Damage Rate in V.V. as a Function of Convective Layer Thickness

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Objectives

- In the configuration suggested during the last Apex meeting where the Convective layer is located inside the V.V. while the blanket is placed outside the vacuum boundary, assess the damage rate in the vacuum vessel as a function of:

  - Type of the Convective layer / structure material
  - Thickness of the Convective layer
  - Li-6 enrichment in the Convective layer

- Damage assessed in terms of 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 the concepts considered.

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

Objectives
(Cont'd)

- The combination of materials studied are:

(a) Convective layer: Lithium
Coolant / V.V. and Blanket structure: 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

Calculational Model

- 1-D calculational model used to simulate the geometrical configuration.
- 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
- 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.
- Calculations performed with ANISN transport code along with 46n-21g library based on FENDL/1.0 data in P5S8 approximation.

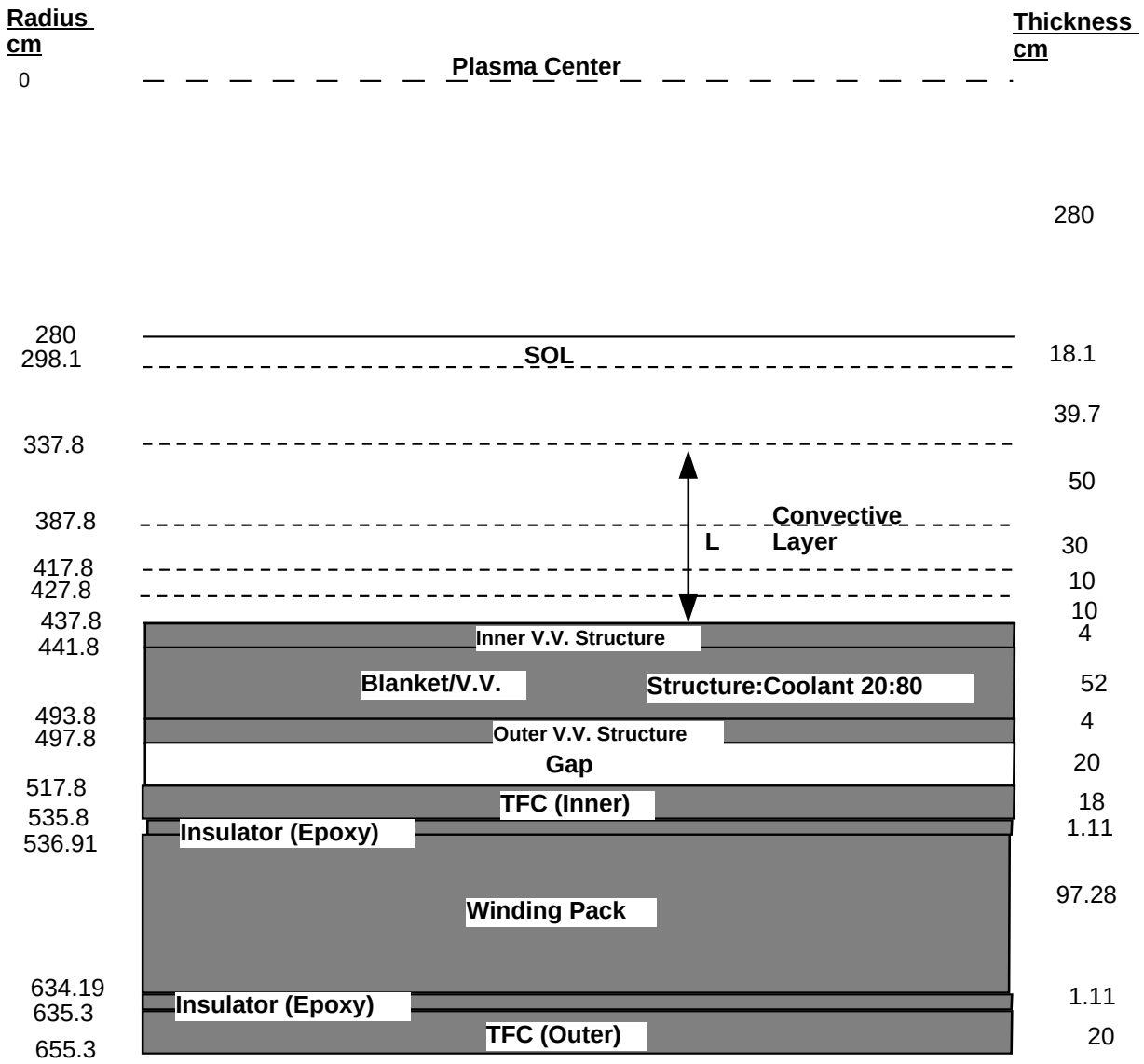


Fig. 1: One-Dimensional Geometrical Model (Cylinder)

