Sn-Li, a New Breeding Material for Fusion

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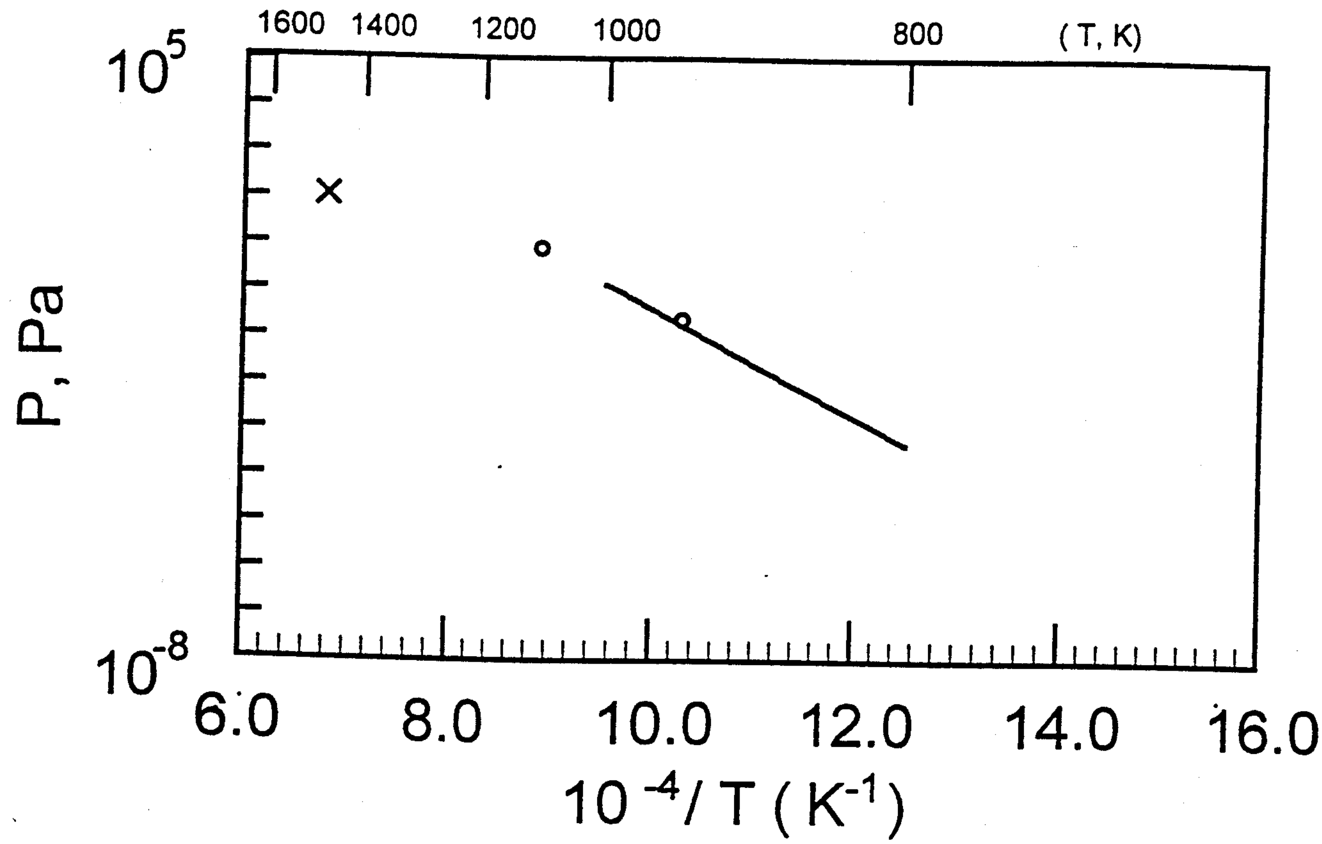
Presented at the APEX Project Meeting
Nov. 2-4, 1998
UCLA, LA, California

LITHIUM PRESSURE



--- Calculated curve with 20 % lithium in liquid

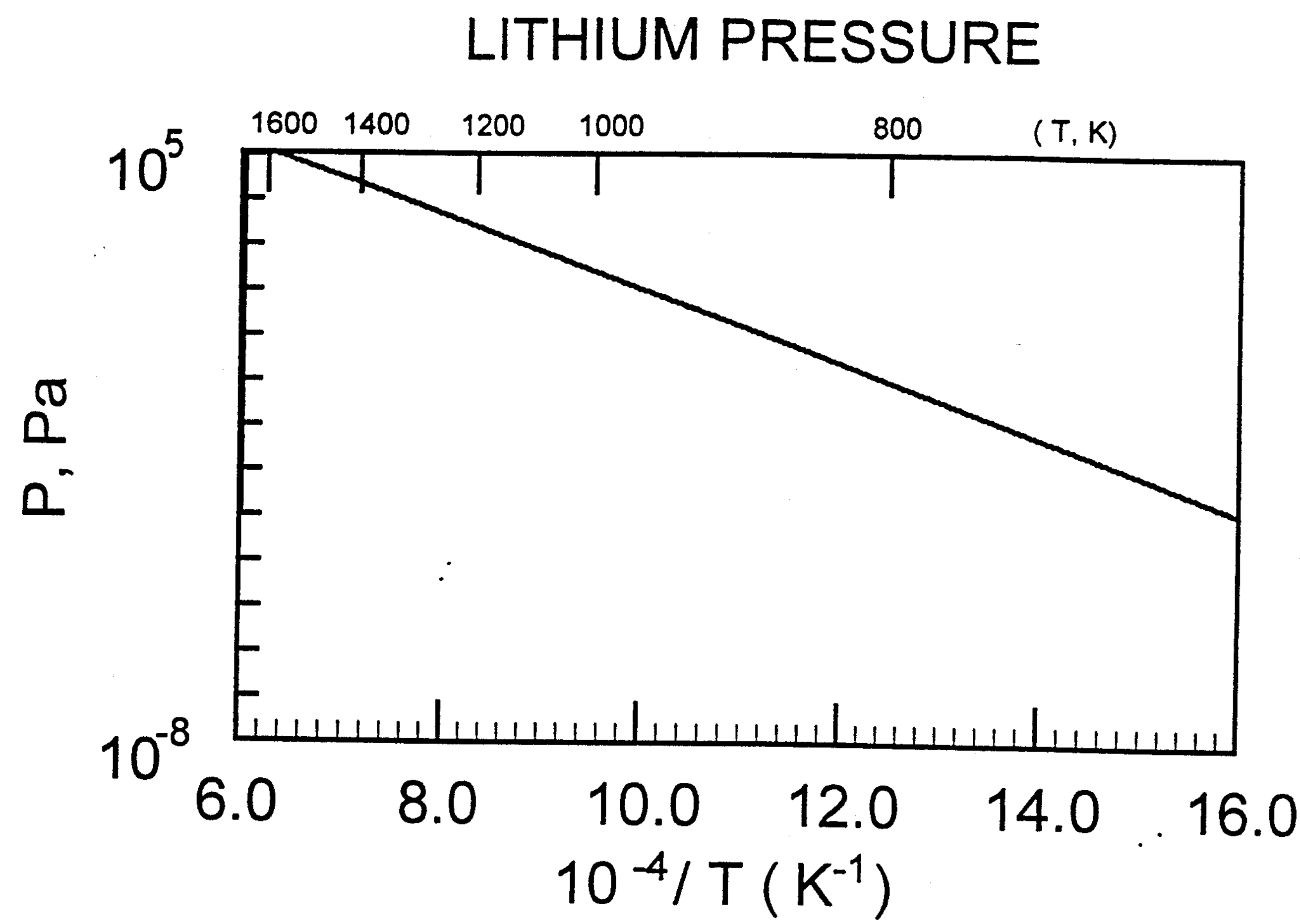
o x Experimental data..

