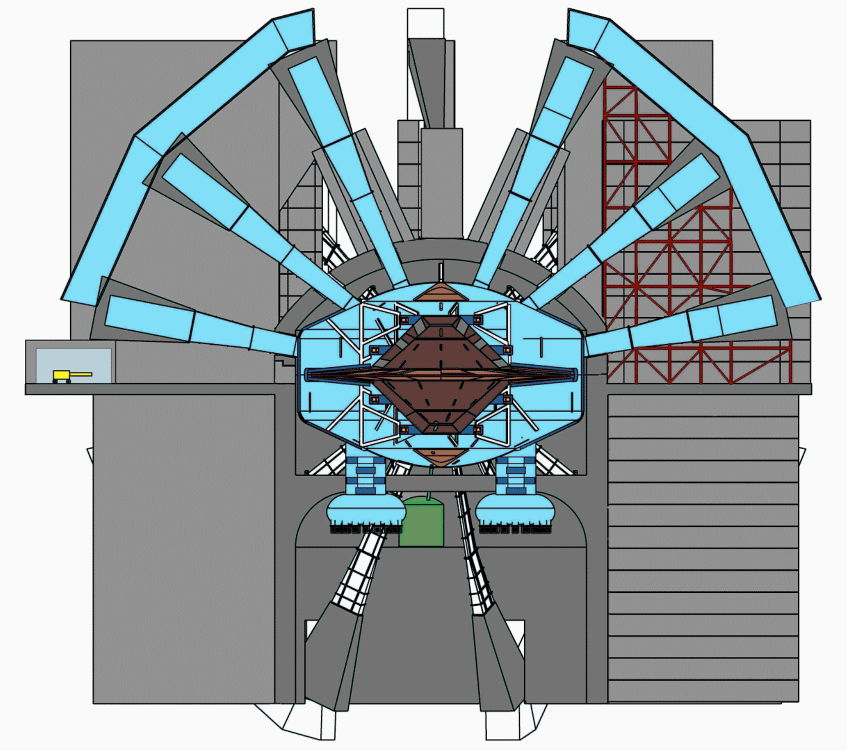
Fuel Recovery and Breeding Blanket Material Options and Comparison



CA. Gentile, M.Aristova,
S. Langish, A. Nobile, J.Wermer,
K. Sessions,
and the HAPL Community

HAPL - 17 Workshop

Naval Research Laboratory , Washington DC

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PPPL
PRINCETON PLASMA
PHYSICS LABORATORY

Motivation

A key technical and economic consideration in the design of the prospective direct drive inertial fusion energy (IFE) reactor is the determination of a suitable mechanism for tritium (fuel) breeding. A review is undertaken to determine the optimal breeding material, examining two candidate compounds: 83Pb-17Li and $(LiF)_2BeF_2$ (FLiBe). In this review, the compounds are evaluated based on chemical and physical properties, structural requirements, feasibility, hazards, and costs of application. Preliminary results seemed to indicate that FLiBe may be the more practical option, due to its mechanical utility and the relative projected efficacy of blanket design. However, much remains to be investigated, particularly the properties of breeder and structural materials in the specific conditions of a reactor. This evaluation process will require further theoretical modeling as well as practical trial, currently planned in other progenitor reactor designs.

