Utilization of a High-Flux DT Neutron Source for Tritium Breeding Experiments

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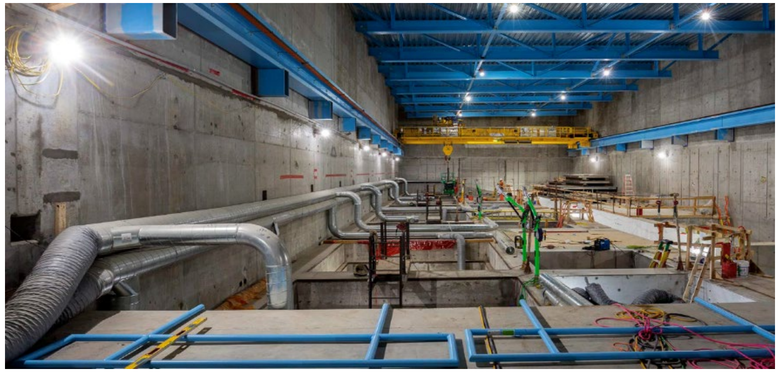
Intro: SHINE's Pathway To Fusion Energy

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**



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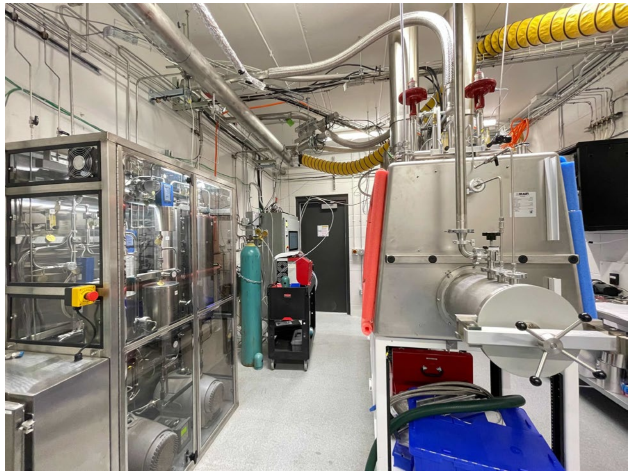
FLARE Facility

DT NEUTRON TEST FACILITY

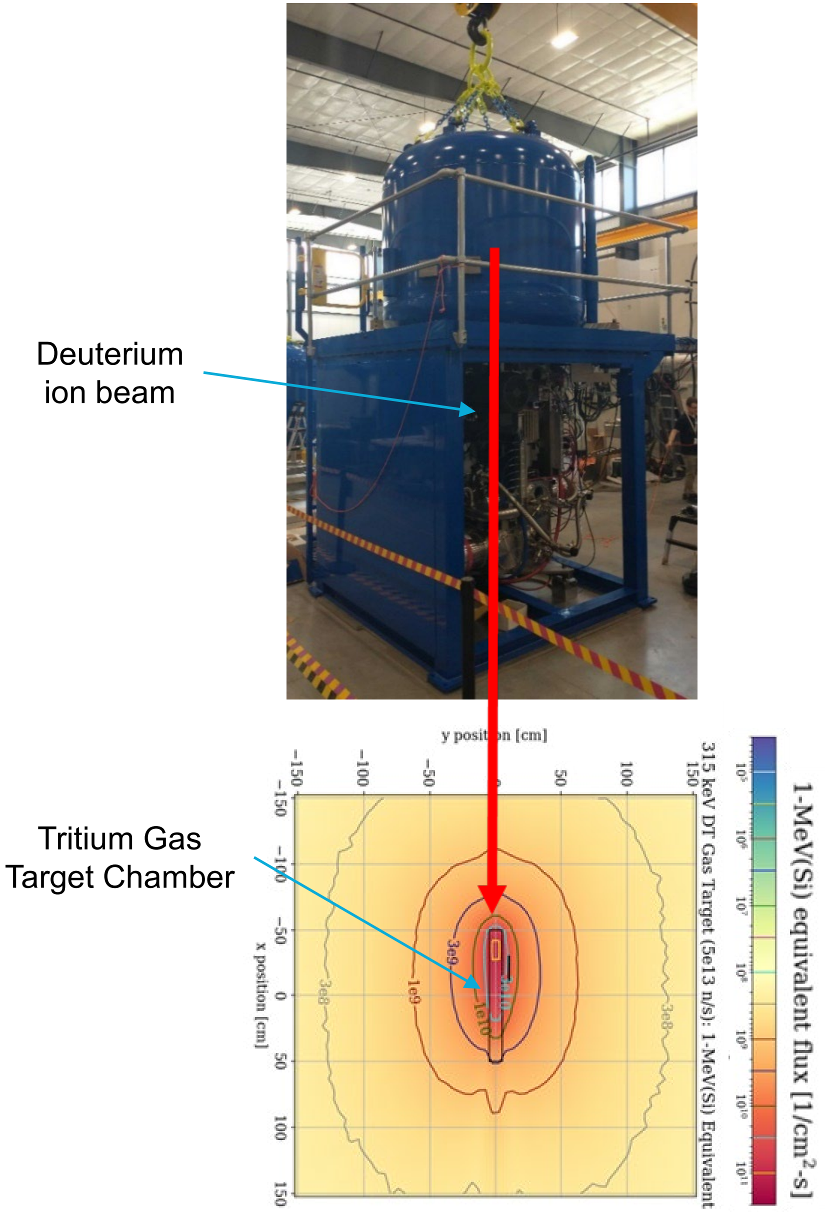
- Steady-state neutron generator
  - Operating production prototype to gain performance and reliability data over the past 4 years (DD and DT operations)
  - 2 units constructed, 2 in commissioning, 4 in assembly
- Tritium Purification System
  - Continuously supplies, purifies, and recovers tritium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