References:

1. --- M. S. Foster, et al, J. Phys. Chem. 70(1966)3042

2. o P. Baradel, et al, Rev. Int. Haute Temper. et Refract. 8(1971)201

3. x A. K. Fischer, et al, J. Chem. Engr. Data 17(1972)280



For pure Lithium

Sn-Li vapor pressure at Lower Temperature

- There have been three measurements of Sn-Li vapor pressure.
- At 650C, the Li vapor pressure is ~ 0.001 Pa.
- The Sn vapor pressure is essentially zero.
- This will have major impact on the APEX/ALPS designs for

1. The coolant velocity can be modest.
2. The heat transfer DT into the coolant can be high.
3. The coolant exit temperature can be high for good thermal conversion.

Safety

- Sn has three long-lived activation products:

  Sn121m(55y half-life), Ag108m(418Y), Sn126(100,000Y)

- The activation from Sn126 is about 5% of the total long-term activation.
- The Sn 126 activity is about a factor of 10 lower than Bi208, from Pb-Li.
- That means Sn-Li is better than Pb-Li in terms of very long activation.
- McCarthy suggested that the short-term activation produced by Sn is not a major safety concern.

Li activity

- The lithium chemical activity over Sn-Li is very low.

- It is expected that the reaction kinetics between Sn-Li wih water/air will be very low.

- Sn will act as heat sink if there is Sn-Li reaction with water/air.

- It is expected that the chemical reactivity Sn-Li will be very similar to Pb-Li.

Tritium Solubility

- The tritium solubility in the Sn-Li (from lithium effect) is expected to be low due to the low chemical activity of Li.

- However, Sn has a much larger tritium solubility than Pb. (but is still rather low).

- It is expected that tritium solubility in Sn-Li will be low, but higher than in Pb-Li.

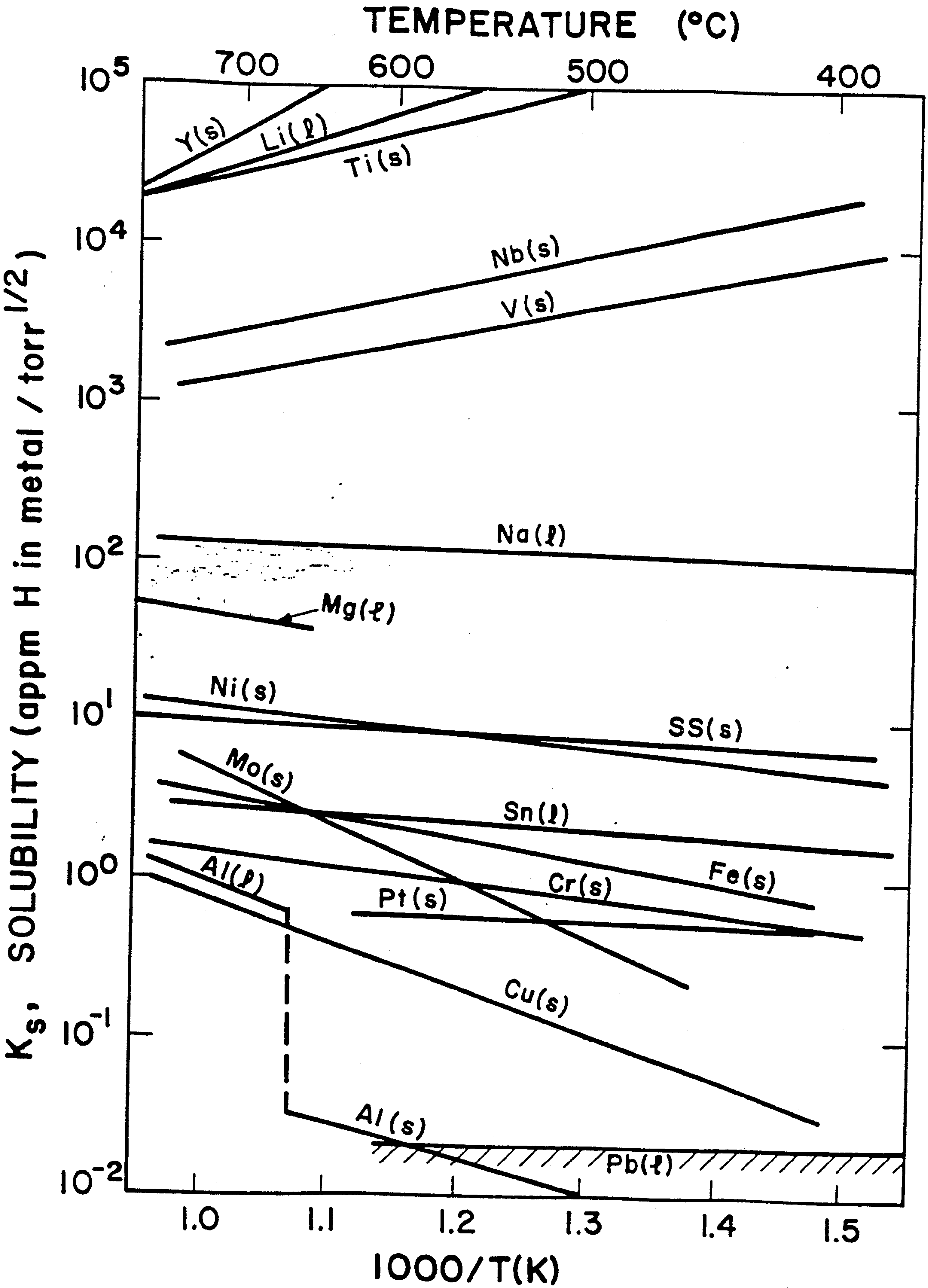
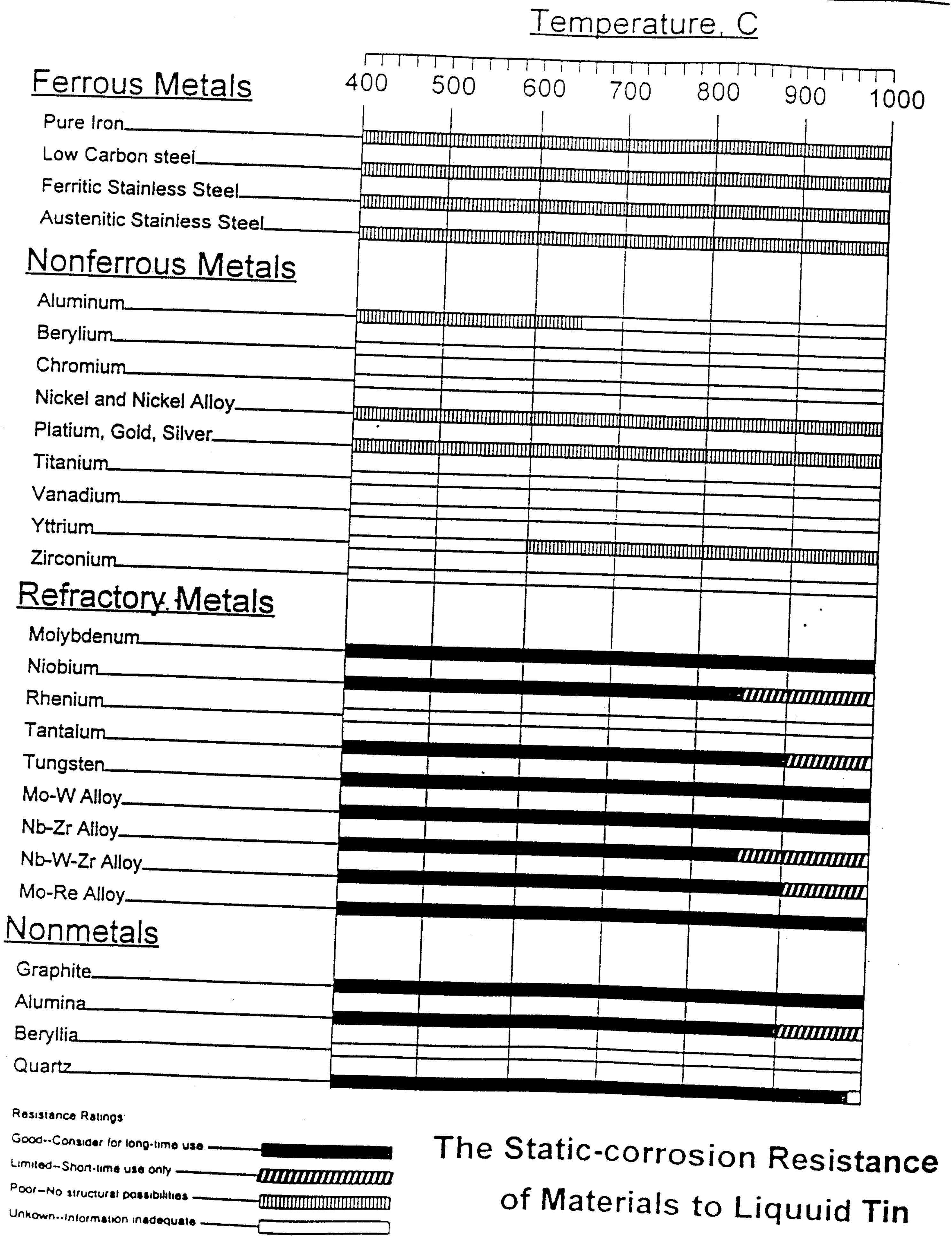


