APEX Study
Memorandum
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Title: Damage Rate in V.V. as a Function of Convective Layer Thickness

To: APEX Study Participants

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I. Introduction:

Preliminary calculations were performed to access the damage rate in the vacuum vessel as a function of the thickness and Li-6 contents of a Convective layer that flows poloidally from the top of the Tokamak to cover the inner surface of the V.V. The configuration conforms with the suggestion made during the last Apex meeting where the Convective layer is located inside the V.V. while the blanket is placed outside the vacuum boundary. The objectives of the analysis are:

- Evaluate the rates at which displacement, helium, and hydrogen are produced in the vacuum vessel under various configuration/material selection scenarios which has direct impact on the mechanical design/maintainability of this vacuum boundary and the blanket that follows.

-Evaluate the e-fold thickness of the Convective layer that is needed to reduce damage parameters at the V.V. by an order of magnitude.

The combination of materials studied sofar are:
(a) Convective layer: Liquid Lithium
Coolant/V.V. and Blanket structure: Liquid Lithium/V4Cr4Ti
(b) Convective layer: Flibe
Coolant/V.V. and Blanket structure: Flibe/Ferritic Steel

Analysis of the following coolant/structure combination is in progress:
Li/Ferritic steel - Li17Pb83/Ferritic Steel
Flibe/V4Cr4Ti - Li17Pb83/V4Cr4Ti
Li/SiC - Flibe/SiC - Li17Pb83/SiC

II. Calculational Model and Parameters Varied:

Figure 1 shows the 1-D calculational model used to simulate the geometrical configuration. The thickness of the Convective layer, L, varies as L = 0, 10 cm, 20 cm, 50 cm, 100 cm, and 140 cm. The inner and the outer walls of the V.V. is 4 cm-thick and a blanket of 52-thick is placed between these two walls and made of 80% coolant-20% structure. The TFC configuration is accounted for in the calculations as shown in Figure 1. A wall load of 7 MW/m2 was applied at the inner surface of the V.V. and maintained as such for all the cases considered. Natural Li was considered in the Analysis. The calculations were performed with ANISN transport code along with 46n-21g library based on FENDL/1.0 data in P5S8 approximation.

III. Results and Discussion:

The mean free path (MFP) of neutrons incident on lithium and Flibe layer is shown in Figure 2. At 14 MeV, the MFP is ~ 16 cm in Li and 7 cm in Flibe. Note that at all energies above ~ 3 eV, the MFP in lithium is much larger than those in Flibe by as much as an order of magnitude whereas at the thermal energies (below 1 eV) the MFP in lithium is a factor of ~6-8 lower than in Flibe. Thus, the lithium layer is much *more "transparent" to high-energy neutrons and much less "transparent" to low-energy neutrons* as compared to the Flibe. These features have direct impact on the total neutron flux, the dpa, he-4, and h production rates in the walls of the V.V.

At 7 MW/m2 wall load, the neutron flux at the inner wall of the V.V. is shown in Figure 3 as a function of the thickness of the Convective layer. At bare wall case (L= 0 cm), the flux with the Flibe/FS combination is slightly larger than the case of Li/V combination (4 x 10^{15} n/cm2/sec). As L increases, the flux decreases with much larger rate in the case of the Flibe/FS as compared to the Li/V case. The neutron spectrum at this location is shown in Figures 4 for L= 50 cm. As shown, the low-energy neutrons (below 1 eV) is ~ 4 orders of magnitude less in the Li/V case than in Flibe/FS case. However, since lithium has much larger MFP for high-energy neutrons, this neutron component (which dominates the total flux) is much larger in the Li/V case, particularly for thick Convective layers as shown in Figure 4.