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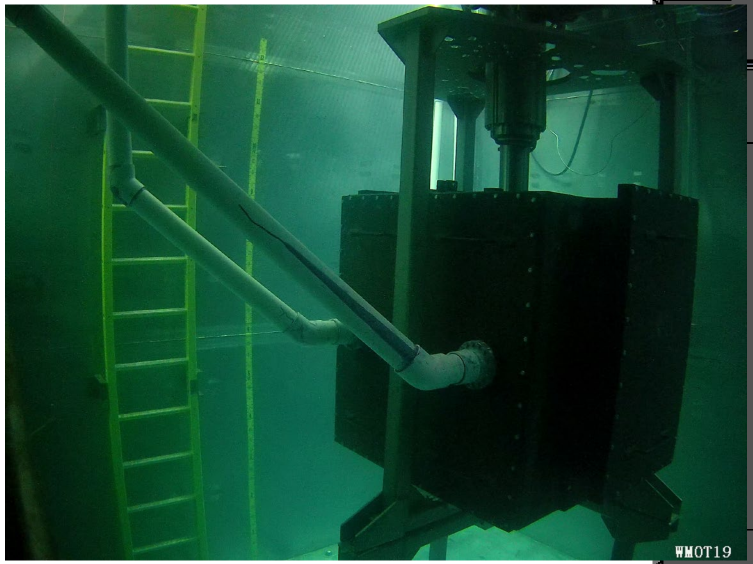
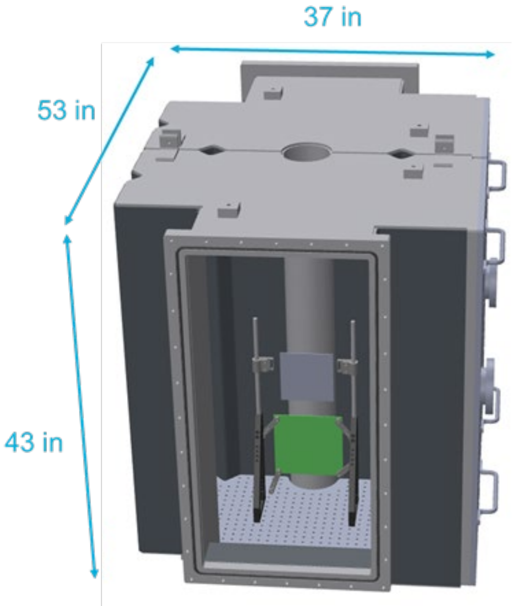
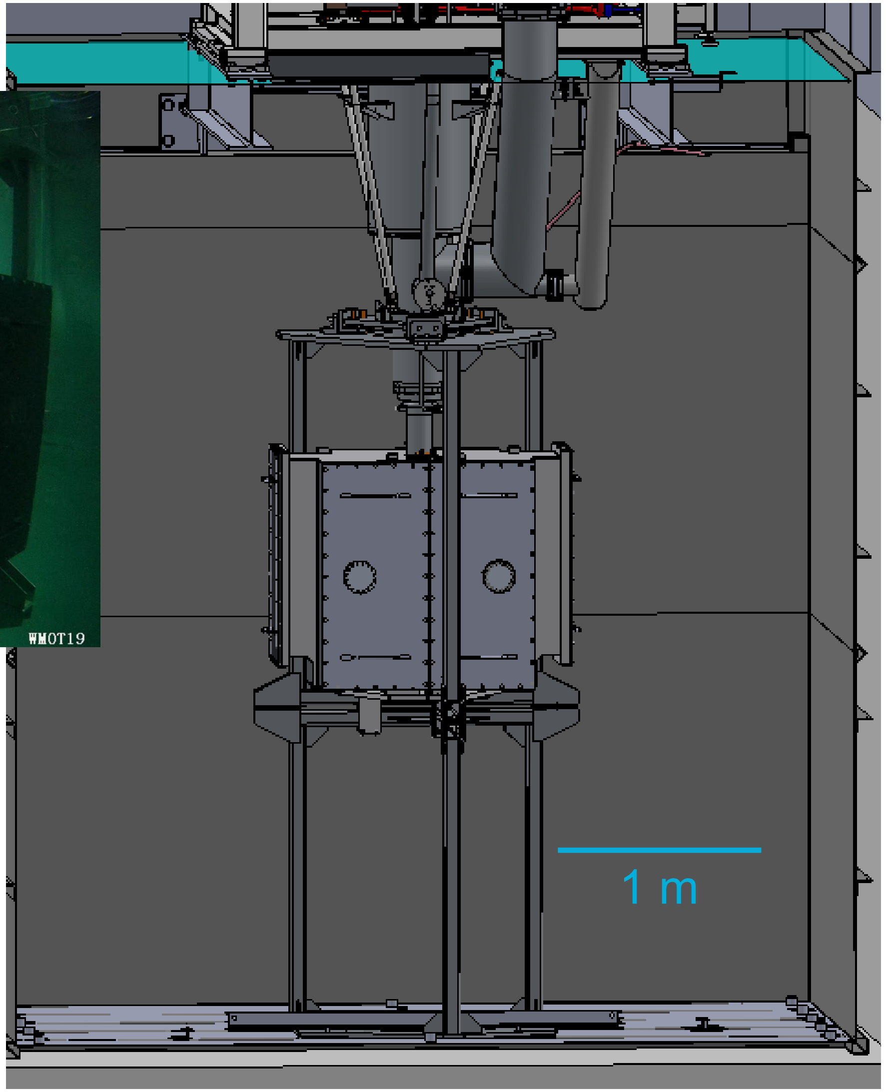
DT Neutron Irradiation Services Available Today