Related Presentations at HAPL-17

- Target Chamber Mechanical Pumping System.
  K. Tresemer, et al

- Balance of Plant Systems.
  C. Priniski, T. Kozub, et al

- Magnetic Intervention Concept.
  F. Dahlgren, T. Dodson , et al

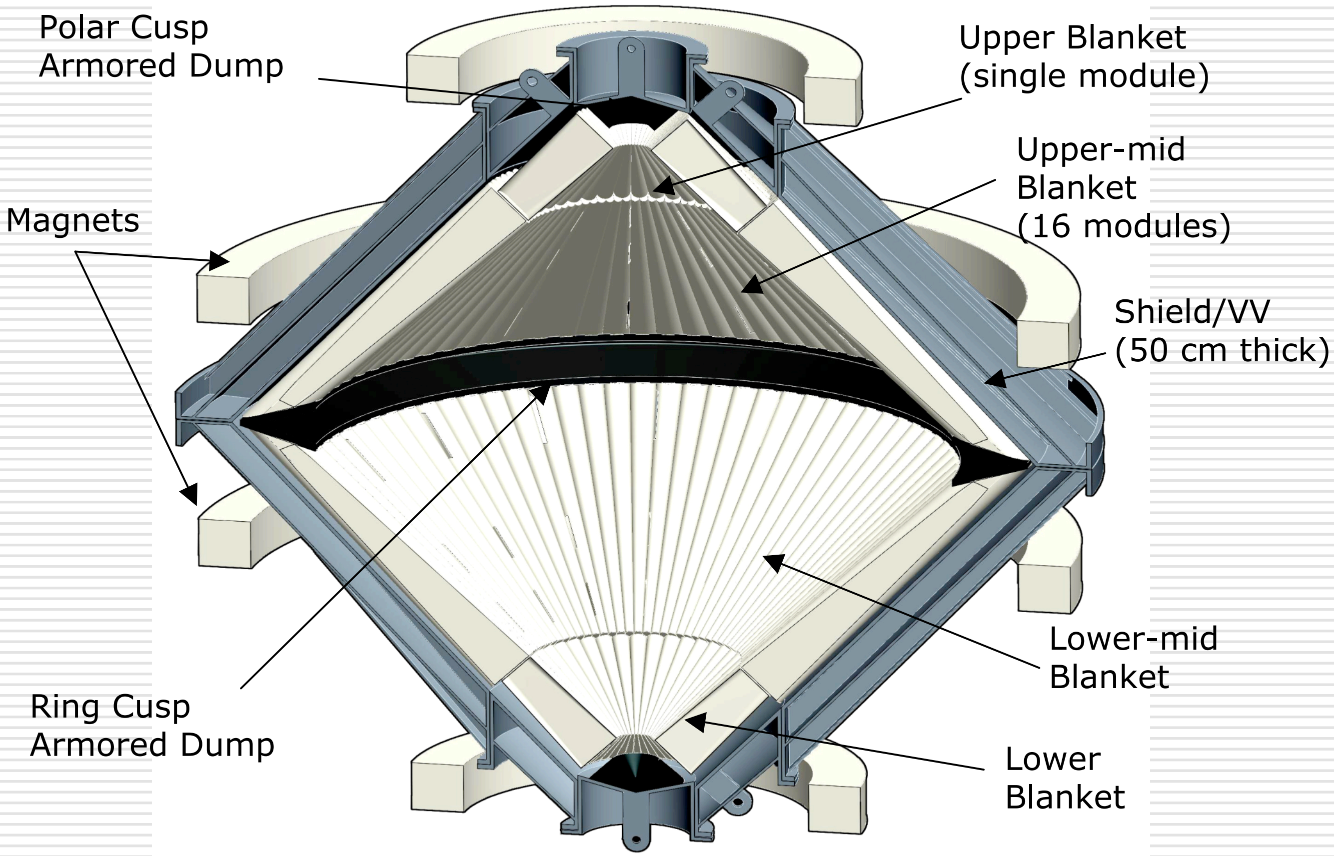
Motivation for Tritium Breeding

- IFE target contains ~ mg quantities of T. Targets expended at a rate of 5Hz. ~ 72% is not used in reaction, and can be recovered through the Fuel Recovery system. Need to breed T to make up expended T.
- Deuterium is readily available from natural water
- Tritium is costly (at about $40 -$120/mg) to produce, and decays relatively quick.
- To make commercial power production feasible, the IFE reactor must incorporate a reliable mechanism for producing T.

Basic Mechanism

- T breeding will most likely use a liquid breeder blanket: a module facing the first wall.
- Inside, liquid alloy at high temperatures is circulated. Neutrons that pass through the first wall react with this alloy to produce T.
- Other reactions can multiply incoming neutrons so that the breeding ratio is greater than 1.
- Target breeding ratio needs to be about 1.2 at any local point, so that the overall breeding ratio is about 1.1 (Taking into account losses through permeation and dissolving).