The maximum rate of DPA, he4, and hydrogen production in the inner wall of the V.V. are shown in Figures 5, 6, and 8, respectively. Because the DPA cross-

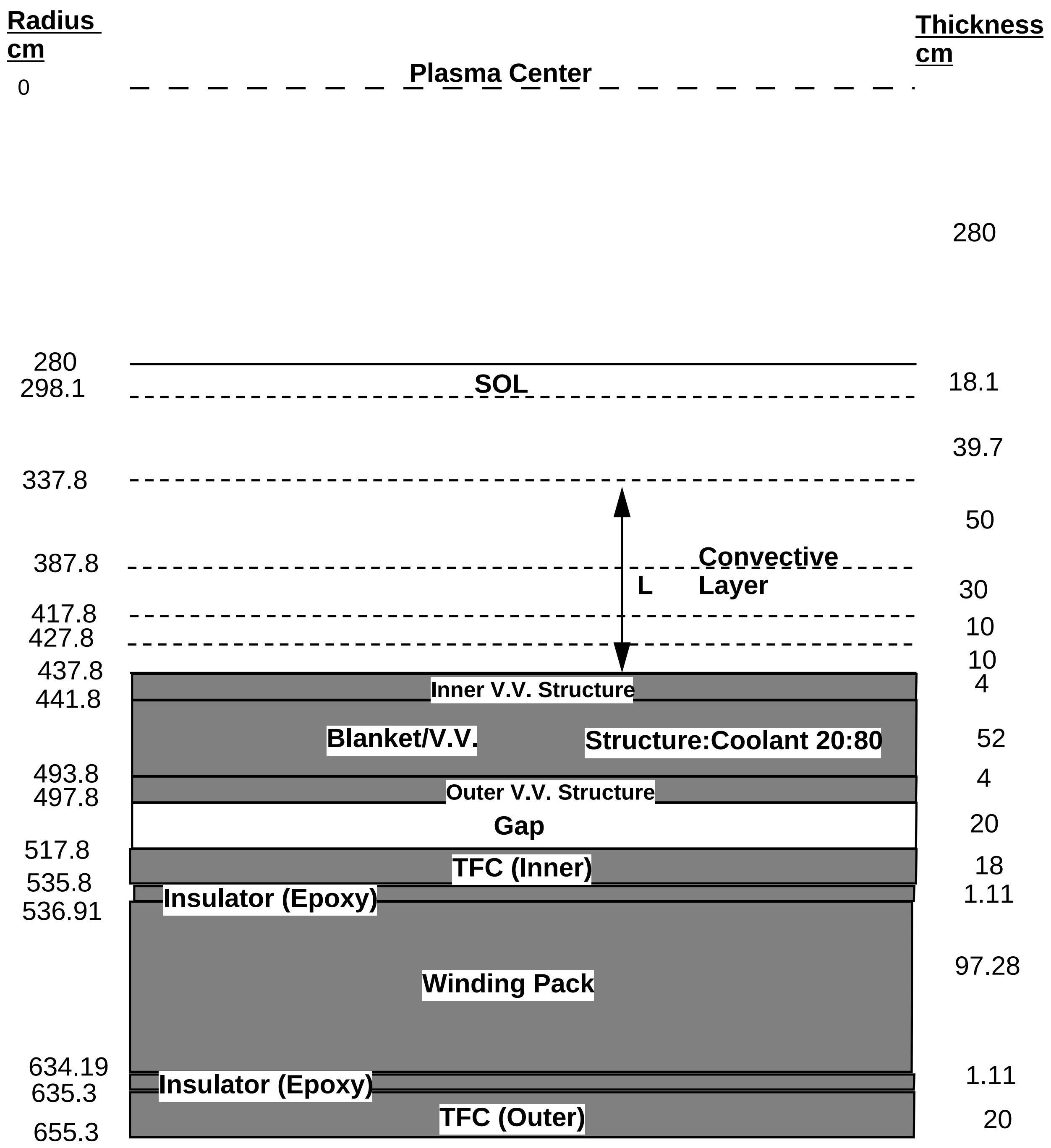


Fig. 1: One-Dimensional Geometrical Model (Cylinder)

Fig. 2: Mean Free Path of Neutrons as a Function of Energy in Lithium, Flibe, and Li17Pb83