- 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

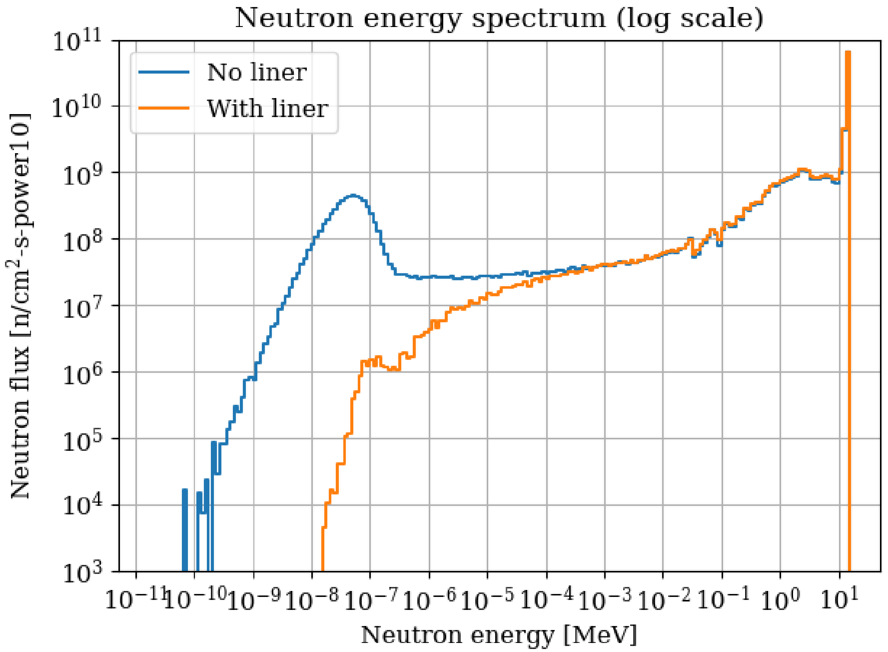




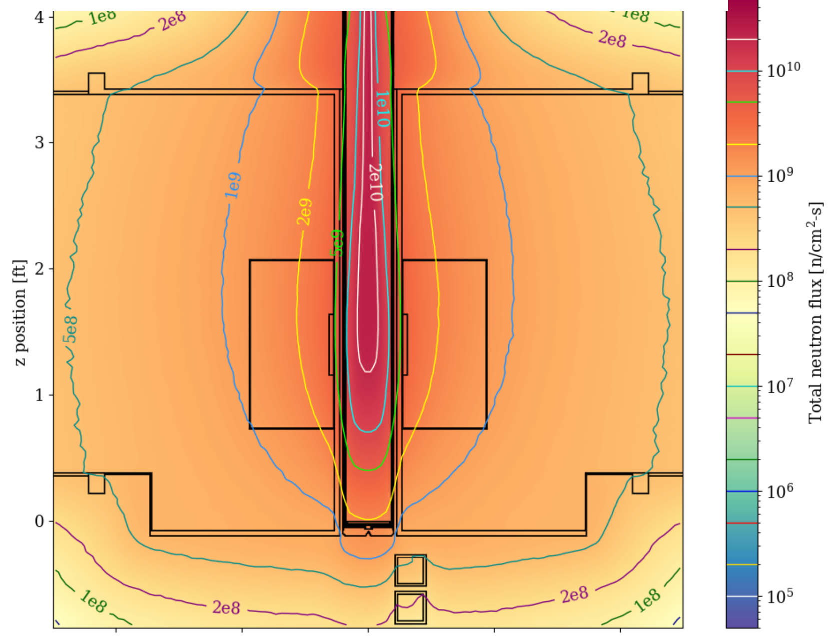


Available Neutron Flux Today

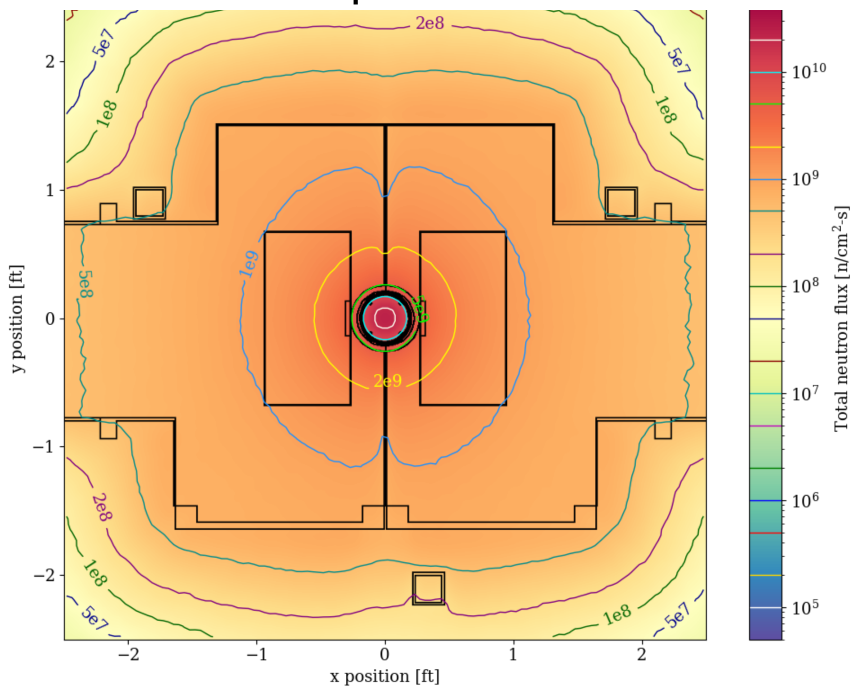
- Recently operating with source strength of 1.7e13 n/s
- Peak total flux = 7.2e9 n/cm^{2}s
- Fluence = 5.9e14 n/cm^2 (per day) or 3.2e15 n/cm^2 (per week)
