July 09, 2025

LIBRA: Liquid Immersion Blanket Robust (tritium) Accountancy update

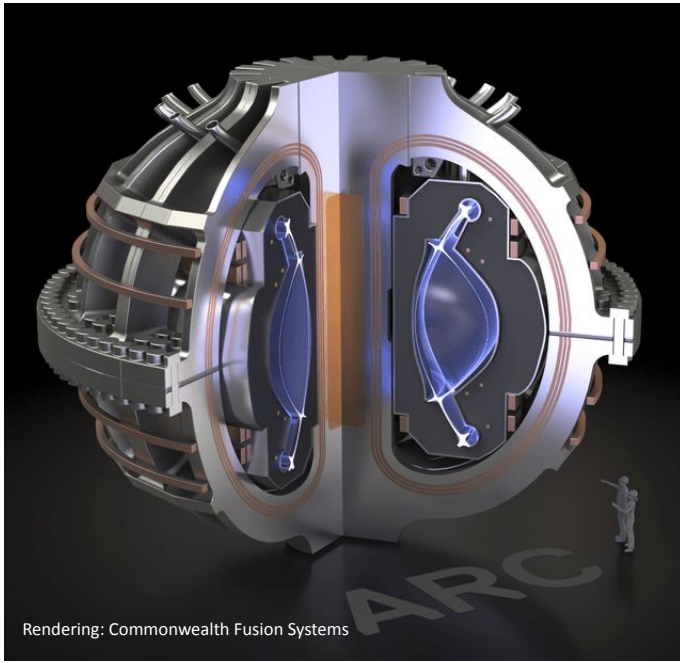
Kevin B. Woller, kbwoller@mit.edu, on behalf of the LIBRA Team

2025 ARPA-E Fusion Programs Annual Review

DE-AR0001542

PSFC
Plasma Science and Fusion Center

Molten Salt Liquid Immersion Blanket (LIB)

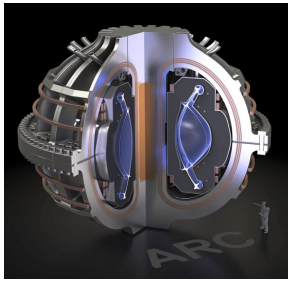


Rendering: Commonwealth Fusion Systems

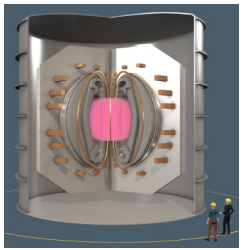
- **Maximize solid angle coverage of fusion core to optimize tritium breeding and radiation shielding**
- **Molten salt** interaction with magnetic fields **lower** compared to liquid metals
- Liquid breeder **pump out** for maintenance cycles
- **Online chemistry control to** address corrosion and tritium speciation (T_2, HT over TF)
- Tritium has **low solubility** in molten salts, easing extraction
- Take advantage of good **thermal physical properties** for high power density concepts, efficient thermal cycle

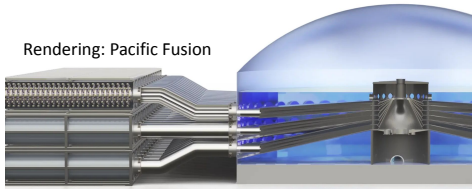
The Liquid Immersion Blanket (LIB) concept addresses market drive for faster, smaller, more efficient fusion energy

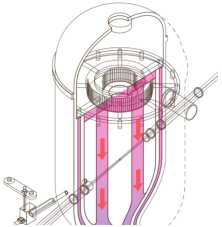
Liquid Immersion Blanket (LIB) technology for the fusion industry

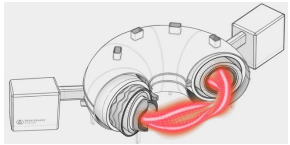


Rendering: Commonwealth Fusion Systems

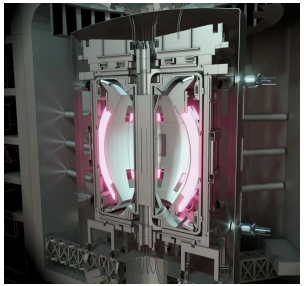

Rendering: Tokamak Energy

Rendering: Pacific Fusion


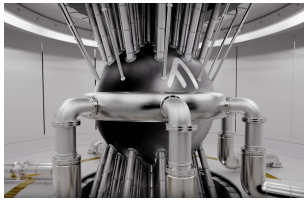

Rendering: Xcimer Energy

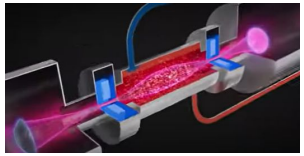

Rendering: Renaissance Fusion


Rendering: Proxima Fusion

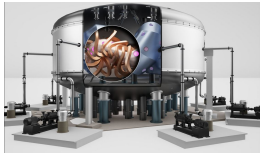

Rendering: UK Atomic Energy Authority


Rendering: ZAP Energy


Rendering: Marvel Fusion

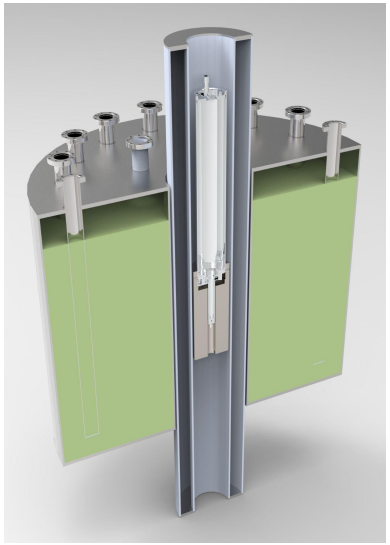

Rendering: Realta Energy

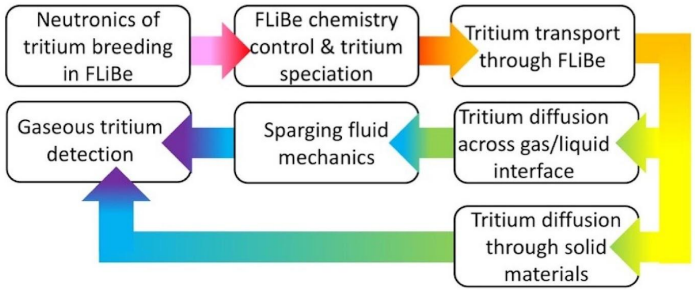
Rendering: Terra Fusion



Rendering: Type One Energy

Tritium breeding blanket research and development is needed in parallel to fusion core development

LIBRA: Liquid Immersion Blanket - Robust Accountancy





Build, test, revise Liquid Immersion Blanket (**LIB**) technology at fusion power relevant conditions:

★ **550-700 C** operation for increased heat extraction efficiency

★ **14.1 MeV** neutrons from D-T fusion source

★ **100s of liters** of liquid breeder for typical blanket thickness for fusion energy device.

