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Fabrication and neutron irradiation of Li_7Pb_2 and Li-6 enriched Pb15.7%Li specimens

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34th SOFT 2026

34th SYMPOSIUM ON FUSION TECHNOLOGY

SEPT. 21-25, 2026 AIX-EN-PROVENCE, FRANCE

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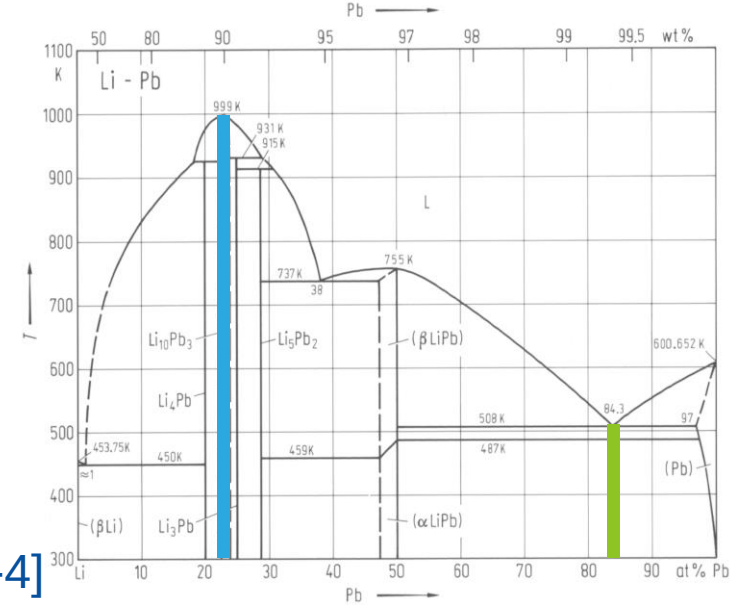
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This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Isotope R&D and Production

Considerations for LiPb alloys: Li_7Pb_2 and PbLi

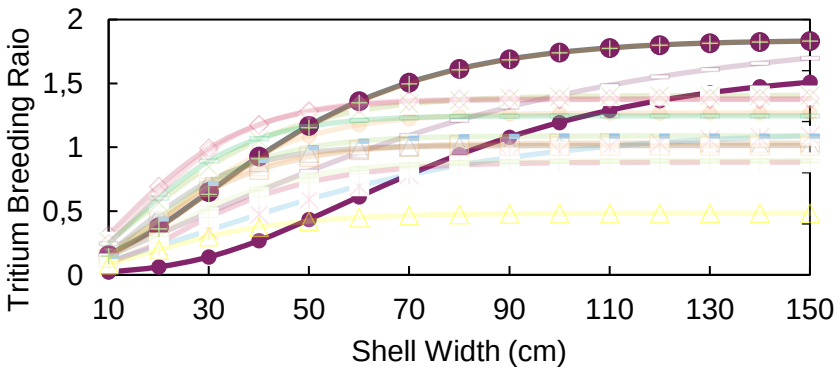
Li_7Pb_2: solid breeder

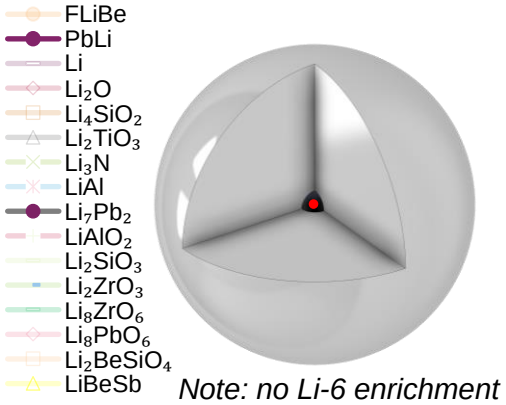
- Dystectic composition: 77.8 at%, 10.5 wt%
- Relatively low T_{melt}: 726°C
- Very productive tritium breeder.
- May not require enrichment or multiplier.
- Was irradiated in 1970-1980's. [1-4]