Fig. XI-C-3 THE SOLUBILITY OF HYDROGEN IN SELECTED METALS AND ALLOYS AS A FUNCTION OF TEMPERATURE

Compatibility with Structural Materials

- Both Fe and Ni based alloy may not be compatible with Sn-Li.
- Most refractory metals, such as Ta, Nb and W are compatible with Sn up to a rather high temperature (850 to 1000C).
- Because Nb is compatible with Sn up to 850C, there is some possibility that V is compatible with Sn, maybe to 700C.
- Sn is compatible with many ceramics.
- Since Sn is compatible with many ceramics, there is some possibility that Sn is compatible with SiC.
- Sn-Li is compatible with Ta up to 1200C.



The Static-corrosion Resistance of Materials to Liquuid Tin

Comments from Jack DeVan

1.)There is some clear advantage of using Sn-Li over either Li and Pb-Li.

Advantages are low vapor pressure (important only for wet wall concept) and possibility of using oxide ceramics as insulating coatings (as noted below).

2.)A most critical problem of using liquid metal in a MFE environment is the requirement and the difficulty of developing a reliable insulating coating. There are more possibilities of developing a reliable insulating coating for Sn-Li, than pure lithium.

With Useful Input from

Sam Berk

Mark Tillack

Jack DeVan

Kathy McCarthy

Steve Zinkle

3.)The ability to use either Ni-alloy and Fe alloy facing Sn-Li is questionable.

Ni-base alloys would not be suitable, period. Fe-based alloys would probably be limited to temperatures of <500 C

4.) The possibility of using refractory metals, such as V, Nb, Ta, Mo, with Sn-Li exist.

True statement, although the present state of the art for Mo is such that thick section welds are too brittle to allow fabrication of complex shapes.

5.)SiC also has some potential.

SiC may be compatible, but it still isn't a structural material in the usual sense.

6.) One of the difficulties of using refractory metals with Sn is the control of the O potential. Li maybe able to control the oxygen potential.

Problem exists for V, Nb, and Ta, not for Mo. The worry here is with the external surfaces of coolant circuit piping, and the power conversion system.

7.) Static loop (should be static capsule) will not provide much useful information. Natural convection loop is reasonable to construct, and can be used to generate much more useful information.

You really mean static capsule rather than static loop. Thermal gradient mass transfer is the key issue and can not be assessed in static, isothermal tests.

8.) One of the possible material to be used for the loop is quartz.

Material Properties

- The thermal conductivity of Sn is much higher than that of Pb.
- If the thermal conductivity of Sn-Li can be that high, it will be very useful for a self-cooled blanket design.
- The volumetric heat capacity of Sn is even higher than that of Li.
- The flow velocity and, therefore, the MHD pressure drop, can be lower with higher volumetric heat capacity.
- Therefore, the material properties of Sn-Li maybe better than Pb-Li.

The Purpose of Developing Sn-Li

- To develop a new breeding material for APEX/ALPS applications.

- Needs to have low vapor pressure.

Why Sn-Li

- Li is required for tritium breeding.
- Sn has very low vapor pressure.
- Pb in Pb-Li tie down lithium, and reduces lithium activity, and also lithium vapor pressure.
- Sn may also have similar effect to Sn - Li.

Sn-Li vapor pressure

- Sn-Li vapor pressure was measured for the battery program.
- At 1200C, the lithium vapor pressure is only 0.7 torr.
- This vapor pressure is a factor of 500 lower than that of pure lithium.
- Th Sn vapor pressure is so low that it can not be measured accurately.

Figure 1

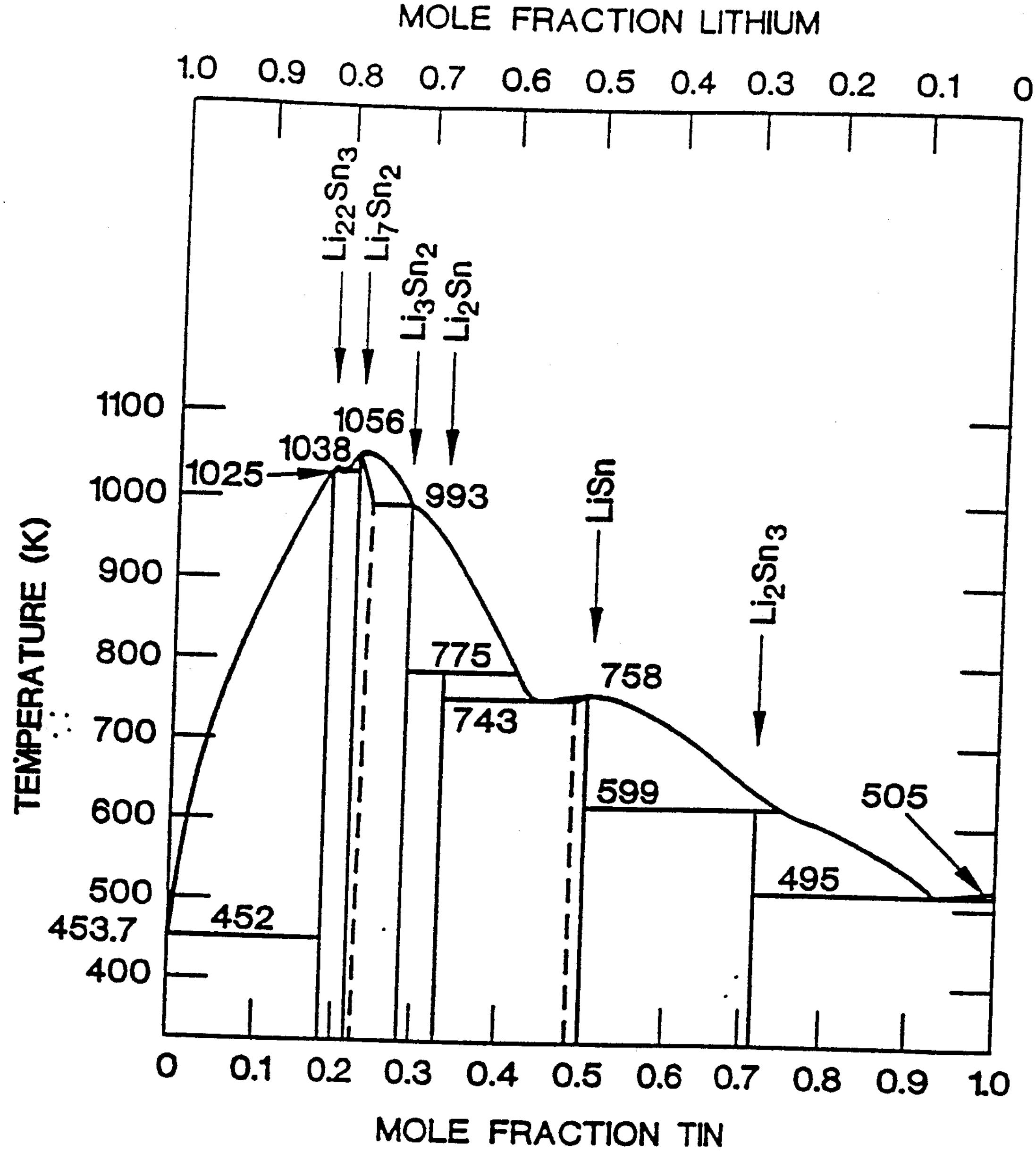


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Table 1. Experimental Data for lithium and Calculated Results for Tin in Lithium-Tin System at 1200°C