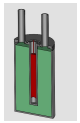
Baked-in design challenges:

- Moderate and absorb D-T neutrons (14.1 MeV) with FLiBe (efficient breeder)
- Work through materials issues
  - Materials compatibility, corrosion
  - Tritium chemistry and transport
- Management of hazards, safety strategies
  - Beryllium
  - Fluorine, HF
  - Radiation, activation

ARPA-E AWARDEE
OPEN 2021

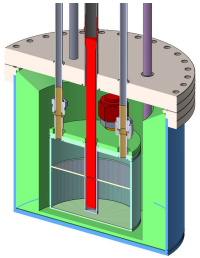
Progression to Full-scale LIB tech: Build A Better Yield (BABY), LIBRA Pi, LIBRA ONE

BABY-0.1L
0.1 L volume



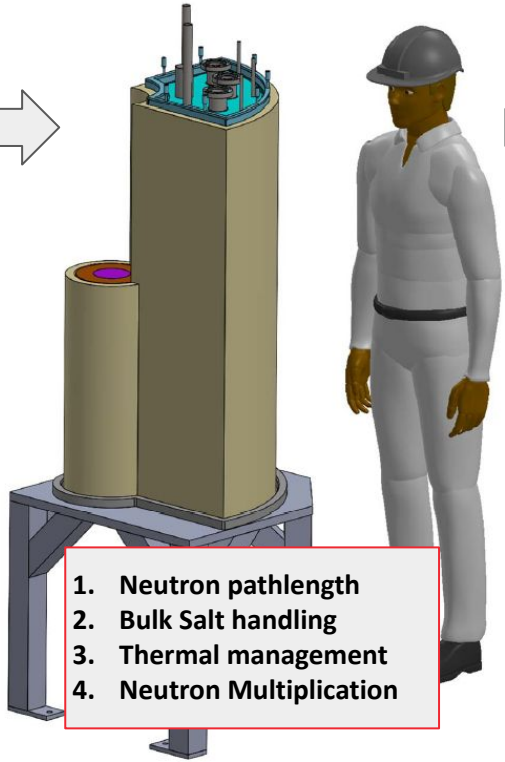
1. Non-beryllium salt
2. Hazardous gas monitoring
3. Tritium sensing

BABY-1L
1 L volume



1. Tritium permeation
2. Tritium release strategies
3. Materials testing
4. Alternate breeder testing
5. Beryllium management strategies

LIBRA Pi
~100 L volume



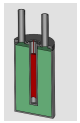
1. Neutron pathlength
2. Bulk Salt handling
3. Thermal management
4. Neutron Multiplication

LIBRA ONE
700 L volume

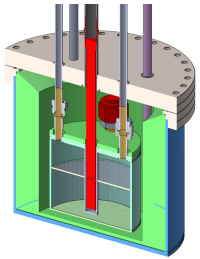
1. Tritium Breeding Ratio > 1
2. FLiBe breeding salt
3. Engineered Tritium breeding blanket for D-T fusion source

Progression to Full-scale LIB tech: Build A Better Yield (BABY)

BABY-0.1L
0.1 L volume



BABY-1L
1 L volume



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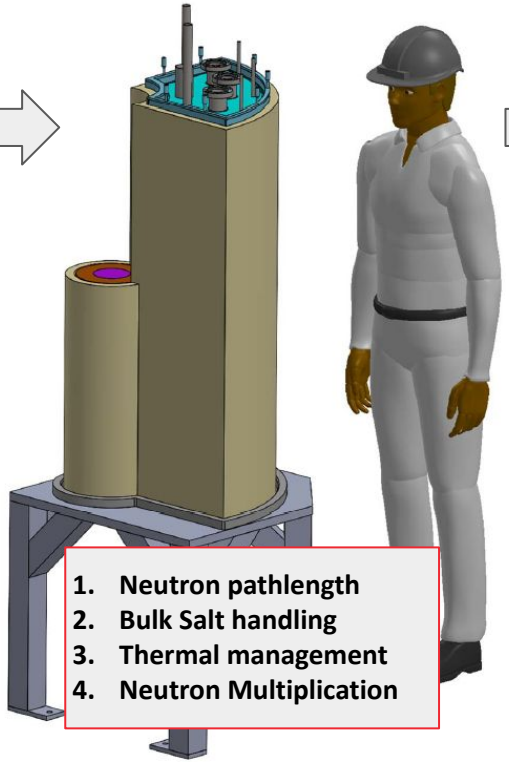

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LIBRA ONE
700 L volume

1. Tritium Breeding Ratio > 1
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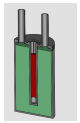
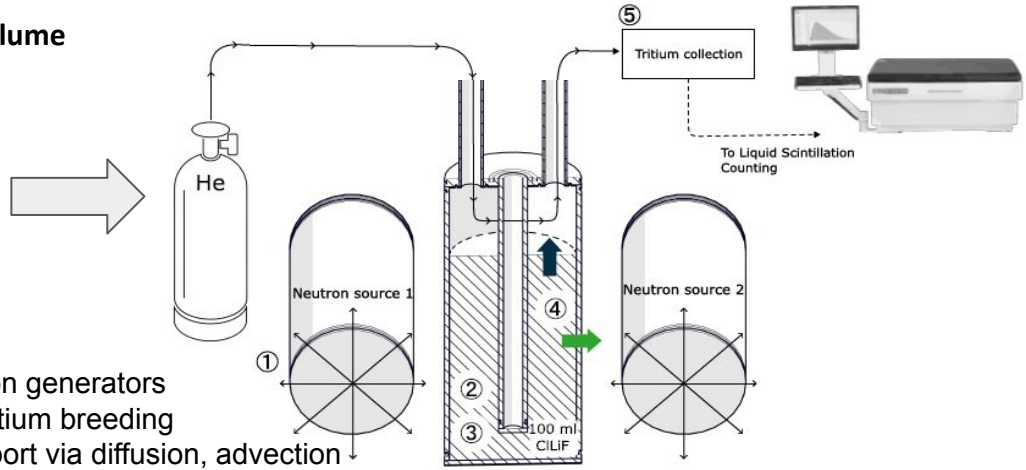
3. Engineered Tritium breeding blanket for D-T fusion source

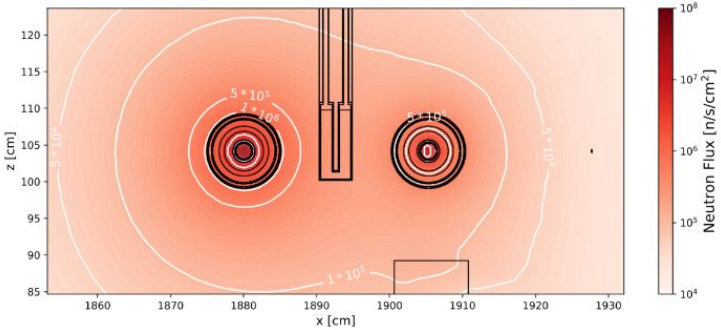
0.1 L BABY testing for neutron and tritium detection, salt chemistry tests