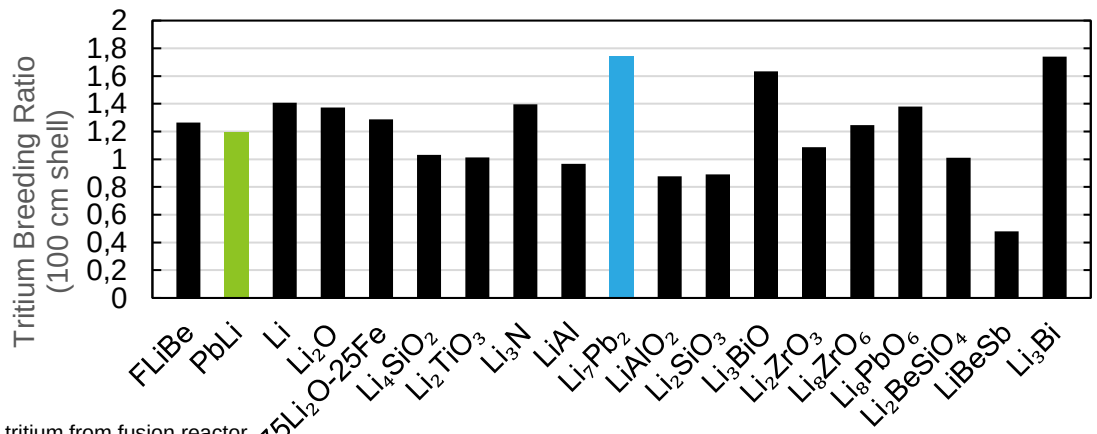
PbLi: liquid breeder

- Eutectic composition: 15.7 at%, 0.620 wt%
- Low T_{melt}: 235°C
- One of three potential liquid breeders.
- Extensively studied for decades.





Note: no Li-6 enrichment



1. Clemmer, R. G. *et al.* Tritium production and distribution in a zircaloy-clad Li7Pb2 assembly irradiated in the oak ridge research reactor. *J Nucl Mater* 118, 275–285 (1983).
2. Okuno, K., Nagame, Y. & Kudo, H. Thermal release of tritium from neutron-irradiated Li7Pb2. J Less Common Metals 119, 211–217 (1986).
3. Wiswall, R. & Wirsing, E. The removal of tritium from fusion reactor blankets. Brookhaven National Laboratory BNL 50748, (1977).
4. Yang, L., Medico, R., Baugh, W. & Schultz, K. Irradiation study of lithium compound samples for tritium breeding application. J Nucl Mater 103, 585–589 (1981).

Tritium breeder irradiation experiments

Performance of solid breeder materials under neutron irradiation

1. Inconsistent results in legacy studies.
2. New and novel solid breeder materials.
3. No current programs or capabilities in the US:
   - Irradiate solid breeder materials.
   - Evaluate tritium release characteristics.

1. Li_2O
2. Li_2O 50%Fe
3. Li_8ZrO_6
4. Li_8CeO_6
5. Li_2TiO_3
6. Li_2ZrO_3
7. Li_2ZrO_3**
8. Li_2BeSiO_4
9. Li_7Pb_2*
10. Li_2TiO_3
11. Li_2TiO_3
12. Li_4SiO_4
13. Li_8SnO_6
14. $Li_80.5Sn0.5ZrO_6$
15. Li_8PbO_6**

- New and novel solid breeder materials: **traditional** **novel**

Irradiation experiments to measure tritium production from Li-6 enriched PbLi

1. Irradiation testing of enriched breeder materials has been limited.
2. Validate and refine neutronic libraries.

- Experiment variable: Li-6 enrichment in PbLi eutectic
  - Natural
  - ^6Li: 25%
  - ^6Li: 50%
  - ^6Li: 75%
  - ^6Li: 95.5%



Goal	Breeding Blanket	This Irradiation
Tritium production	Achieve a given TBR	Breed a measurable quantity of tritium
Temperature	Irradiate hot to release T	<100°C to limit T release
Geometry	Molten metal/solid pebbles	Solid cylinder (12.7 mm dia x 12.7 mm)
Neutron energy	<14.1 MeV	Thermal

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Isotope R&D and Production

Fabrication of Li-6 enriched PbLi eutectic



Material Partitioning

- Li-6 (95.5% enriched)
- Li-7 (99.99% enriched)
- Pb (99.999% purity)
- Inert atmosphere glovebox setup (ISO-9001)



Material Preparation

- Cleaning of Li-6/Li-7
- Repeat rinses in anhydrous methanol under an Ar cover gas.
- Removal of lead oxide
- Granulated lead melted and cast into ingots to remove lead oxide slag layer.



Alloying

- Minimizing lithium evaporation.
- Mitigation of density differences between Pb/Li.
- Contact-free mixing.