Atom Fraction Lithium in liquid	Total lithium vapor pressure, torr[a]	Monatomic lithium vapor pressure, torr	Activity of lithium	Activity coeff of lithium	Activity coeff of tin[b]	Activity of tin[b]
0.100	0.266	0.266	1.09×10^{-3}	0.0109	0.994	0.895
0.200	0.705	0.705	2.89×10^{-3}	0.0144	0.947	0.758
0.296	1.62	1.62	6.63×10^{-3}	0.0223	0.817	0.574
0.300	2.41	2.41	9.87×10^{-3}	0.0328	0.695	0.486
0.400	4.84	4.83	0.0198	0.0496	0.553	0.332
0.500	9.2	9.2	0.0377	0.0754	0.388	0.194
0.600	19.1	18.9	0.0775	0.129	0.195	0.0780
0.700	46.2	45.3	0.186	0.266	0.0517	0.0155
0.800	90.0	86.6	0.354	0.442	0.0108	0.00216
0.900	195	180	0.739	0.821	2.57×10^{-4}	2.57×10^{-5}

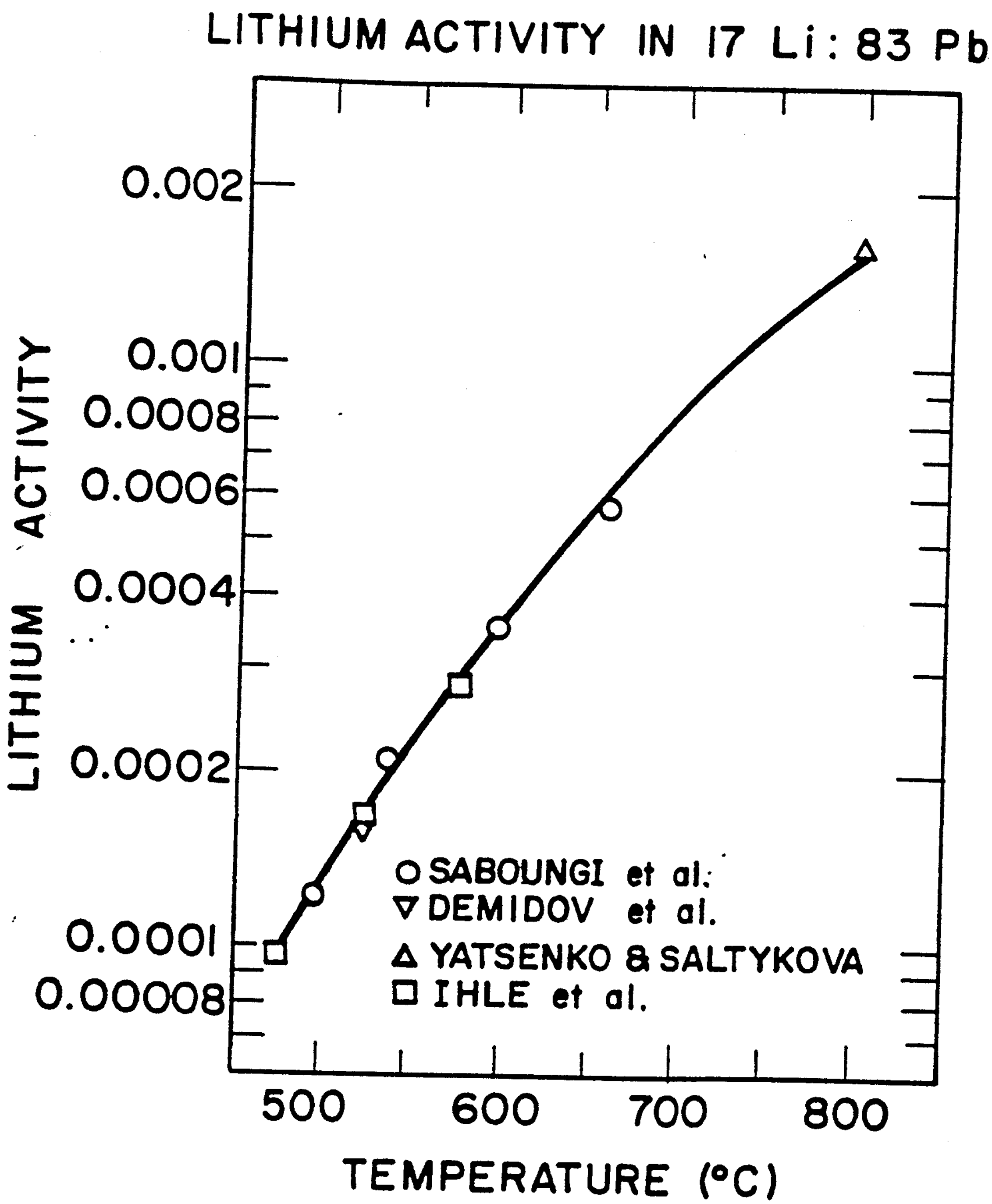
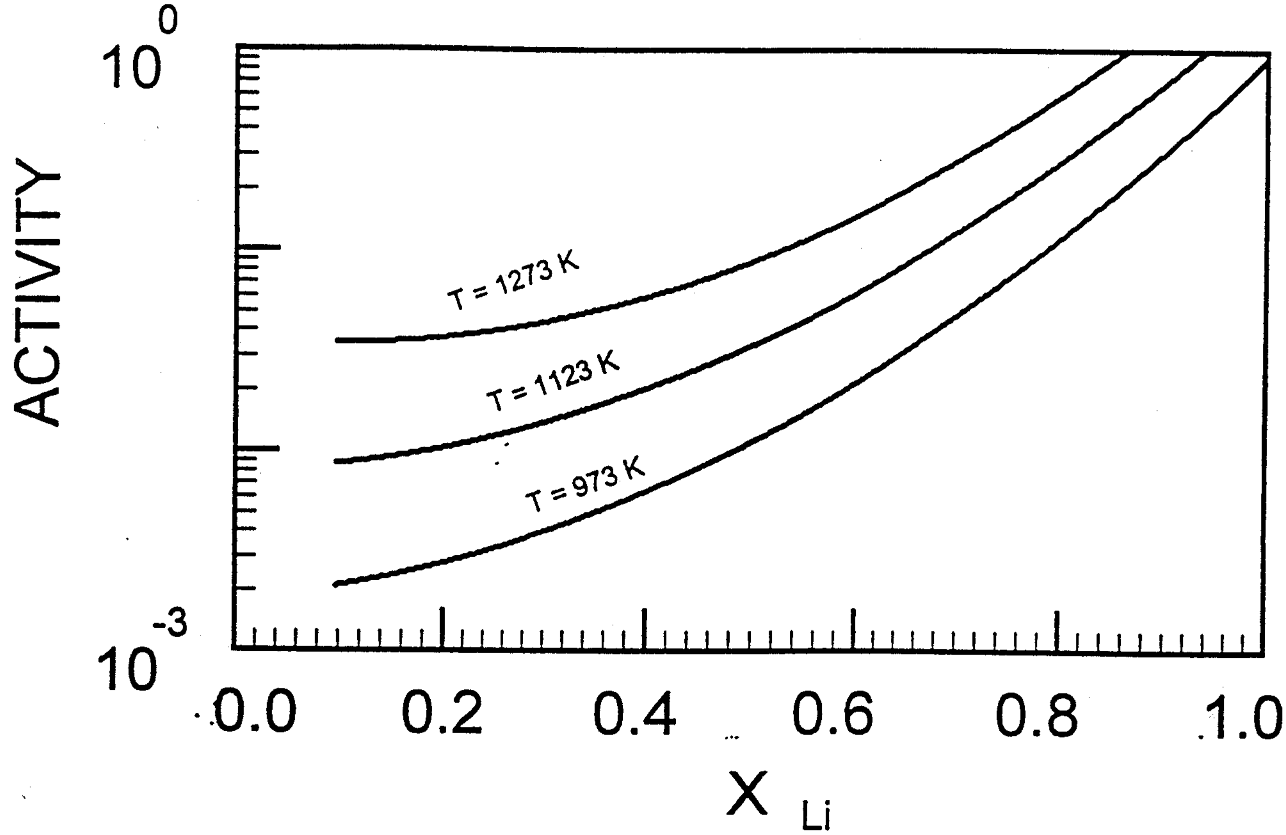

