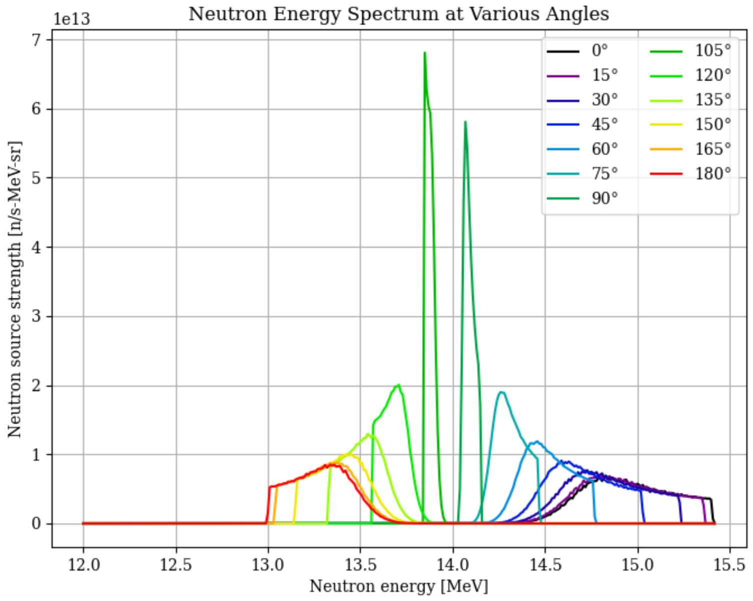
Neutron source definition generation process

- Python model of the beam-target physics used to establish predicted shape and intensity of the neutrons
  - Beam input determined by voltage and current
  - Stopping power values from SRIM
    - Gas constituents, temperature, and pressure all affect the density
  - Energy-dependent cross sections used to evaluate neutron output at each 1 cm increment through the target
    - Neutron intensity, energy spectrum, and angular distribution
  - Output is a multi-variable line source that feeds into an MCNP SDEF card







