Tritium Safety Issues & Results for IFE Power Plants*

Jeff Latkowski & Susana Reyes
Lawrence Livermore National Laboratory

*With assistance from the GA & LANL Target Fabrication Team
and the Fusion Safety Program at INEEL

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Tritium safety is a key issue for IFE power plants

- Power plant will have significant tritium inventory:
  - HYLIFE-II report estimated 140 g in chamber walls & piping (negligible amount in flibe coolant)
  - Sombrero estimated only 10 g in C/C composite (~ 170 g elsewhere in target building) → recent work shows that irradiated carbon retains much more tritium (kg quantities likely)

- Target fabrication facility has potential for very large tritium inventory:
  - LANL & LLNL results agree quite well despite different approaches
  - 0.8-65 kg tritium in facility depending upon target design and fill and assembly methods

Tritium release assumptions

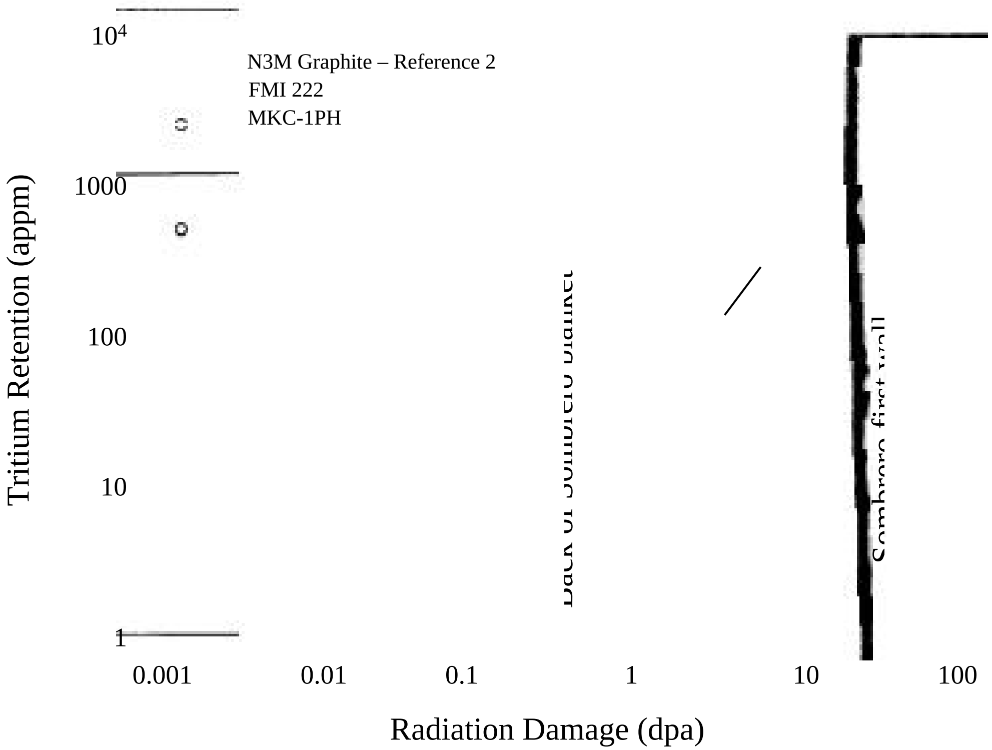
- We conservatively assume a ground-level release
- Weather conditions are important consideration:
  - In previous work, we assumed ***average weather*** along with dose conversion factor of 3.6e-5 Sv/g tritium (1 rem from 280 g T release)
  - We have converted to the accepted value of 6.7e-5 Sv/g (1 rem from 150 g T release)
  - Recent DOE emergency planning guidance makes it clear that one must use ***conservative*** weather conditions—increases the dose per gram released by 10×!
  - We now present results for ***both*** average and conservative weather conditions
- To date, we have taken no credit for filtration

