237D Fusion Technology
Introduction to Solid Breeder

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Key Concepts

1. Use of a lithiated ceramic must have:
   - high melting temperature
   - desirable neutronics and irradiation characteristics (no bad transmutation nuclides)
   - chemical stability & compatibility with structural material
   - sufficiently high T release rates
   - high Li density
   - open porosity for purging T
2. Always separately cooled with (with *e.g.* helium or water)
3. Necessity of neutron multiplication
4. Surrounded by a structure of reduced-activation ferritic steel

Disadvantages of lithium

- It is chemically active meaning safety is an issue. As an example, here are two reactions with oxygen along with their heats of formation

  $$2\mathrm{Li} + \frac{1}{2}\mathrm{O} \rightarrow \mathrm{Li_2O} - 142.75 \text{ kCal/mol}$$
  $$2\mathrm{Li} + \mathrm{O} \rightarrow \mathrm{Li_2O_2} - 151.9 \text{ kCal/mol}$$

  note: a negative heat of formation means an exothermic reaction. Lithium will exothermically react with water (or air, concrete, or any moisture-containing materials) with high amounts of energy released. Of primary concern in lithium fires is the peak flame temperature. This will determine, to a large extent, whether many radioactive species become air-borne by vaporization. The flame temperature depends on many variables. Some investigations found it to be about 2500 K which would cause some materials to melt but not vaporize.

- MHD effects – liquid metals have high electrical conductivity. In a magnetic field this leads to a $\vec{J} \times \vec{B}$ force. This in turn leads to pressure drops in the magnetic fluid. To overcome the pressure drop requires increased pressurization and pumping power. The increase in pressurization leads to an increase in stresses of the containing structures and pumping power means more leeching of power from the reactor power plant.

- Liquid metals tend to be corrosive. Corrosion products transport from radioactive structural materials and are carried downstream into sensitive regions.

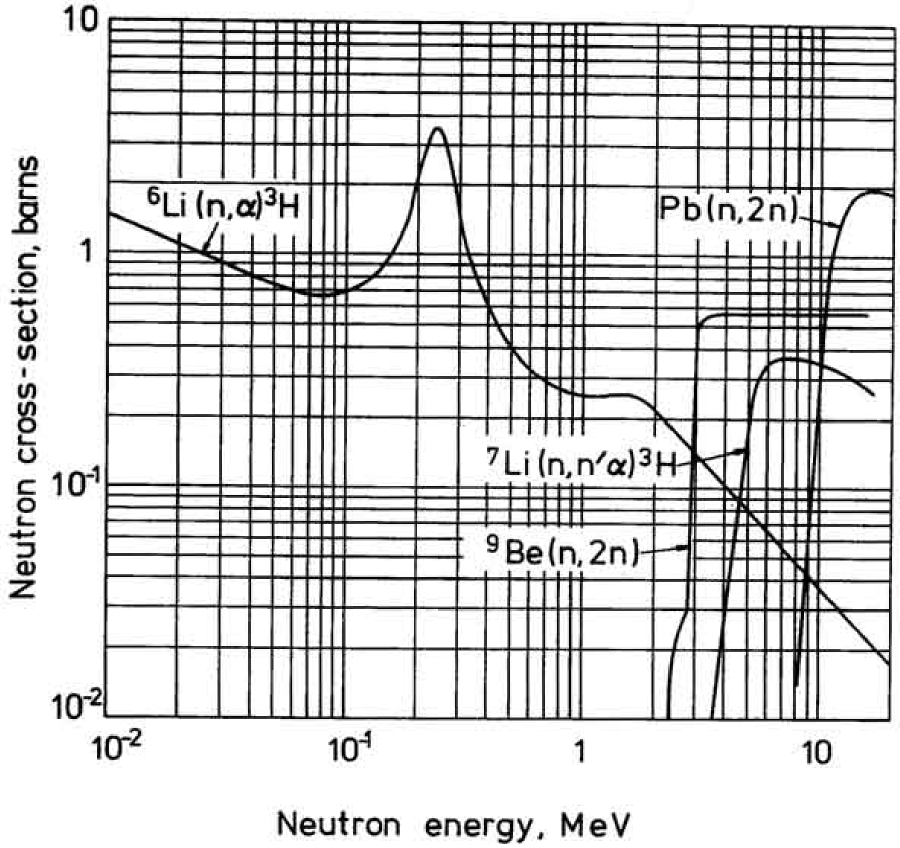

Figure 1: Cross-sections of various blanket materials. Note the threshold for the ^{7}Li and neutron multiplying reactions.

