Displacements per $\frac{MW}{m^2}$

Definition of dpa (displacements per atom) is the number of times that an atom is displaced for a given fluence.

$$\frac{N_d}{N_o} = \varphi t \sigma_d$$

Example of 1 $\frac{MW}{m^2}$

$$\varphi = 4.43x10^{13} \frac{n}{cm^2 - s}$$

$$\sigma_d = 3{,}000b$$

$$\frac{N_d}{N_o t} = 4.43x10^{13} \bullet 3x10^{-21}$$

$$= 1.3x10^{-7} \frac{dpa}{s}$$

$$\approx 4 \frac{dpa}{FPY}$$

Damage Rate in CTR materials	
Material	**dpa/FPY per MW/m^2**
316 SS	10
V	12
Mo	8
SiC	30
Al	17

Embrittlement

- Loss of ductility due to helium collecting at grain boundaries.

- Try to keep the uniform elongation > 1%

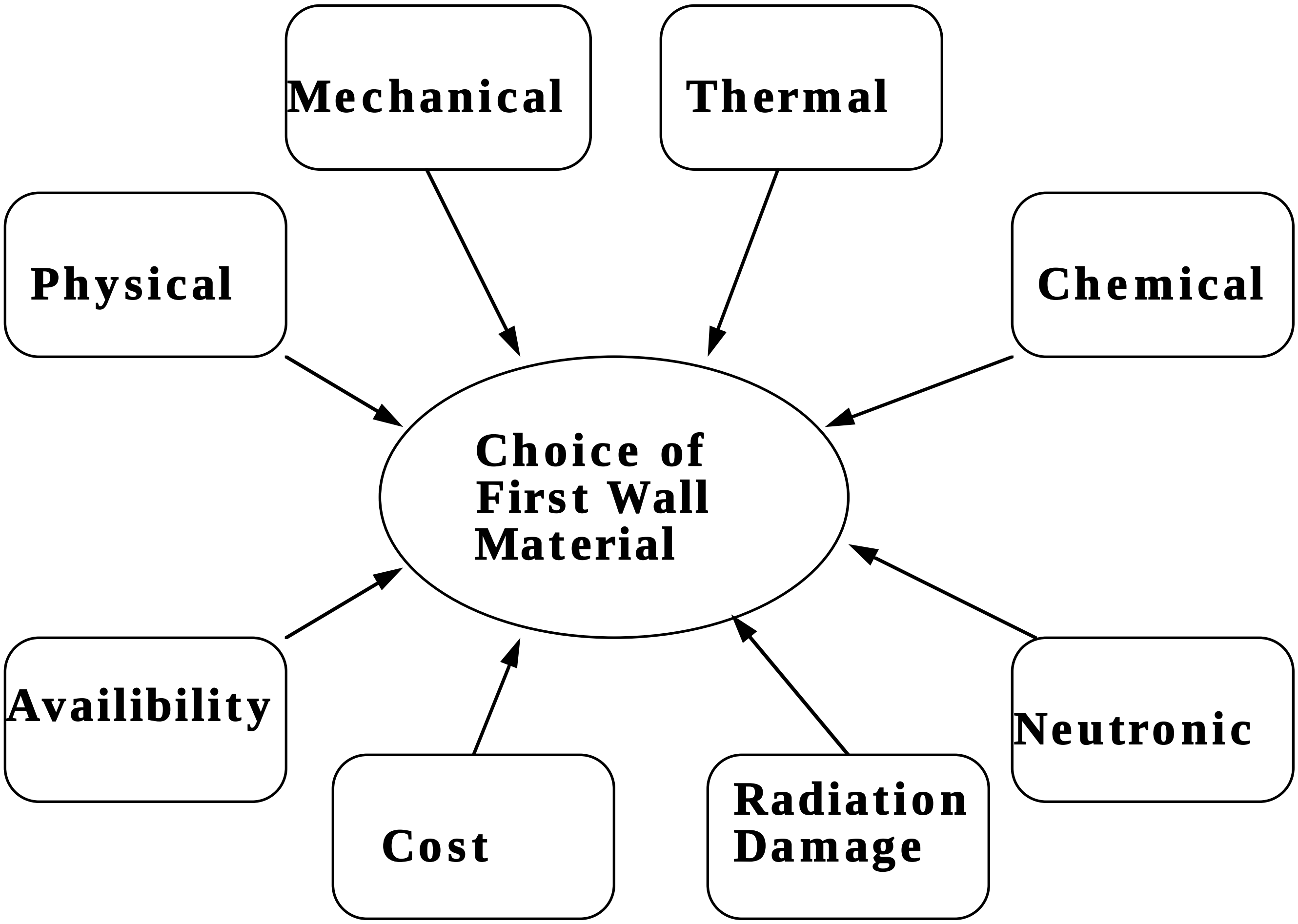
- In ferritic steels, the shift in the ductile to brittle transition temperature is the important thing.