LITHIUM ACTIVITY IN 17 Li : 83 Pb
LITHIUM ACTIVITY
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.00008
500
600
700
800
TEMPERATURE (°C)
○ SABOUNGI et al.
▽ DEMIDOV et al.
△ YATSENKO & SALTYKOVA
□ IHLE et al.

Fig. XI-C-1

ACTIVITY OF LITHIUM



Experimental conditions:

$800 < T < 1050$ K

$X_{Li} > 0.1$

References:

M. S. Foster, et al, J. Phys. Chem. 70(1966)3042

Since Sn is compatible to with many ceramics, there is some possibility that Sn will be compatible to SiC.

Sn-Li is compatible with Ta up to 1200°C. This is the structural material used for the measurement of SnLi vapor pressure at 1200°C.

Many experiments will be required to determine the optimum structural material for SnLi and the maximum allowable temperature.

Table 3

The material properties for Pb, Sn and Li are summarized on Table 3.

	Sn	Pb	Li
Temperature at P= 1 torr, C	1492	987	745
Density, g/cc	6.8	10.4	0.5
Heat capacity, cal/g-C	0.076	0.037	1.0
Volumetric heat capacity, cal/cm3-C	0.52	0.38	0.5
K, cal/s-cm-C	0.08	0.038	0.09
Viscosity, cp	1.2	2.0	0.5
Elec. Resis. Mic-ohms	60	100	50

Material properties:

Tritium Breeding Calculations in SnLi Blankets

- Geometry: 1 - D, Cylindrical
- Zone and Material Compositions

  First Wall: 3 mm Tungsten
  Blanket: 50 - 70 cm, 5 % W + 95% SnLi (Sn75Li25)
  Reflector: 30 cm, SS

- Nuclear Data Library: FENDL - 1

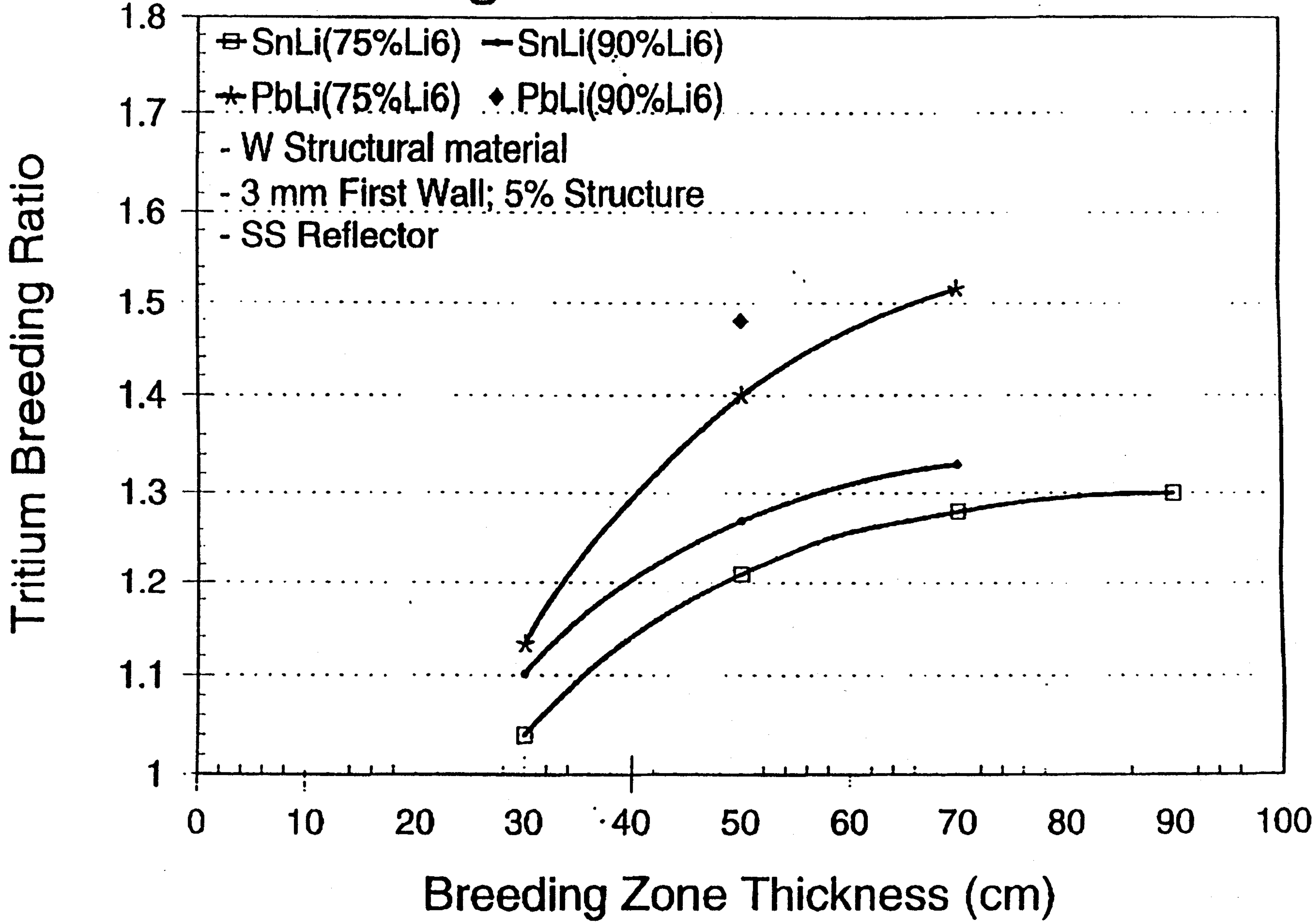
Results

Blanket Thickness	50 cm		70 cm	
Li6 Enrichment	75 %	90 %	75 %	90 %
T6 - Li6 (n, α) T	1.201	1.265	1.266	1.325
T7 - Li7 (n, n'α) T	0.012	0.0048	0.012	0.0048
Sn (n, γ)	0.364	0.324	0.381	0.338
W (n, γ) : Total First Wall Blanket	0.0864 0.0139 0.0725	0.0755 0.0126 0.0629	0.0895 0.0138 0.0757	0.0779 0.0126 0.0653
SS (n, γ)	0.109	0.0956	0.0287	0.0235
Total N/D - T N	1.760	1.760	1.765	1.764