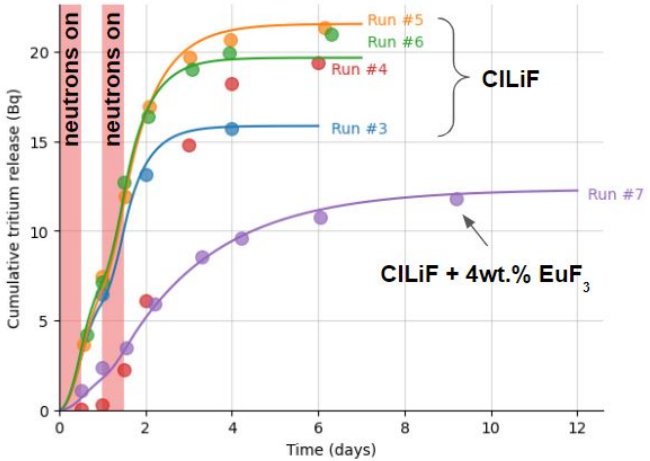
0.1 L volume





1. Neutron generators
2. Salt tritium breeding
3. Transport via diffusion, advection
4. Release via top surface or permeation
5. Water bubbler collection



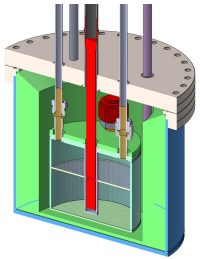


R. Delaporte-Mathurin et al., "Advancing tritium self-sufficiency in fusion power plants: insights from the BABY experiment", 2025. *Nuclear Fusion*