Current General Structure of Blanket Concept



Polar Cusp
Armored Dump

Upper Blanket
(single module)

Upper-mid
Blanket
(16 modules)

Magnets

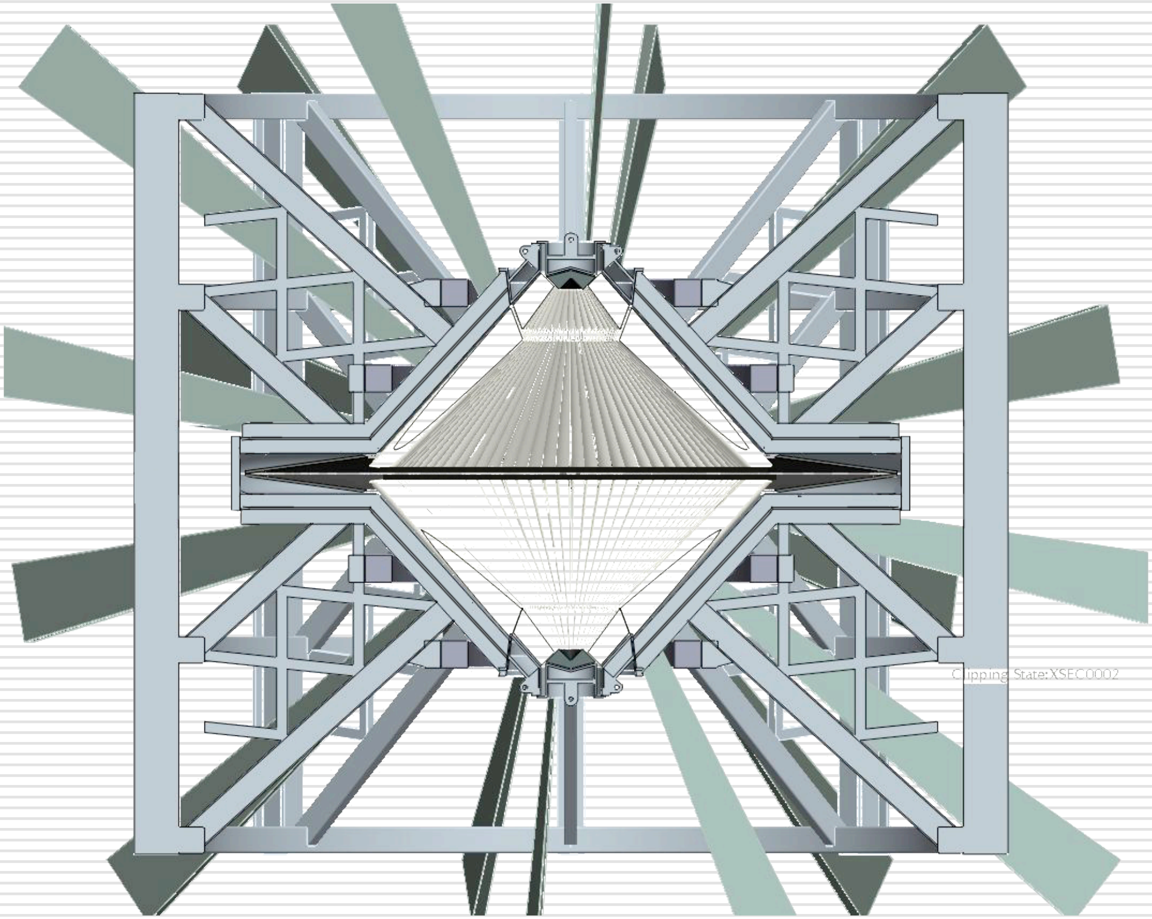
Shield/VV
(50 cm thick)

Lower-mid
Blanket

Ring Cusp
Armored Dump

Lower
Blanket

Orientation of Blanket in Chamber



Chemical Process

- Lithium is the most viable reactant for breeding:
- $^{6}Li + n \rightarrow {}^{4}He + {}^{3}H + 4.8\ MeV$
- $^{7}Li + n_{fast} \rightarrow {}^{4}He + {}^{3}H + n_{slow}$

Candidate materials

- Pure lithium is difficult to implement because it is highly reactive with water and oxygen. Some Li-containing compounds will probably not be used for reasons of feasibility, such as Li_2O, Li_4SiO_4, Li_2TiO_3, Li_2ZrO_3
- The most promising alloys for use in a blanket systems appear to be 83Pb - 17Li and FLiBe (2LiF - BeF_2). These materials breed tritium efficiently and do not yield long-term radioactive species.
- These materials vary considerably in their chemical and physical properties as well as different factors that may affect feasibility.