Results and Discussion

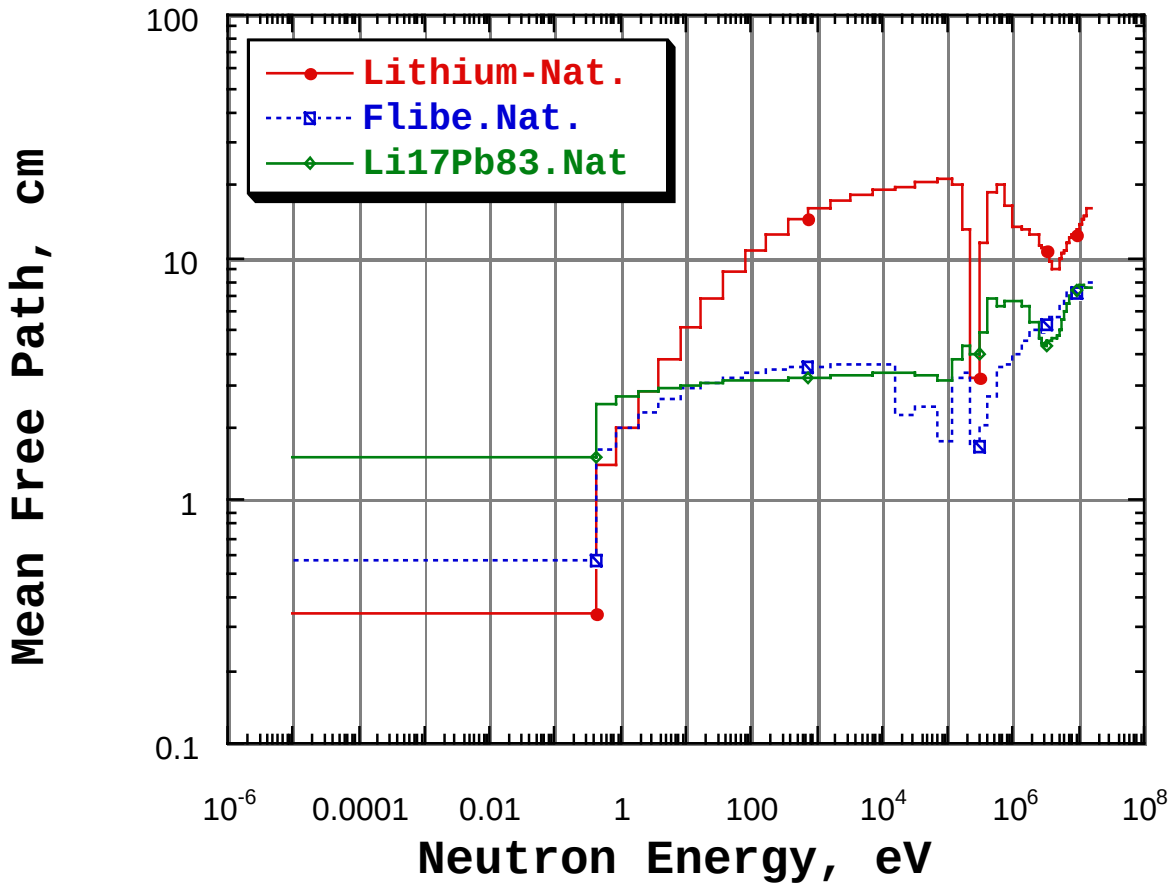
- Neutron Mean Free Path (MFP) and Spectrum

  - At 14 MeV, the MFP is ~ 16 cm in Li and 7 cm in Flibe.

  - At all energies above ~ 3 eV, the MFP in lithium is larger than those in Flibe by as much as an order of magnitude . At thermal energies (below 1 eV) the MFP in lithium is a factor of ~6-8 lower than in Flibe.

  - 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.

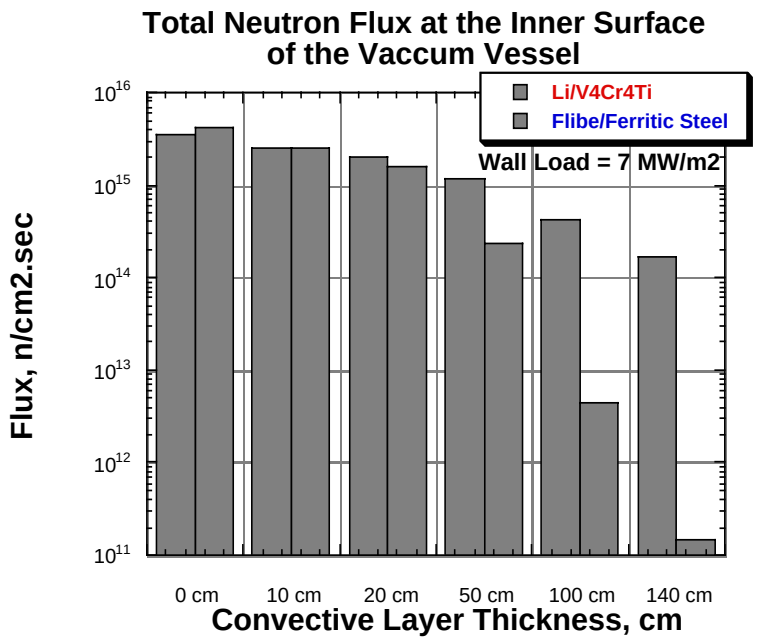
Mean Free Path of Neutrons as a Function of Energy in Lithium, Flibe, and Li17Pb83

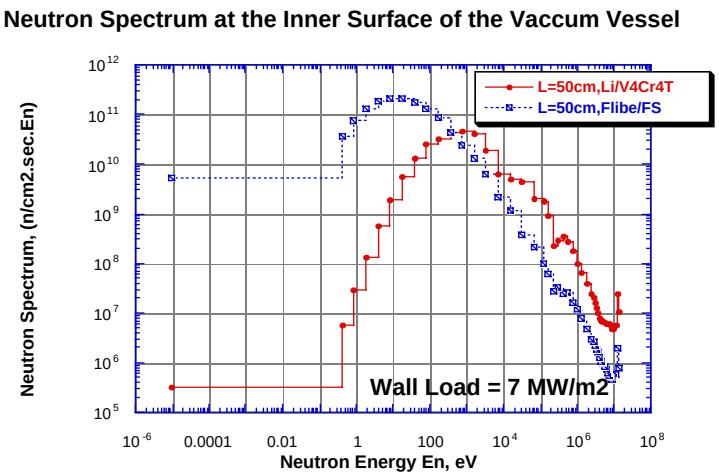


- Neutron Mean Free Path (MFP) and Spectrum (Cont'd)