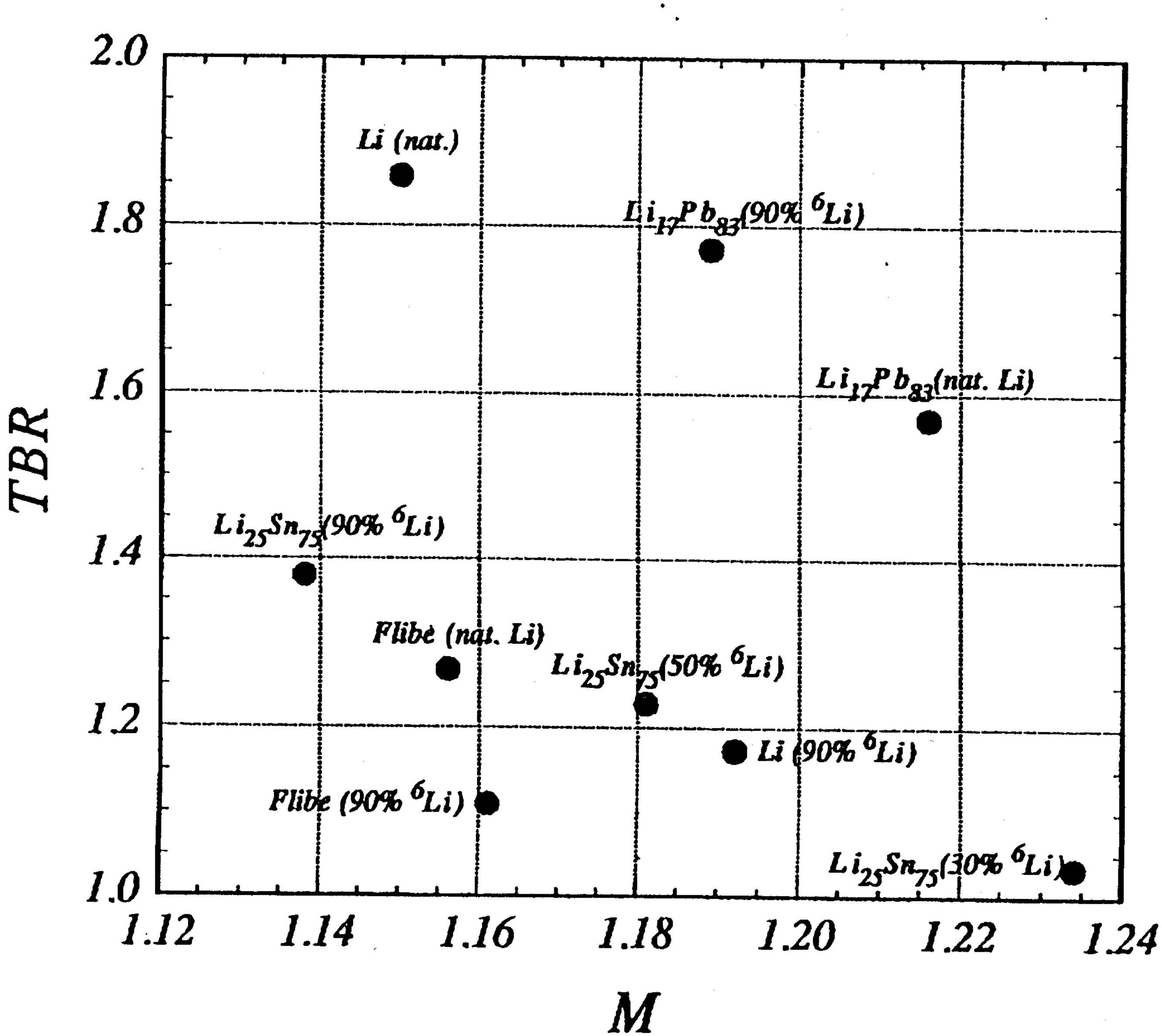
Discussion

- Neutron multiplication reactions in Sn and in W provide ~ 0.8 additional neutrons per D - T neutron. A Sn (n, 2n) cross section of 1.52 barns at 14 MeV is assumed for these calculations.
- Neutron absorption reactions in Sn and W take away > 0.4 neutrons per D - T neutron.
- Improvement in Tritium Breeding is possible when:
  - Higher Sn (n, 2n) cross section at 14 MeV (Unlikely, per Chadwick, et al.),
  - Low neutron absorbing structural material (such as V) is used, or
  - Neutron spectrum in the blanket is changed in factor of Li5 (n, α) T reaction.
- A better understanding of neutron reaction data in Sn isotopes is needed.