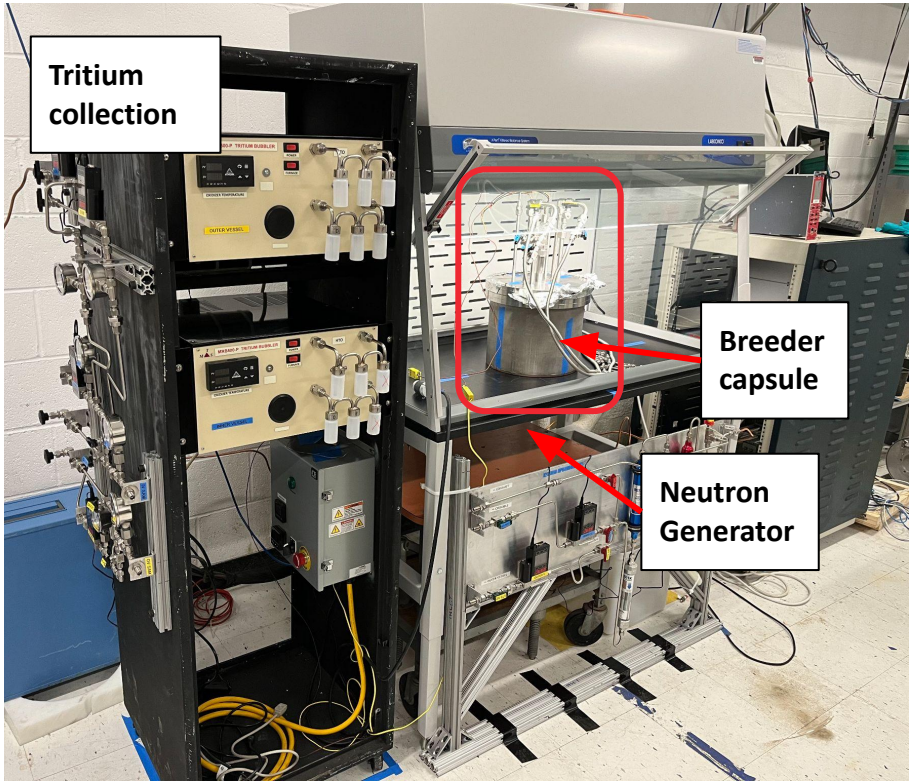
bit.ly/100mL-BABY

Tritium breeding experiments under development for FLiBe

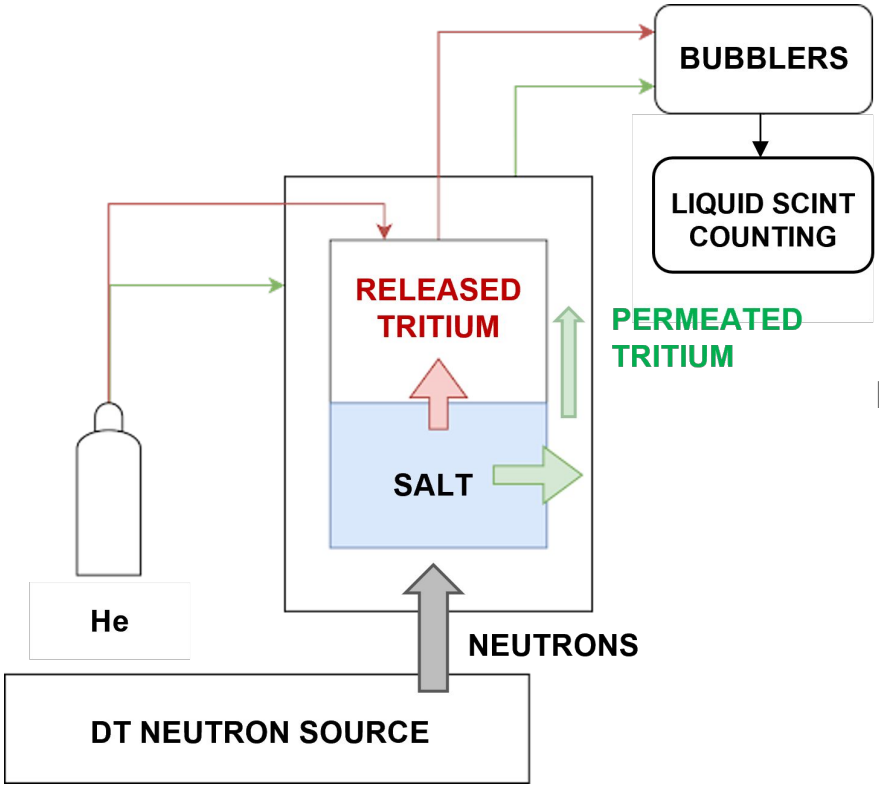
1 L volume

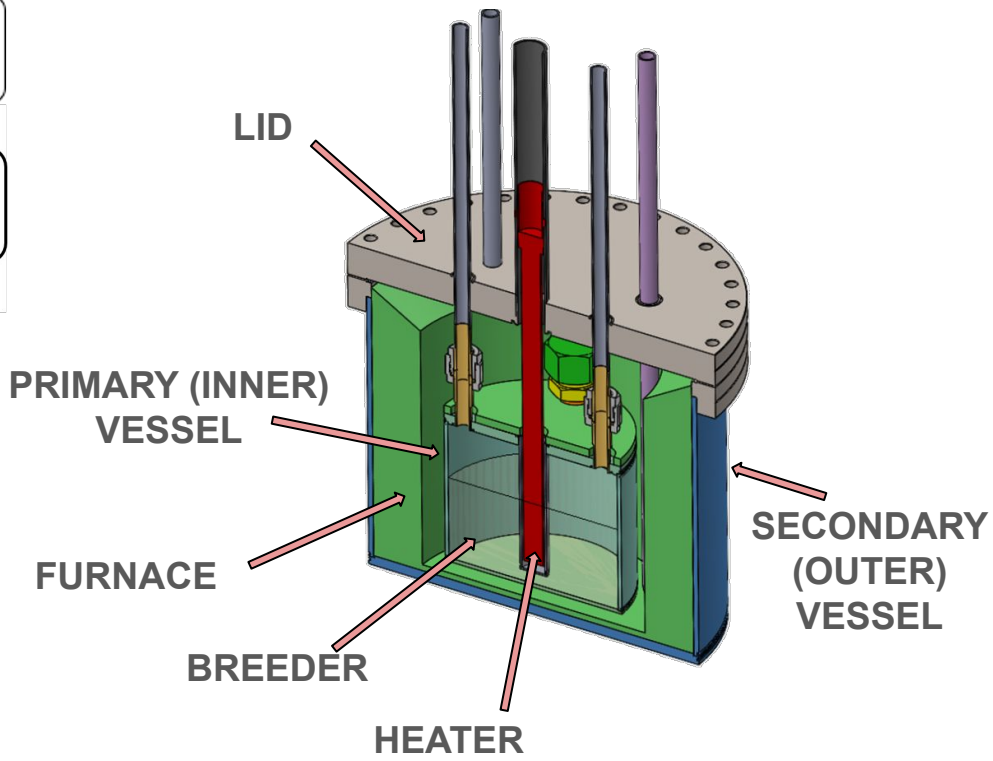


1. Process development for gas sweep/sparging
2. Analysis of permeated tritium
3. Test bed for larger-scale tech

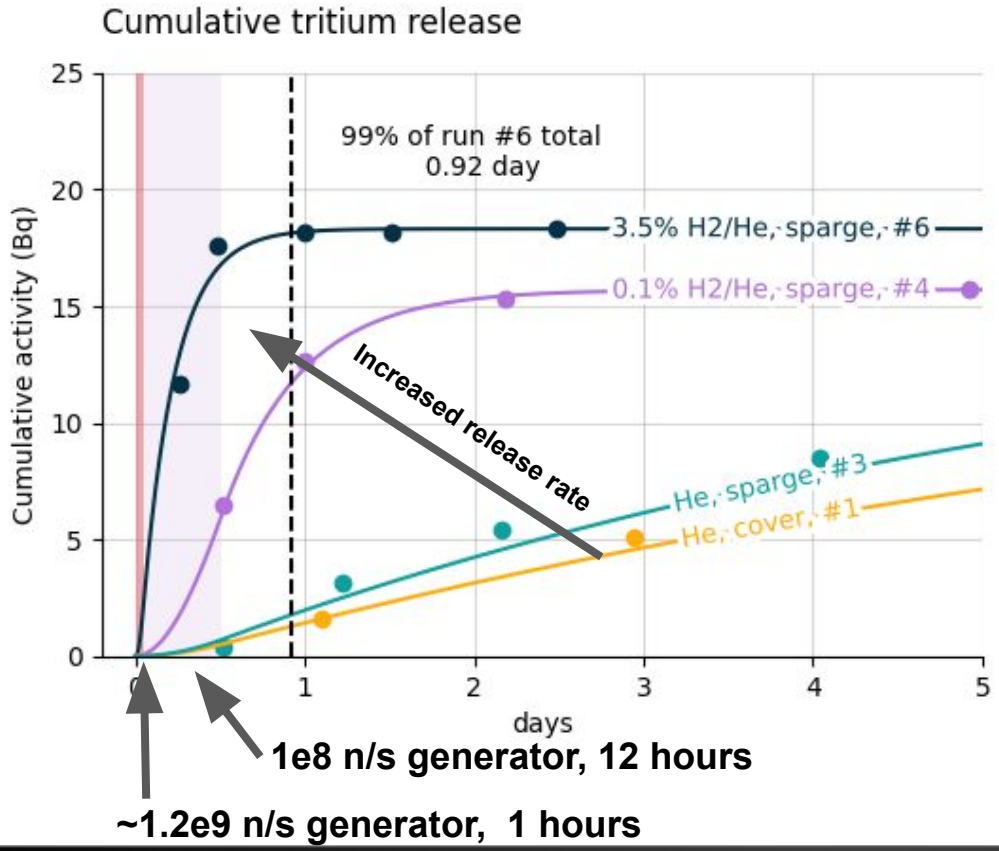


1L BABY test platform is suitable for a variety of experiments





Improved tritium release rates and increased neutron flux



More powerful neutron generator received and approved for operation

->12-24 hr irradiation runs down to 1 hr or less

Increased tritium release rates with sparging and/or H2 sweeping

-> 1-2 month collection runs down to a few days

Increased confidence in operations

-> Preparing for first FLiBe test

Experimental iterations rapidly increased, see us at poster for many more experimental results and discussion

Preparing for FLiBe testing at small-scale

Shared Radiation Vault facility

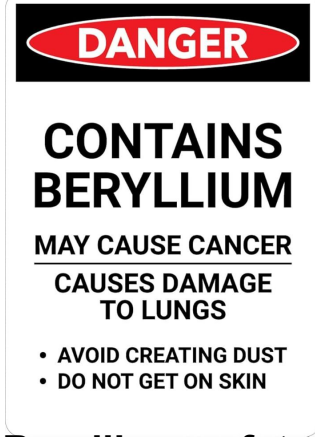
Safety/stewardship mentality:
Ensure there is no impact from FLiBe experiments on other users

- No release to the environment during testing
- No release to the environment in commissioning/decommissioning

Procedures and Decon. planning

Environmental monitoring

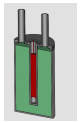
Access control



Beryllium safety and education

Progression to Full-scale LIB tech: LIBRA Pi

BABY-0.1L
0.1 L volume



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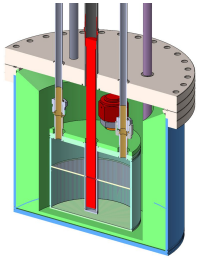

1. Tritium permeation
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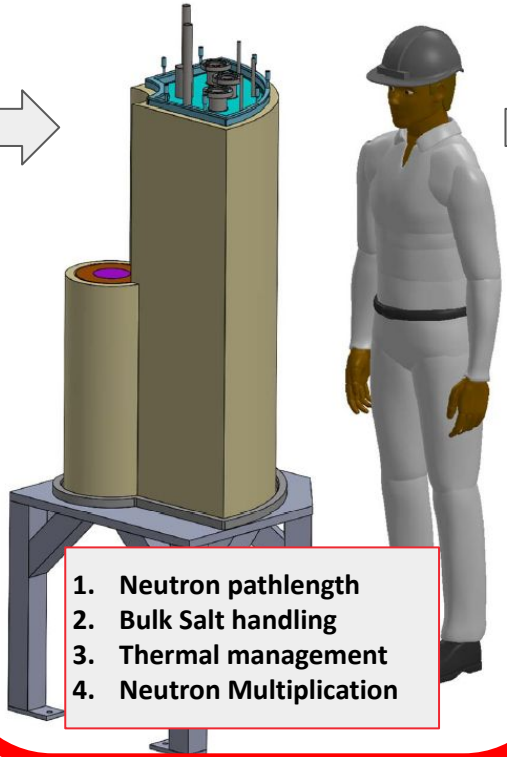
LIBRA Pi
~100 L volume