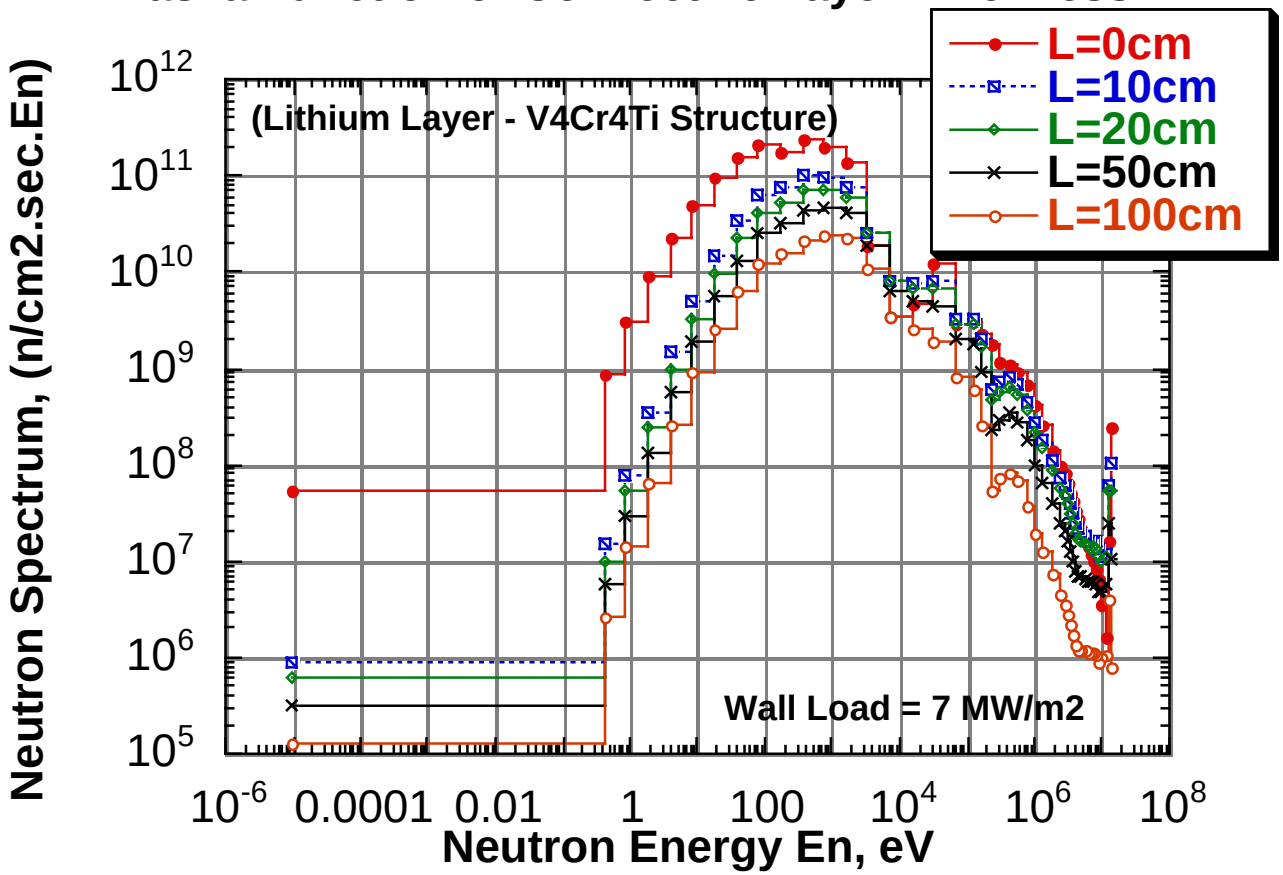
  - At a bare wall case (L=0 cm) and 7 MW/m2 wall load, the total neutron flux with the Flibe/FS combination is slightly larger than the case of Li/V. As L increases, the flux decreases with much larger rate in the case of the Flibe/FS as compared to the Li/V case.

  - For L= 50 cm, 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.

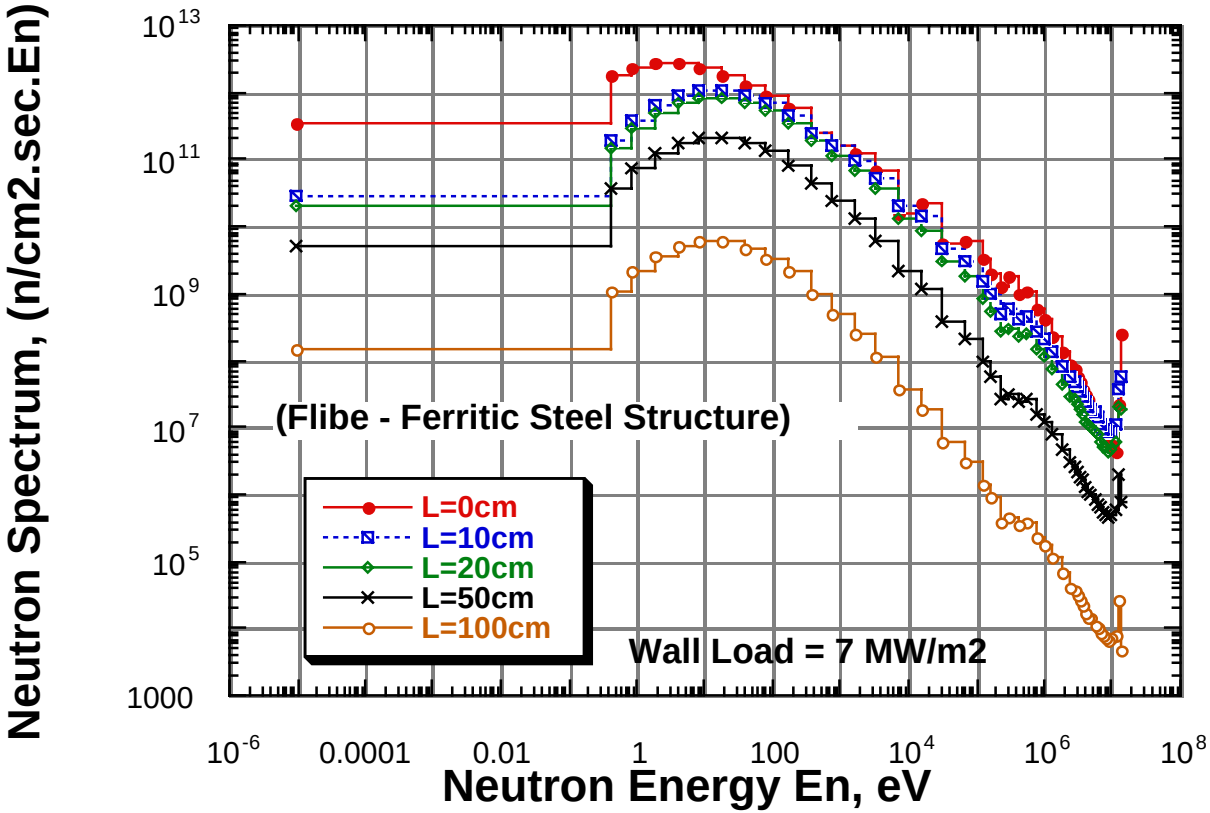

Total Neutron Flux at the Inner Surface of the Vaccum Vessel
Li/V4Cr4Ti
Flibe/Ferritic Steel
Wall Load = 7 MW/m2
Flux, n/cm2.sec
10^16
10^15
10^14
10^13
10^12
10^11
0 cm
10 cm
20 cm
50 cm
100 cm
140 cm
Convective Layer Thickness, cm