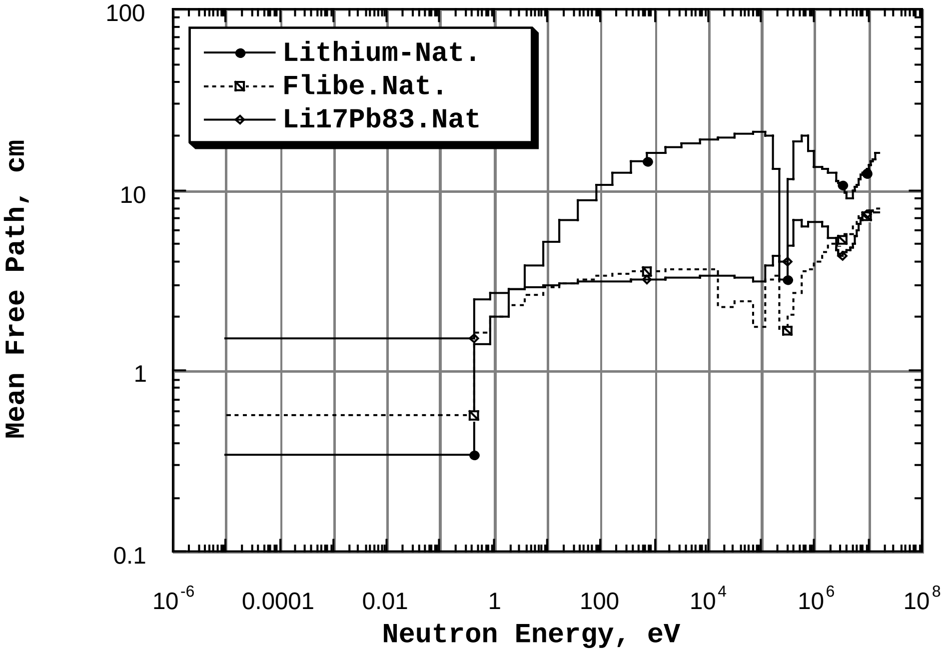


Fig.3: Total Neutron Flux at the Inner Surface of the Vaccum Vessel

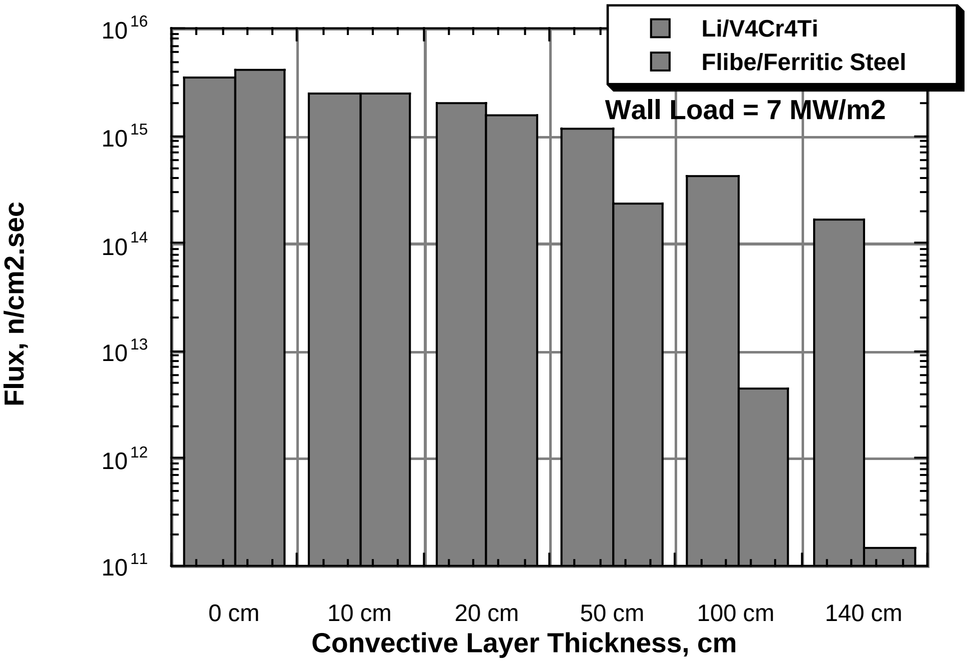
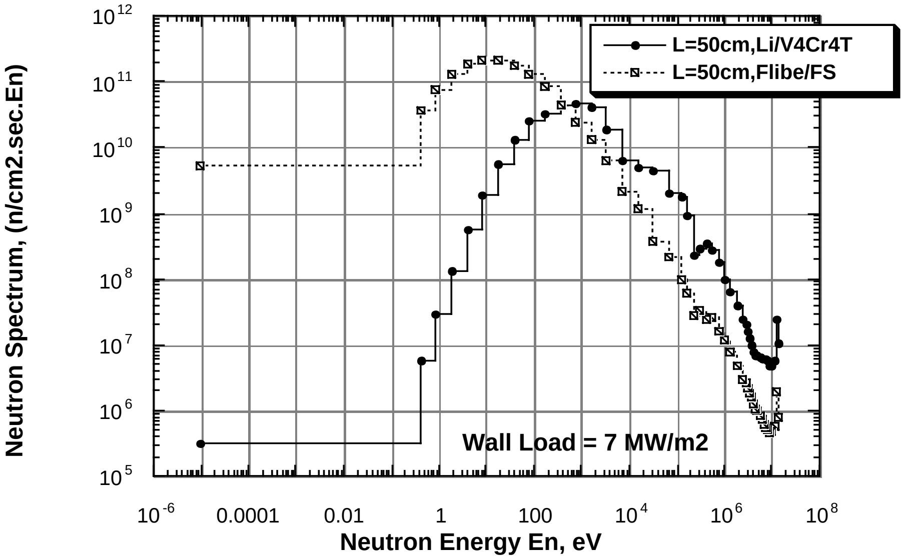