- Large volume with flux averaging 2.5e9 n/cm^{2}s
- 72% of neutrons are >10 MeV at the highest flux locations
  - Thermal absorbers or reflectors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



Side View



Top View



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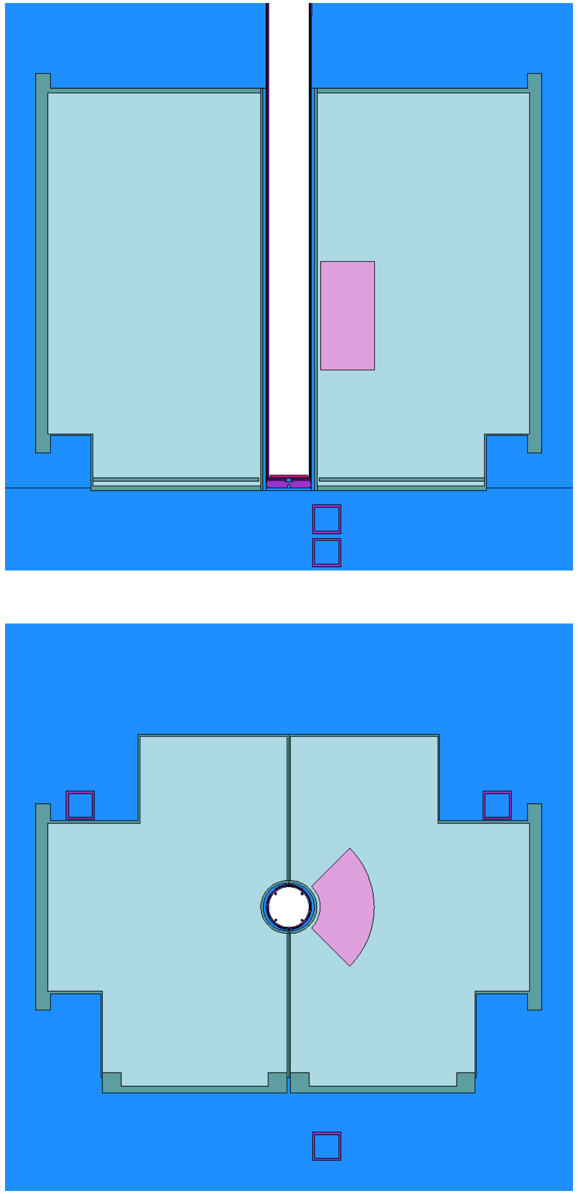
Tritium Breeding Testing