Two accident scenarios were modeled for the HYLIFE-II design

- 140 g of tritium resides in chamber walls & piping
- Tritium is rapidly mobilized from SS304 tubes and walls at 675 C:
  - TMAP calculation (courtesy R. Causey) shows > 90% mobilized in first 1.5 hours
  - We assume 100% mobilization
  - Should we reduce mobilization to account for tritium outside chamber?
- Two very conservative accident scenarios analyzed:
  - Loss-of-coolant accident with loss-of-confinement (86% HTO released)
  - Loss-of-flow-accident with beamtube bypass (100% HTO released)
- 140 g T released as HTO gives significant site boundary doses:
  - 9.3 mSv (0.93 rem) for average weather conditions
  - 93 mSv (9.3 rem) for conservative weather conditions
- Future work is needed to:
  - Validate 140 g inventory calculated in original study
  - Add engineering detail to models such as a detritiation system in the confinement building → this will require mechanical engineering support to further develop building layout

The Sombrero tritium inventory is likely to be higher than originally estimated

- Original study estimated 10 g in C and 172 g elsewhere in confinement
- Work on tritium retention in irradiated graphite suggests that radiation damage and irradiation temperature are key parameters
- If we use a retention of only 100 appm to account for higher temperature, we calculate:
  - 100 appm T = 25 wppm T in C
  - 600 tonnes C → 15 kg T
- Recent, unpublished work by Wittenberg calculates lower value:
  - Takes credit for addition of steam in He carrier gas (converts HT to HTO and reduces retention)
  - Total tritium inventory estimated at 2.16 kg



A loss-of-vacuum accident has been modeled for the Sombrero design

- LLNL and INEEL calculations both show that Sombrero’s first wall/blanket will burn in a loss-of-vacuum event
- We assume that tritium is mobilized as HTO if C/C composite is burned
- MELCOR calculations show 19% HTO release fraction
- Assuming 1 kg inventory →190 g T (as HTO) is released:
  - 12.7 mSv (1.27 rem) per kg inventory under average weather
  - 127 mSv (12.7 rem) per kg inventory under conservative weather
- Future work is needed to:
  - Accurately determine the C/C composite tritium inventory
  - Add engineering detail to models:
    - Detritiation system in the confinement building
    - Active valves and/or shutters on beamports
  - Consider systems to prevent C/C composite combustion (e.g., inert gas fire suppression system)

Tritium safety will be important issue for an IFE target fabrication facility

- When operating at 5-10 Hz, an IFE power plant has a daily throughput of ~ 1 kg of tritium

- A target fabrication facility ***must***:
  - Fabricate ~ 500,000 targets per day
  - Safely contain relatively large quantities of tritium the site boundary dose must be less than 10 mSv (1 rem)

- A target fabrication facility ***may need to***:
  - Work with and safely contain activated, high-Z target materials
  - Store a reasonable surplus of (nearly completed) targets to allow the power plant to be started in a timely fashion

- We have examined radiological safety issues for a simple IFE target fabrication facility