Neutron Spectrum at the Inner Surface of the Vaccum Vessel
L=50cm,Li/V4Cr4T
L=50cm,Flibe/FS
Wall Load = 7 MW/m2
Neutron Spectrum, (n/cm2.sec.En)
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^-6
0.0001
0.01
1
100
10^4
10^6
10^8
Neutron Energy En, eV

Neutron Spectrum at the Inner Surface of the Vaccum Vessel as a Function of Convective Layer Thickness



Neutron Spectrum at the Inner Surface of the Vaccum Vessel as a Function of Convective Layer Thickness



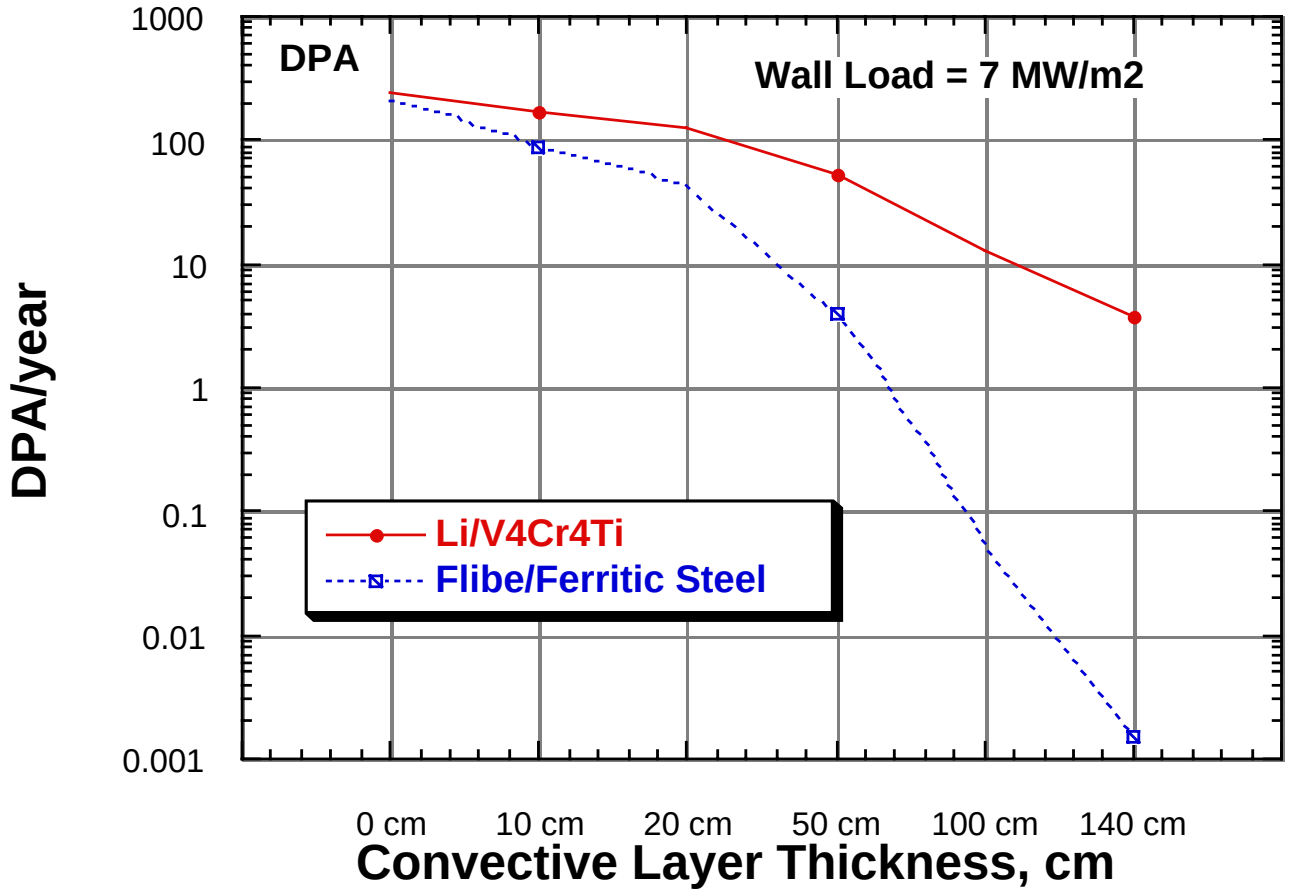
DPA, Helium, and Hydrogen Production

- Because the DPA cross-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.

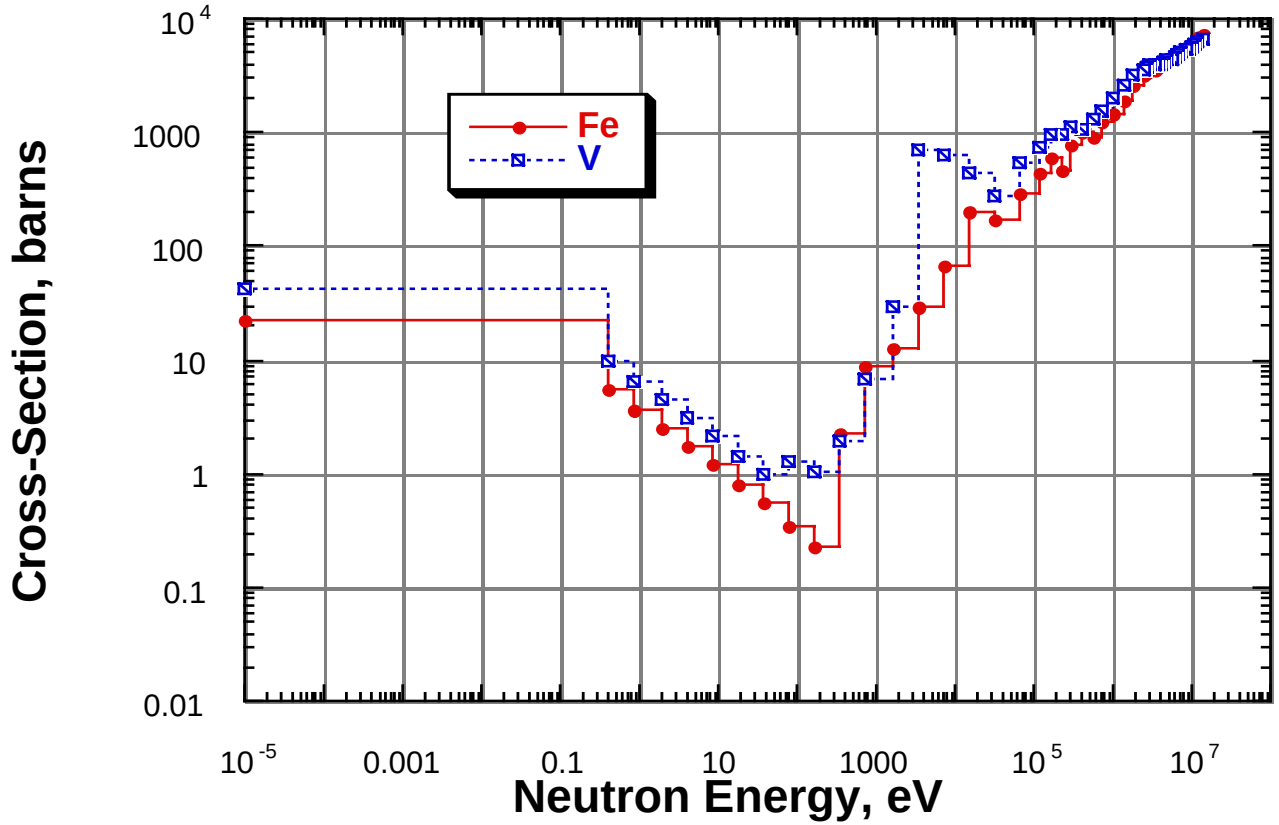
- The difference however gets much larger as the thickness of the Convective layer increases due to the large values of the total flux in the Li/V case as compared to the Flibe/FS case.