- SHINE is well positioned to perform small-scale T_2 breeding tests in 2024
  - Intense DT neutron source
  - Air cavity provides a natural secondary safety barrier
  - Radiological license allows for 17 kCi of possession
    - Currently seeking an amendment that will allow for deliberate tritium production

- T_2 production are provided in the table for a small-scale test
  - NDAS operating at 1.7e13 n/s source strength
  - 90° wedge-shaped vessel placed in highest flux location
  - 10 L volume
  - 90% Li-6 assumed in all cases

Material	T_2 Production Rate [atom/s]	T_2 Production Rate [µCi/hr]	T_2 Production Rate [mCi/day]
Li	4.8e11	84	2.0
FLiBe	4.6e11	79	1.9
LiF	6.9e11	119	2.9
PbLi	3.4e11	58	1.4



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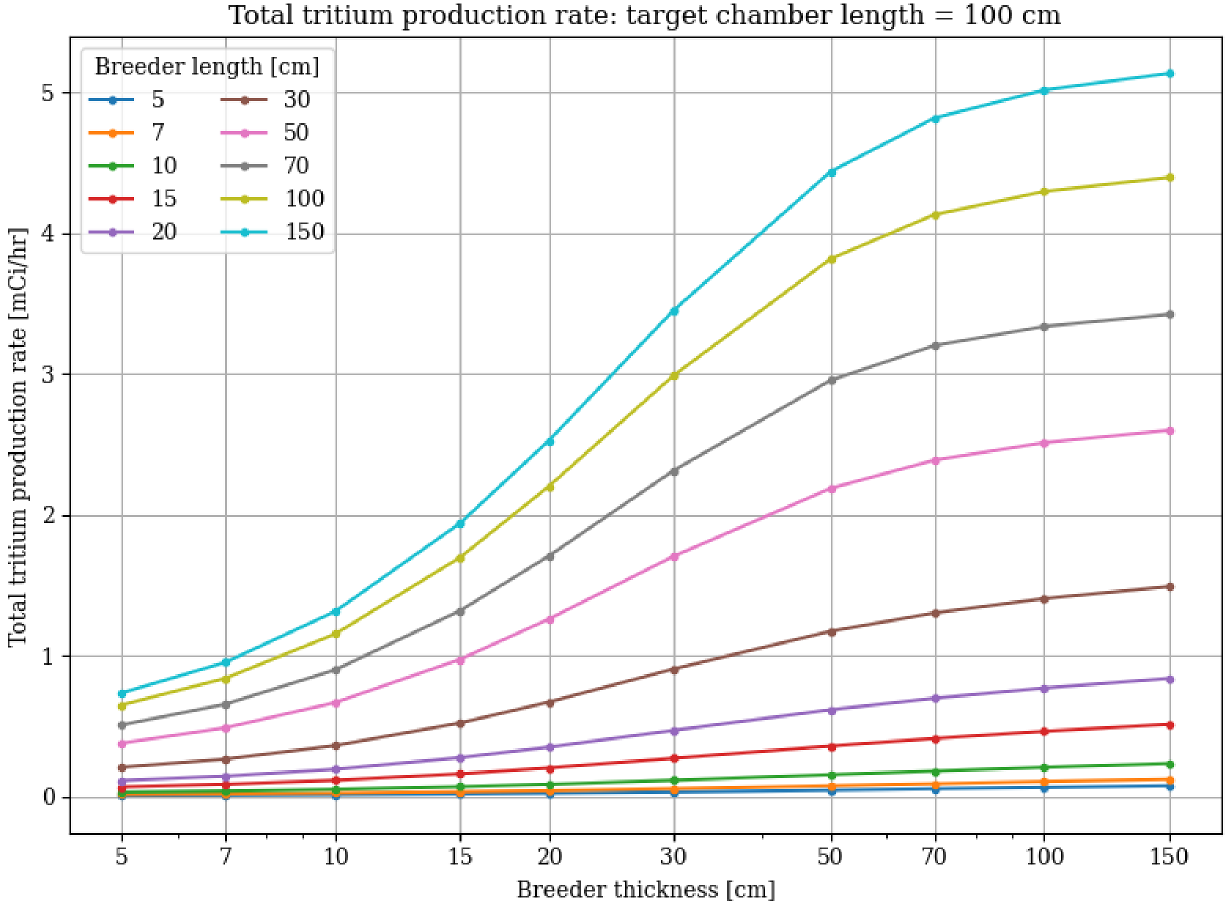