We have assumed diffusion fill of targets

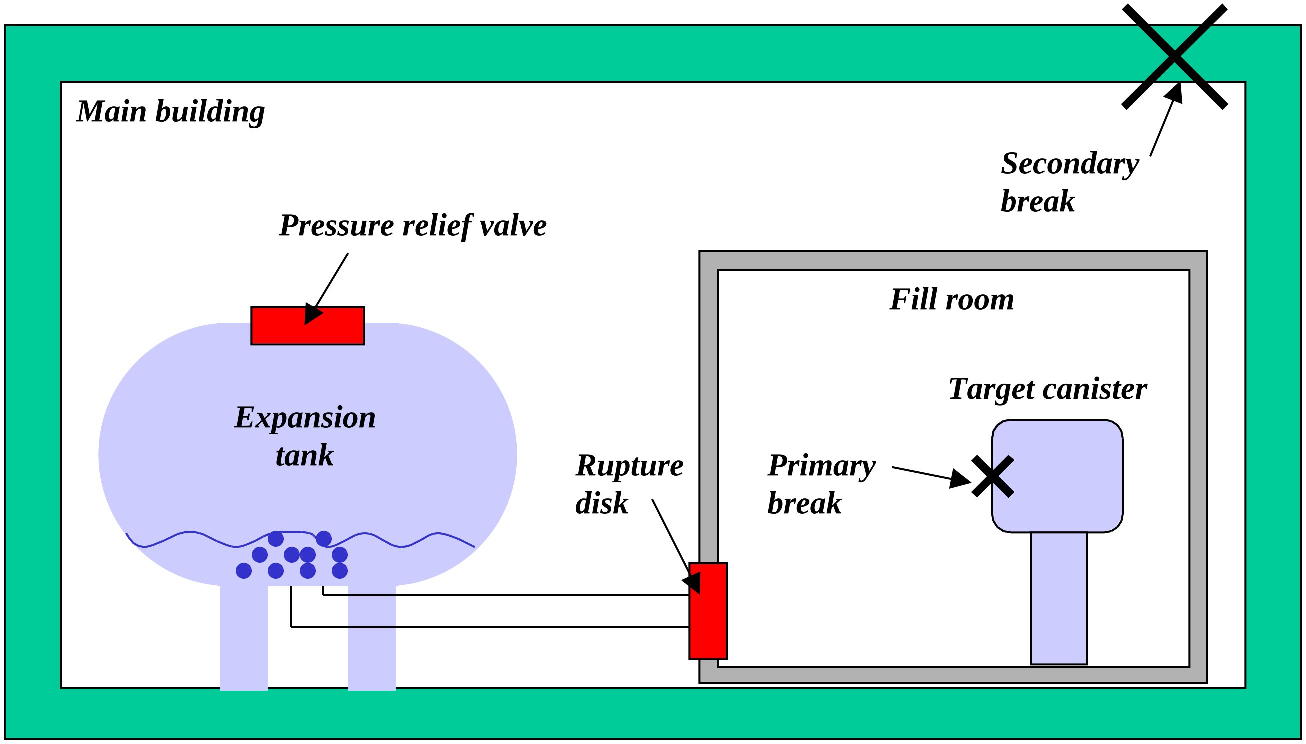
- Indirect-drive fill times:
  - 24 hours at room temperature; peak pressure is 68 MPa
  - 11 hours at 400 K; peak pressure is 84 MPa
- Direct-drive fill times are longer due to thinner shells, which support lower pressure differentials:
  - 580 hours at 300 K; peak pressure is 128 MPa
  - 285 hours at 400 K; peak pressure is 161 MPa
- Other activities (pump out, cool down, etc.) are assumed to require 6 hours
- Fill times courtesy Neil Alexander, General Atomics

Tritium inventories for the various target designs and fill assumptions

Case	Capsule fill time (hours)	Total plant inventory (kg)
Indirect-drive: Full-size or close-coupled target/400 K fill/***cold assembly***	11	0.8
Indirect-drive: Full-size target/300 K fill/***warm assembly***	24	25.7
Indirect-drive: Close-coupled target/300 K fill/***warm assembly***	24	11.3
Direct-drive: Plastic target/400 K fill (300 K fill)	285 (580)	12.7 (25.7)
Direct-drive: ***CH-foam target***/400 K fill (300 K fill)	285 (580)	32.2 (65.1)