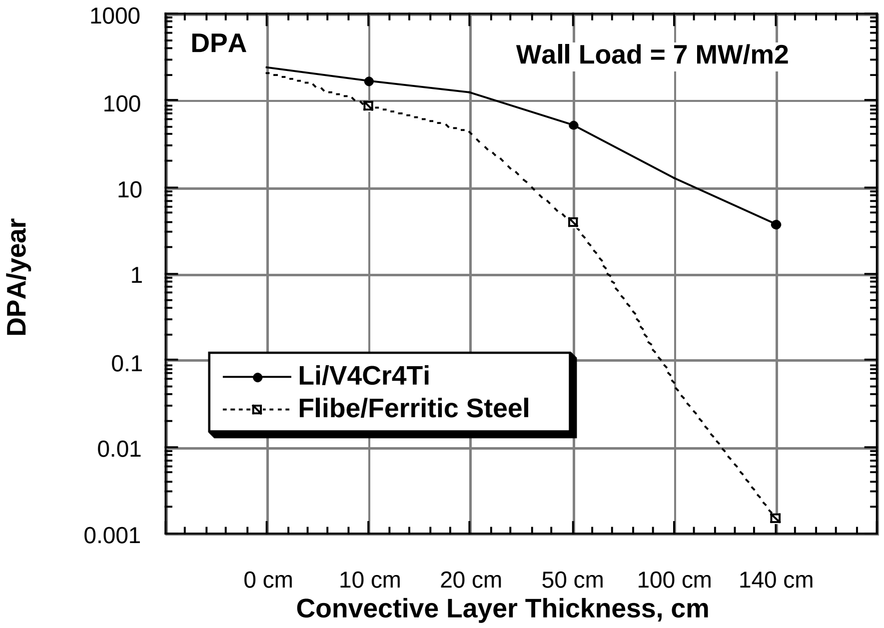
Fig.4: Neutron Spectrum at the Inner Surface of the Vaccum Vessel



section in vanadium is slightly larger than that of Fe, the DPA rate in Li/V case is also slightly larger than in the case of Flibe/FS at L= 0 cm.