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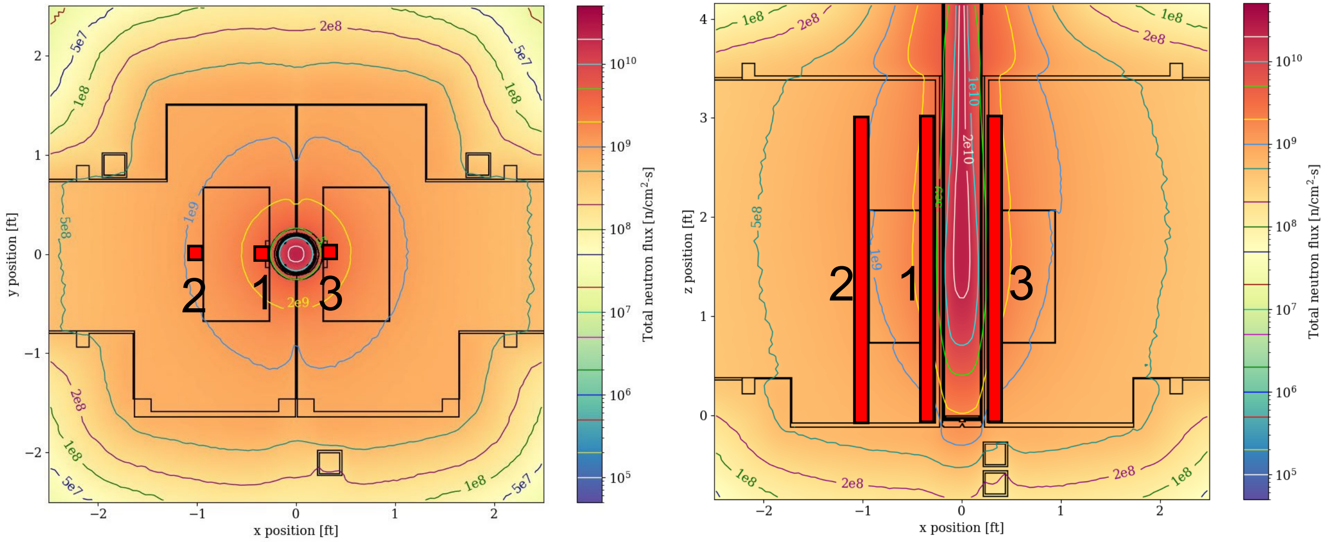
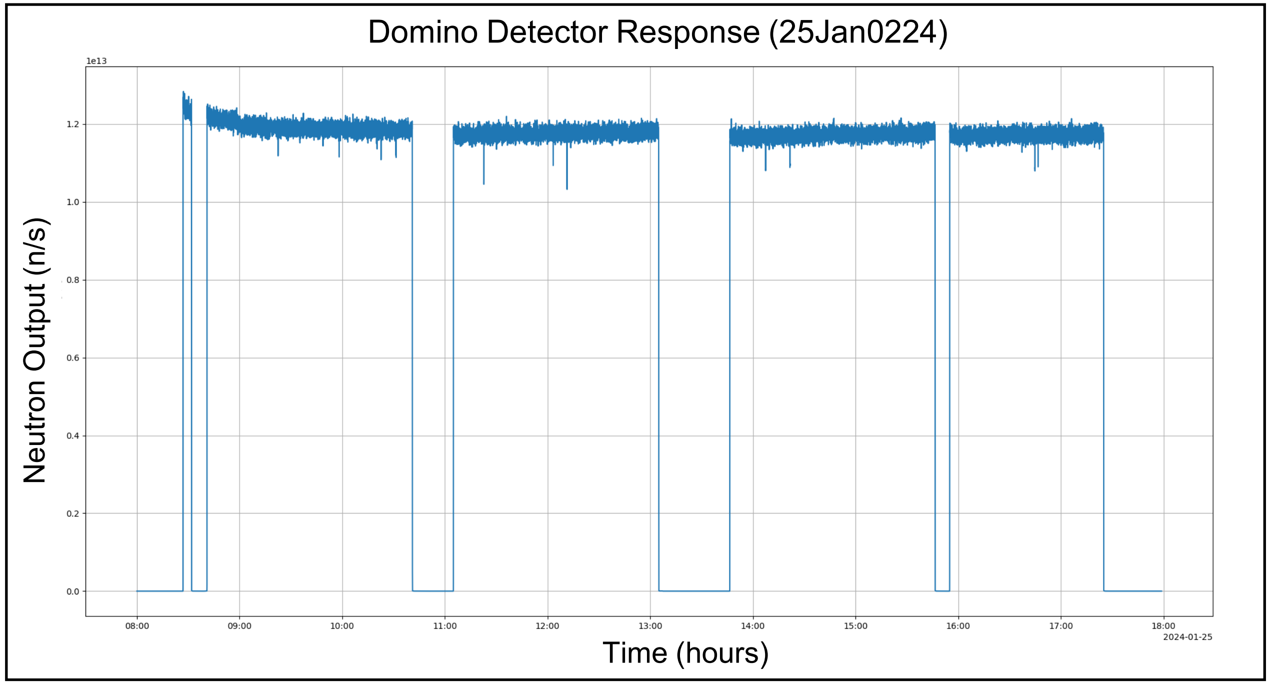
Activation foils

- Niobium foils are used to determine the magnitude and shape of the neutron source
  - The $^{93}Nb(n,2n)^{92m}Nb$ reaction has a 9 MeV threshold and well-validated cross sections which makes it suitable for quantification of DT neutrons
  - When requested by customers, additional foils are used to better quantify full energy spectrum
    - Au-197 (Cd covered/uncovered), Ni-58, Nb-93, Zr-90
- Three arrays of Nb foils were installed at different locations in FLARE with each array having multiple foils spaced out vertically
  - Measured with Canberra GC2018 HPGE detector
  - Calibrated with NIST-traceable source with same geometry as foils
- A pair of RDT Domino thermal neutron detectors are used to track real-time neutron output
  - Used as a surrogate to infer integrated current