(Figures)

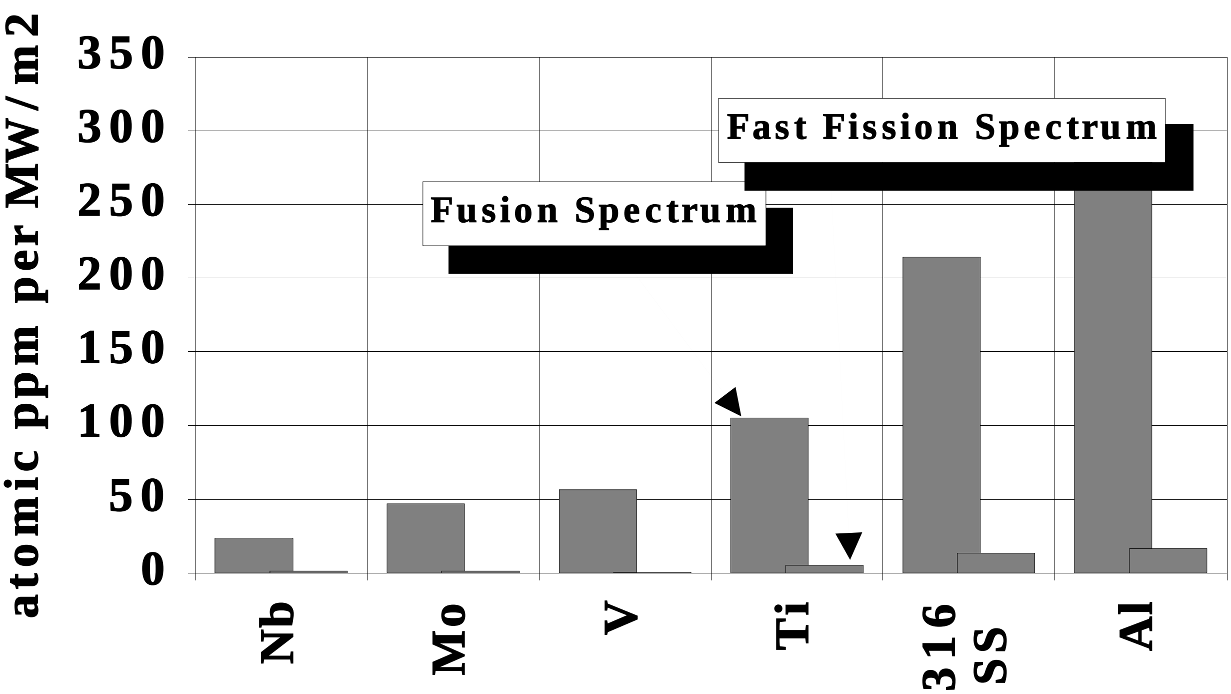
Overall Conclusions

- In DT devices , displacement and transmutation effects will limit useful lifetimes to a few full power years. Hence replacement of the FW, blanket, components will have to be done on a regularly scheduled basis.