Chemical Properties

83Pb - 17Li	FLiBe (2LiF - BeF_2)
•Pb acts as neutron multiplier (n, 2n) •Transmutation reaction yields Po- •With enriched Li, breeding ratio: 1.06 (SiC structure) - 1.16 (Steel structure) •Sievert's constant for T temperature-independent; experimentally about 5.1± 1.1 appm/torr$^{1/2}$. •Higher T solubility → higher T inventory •Negative free energy of reaction with SiC	•Be acts as neutron multiplier $^{9}Be + {}^{1}n \rightarrow 2\,{}^{1}n + 2\,{}^{4}He$ •Li reaction liberates F→TF •RedOx agent is required to control free fluorine •RedOx reaction: $xM + F_2 = xMF_{2/x}$ •In laboratory-scale experiments, Be was 90% effective •Breeding ratio: 1.27 (no multiplier) •Dominant H-bearing species; TF; $[T_2]$ low. •Low T solubility → permeation

Physical Properties

83Pb - 17Li	FLiBe (2LiF - BeF$_2$)
•Melting temperature: 507 K •Higher thermal conductivity, lower electrical resistivity •Temperature range: 673-973 K •Average liquid density: 8800 kg/m^3 •Liquid specific weight: 93195 kN/m^3 •Specific heat: 195 - 9.116 * 10^{-3} *T (little change over temperature range)	•Melting Temperature: 742 K •Much lower surface tension •Dynamic viscosity higher by order of magnitude •Slightly higher vapor pressure •Temperature range : 473 – 973 K; avg. 6 K •Average liquid density: 1992 kg/m^3 •Liquid specific weight: 19541.52 kN/m^3 •Specific heat: constant at 2380 J/kg-K

Structural Requirements

83Pb - 17Li	FLiBe (2LiF - BeF$_2$)
• Assume 130.6 m^3 required •Total mass: 1,240,700 kg •Pumping system •Flow rate: 8.0 *10^{7}g/s •SiC components	• Assume 130.6 m^3 required •Total mass: 260,155.2 kg •SiC components •Be pebbles may need to be used for neutron multiplication •Additional Be needed to control fluor produced in T breeding •Flow rate: 6.3 * 10^{6}g/s

Hazards

83Pb - 17Li	FLiBe (2LiF - BeF_2)
•Produces radioactive Po-210 (half-life 138.39 days) through Bi-209 content •Creates Pb-Po compounds •Corrosion •High tritium pressure •Large lead inventory presents hazard	•Contains F, Be, as well as other volatile species such as tritium fluoride (after reaction) •Potential for overbreeding •Corrosion •High temperature

Cost

83Pb - 17Li	FLiBe (2LiF - BeF_2)
•$16.92 / kg [1992 price adjusted for inflation] •For 130.6 m^3, cost of PbLi: $19,445,818.00 •If two blanket layers are used, the outer layer will need to be replaced every ~ 5 years; inner layer functional much longer	•$45.76 / kg [1994 price adjusted for inflation] •For 130.6 m^3, cost of FLiBe: $11,904,702.00 •A similar design projects use of one FLiBe blanket for ~ 15-30 years •Costs of transportation and insulation may be significant

Other Considerations

83Pb - 17Li	FLiBe (2LiF - BeF_2)
	• US standards for Be storage recently tightened

Need for Further Research

83Pb - 17Li	FLiBe (2LiF - BeF_2)
•Compatibility with SiC structural materials •Tritium Extraction Processes •MHD effect •Use of flow channel inserts to eliminate magnetic field influence	•Kinetics of RedOx reaction in reactor conditions - fast enough to contain free fluoride? •Compatibility with SiC structural materials •Tritium extraction Processes •MHD effect •Use of flow channel inserts to eliminate magnetic field influence

Conclusions

- FLiBe is a more effective breeding material and is appears to be more economical; however, it has hazardous components despite RedOx possibilities, is viscous, and may result in overbreeding.
- PbLi has been studied more thoroughly, is less corrosive and contains fewer volatile species; however, it is less efficient, more costly, and mechanically cumbersome.
- Pending further research, FLiBe may be preferred material for the IFE reactor.