- These features are similar for the hydrogen production rate.

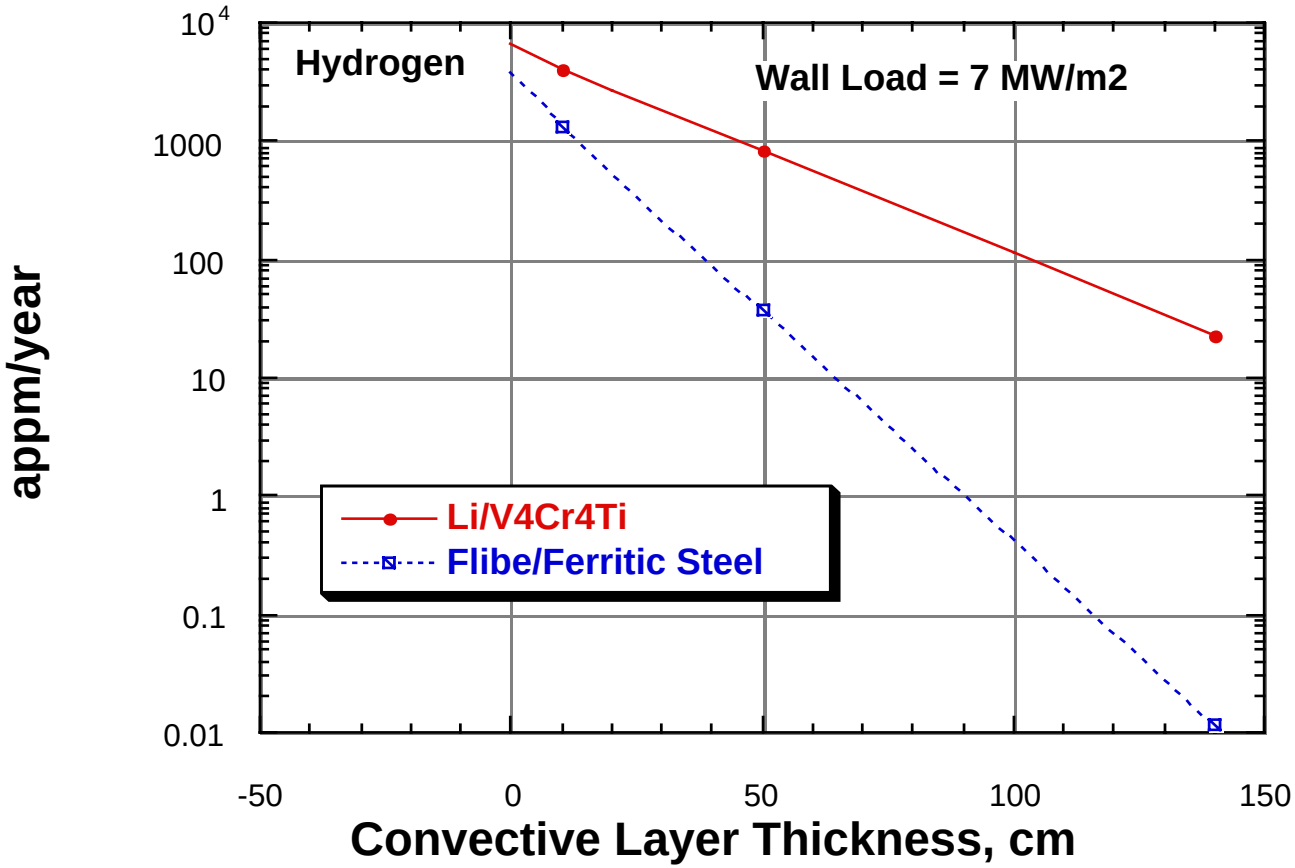
Maximum Rate of Displacement per Atom in the Vacuum Vessel Versus Convective Layer Thickness