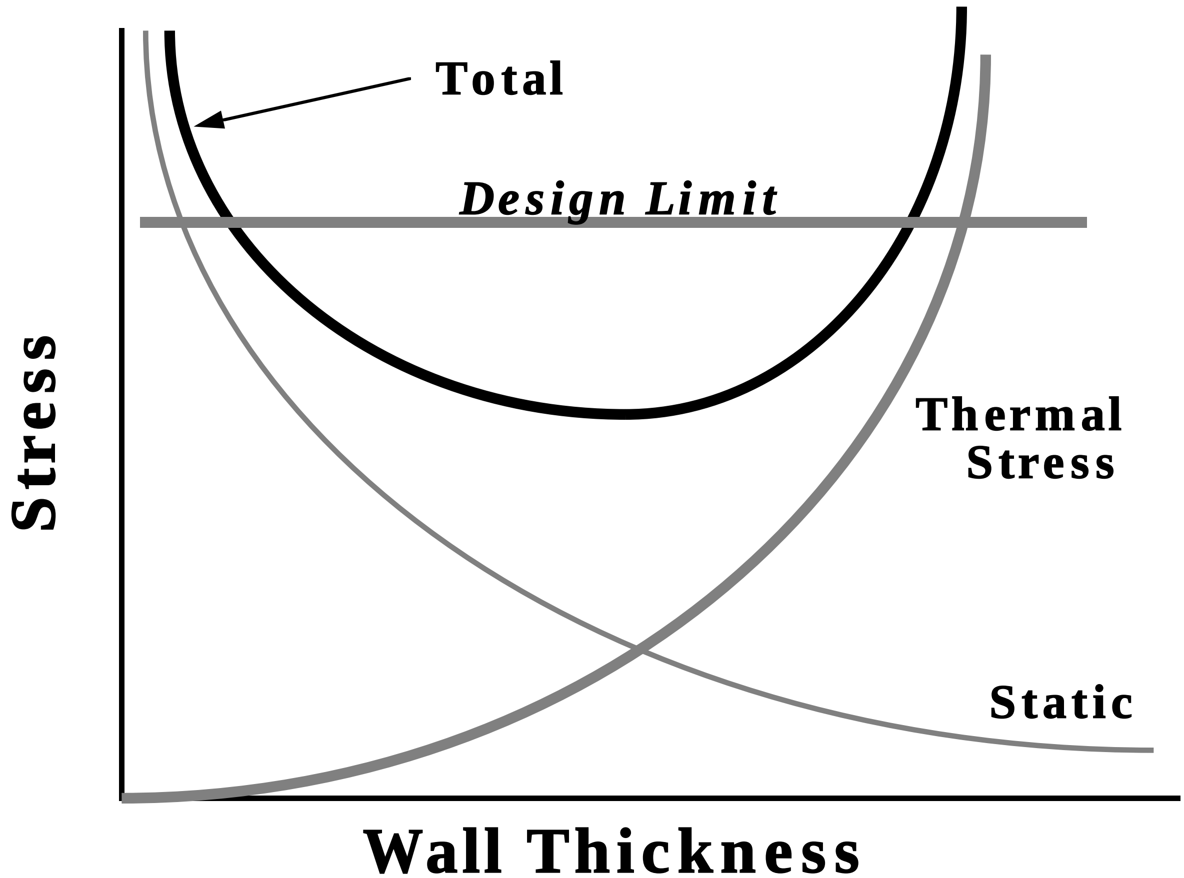
- Use of advanced fuels will drop the neutron wall loading by a factor of ≈ 30 which means that the structural materials can last for the life of the reactor.