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Back up

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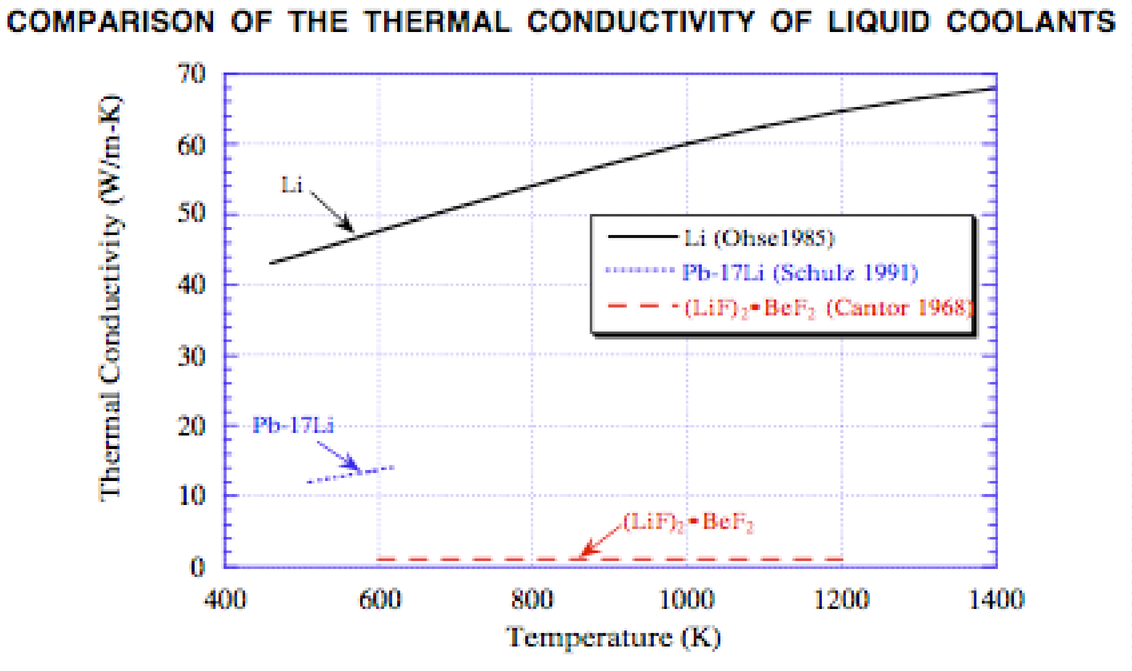
Thermal Conductivity



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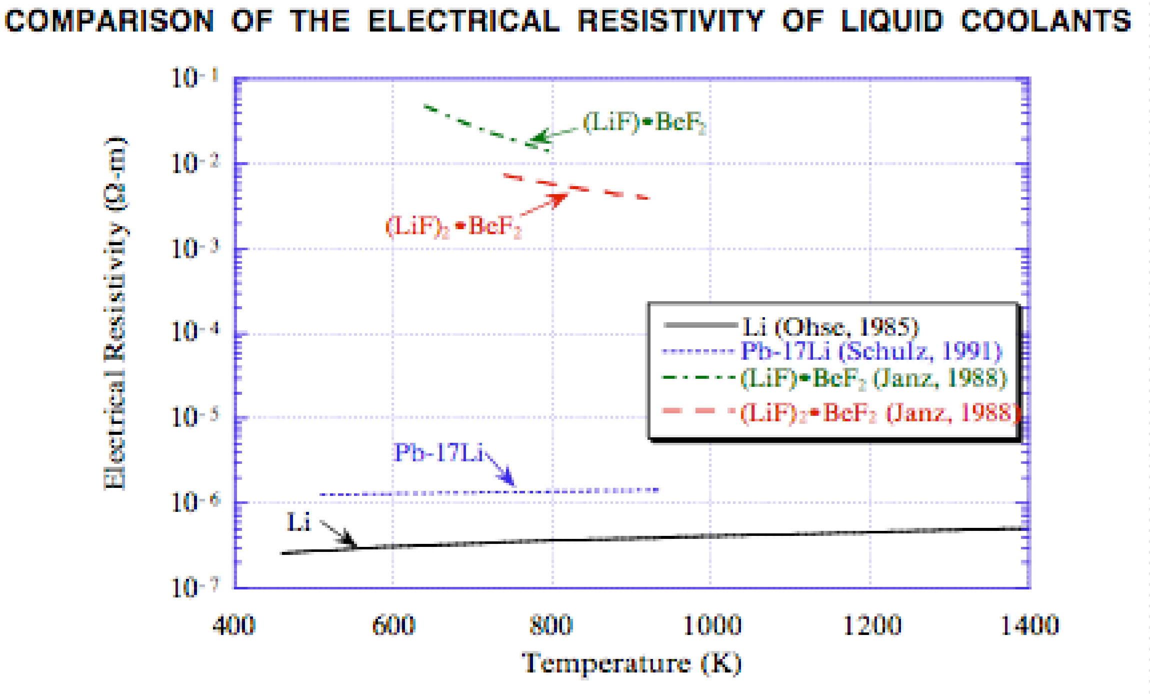