1. Neutron pathlength
2. Bulk Salt handling
3. Thermal management
4. Neutron Multiplication

LIBRA ONE
700 L volume

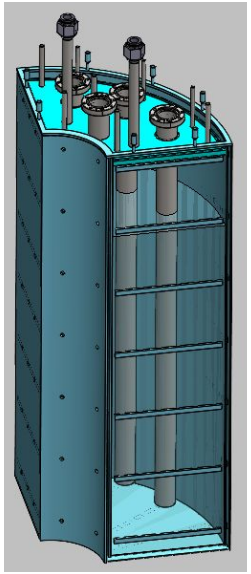
1. Tritium Breeding Ratio > 1
2. FLiBe breeding salt
3. Engineered Tritium breeding blanket for D-T fusion source

LIBRA Pi heating to follow from Radiative heater test

- ~100 L breeder volume
- Inconel 625 material
- Double-walled construction for tritium permeation sensing

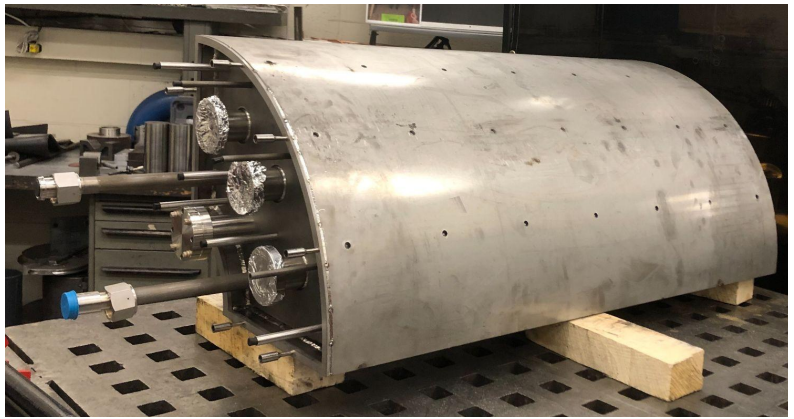
- ~70LiCl:30LiF (ClLiF) breeder
- Alumina permeation barrier on exterior to reduce secondary permeation

LIBRA Pi CAD



LIBRA Pi inner vessel

LIBRA Pi outer layer welding



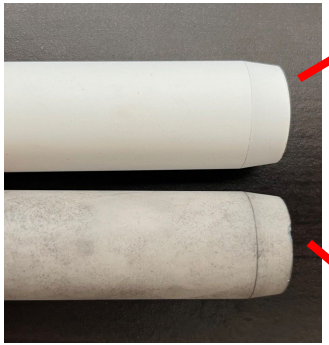
LIBRA Pi coated in Alumina

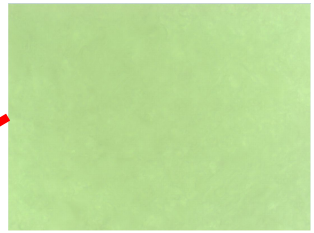
LIBRA Pi coated in plasma spray alumina to mitigate tritium permeation losses

0.1” thick Al2O3 on 316 SS

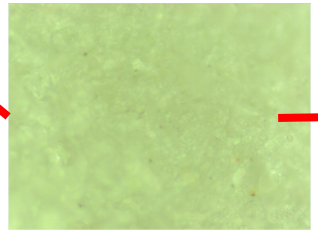
Optical Micrographs

Before bake





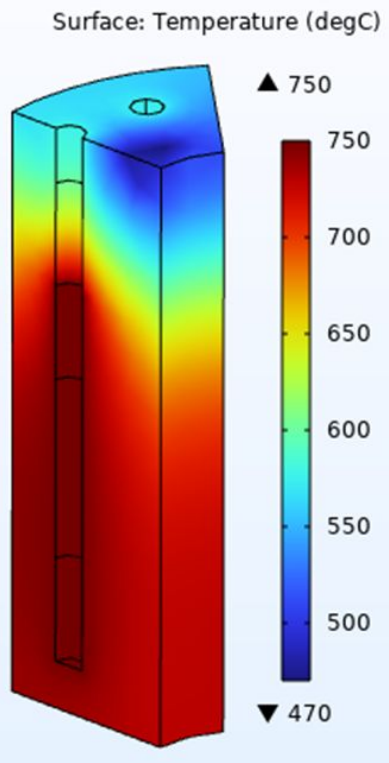
After 750C, 4 hrs

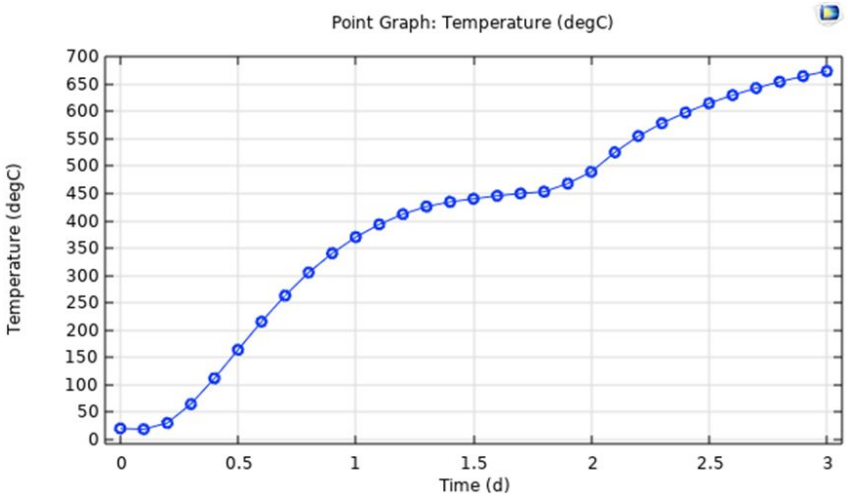


Assessing tritium permeation barrier coating with BABY 1L and LIBRA Pi that simplifies LIBRA ONE design/fabrication

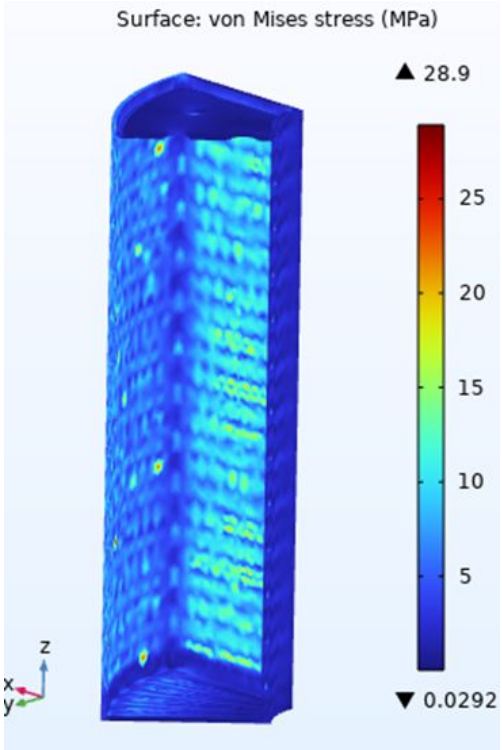
No macro-, microscopic cracks, good adhesion Coated Inconel 625 1L BABY vessel for T permeation barrier experiment with FLiBe 1L BABY experiment

LIBRA Pi thermal and structural stress analysis





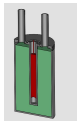
Heating time several days to melt salt and reach 700C for experiments.