Casting

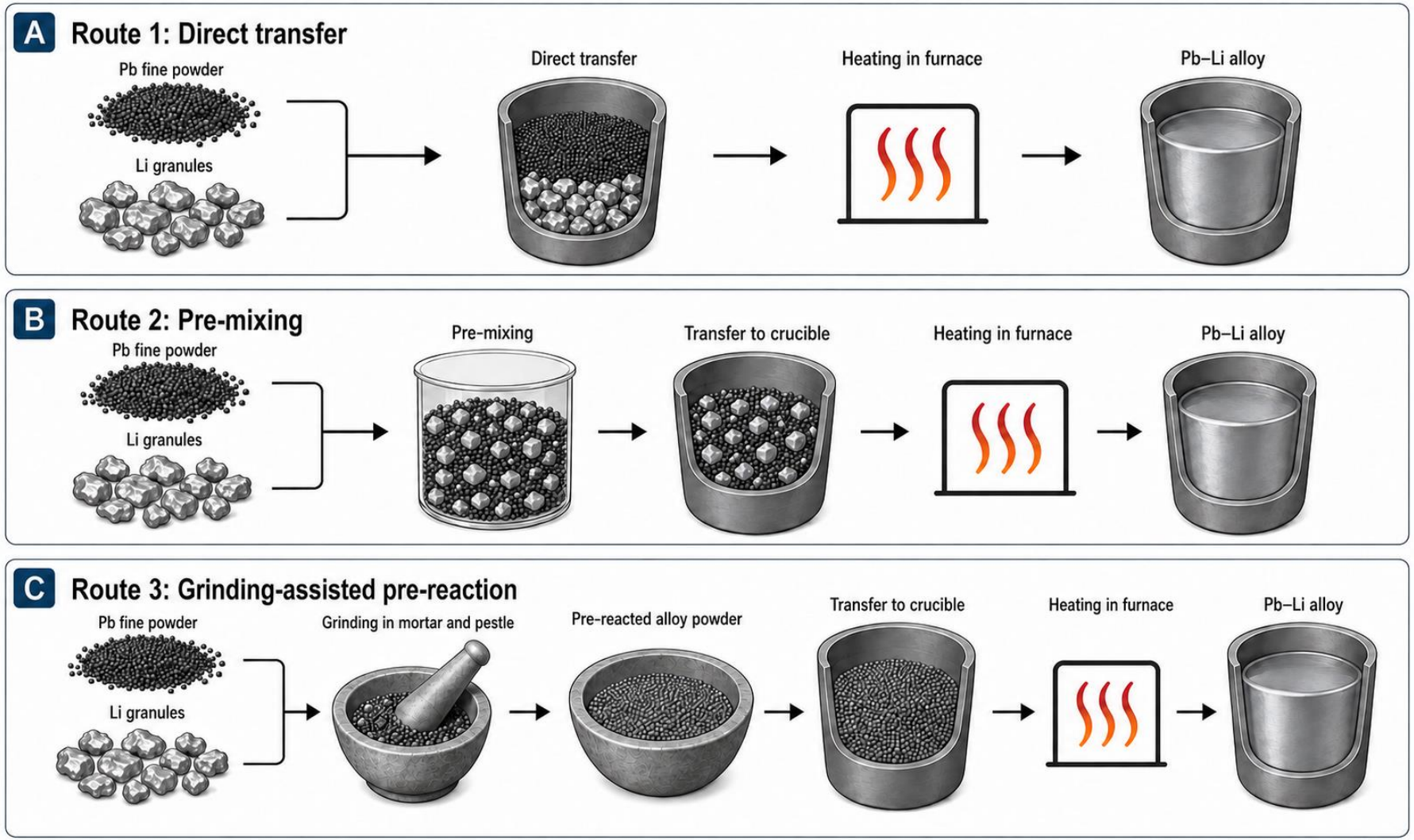
- Minimizing lithium evaporation.
- Mitigation of density differences between Pb/Li.
- Contact-free mixing
- Graphite crucibles and ingot molds baked out at 500°C to evaporate absorbed moisture.