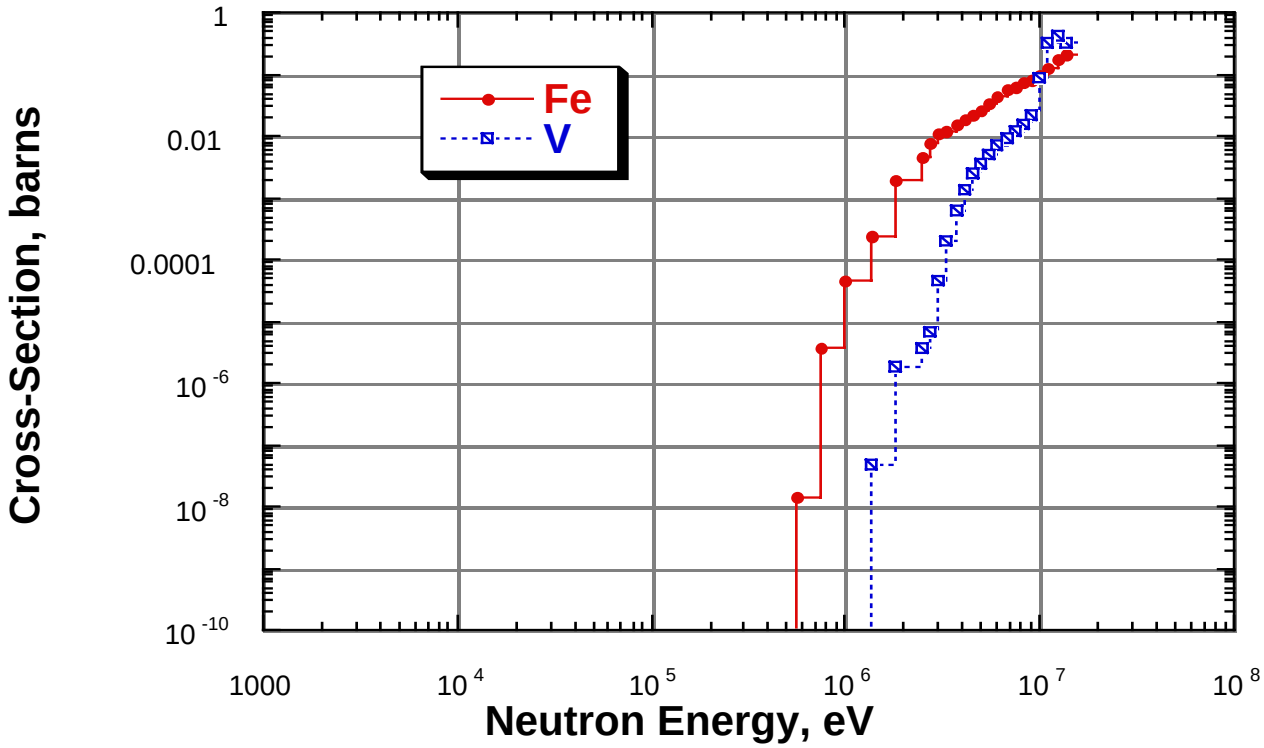
DPA Cross-Section of Several Materials



Maximum Rate of H Production in the Vacuum Vessel Versus Convective Layer Thickness



Hyrogen Production Cross-Section of Several Materials



DPA, Helium, and Hydrogen Production (Cont'd)

- The helium production 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.

- The ratio He-4/DPA is :

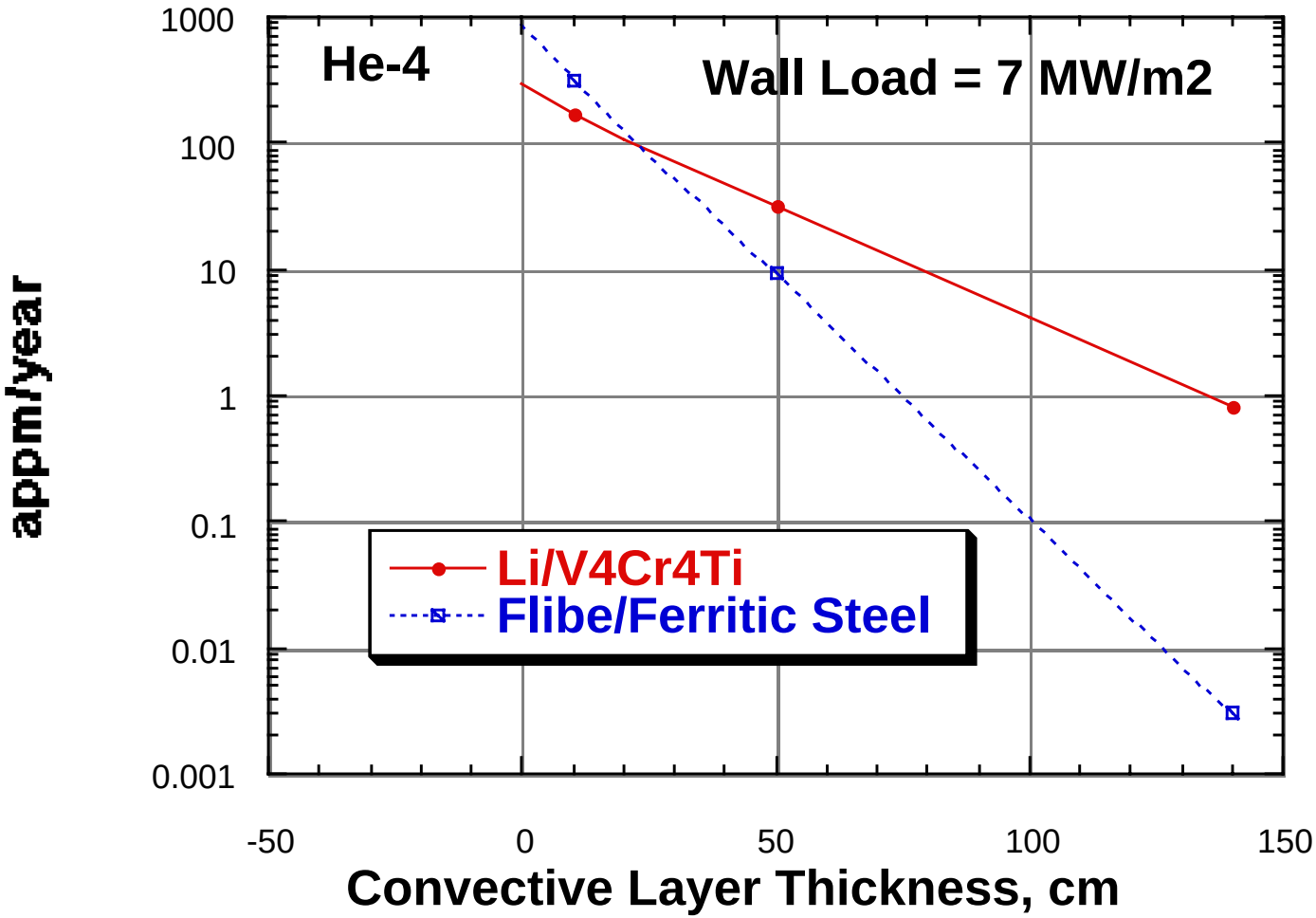
	Bare Wall (L=0 cm)	Layer L=10 cm
Li/V4Cr4Ti	1.2	1.0
Flibe/FS	4.3	3.5

i.e. reduction by ~17% (Li/V) and ~ 19% for inclusion of 10 cm-thick convective layer