The difference however gets much larger as the thickness of the Convective layer increases due to the large values of the total flux in the Li/V case as compared to the Flibe/FS case. These features are similar in the hydrogen

Fig. 5: Maximum Rate of Displacement per Atom in the Vacuum Vessel Versus Convective Layer Thickness



production rate as can be seen from Figure 8. As for the helium production rate, the damage rate is less in the Li/V case for thinner Convective layer thickness (L < ~40 cm) due to the much lower he4-production cross-section in vanadium as compared to Fe. At larger L (> 40 cm), the impact of larger total neutron flux in the Li/V case dominates the effect of differences in the cross-section and the he4 production rate gets larger in Li/V case for L = 50, 100, and 140 cm, as shown in Figure 6. The ratio of DPA to He-4 production is shown in Figure 7. As shown, this ratio can be as large as 4.8 in the case of Li/V4Cr4Ti case at L = 140 cm due to the rather large value of DPA rate at that thickness whereas this ratio is more or less constant and lower than unity (~ 0.4) in the case of Flibe/FS.

Fig. 6: Maximum Rate Helium Production in the Vacuum Vessel Versus Convective Layer Thickness

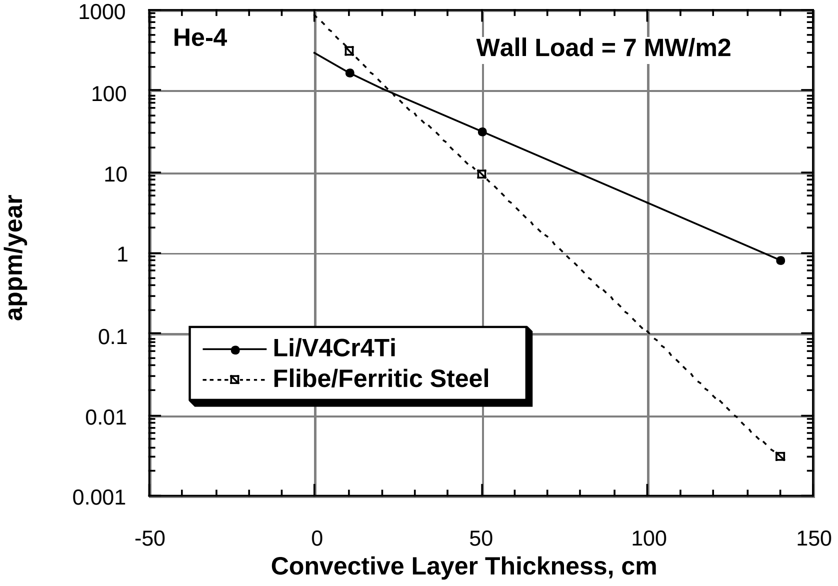


Fig. 7: Ratio of Displacement per Atom To He-4 Production Rate in the Vacuum Vessel Versus Convective Layer Thickness