Tritium (as HTO) releases have been modeled with MELCOR

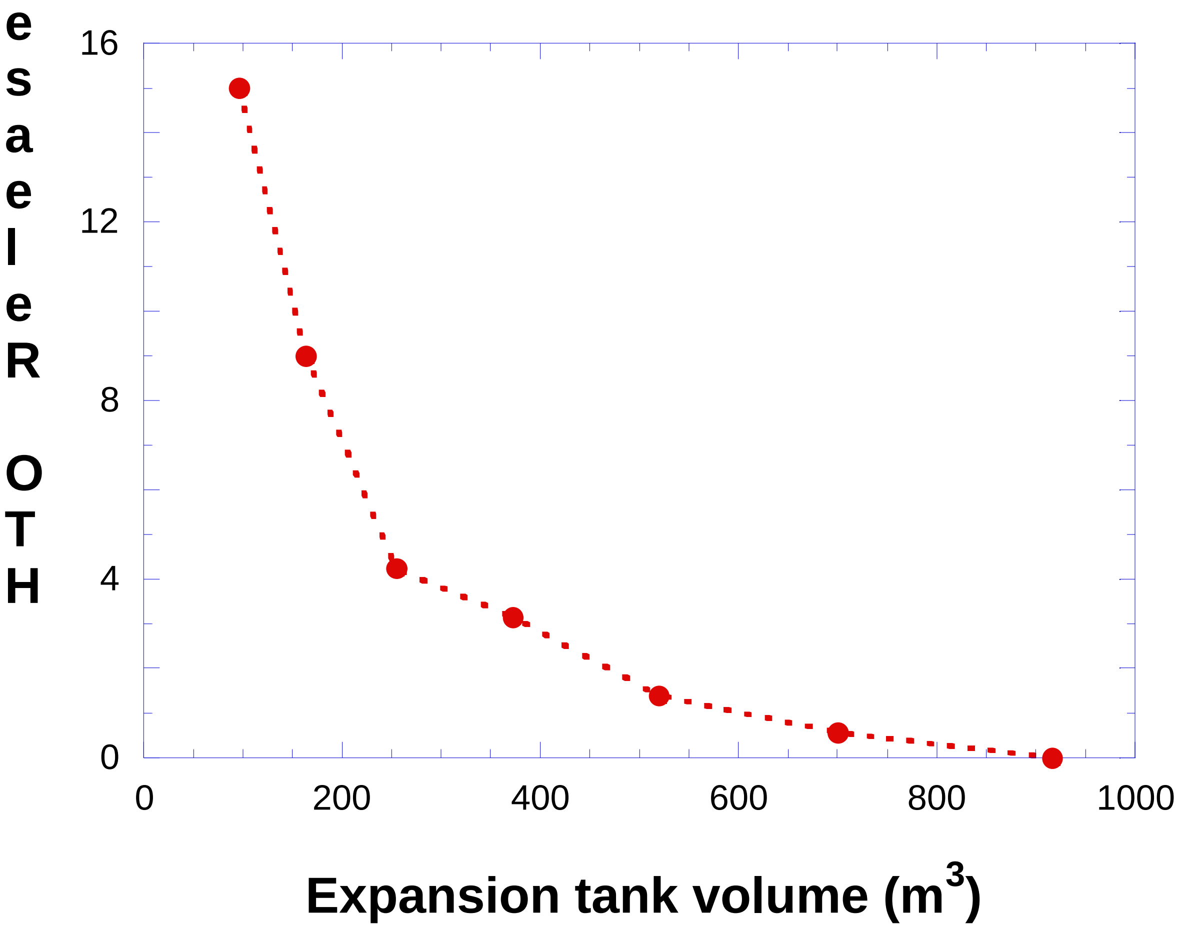
- We have modeled the failure of a single canister:
  - Break area of 1 cm^2 assumed
  - Fill room pressurizes and rupture disk breaks at $\Delta p = 10$ kPa
  - Tritium flows into expansion tank; pressure relief valve opens at $\Delta p = 10$ kPa
  - Tritium fills main building and has opportunity to leak via 1 m^2 break in wall



Modeling assumptions

- Expansion tank volume is taken as a variable:
  - Modeled as 5-m-long cylinder with hemispherical ends
  - As radius increases from 2.0 m to 3.5 m, volume increases from 96 to 372 m^3
- Release fractions depend strongly upon size of expansion tank:
  - 15% release fraction for full-size target & warm assembly (largest canister) at 400 K / 84 MPa
  - Smallest expansion tank gives release of 0.77 kg and site boundary dose of:
    - 51 mSv (5.1 rem) for average weather conditions
    - 510 mSv (51 rem) for conservative weather conditions
  - Increasing expansion tank volume to 700 m^3 reduces release to 0.6%
    - 2.0 mSv (0.2 rem) for average weather conditions
    - 20 mSv (2.0 rem) for conservative weather conditions