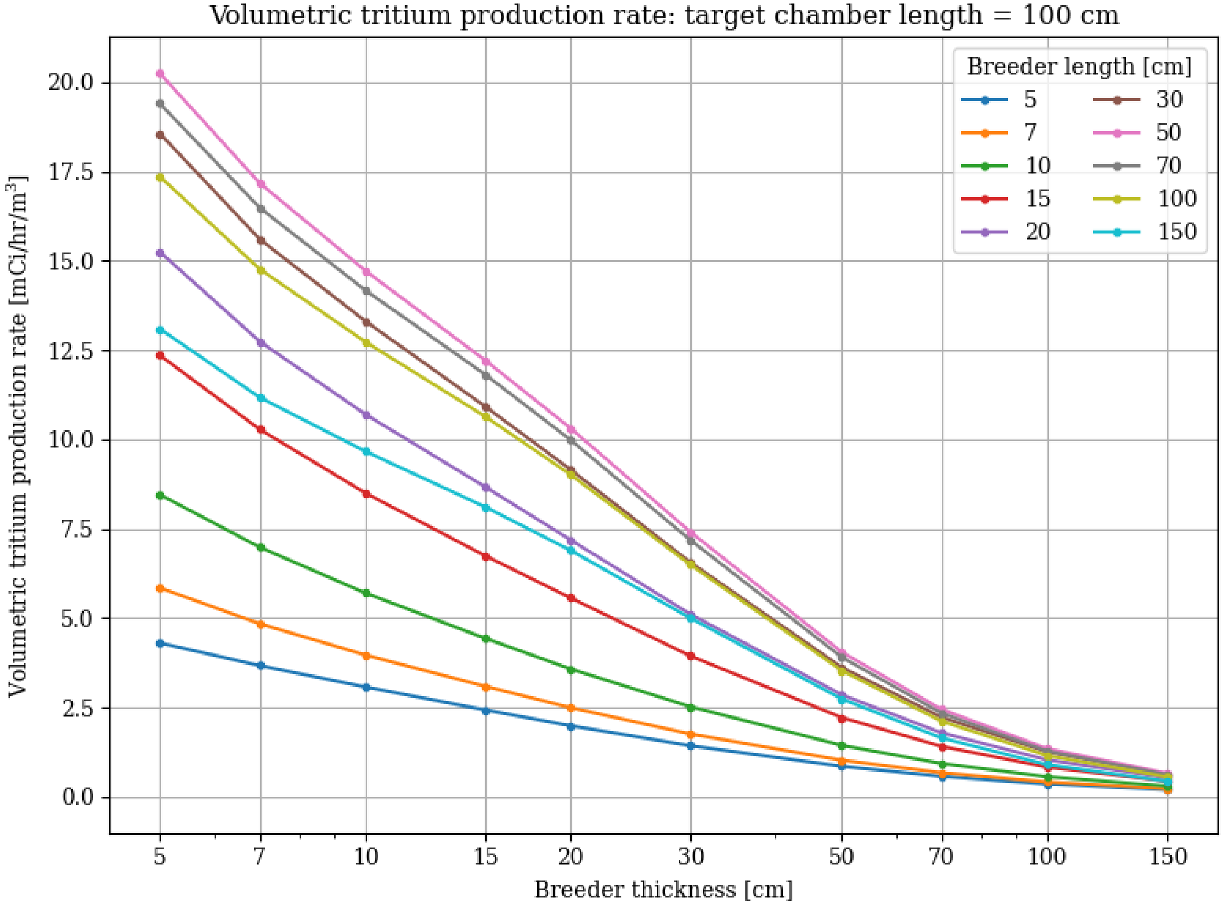
Larger-Scale Breeder Blanket Testing

- Assessment of larger scale tritium breeding was assessed with MCNP 6.2
- Goal: Determine T_2 produced and T_2 /liter for a range of geometries and materials

- Assumptions/Parameters
  - Annular configuration – varying the height and thickness
    - Representative W/SS first wall and interstitial cooling channels (SS/H_2O)
  - DT neutron source strength of 1.7×10^{13} n/s
  - FLiBe and PbLi evaluated to date
    - Natural lithium (non-enriched)
    - Heated to 900 K

Larger-Scale Breeder Blanket Testing – **FLiBe** Results





- Example: 30 cm tall vessel with 50 cm thickness (FLiBe breeder)
  - FLARE facility could generate 58.7 mCi of tritium during a 50-hour experiment
  - Results in 181 μCi of tritium **per liter** at end of irradiation.