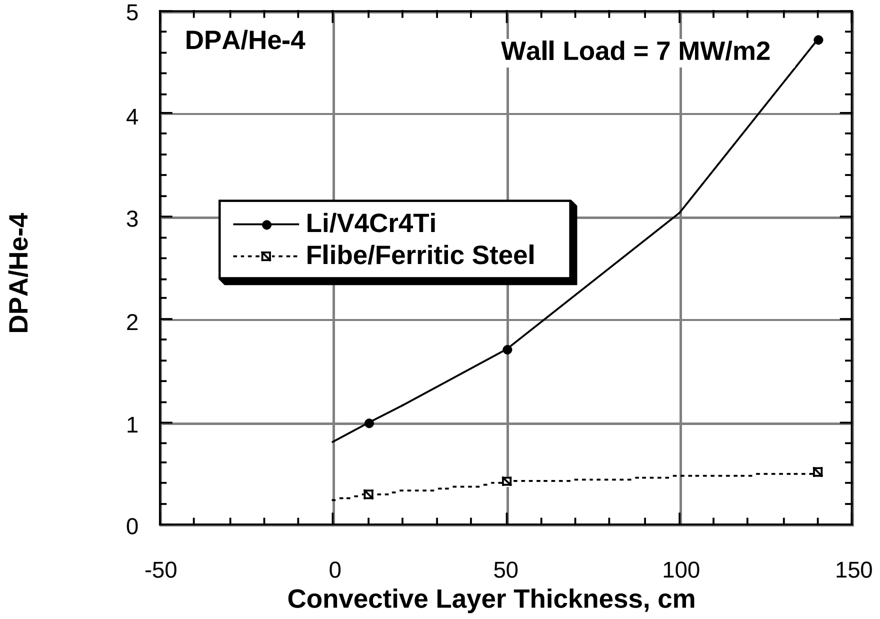
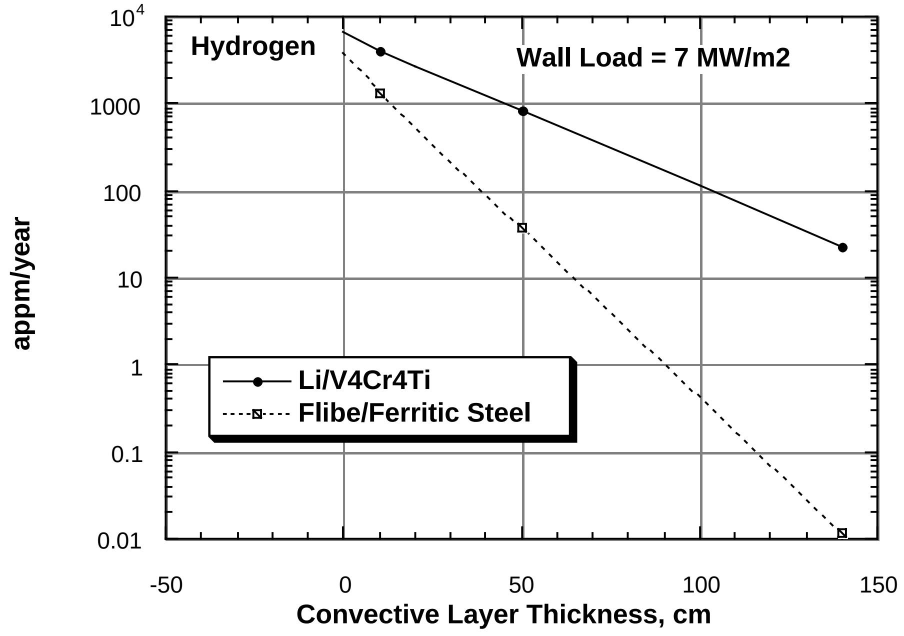


Fig. 8: Maximum Rate ofHydrogen Production in the Vacuum Vessel Versus Convective Layer Thickness



Base on the above results, estimates were made to the e-fold thicknesses of the Convective layer for the various responses considered. The e-fold thickness is defined as the required thickness of the layer that results in an order of magnitude reduction in the response under consideration. These estimates vary, depending on the thickness of the Convective layer at which these estimates are derived.

Figures 9-12 give the e-fold thickness of the Convective layer for the total neutron flux, dpa, he4, and h production rate, respectively. In all responses, the e-fold thickness (EFT) is much larger for lithium as compared to Flibe. Also, the values of the EFT at larger L are more representative than those derived from thinner L. These estimates are listed in Table I.

Fig. 9: Required e-fold thickness of Convective layer to reduce Total Neutron Flux at the V.V. by an Order of Magnitude