Tritium Breeding in SnLi and PbLi Blankets

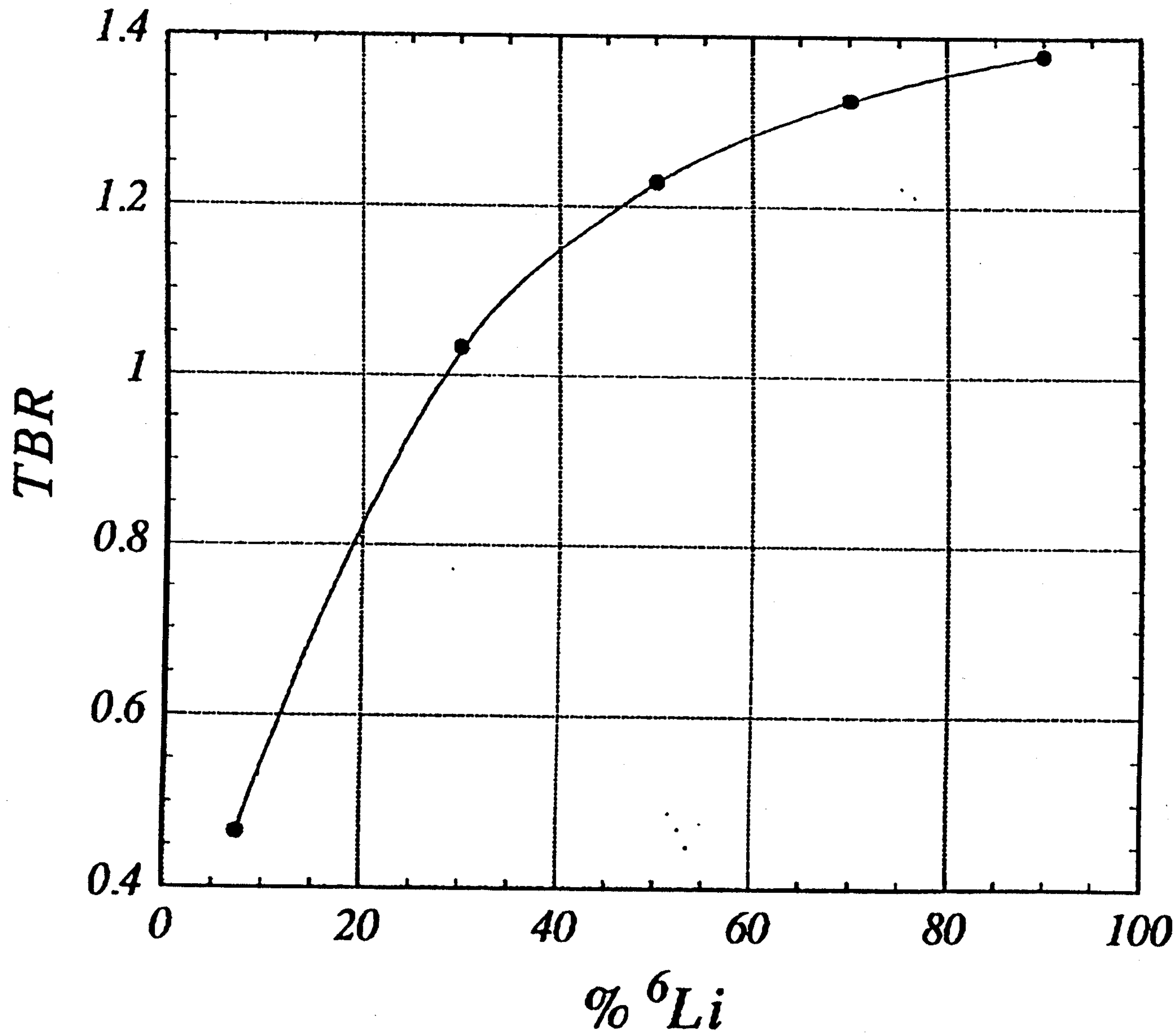


TSI Research, Inc. - October 1998



2.0
1.8
1.6
1.4
1.2
1.0
TBR
1.12
1.14
1.16
1.18
1.20
1.22
1.24
M
Li (nat.)
$Li_{17}Pb_{83}$(90% ^{6}Li)
$Li_{17}Pb_{83}$(nat. Li)
$Li_{25}Sn_{75}$(90% ^{6}Li)
Flibe (nat. Li)
$Li_{25}Sn_{75}$(50% ^{6}Li)
Li (90% ^{6}Li)
Flibe (90% ^{6}Li)
$Li_{25}Sn_{75}$(30% ^{6}Li)

TBR as a Function of Li Enrichment in $Li_{25}Sn_{75}$ (No Structure, No Multiplier)



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To Dai Kai Sze		Date 10/9/9?	# of pages ▶ 2
Co./Dept. ANL		From M. Sawan	
Phone #		Co. UW	
Fax #		Phone #	
		Fax #	

Proposed R/D Activities

- Sn-Li preparation.
- screen test for material compatibility.
- Tritium solubility measurement.
- Material properties measurement.
- (Sn-Li)-water/air reactivity test.
- Sn cross section documentation.
- Vapor pressure measurement.
- Sputtering calculation.

Conclusions

- A new coolant/breeding material has been identified.
- This material will be well suited for APEX/ALPS and IFE applications.
- This material also have many interesting features for conventional blanket system.
- Many questions remained to be solved.

Sn-Li, a new breeding material for Fusion

Dai-Kai Sze, Rich Mattas, Zhanhe Wang, Argonne National Laboratory
Edward Cheng, TSI

With useful inputs from Sam Berk, Mark Tillack, Mohamed Sawan, Cathy McCarthy, and Steve Zinkle

Introduction:

The US fusion community is investigating the concept of free flowing blanket (APEX) and divertor (ALPS) to increase the power handling capability of the fusion power plant. Also, IFE has been studying the concept of free flowing blanket during the past 20 years (Hylife and Hylife-II). To increase the power handling capability, the free flowing coolant has to be able to operate at a high temperature, both to increase the heat transfer DT, and to obtain high coolant exit temperature for efficient power conversion. The more conventional coolant/breeding material, such as Li, PbLi, and flibe, all have rather high vapor pressures (around 1 Pa) at a modest temperature range (400 to 600°C).

A new breeding material has been identified which has very low vapor pressure. The material is a eutectic of 80Sn-20Li. This memo summarizes some initial results of assessment of using this material for D-T fusion applications.

The key reason for investigating Sn-Li:

The eutectic of Sn-Li has several attractive features. Lithium is necessary for tritium breeding. Sn is useful because of its low vapor pressure. It is also possible, as we have seen from the Pb-Li, that Sn can tied up lithium to reduce the lithium activity. This reduction of lithium activity will reduce the lithium vapor pressure.

For the Pb-Li, the vapor pressure contributed by lithium is very low. This is caused by the low lithium activity, as mentioned above. The vapor pressure of Pb-Li is dominated by Pb. Since Sn vapor pressure is very low, there is reason to believe that Sn will reduce the lithium vapor pressure, but will not contribute to the total vapor pressure, as Pb does over PbLi.

This is the key reason that we investigated Sn-Li.

Phase diagram:

The Sn-Li phase diagram has been established, and shown on Figure 1. The composition we selected was 80Sn-20Li. The melting temperature of this compound is 330°C.

Vapor pressure:

There are a number of measurements of the vapor pressure over Sn-Li. The work by Fisher is listed on Table 1. The idea that the activity of lithium is Sn-Li is very low is confirmed by this experimental result. The lithium vapor pressure at 1200°C is only 90 Pa, while the Sn vapor pressure is so low that it can not be detected accurately.

Figure 2 shows the Li vapor pressure as a function of Li atomic fraction at 1200°C. The vapor pressure of Li at 1200°C is only 90 Pa. For comparison, the vapor pressure of pure lithium at 1200°C is 40,000 Pa. Therefore, there is a reduction of vapor pressure close to a factor of 500.

Figure 3 shows the chemical activity of lithium also at 1200°C. The chemical activity of lithium is very low. That means the chemical reactivity of lithium in the Sn-Li is reduced by almost a factor of 500, due to the presence of Sn. Also, Sn will act as heat sink if there is any Sn-Li to water/air chemical reaction. For this reason, it can be concluded that the chemical reactivity between Sn-Li and water/air is very benign. Also, since Li is bonded tightly by the Sn, the tritium solubility in the Sn-Li will be very low.

Figure 4 shows the vapor pressure of 80Sn-20Li as a function of temperature. At 650°C, the estimated Li vapor pressure is about 0.001 Pa. The Sn vapor pressure at this temperature is 10(-5) Pa.

This very low vapor pressure is very important for APEX/ALPS applications. Not only the coolant can operate at a high temperature so that operating window will be much larger, it also reduces the requirement of high coolant velocity, increase the heat transfer capability, and increases the coolant exit temperature for efficient power conversion.

Not only Sn-Li has a very low vapor pressure; the vapor is dominated by lithium. Therefore, it has a very low Z. For Pb-Li, the vapor is dominated by Pb, which has a very high Z.

Tritium breeding:

For a D-T power plant, any coolant/breeding material has to have high breeding capability. Since the lithium atomic density is reduced by the presents of the Sn, it is necessary that Sn will provide extra (N,2N) reaction to improve

2.) Most of the refractory metals, such as Ta, Nb, or W are compatible with Sn to rather high temperatures (850 to over 1000°C).

3.) Because Nb is compatible with Sn up to 850°C, there is some possibility that V is compatible to Sn to maybe 700°C.

4.) Sn is compatible with many ceramics.

4.) Since Sn is compatible to with many ceramics, there is some possibility that Sn will be compatible to SiC.

Sn-Li is compatible with Ta up to 1200°C. This is the structural material used for the measurement of SnLi vapor pressure at 1200°C.

Many experiments will be required to determine the optimum structural material for SnLi and the maximum allowable temperature.

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Viscosity, cp	1.2	2.0	0.5
Elec. Resis. Mic-ohms	60	100	50

Material properties:

It can be seen that the material properties of Sn are more similar to Li than to Pb. The important properties are thermal conductivity and volumetric heat capacity. The first one determines the heat removal capability. The second one determines the coolant velocity, which determines the MHD effects. Both properties of Sn are similar to that of Li.