0.0.1 Lithium

Review lithium reactions...

$$\mathrm{n} + {}^7\mathrm{Li} \longrightarrow \mathrm{n} + \alpha + \mathrm{T} - 2.47 \text{ MeV} \tag{1}$$

$$\mathrm{n} + {}^6\mathrm{Li} \longrightarrow \alpha + \mathrm{T} + 4.78 \text{ MeV} \tag{2}$$

Natural lithium occurs with the isotopic abundances of 92.58% for ^7Li and 7.42% for ^6Li. Lithium metal is soft, has a low density (of 0.53 g/cm^3), and has a physical appearance similar to lead. The average abundance of lithium in the Earth's crust is approximately 65 parts per million by weight. The concentration of lithium in sea water is also about 0.17 g/m^3. Lithium reserves are estimated to be sufficient for the United States' electrical demand for more than 600 years.

Mean-free-path of tritium-producing reaction in natural lithium

$$\lambda_t > 70\,\mathrm{cm} \qquad\qquad n(14\,\mathrm{MeV})$$
$$\lambda_t \approx 2\,\mathrm{cm} \qquad\qquad n(1\,\mathrm{eV})$$

In 90% enriched lithium-6,

$$\lambda_t \approx 0.15\,\mathrm{cm} \qquad\qquad n(1\,\mathrm{eV})$$

lithium-6 cross-section at 0.025 eV is

Intentionally shifting to softer neutron energy spectrum to shorten mean-free-path will preclude the lithium-7 reaction.

Inelastic scattering of other materials with drop neutrons below lithium-7 threshold.

Must have neutron multiplier

0.1 Neutron multiplication in solid breeder

(n,2n) reactions are always endothermic and therefore always have threshold energies

(n,2n) help raise tritium breeding ratio and increase neutrons for energy multiplication

The two most prominently analyzed neutron multipliers for a fusion reactor are beryllium and lead. Beryllium has a very high nuclide density while also being very light, with a high melting temperature, and high thermal conductivity. However it undergoes a 2-α reaction that causes trapped helium to swell the material. There is also a rarely occurring reaction with beryllium that generates tritium; it is frequent enough to cause a concern with contamination.

$$\mathrm{n} + {}^{9}_{4}\mathrm{Be} \longrightarrow 2\mathrm{n} + 2\alpha + \mathrm{T} - 1.57\ \mathrm{MeV} \tag{3}$$

melting temperature of beryllium is 1250 C, melting temperature of lead is 327 C. Thermal energy of Be is 1.7 MeV, Pb is 7 MeV. Choose beryllium for non-mobile breeder.

Chemical composition of beryllium,

- BeO
  - excellent compatibility with structural steel
  - carciongen, causes beryllium disease if inhaled
- Be
  - incompatibility with strucuture steel, forming FeBe13
  - Be reaction with water forming BeO (Be + H2O -> BeO + H2)

- 2Be + O2 -> 2BeO

- Be12Ti
  - compatible with ss.
  - high metling temperature
  - less swelling than Be
  - higher chemical stability
  - high Be density maintains neutron multiplication characteristics

Bear in mind limited Be abundancy on Earth. (remember Homework set)

Beryllium will also exist as a pebble bed. The following reaction has small probability of occurance (check cross-section for this reaction)

$$\mathrm{n} + {}^{9}_{4}\mathrm{Be} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{6}_{2}\mathrm{He} \tag{4}$$

$$ {}^{6}_{2}\mathrm{He} \longrightarrow {}^{6}_{3}\mathrm{Li} + \beta^{-} \tag{5}$$

$$\mathrm{n} + {}^{6}_{3}\mathrm{Li} \longrightarrow T + \alpha \tag{6}$$

Diffusional release of T from irradiated beryllium is very slow, measured in BeO to be about 1 10^{15} cm2/sec at 900C. The diffusional path should be kept aroudn 1 micron for T inventory concerns.

0.2 Lithium ceramic