Structural analysis shows no buckling, allowable stresses

Progression to Full-scale LIB tech: LIBRA ONE

BABY-0.1L
0.1 L volume



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BABY-1L
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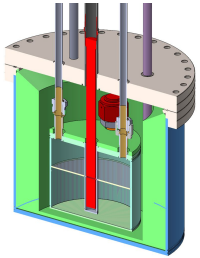

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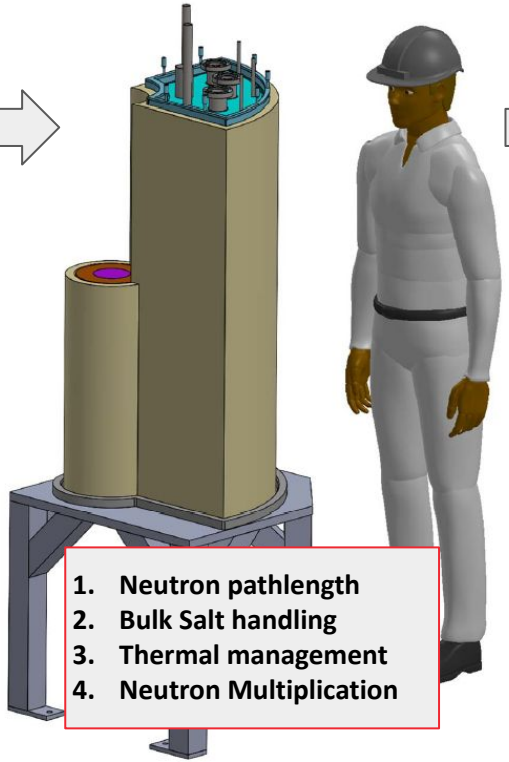
LIBRA Pi
~100 L volume



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LIBRA ONE
700 L volume

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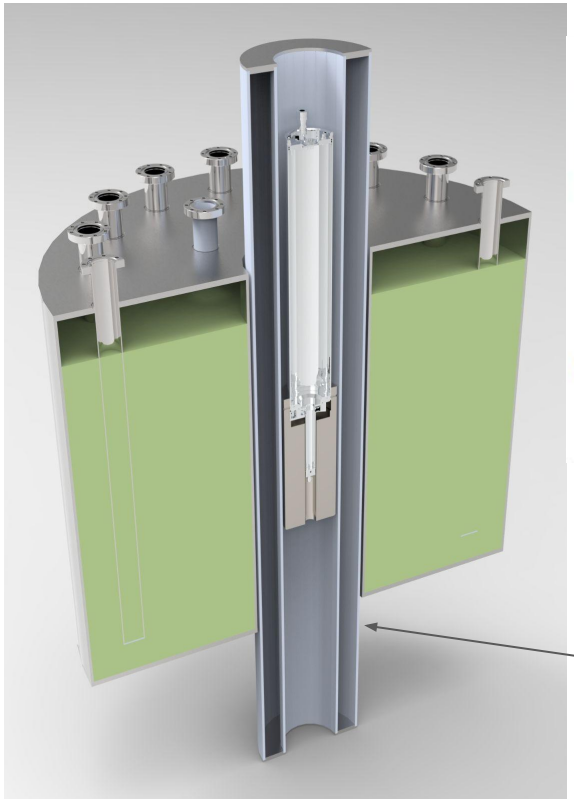
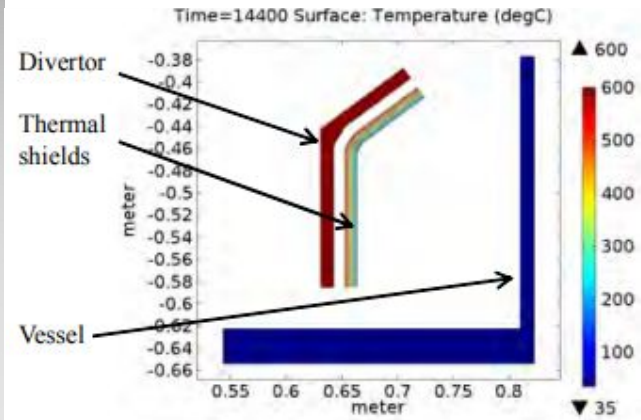
LIBRA ONE places sensitive neutron generator inside 700C environment!

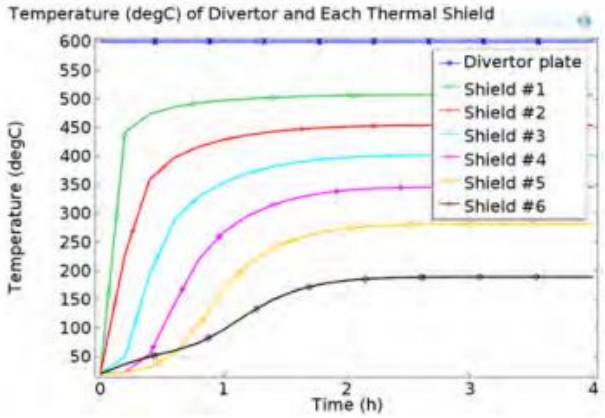


Vacuum Insulation sleeve conceived from thermal shield of Alcator Advanced Outer Divertor



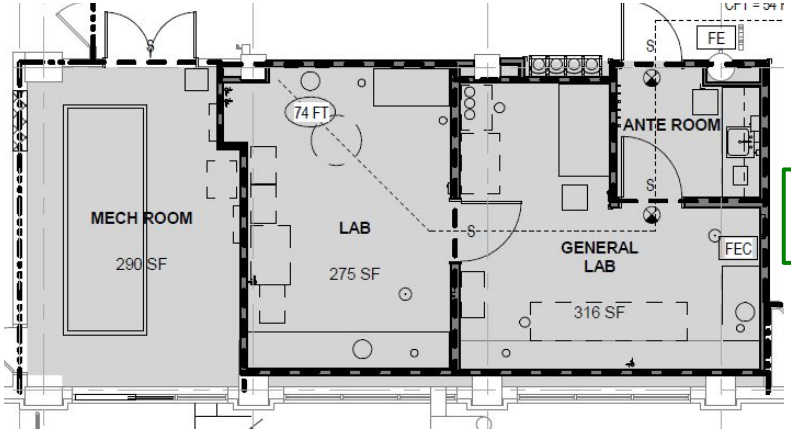
Analysis shows 700C to 38C in 5 cm thickness of vacuum thermal shielding

Considered also for exterior thermal shield



MIT Salt Lab under construction for large-scale FLiBe handling

FLiBe Lab design

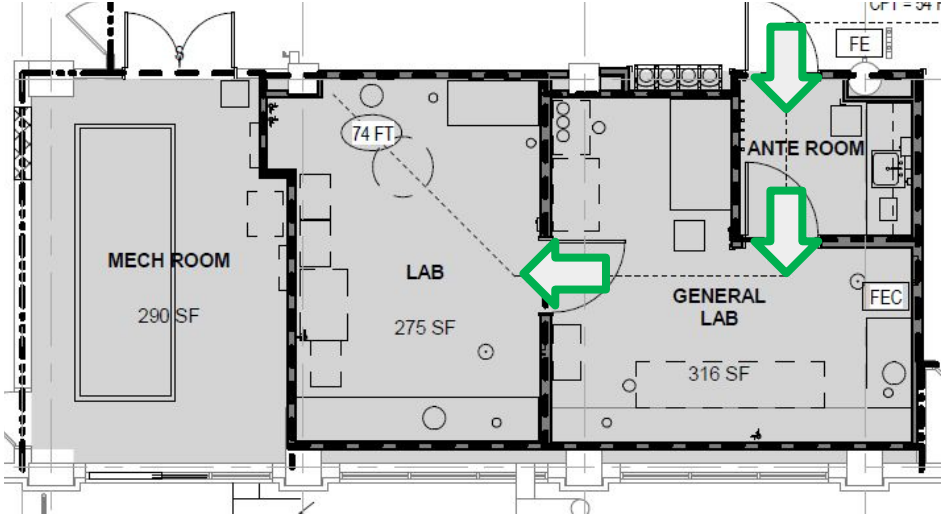


FLiBe Lab start of demolition Dec. ‘24, Completion expected August ‘25

As of May 20

MIT Salt Lab under construction for large-scale FLiBe handling

Salt Lab design



Cascaded negative pressure lab spaces from common hallway to interior lab space.