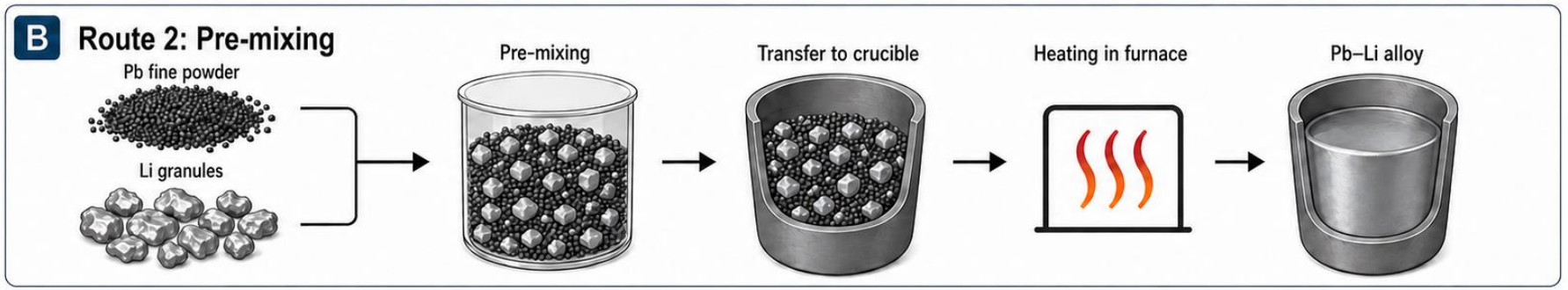
Pellet Production

- Die-set preparation.
- Physical pellet pressing.
- Product quantification and analysis.

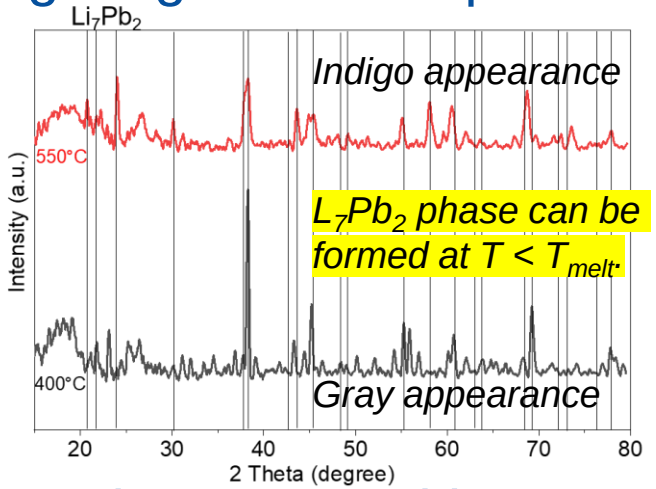
Fabrication of Li_7Pb_2



Fabrication of Li_7Pb_2



- After alloying multiple batches at 700°C for complete reaction
  - Ingots removed from boron nitride crucibles.
  - Ingots ground into powder.



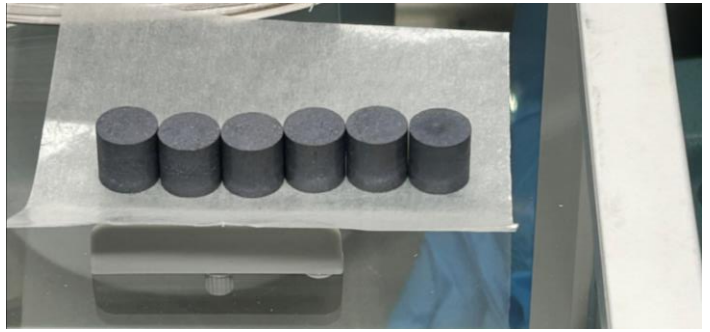
  - Powders pressed into pellets.