Conclusions:

A new coolant/breeding material has been identified. This material was investigated for the APEX/ALPS applications, because of its very low vapor

Figure 1

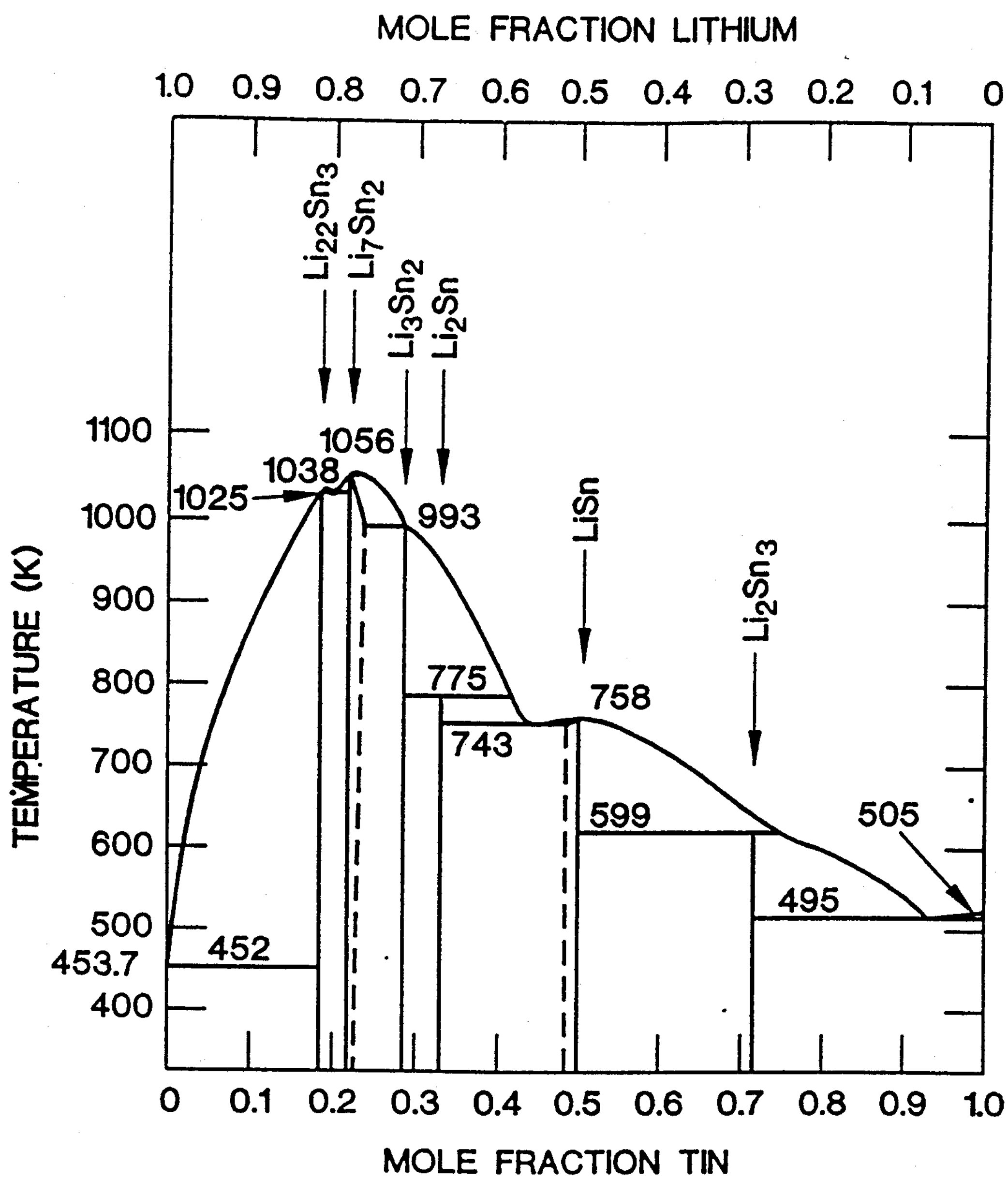

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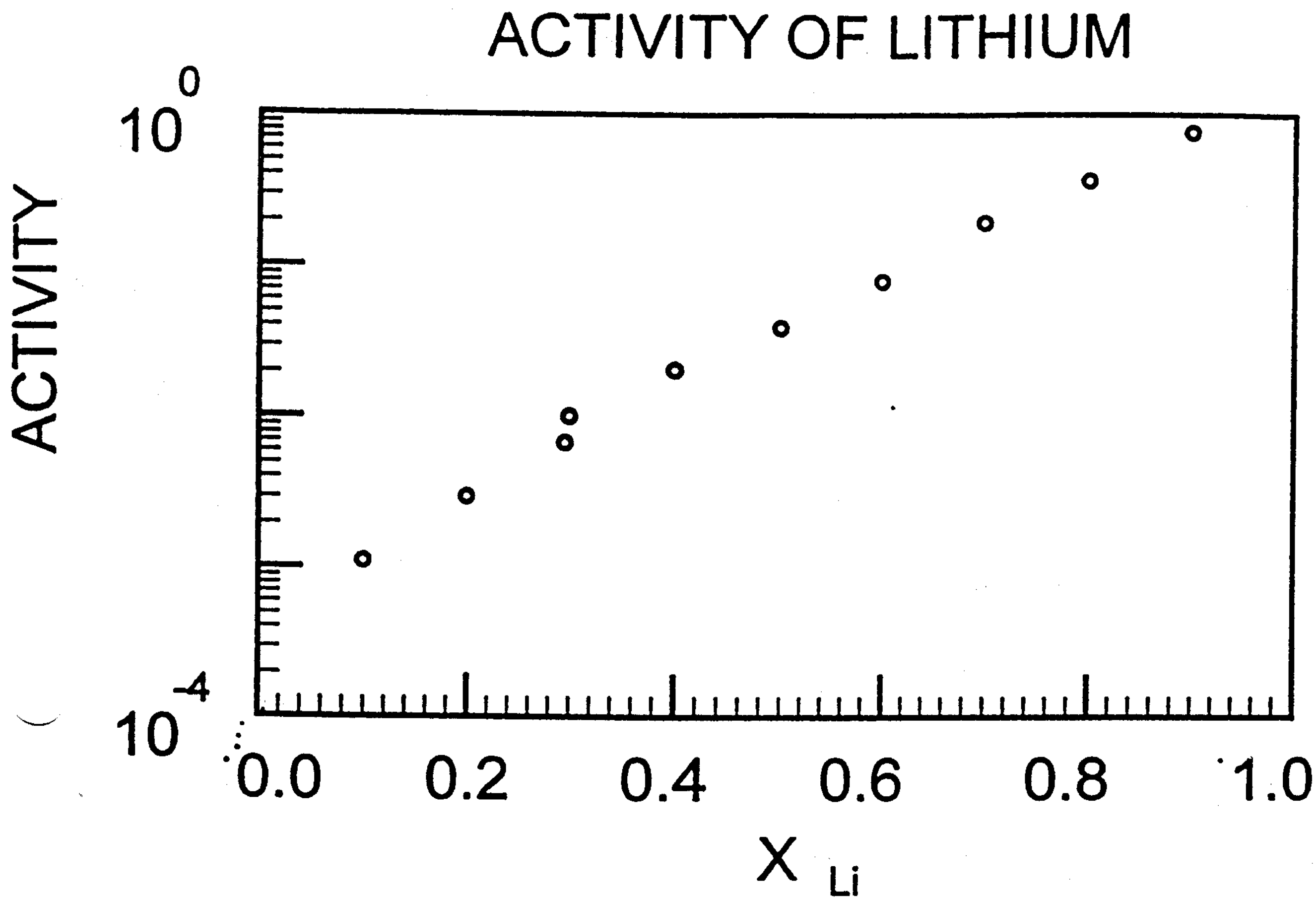
Figure 3



* Experimental data at 1200 C

References:

1. A. K. Fischer, et al, J. of Chem. and Engr. Data. 17(1972)280

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2. Zone and Material Compositions
   First Wall: 3 mm Tungsten
   Blanket: 50-70 cm, 5% W + 95% SnLi (Sn75Li25)
   Reflector: 30 cm, SS

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Total N/D-T N	1.760	1.760	1.765	1.764

5. Discussions:

- Neutron multiplication reactions in Sn and in W provide ~ 0.8 additional neutrons per D-T neutron. A Sn(n,2n) cross section of 1.52 barns at 14 MeV is assumed for these calculations.

- Neutron absorption reactions in Sn and W take away > 0.4 neutrons per D-T neutron.

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  - Low neutron absorbing structural material (such as V) is used, or
  - Neutron spectrum in the blanket is changed in favor of Li6(n,α)T reaction.

- A better understanding of neutron reaction data in Sn isotopes is needed.