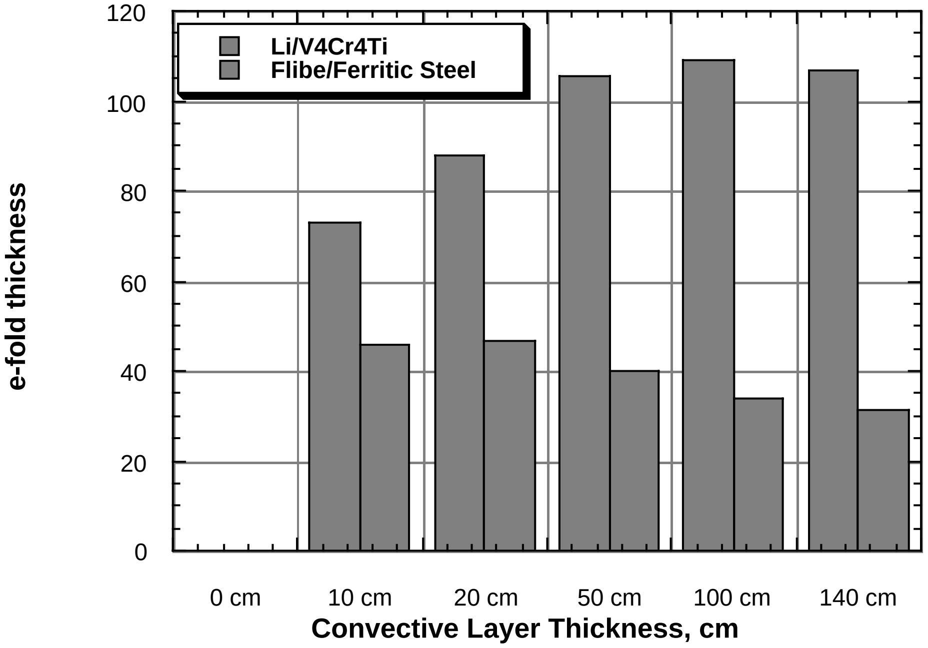


Fig. 10: Required e-fold thickness of Convective layer to reduce DPA rate at the V.V. by an Order of Magnitude

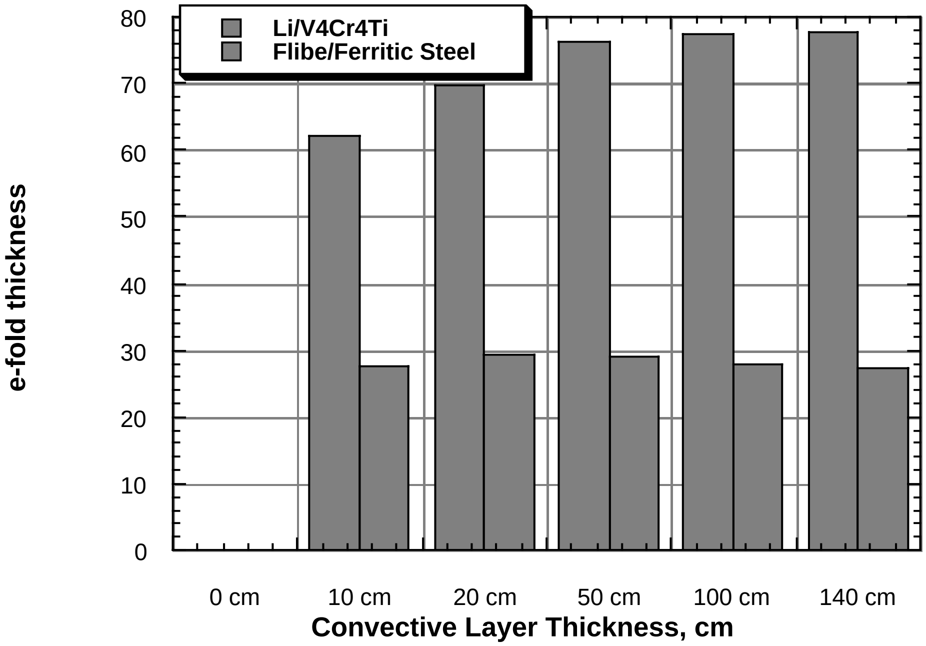


Fig. 11: Required e-fold thickness of Convective layer to reduce Helium Production rate at the V.V. by an Order of Magnitude