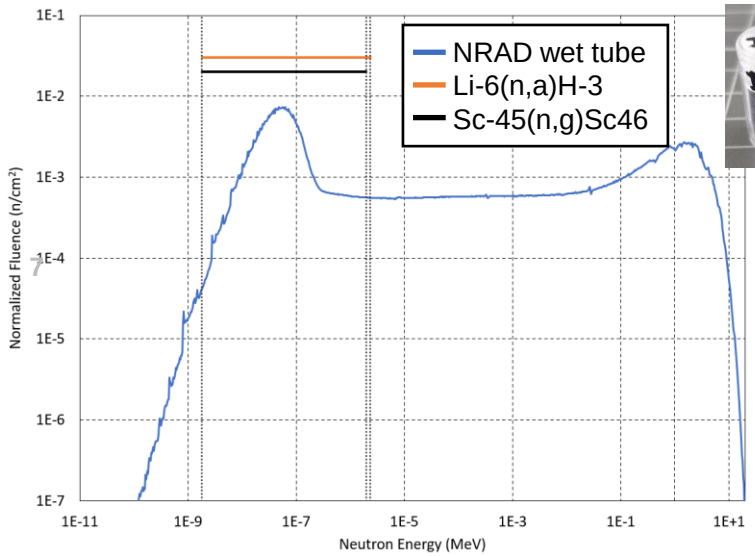
Dark indigo color of Li_7Pb_2

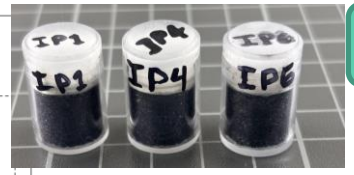




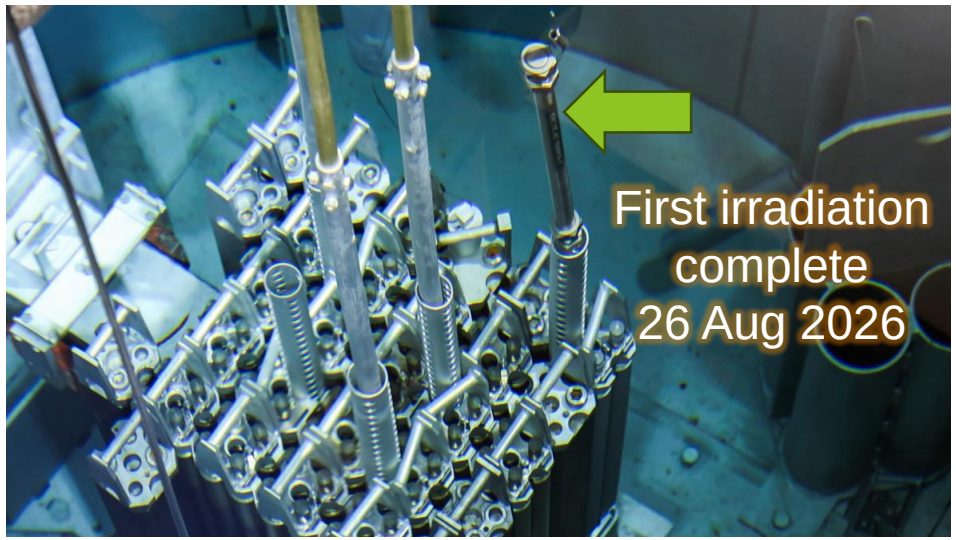


Neutron fluence and energy passive monitors

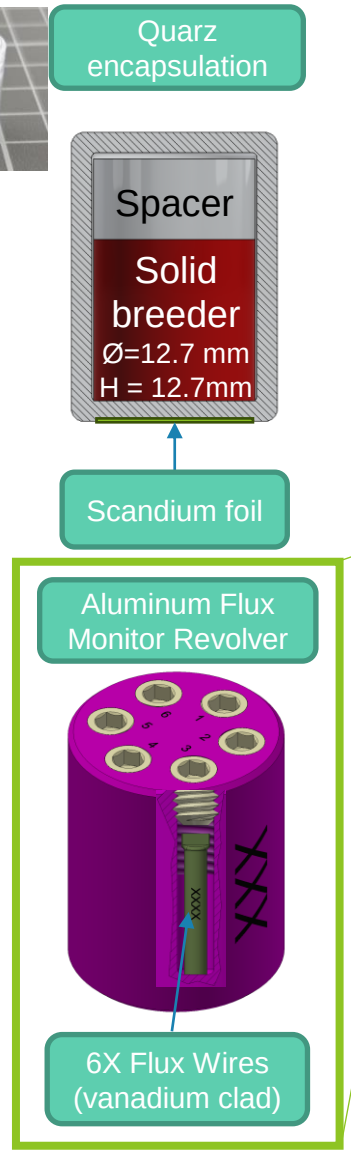


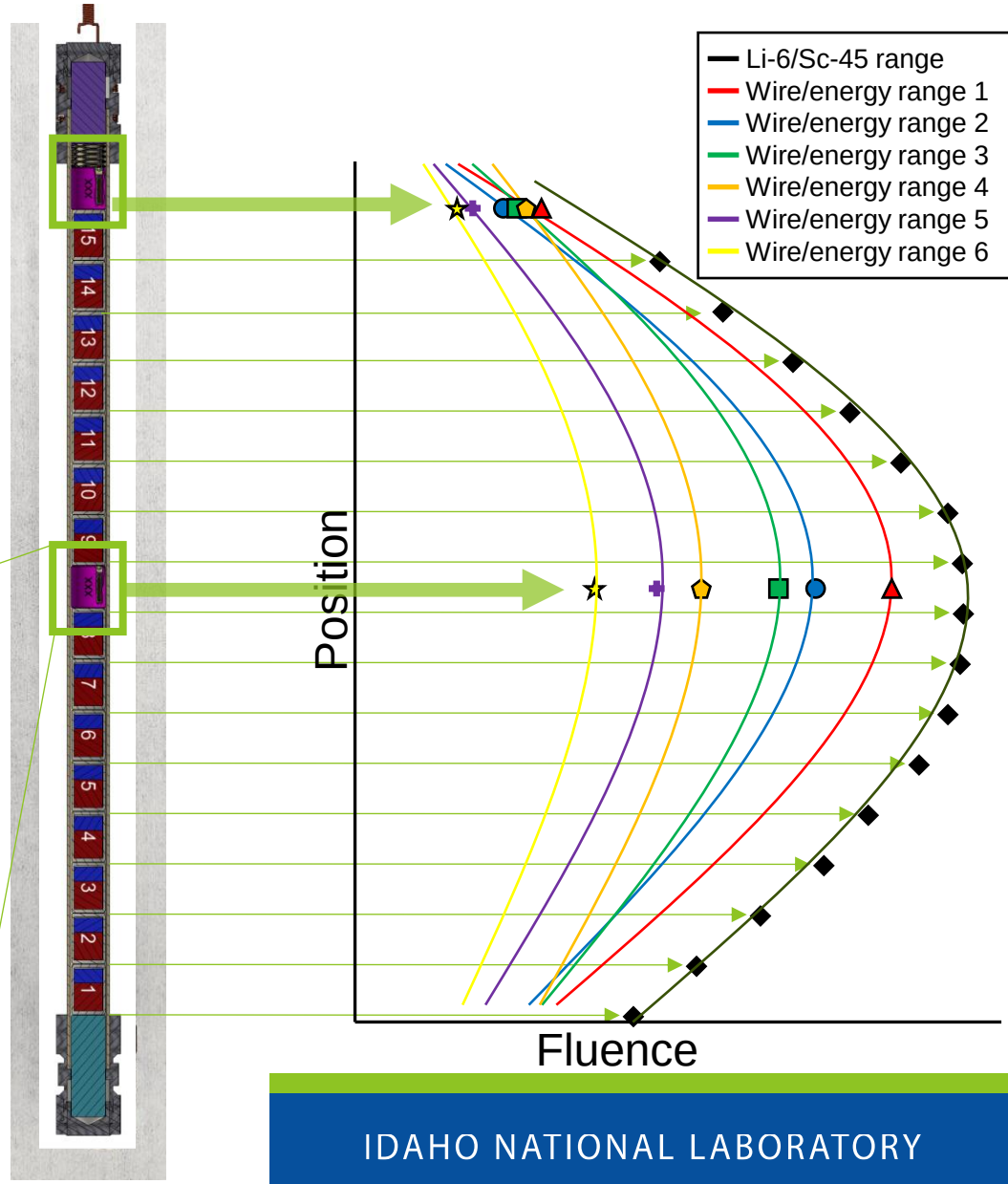


Encapsulated Li_7Pb_2



Thermal neutron flux (250 kW) = $5x10^{12}$ n/cm²sec





Post irradiation examination: quantifying tritium

Li_7Pb_2: solid breeder (70-366 MBq/sample)