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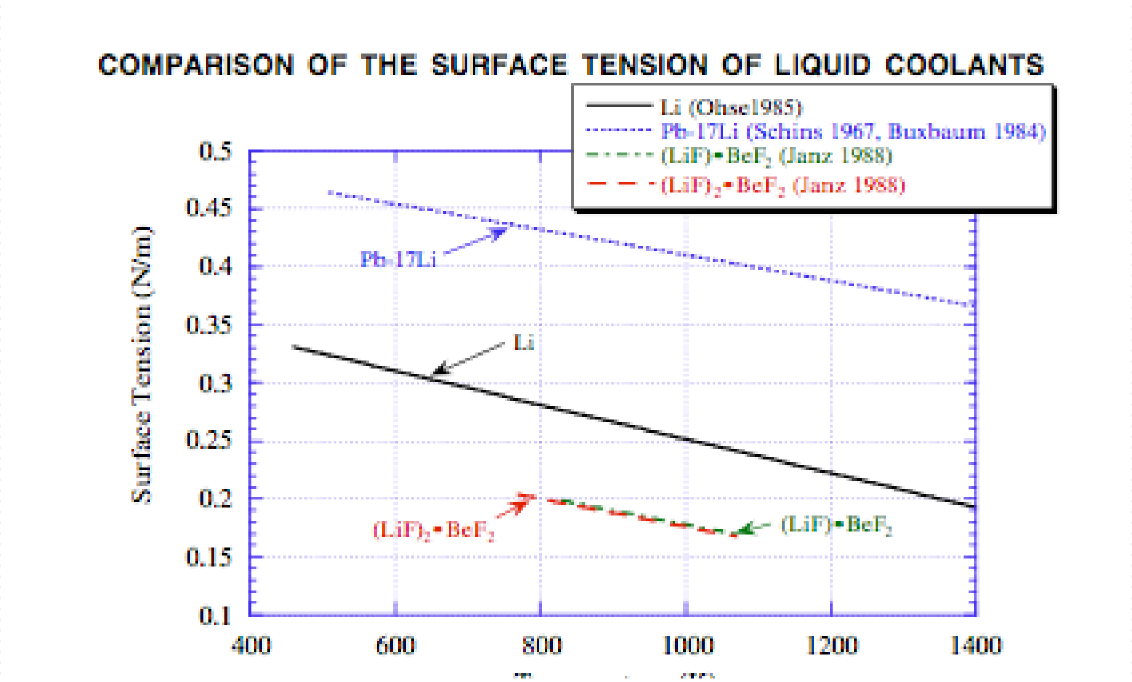