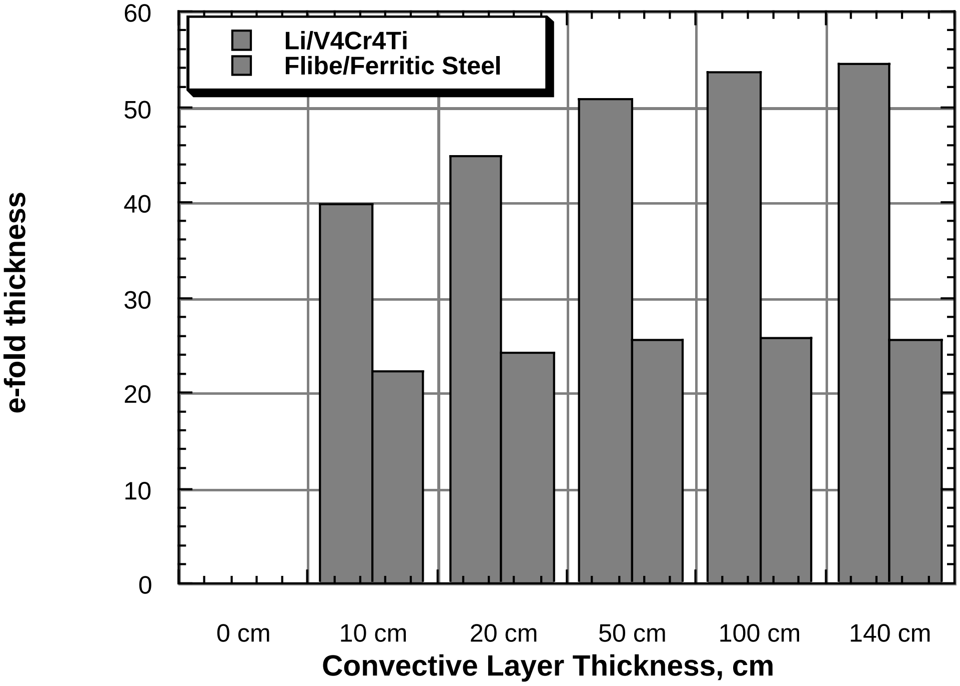


Fig. 12: Required e-fold thickness of Convective layer to reduce Hydrogen Production rate at the V.V. by an Order of Magnitude

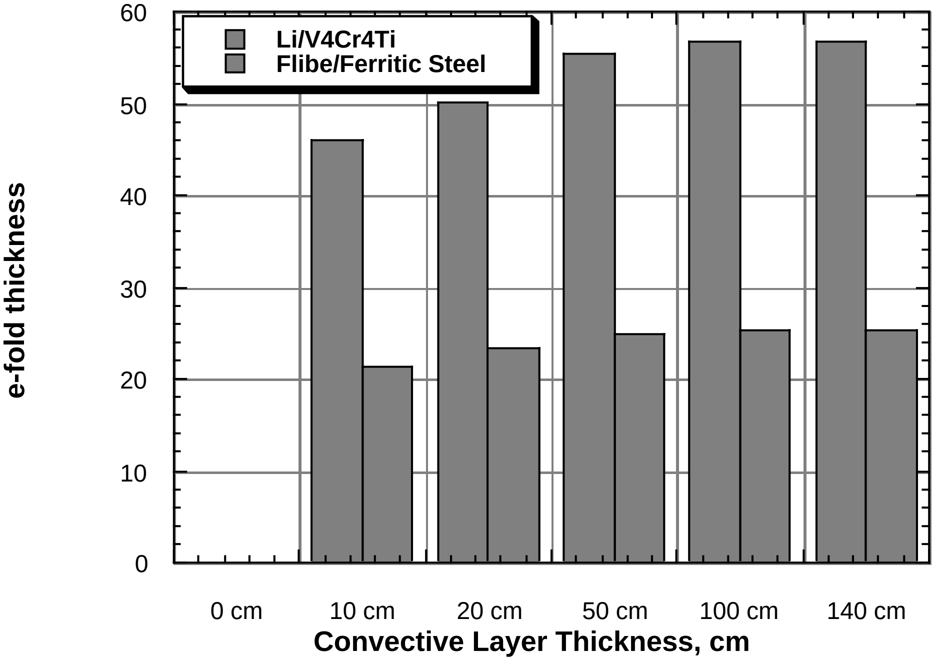


Table I: Estimates of the e-fold thickness of the Convective Layer of Lithium and Flibe for Various Nuclear and Damage responses

	Li/V4Cr4Ti	Flibe/Ferritic Steel
Total neutron flux	~ 105 cm	~ 30 cm
DPA Rate	~ 78 cm	~ 28 cm
Helium Production Rate	~ 54 cm	~ 26 cm
Hydrogen Production rate	~ 56 cm	~ 25 cm

While the e-fold thickness of the Flibe is confined between the values of 25-30 cm for all the responses, it varies in the case of lithium to be as low as ~ 56 cm for H-production rate and as high as ~ 105 cm for the total neutron flux.