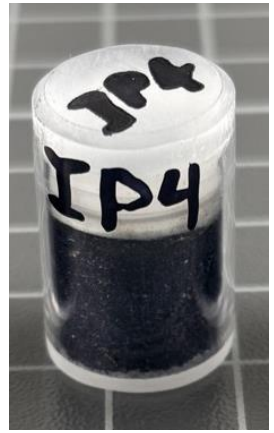
- Primary objective: Quantify tritium release behavior
  - Measured through thermal desorption spectroscopy (TDS).
- Total bred tritium quantification:

1. Gaseous tritium in capsule.
2. Tritium desorbed during TDS.
3. Retained tritium not thermally desorbed.

PbLi eutectic (63-106 MBq/sample)

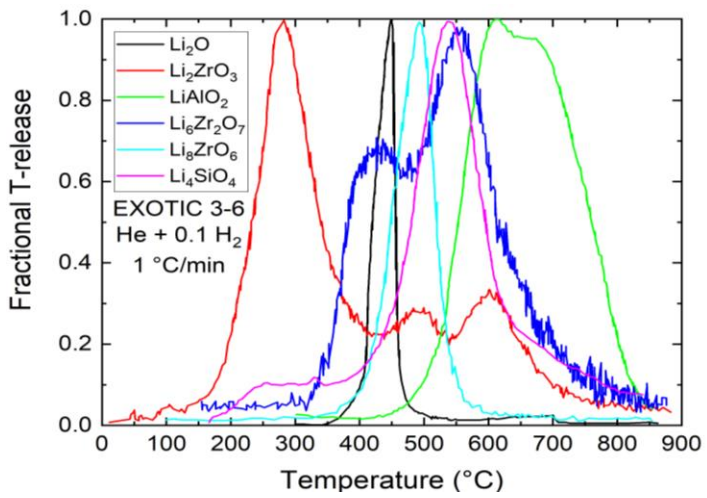
- Primary objective: Quantify tritium production and ^{6}Li burnup.