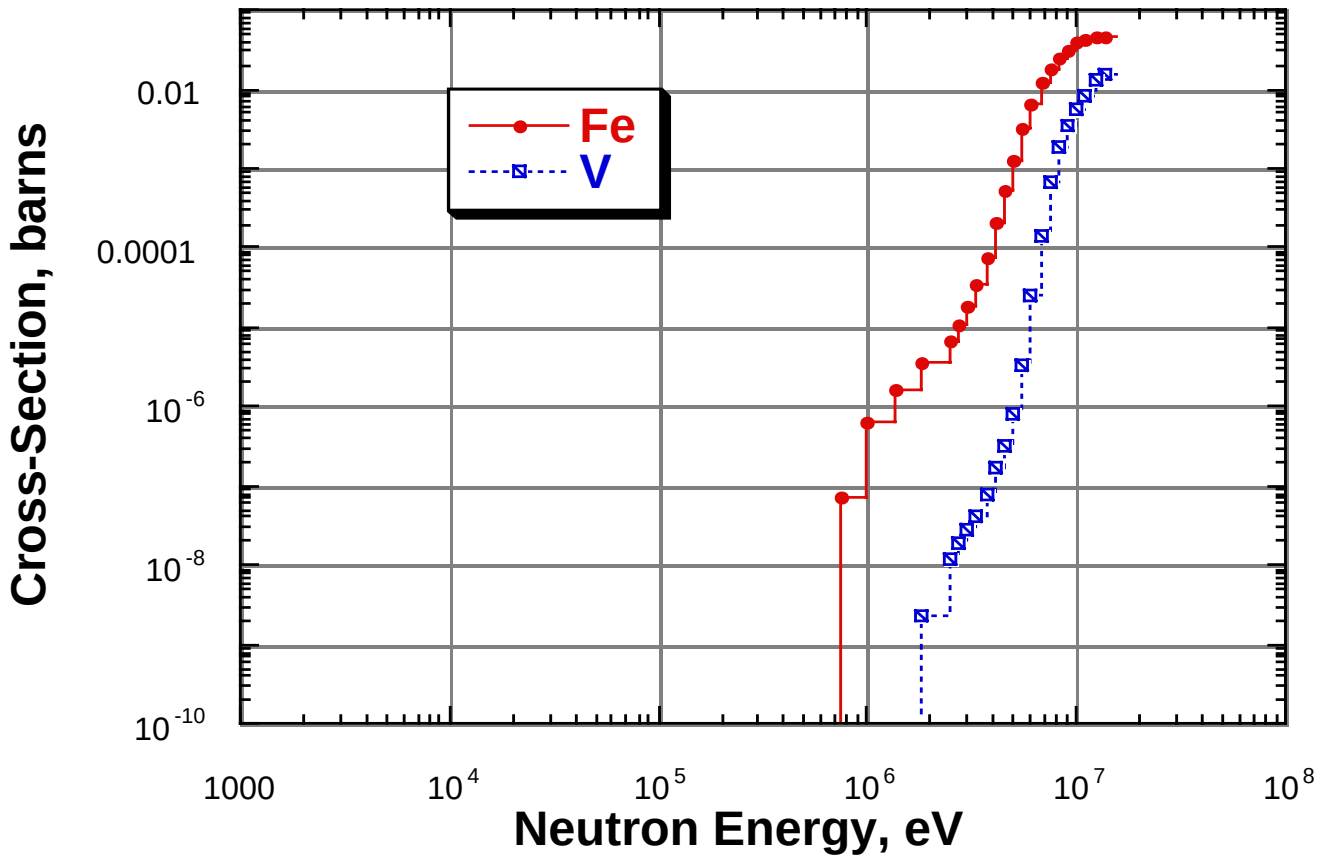
- *Normally the ratio He-4/DPA is ~ 10 in a bare FS FW/water case. Here, the corresponding value of 4.3 is rather small for FS FW/Flibe case because of the larger moderation power of Flibe (lower He-4 rate)*

- *As L= increases, the He-4/DPA ratio approaches values found in fission reactors (much less damage rates)*

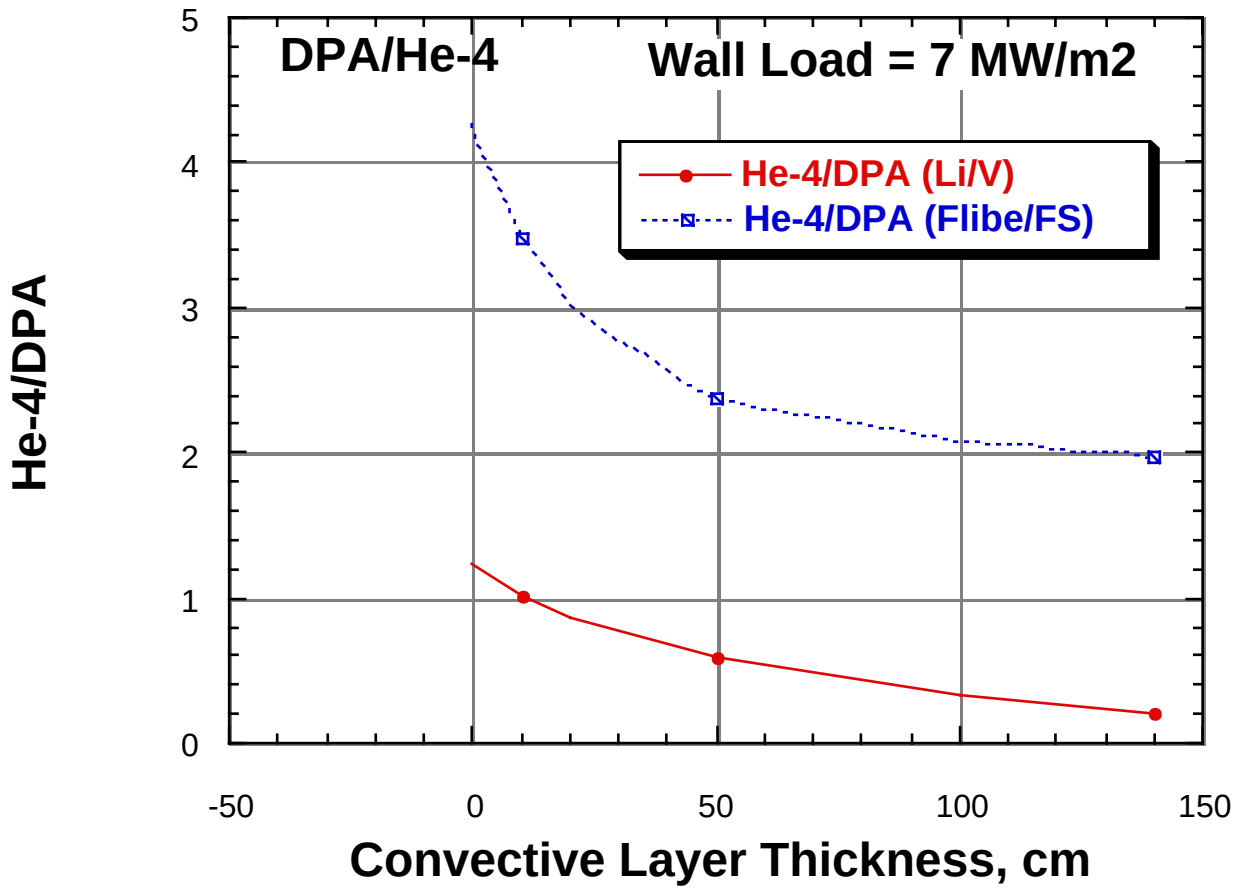
Maximum Rate of He-4 Production in the V.V. Versus Convective Layer Thickness