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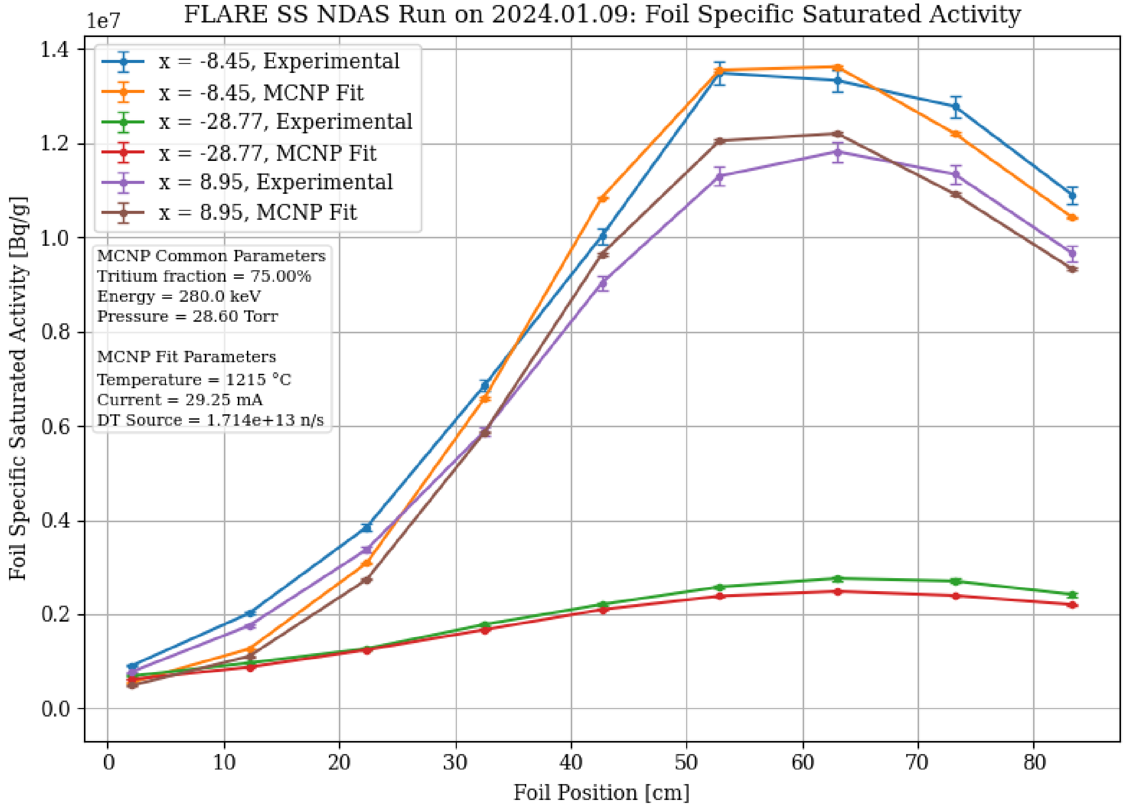
Fitting the Neutron Source Profile

- Constant values are set prior to the run
  - Beam voltage, tritium fraction, pressure
- Unknown values are calculated from the activation foils with a least-squares fitting process
  - Beam current (changes total magnitude)
  - Temperature (shifts profile up or down)
- Once all values are known, the magnitude and shape of the neutron source can be calculated with a high degree of accuracy
- Experimentally validated neutron source strength = 1.7e13 n/s
- Flux maps are then generated from this final source term



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Summary

- Over the past decade, SHINE has developed an intense steady-state DT neutron source
  - Peak total flux available today = 7.2e9 n/cm^{2}s
  - Fluence = 3.2e15 n/cm^2 per week
- SHINE has established a new business unit that utilizes this source to provide irradiations services
  - Primarily serving DoD customers to date, but some fusion-related customers in the pipeline
- SHINE is improving performance (flux, spectrum, operational processes) to create more value for customers and increase testing capacity
- **SHINE is looking for opportunities to apply our hard-gained experience and expertise to support the broader fusion community**

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