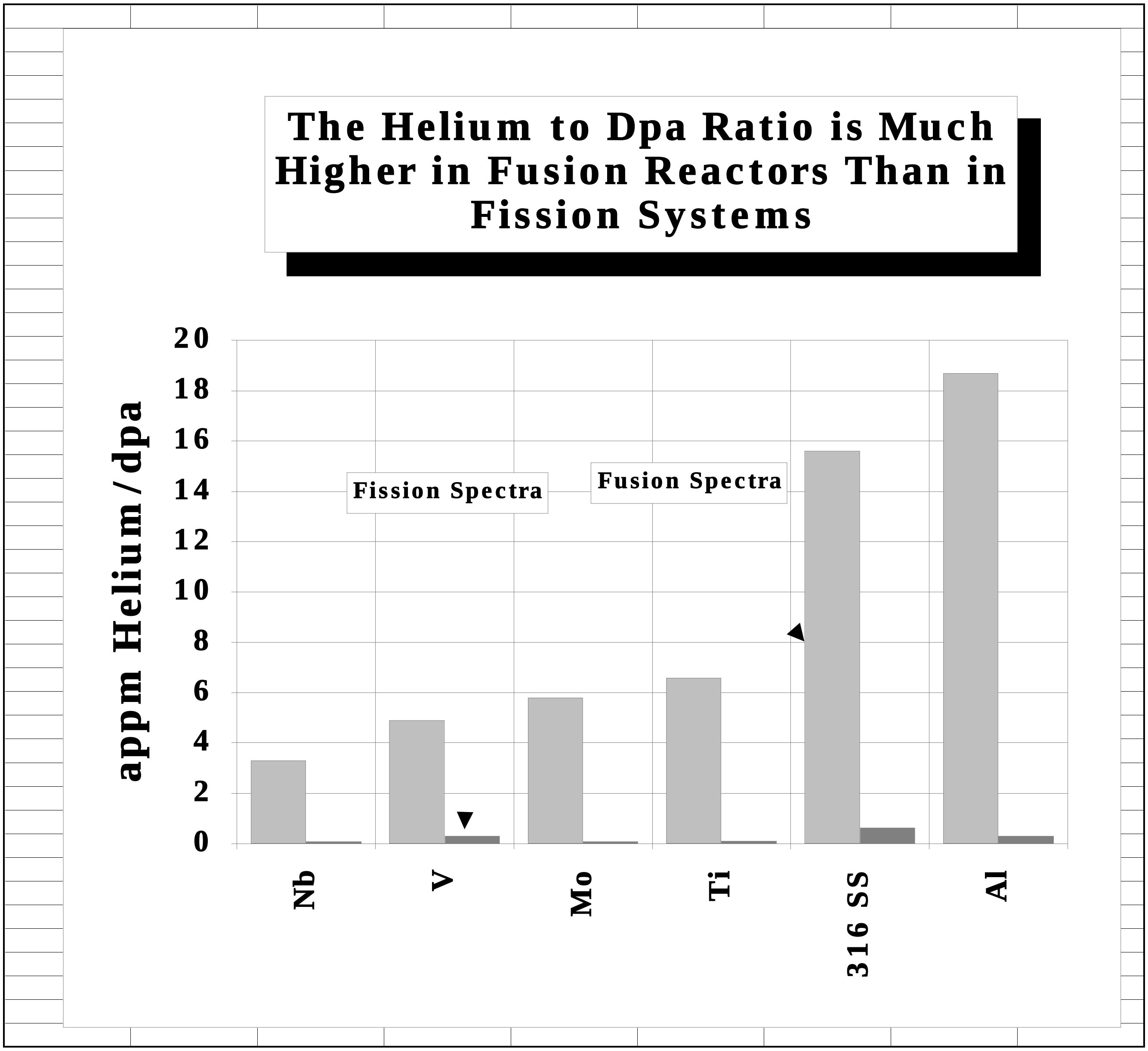

Mechanical
Thermal
Physical
Chemical
Choice of First Wall Material
Availibility
Neutronic
Cost
Radiation Damage

The Production of Helium Gas in Metals and Alloys is much Greater than in Fission Reactors