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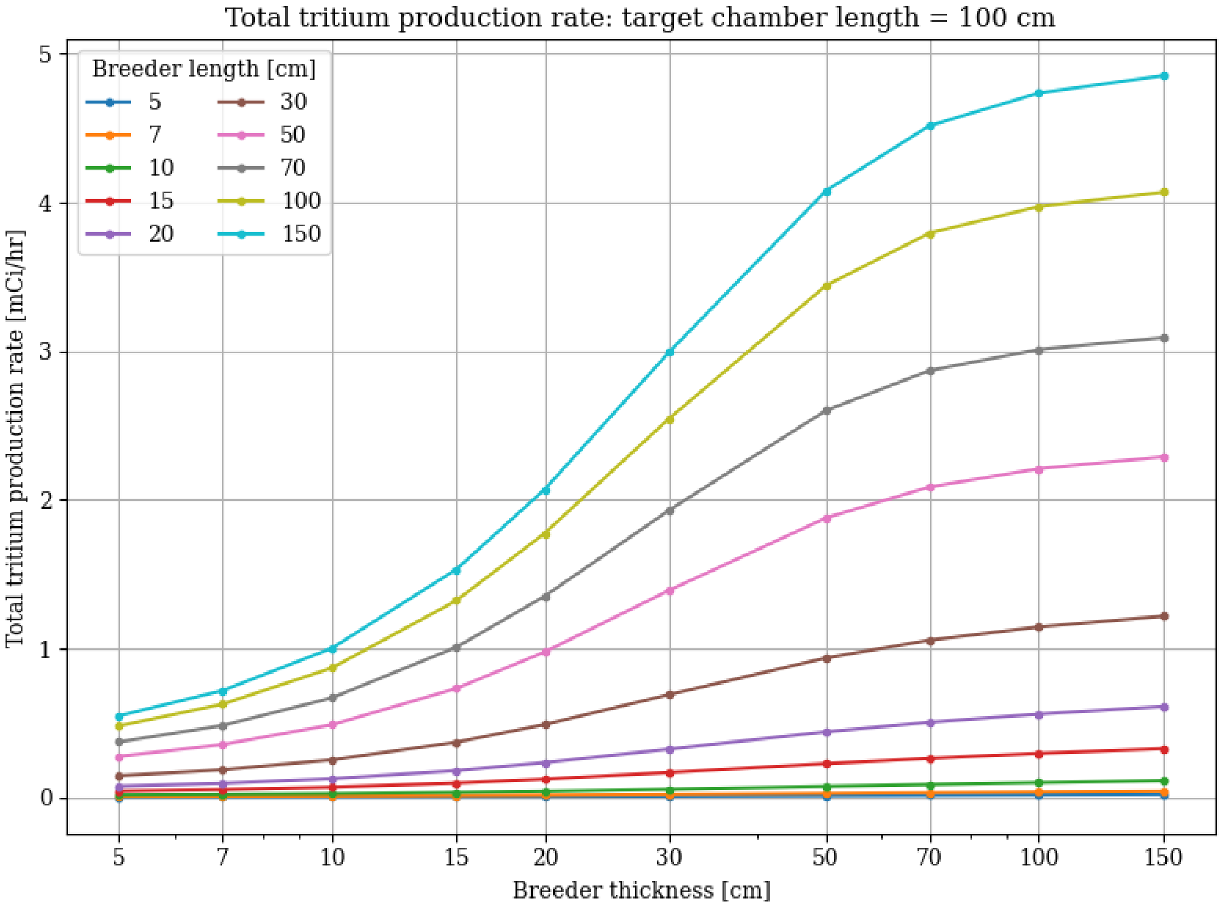
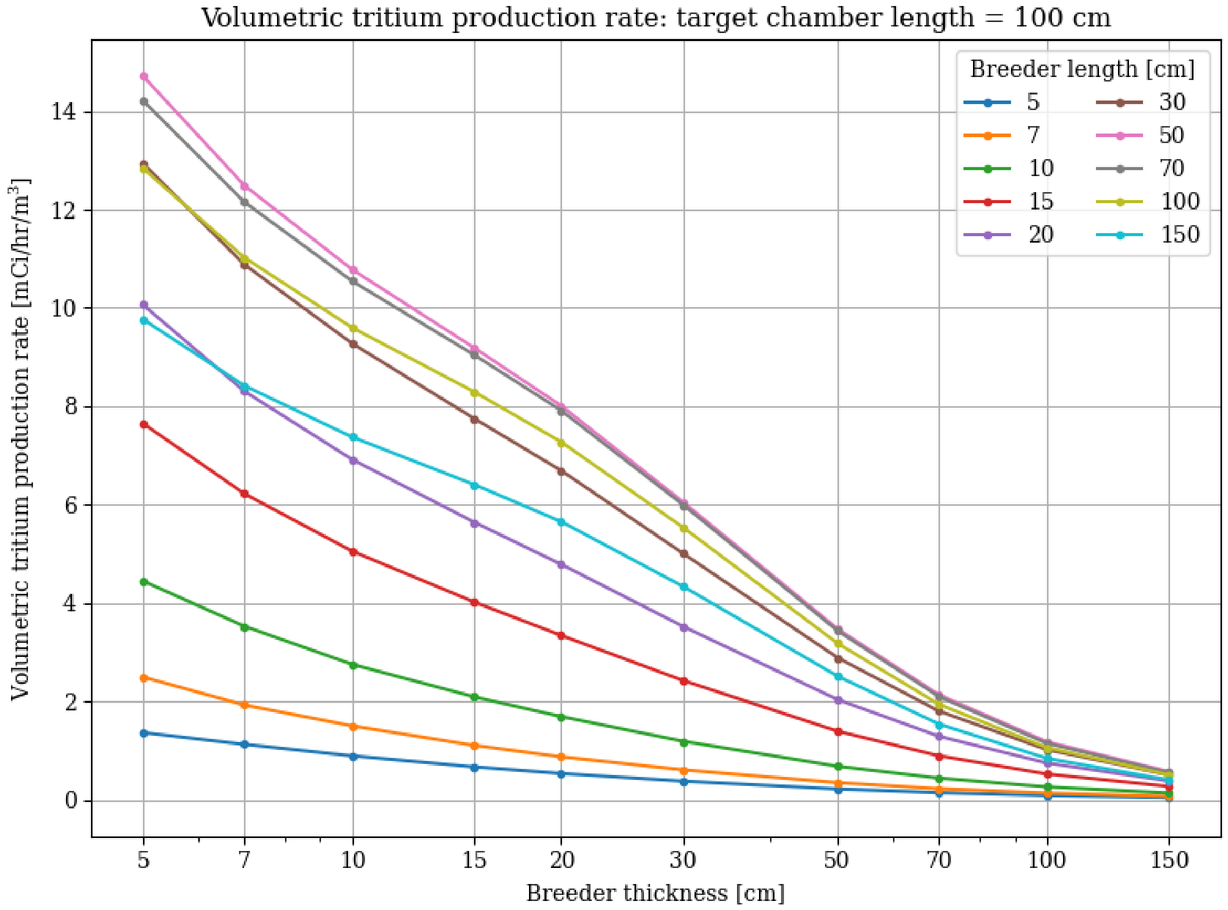
Larger-Scale Breeder Blanket Testing – **PbLi** Results