All irradiations complete November 2026









Example TDS data from the EXOTIC campaign

- Chemical dissolution
- Tritium distillation
- Liquid scintillation counting

4. Lithium chemistry & isotopic quantification

- Inductively coupled plasma
  - Multicollector (MC-ICP-MS)
  - Optical emission spectroscopy (ICP-OES)

Kwast, H., Stijkel, M., Muis, R. & Comrad, R. EXOTIC: Development of ceramic tritium breeding materials for fusion reactor blankets. (1995).

Irradiation experiments for Blanket Nuclear Testing

- Fusion Energy Sciences FIRE Collaborative: Accelerating Fusion Blanket Development through Nuclear Testing (BNT)
  - Task 1: ATR irradiation of thermal convection breeder loop
    Blanket function: 1) Power harnessing, 2) tritium breeding
  - Task 2: HFIR irradiation of solid breeder
    Blanket function: 2) Tritium breeding
  - Task 3: MITR irradiation of high temperature superconducting magnet materials
    Blanket function: 3) Shielding
  - Task 4: Expanding tritium extraction technologies
    Blanket function: 2) Tritium breeding
  - Task 5: Designing a fission-based nuclear blanket component test facility
    Blanket function: 1) Tritium breeding, 2) Power Harnessing, 3) Shielding
- INL LDRD: Performance of Solid Breeder Materials under Neutron Irradiation
  - Irradiate solid breeder materials to produce a measurable quantity of tritium.
  - Characterize tritium release properties using thermal desorption spectroscopy.
- INFUSE (Kyoto Fusioneering + INL): Isotopic characterization of lithium-6 enriched lithium samples under thermal neutron irradiation
  - Irradiate Li-6 enriched PbLi samples and measure $^{6}Li/^{7}Li$ ratio and tritium production.



What can we accomplish today using current capabilities?