Helium Production Cross-Section of Several Materials



Ratio of He-4/DPA in the V.V. Versus Convective Layer Thickness



e-fold Thicknesses of the Convective Layer for the Various Responses

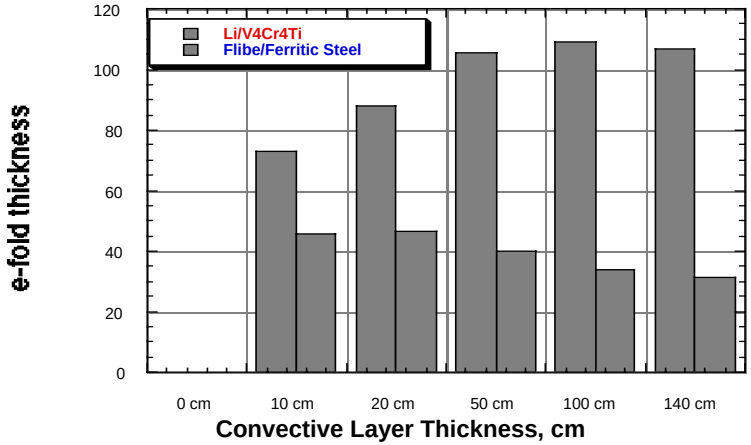
- The e-fold thickness is defined as the required thickness, Le, of the layer that results in an order of magnitude reduction in the response, R, under consideration. It is given by:

$$L_e = \frac{\ln 0.1}{\ln \frac{R_x}{R_o}} \cdot x$$

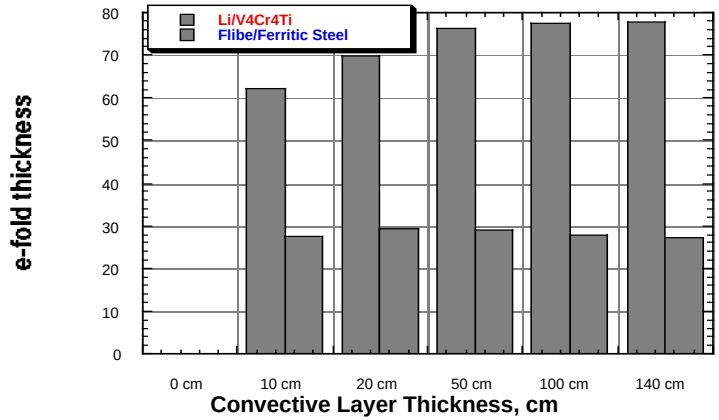
x = Layer thickness at which Le is estimated,
Rx = Response in V.V. with Layer thickness L=x cm
Ro = response at bare wall (L=0 cm)

- 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.

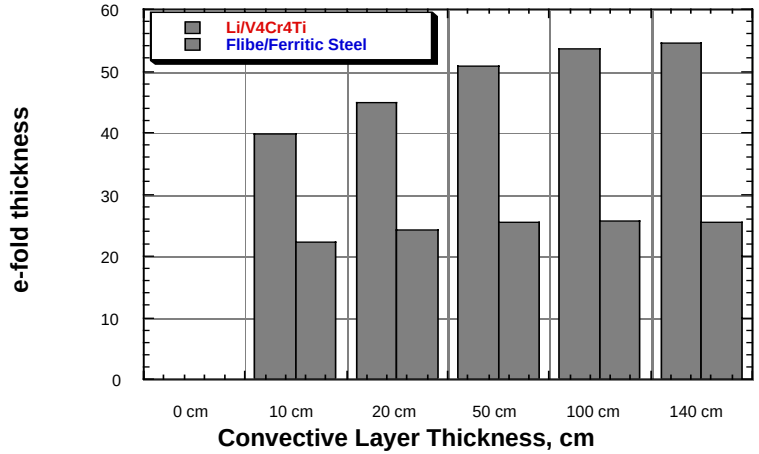
Required e-fold thickness of Convective layer to reduce Total Neutron Flux at the V.V. by an Order of Magnitude



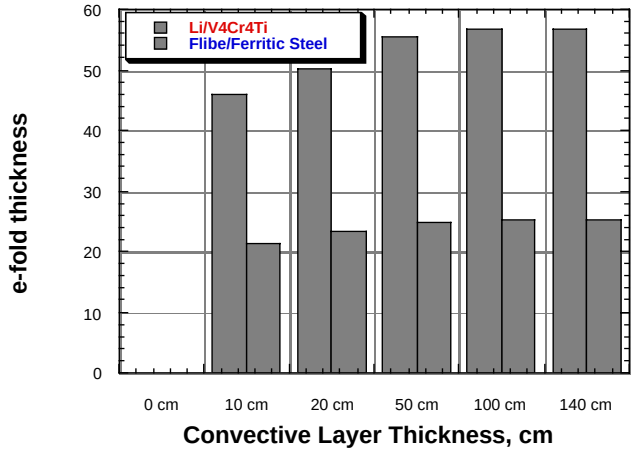
Required e-fold thickness of Convective layer to reduce DPA rate at the V.V. by an Order of Magnitude



Required e-fold thickness of Convective layer to reduce He-4 Production rate at the V.V. by an Order of Magnitude



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



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.