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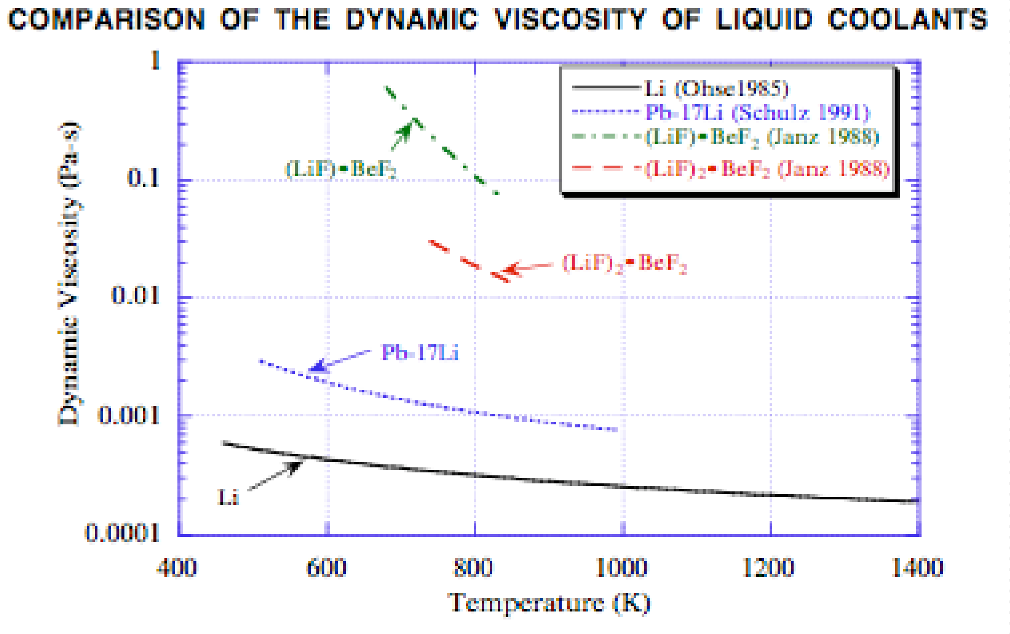

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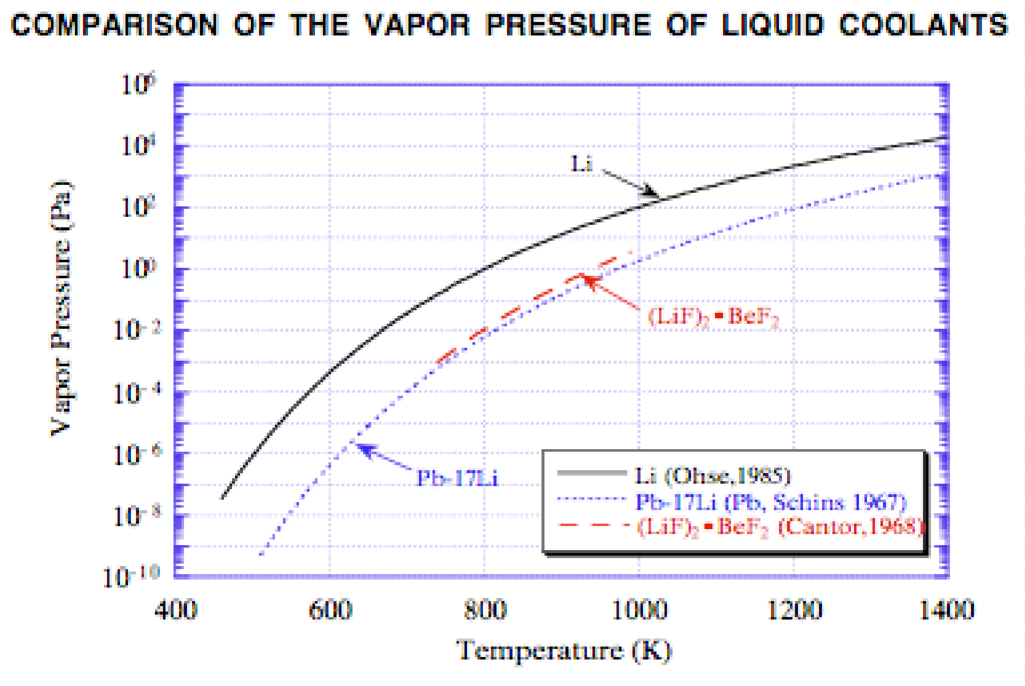
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