1. Anteroom 2. Air Shower 3. General Lab 4. High risk Lab

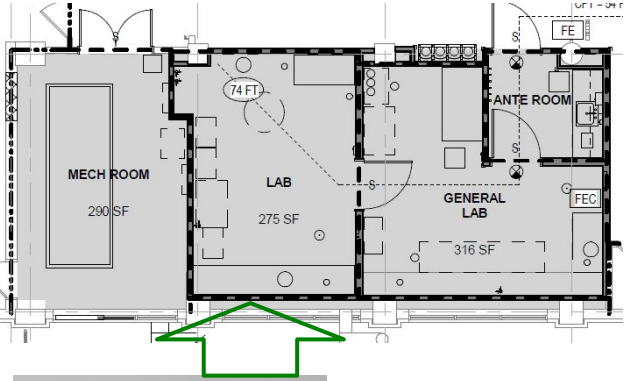
Materion provided lab design review

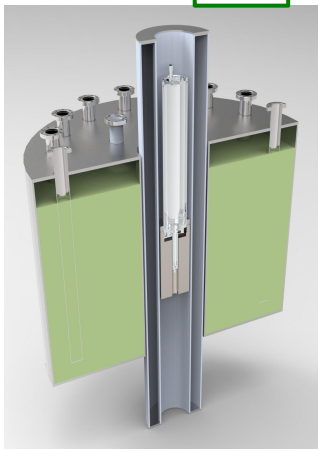
Intend to mirror the Beryllium Worker Protection for the production and handling of FLiBe, presented by Materion at BHSC 2023 Spring Meeting along with best practices learned at US Beryllium Health and Safety Committee and FLiBe subcommittee

PPE Donning/Doffing training, Beryllium Work Plan, Beryllium monitoring and Surveillance development

Beryllium Safe!

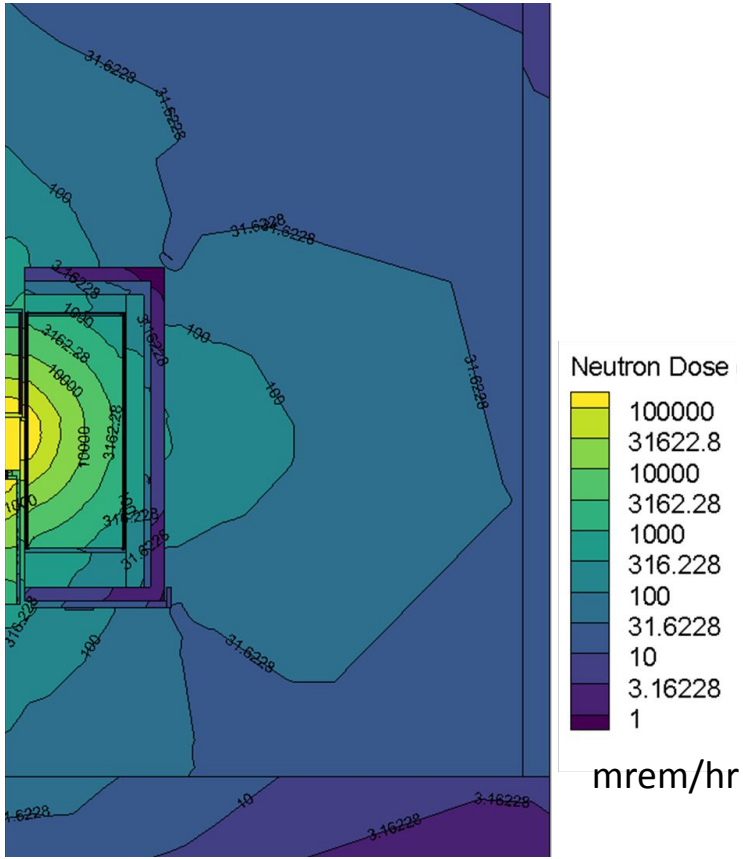
Radiation shielding considerations





Operation of 1E10 n/s, 14 MeV neutron generator within LIBRA ONE in Salt Lab requires additional shielding

- Neutron and Gamma shielding
- FLiBe offers good intrinsic shielding, but if only to TBR~1, then more shielding is required for neutron and photon releases



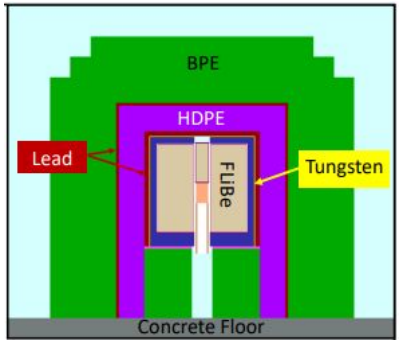
Radiation shielding considerations for LIBRA ONE in MIT FLiBe Lab

- ☐ Reduce combined neutron and photon dose to <2 mrem/hr for radiation workers
- ☐ Reduce combined neutron and photon dose to the general public to <0.1 mrem/hr
- ☐ Minimize shielding mass to <26 metric tons
- ☐ Ensure shielding is modular and can be constructed without the use of cranes

Shielding Description	Effective Dose at 175 cm [mrem/hr]	Shielding Mass [metric tons]
Inner: 5 cm lead Outer: 90 cm BPE	0.88 ± 0.02	20.9
Inner: 90 cm BPE Outer: 5 cm lead	0.65 ± 0.03	36.2
Inner P-shield: 5 cm lead **Inner N-shield: 30cm HDPE** **Middle P-shield: 2.54 cm lead** **Outer N-shield: 65 cm BPE**	**0.64 ± 0.04**	**22.8**