Tritium results



Target fabrication facility conclusions and future work

- The ***target fill time*** is crucial in determining the tritium inventory:
  - New materials that have a higher diffusivity at their maximum temperatures and pressure differentials
  - New methods for filling targets (e.g., injection)
- ***Cold assembly*** would provide a large (13-30×) reduction in tritium inventory for the indirect-drive designs
- Targets with a ***higher burn-up fraction*** result in a target fabrication facility with a lower tritium inventory
- The ***expansion tank*** is a valuable tool in limiting releases during an accident:
  - Future work should focus on its optimization
  - Design allowing failure of a single canister with no release and can accommodate two or more simultaneous failures is desirable

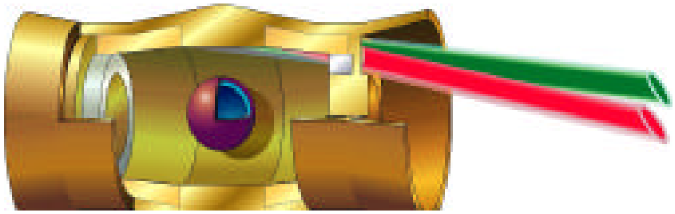
Overall conclusions and future work

- Tritium inventory estimates are still quite uncertain, these need to be improved upon:
  - For Sombrero, have heard range of 10 g to 15 kg in C/C composite
    - Need to verify feasibility of steam in He carrier gas
    - Need to check oxidation rates and consider oxidation prevention mechanisms
  - For target fabrication facility, inventory has large spread
    - Can reduce vulnerable inventory via segregation but increases facility size/cost
    - Big incentive for cold assembly!
    - Expansion tank needs to be optimized
- The switch from average to conservative weather bumps the IFE systems up over the 1 rem no-evacuation plan limit:
  - We can counter this by adding engineering detail to our analyses
  - Will require some ME support as many details were not produced in HYLIFE-II and Sombrero studies

Multiple target designs have been considered

- For indirect-drive targets, we consider the heavy-ion-driven, distributed radiator designs[1]:

Parameter	**Full-size**	**Close-coupled**
Driver energy	5.9 MJ	3.3 MJ
Gain	68	133
Yield	401 MJ	439 MJ
Repetition rate	5-6 Hz	5-6 Hz
Target tritium inventory	2.4 mg	2.4 mg
Hohlraum volume	1.6 cc	0.7 cc



Full-size target

Close-coupled target

[1] D. A. Callahan-Miller and M. Tabak, "A Distributed Radiator, Heavy Ion Target Driven by Gaussian Beams in a Multibeam Illumination Geometry," *Nucl. Fusion* **39** (Jul. 1999) 883 and D. A. Callahan-Miller and M. Tabak, "Increasing the Coupling Efficiency in a Heavy Ion Inertial Confinement Fusion Target," *Nucl. Fusion* **39** (Nov. 1999) 1547.

Multiple target designs, (Cont'd.)

- Two direct-drive designs have been considered:
  - Sombrero[1] target–plastic shell ablator with solid DT fuel layer:
    - 2.4 mg tritium per target
    - Driver energy = ; Gain = ; Yield = 400 MJ
    - Repetition rate of ~ 6.7 Hz
  - CH-foam ablator target filled with frozen DT[2]
    - 2.5 mg tritium per target
    - Driver energy = 1.3 MJ KrF; Gain = 125; Yield = 163 MJ
    - Low burn-up fraction of 11%
    - Requires tritium throughput of ~ 3.5 kg/day and repetition rate of ~ 14 Hz for 1000 MW_e power plant (1.2e6 targets/day)
    - Ongoing work concentrating on design with ~ 400 MJ yield and 5-6 Hz

[1] W. R. Meier et al., Osiris and SOMBRERO Inertial Confinement Fusion Power Plant Designs, W. J. Schafer Associates, Inc., DOE/ER/54100-1, WJSA-92-01, March 1992.

[2] Bodner, S. E. et al., "High-Gain Direct-Drive Target Design for Laser Fusion," *Phys. Plasmas* **7** (Jun. 2000) 2298.