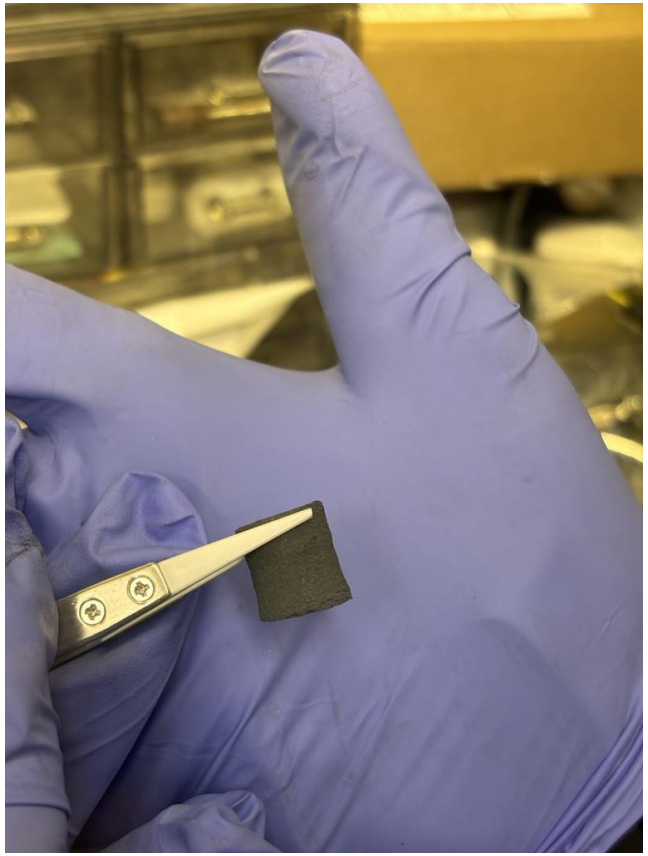


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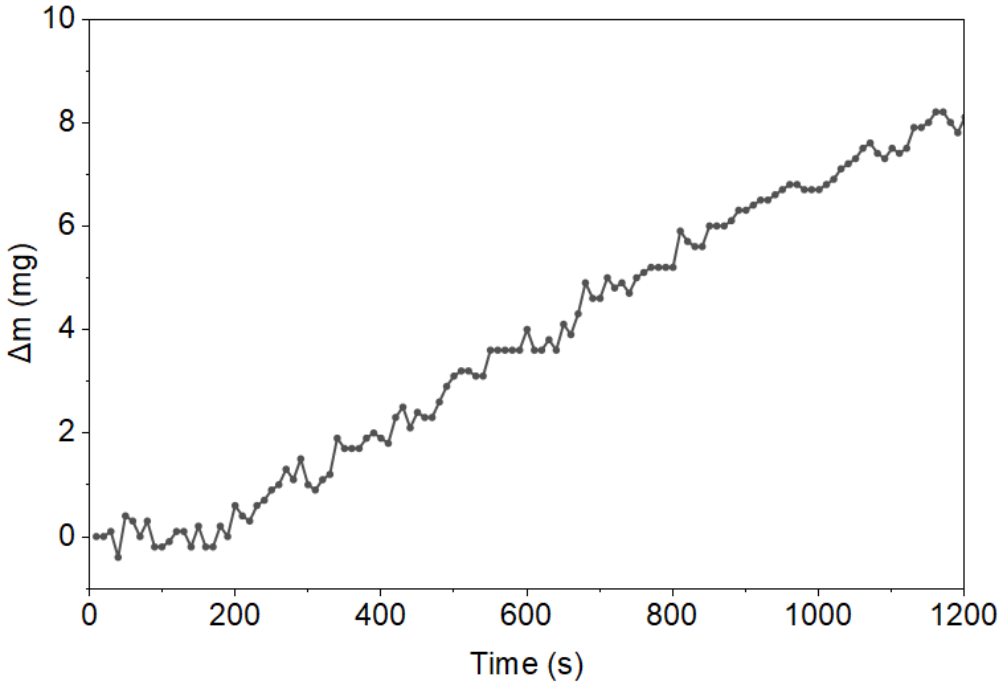
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Lessons learned

- Li_7Pb_2 is highly sensitive to air



Swelling due oxygen absorption



Mass change due to air exposure

Pellet Pressing & Product Quantification

- A 0.5000” diameter steel die-set is prepared with a layer of steric acid and pressed using a hydraulic press prior to adding Pb-Li
  - Pre-pressing inhibits galling and allows for easy pellet extrusion

- 16.6575 +/-2mg of Pb-Li is added to the prepared die and hydraulically pressed with ~700MPa of pressure

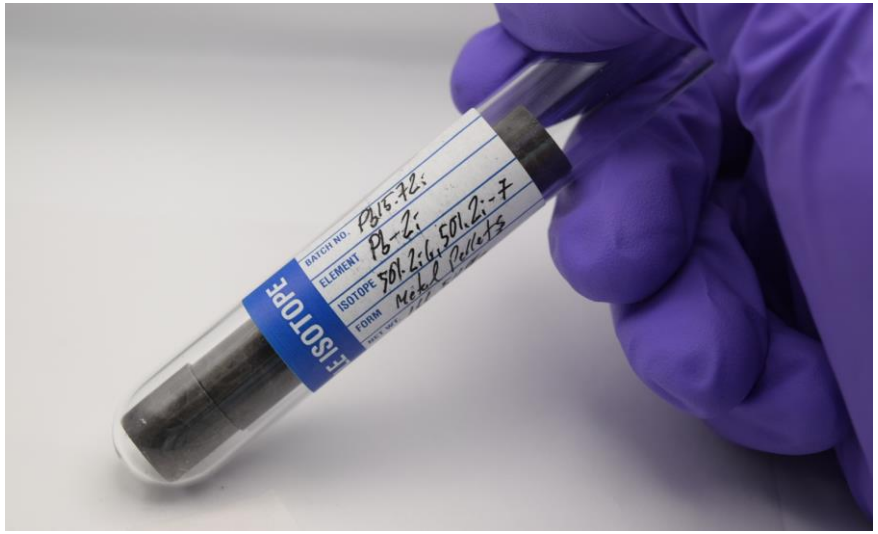


Fig 3.0 Pb15.7Li pellets vacuum sealed in Pyrex tubes

Table 1.0 Pellet property quantification

Alloy Batch	ICP-MS Li-6 Enrichment (%)	ICP-OES Li Composition (at%)	Average Theoretical Density (%)
7.5%	*pending	*pending	101.2
25%	*pending	*pending	101.5
50%	*pending	*pending	101.6
75%	*pending	*pending	101.5
95%	*pending	*pending	101.5

- Flashing around the top and bottom surfaces is removed and pellet mass, height, and diameters taken
  - Theoretical density of greater than 100% due to conservative removal of flashing

- Alloy composition and lithium enrichment determined via ICP-OES/MS