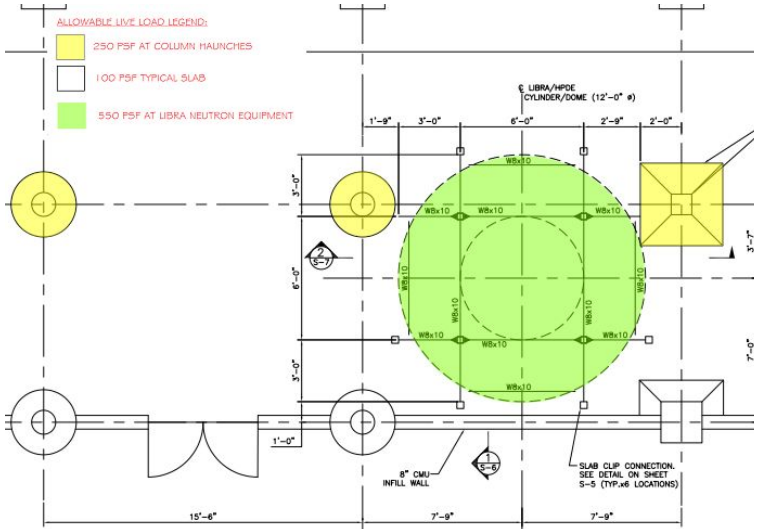
• Materials with the highest attenuations densities were simulated in OpenMC in layered cylindrical configurations around the LIBRA experiment by placing the photon shield on the inside, outside, or in various layers

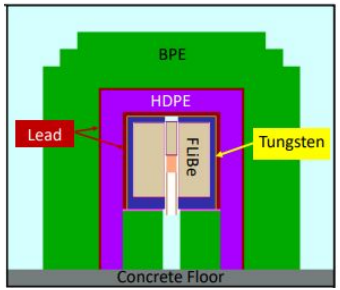
• Since the dose contours are more spherically shaped, mass reduction achieved by cutting out stepped-cylindrical regions in outer shield



Radiation Shielding Model

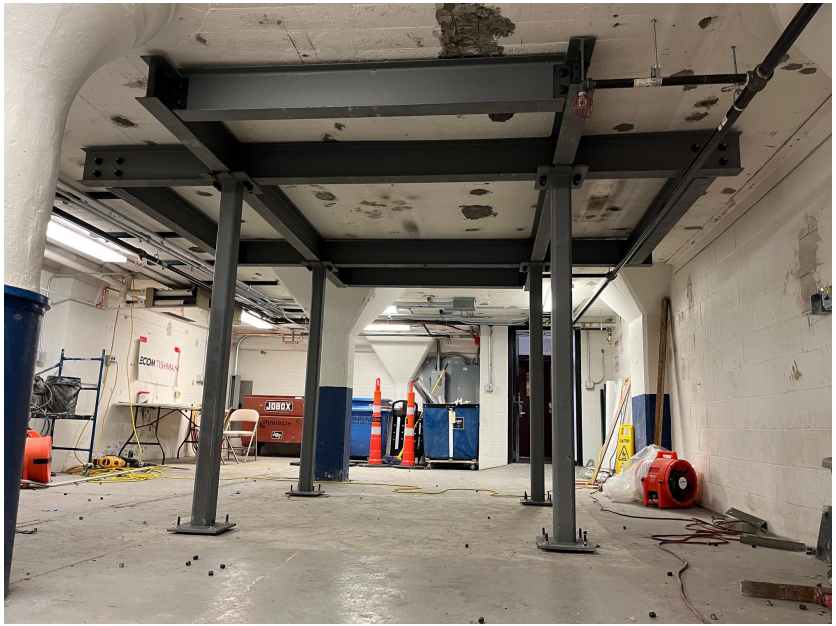
Additional shielding weighs several tons, floor reinforcement required





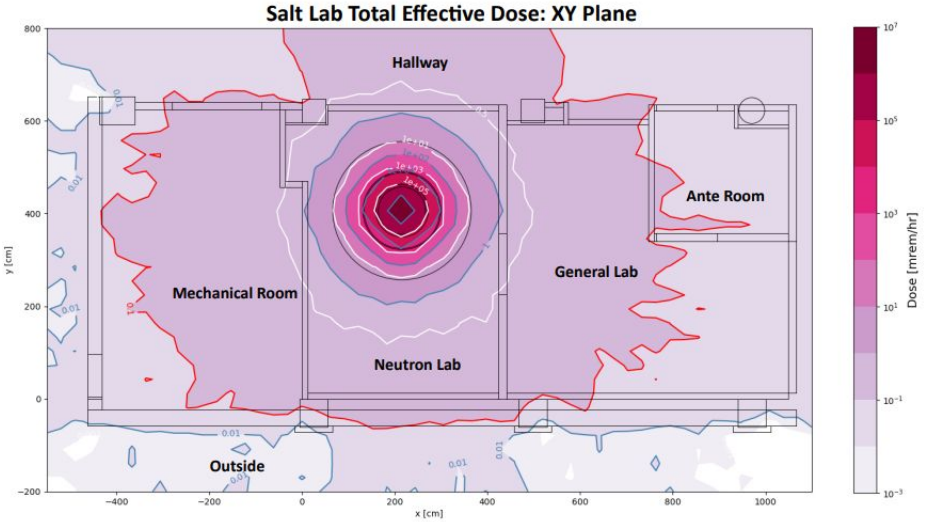
Model Radiation Shielding

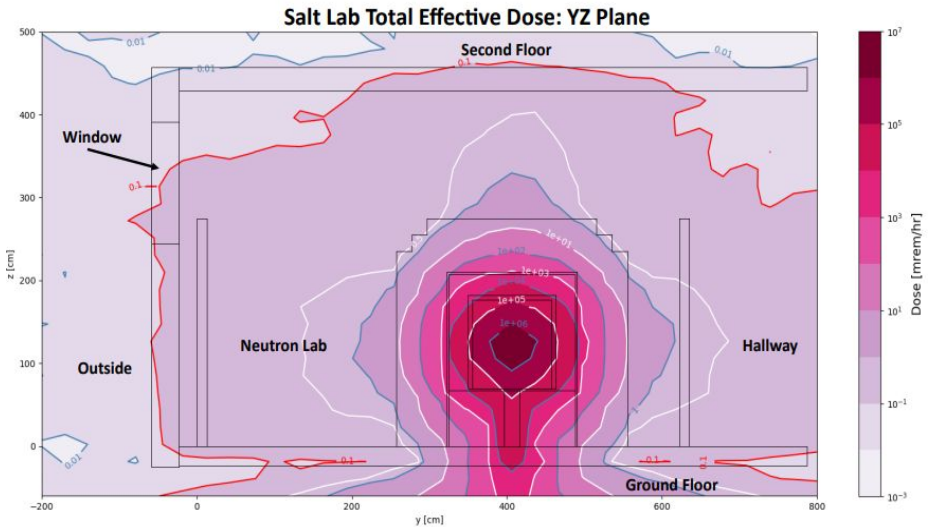
Additional 30 tons considered for shielding and LIBRA ONE experiment



Steel frame floor reinforcement below MIT Salt Lab

Contours show excess dose rates in public hallway if running at max neutron rate





By using the lead-HDPE-lead-BPE cylindrical configuration:

- ☑ Radiation worker dose limited to <0.7 mrem/hr
- ☑ Experiment mass is 24.4 metric tons
- ☑ HDPE, BPE, and lead bricks can be installed modularly
- ☐ Public dose NOT limited to <0.1 mrem/hr

- Assumed operation of 1e10 n/s.
- Actual neutron generator output is 6.5e9 n/s maximum and can be operated at lower neutron rates.
- Feasible to construct shielding adequate for operation of tritium breeding tests in the MIT FLiBe lab.

LIBRA ONE to demonstrate Tritium breeding Ratio of 1!