- Example: 30 cm tall vessel with 50 cm thickness (PbLi breeder)
  - FLARE facility could generate 43.3 mCi of tritium during a 50-hour experiment
  - Results in 140 µCi of tritium **per liter** at end of irradiation.

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Larger-Scale Breeder Blanket Testing - Conclusion

- INL experiments [1] suggest this concentration of tritium in solution will be readily quantifiable, whether measured during a post-irradiation evaluation or via an online measurement of flowing FLiBe or PbLi during irradiation.

- Blanket irradiation experiments at FLARE should provide good validation of breeding ratios in blankets being irradiated with DT neutrons.

- Note: Anticipating ~4.6X higher tritium yield for an optimized system
  - Design neutron output (not constrained by facility limitations)
  - Shorter neutron producing target chamber improves capture fraction

T.F. Fuerst, C.N. Taylor & P.W. Humrickhouse (2023) The Source Permeator System and Tritium Transport in the TEX PbLi Loop, Fusion Science and Technology, 79:1, 77-94, DOI: 10.1080/15361055.2022.2090784

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Summary

- Over the past decade, SHINE has developed an intense steady-state DT neutron source
  - Peak >10 MeV 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, but some fusion-related customers in the pipeline
- Current system is capable of performing tritium breeding experiments that will generate relevant data

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