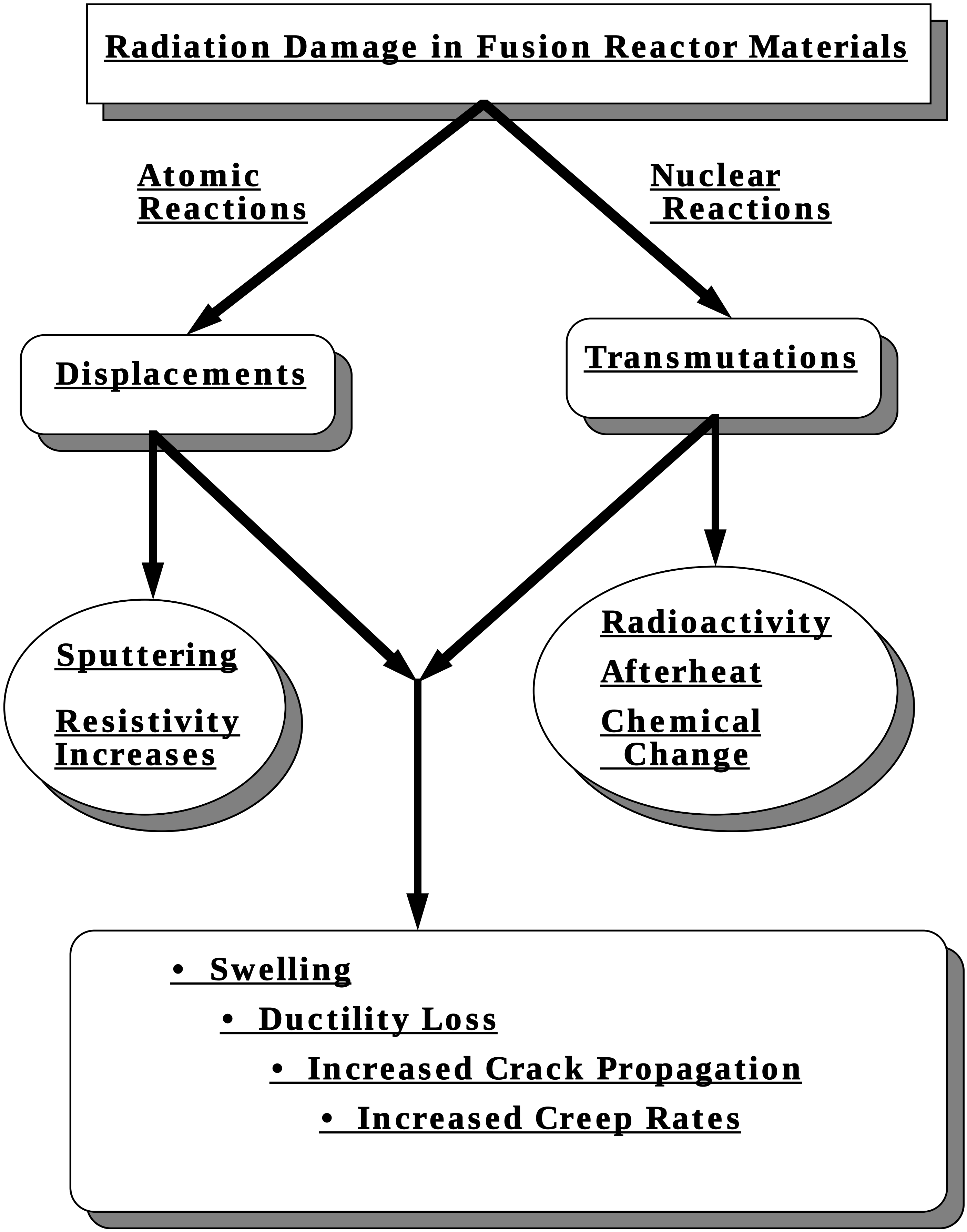


First Wall Heat Flux Limits





The Helium to Dpa Ratio is Much Higher in Fusion Reactors Than in Fission Systems
appm Helium/dpa
20
18
16
14
12
10
8
6
4
2
0
Fission Spectra
Fusion Spectra
Nb
V
Mo
Ti
316 SS
Al



Radiation Damage in Fusion Reactor Materials
Atomic Reactions
Nuclear Reactions
Displacements
Transmutations
Sputtering
Resistivity Increases
Radioactivity
Afterheat
Chemical Change
• Swelling
• Ductility Loss
• Increased Crack Propagation
• Increased Creep Rates

Fundamentals of Radiation Damage

Number of Vacancy/Interstitial Pairs produced by the ith reaction per incident particle of energy E per second , $N_d^i(E)$

$$N_d^i(E) = N_o \int \varphi(E)\sigma^i(E)K(E,T)\nu(T)dT$$

Where:

N_o = Atomic Density

ϕ (E) = Flux of particles of energy E

σ^i (E) = Probability that the incident particle with energy E, causing reaction i, will undergo an interaction with a matrix atom

K(E,T) = Probability that if an interaction takes place, it will produce a primary knock-on-atom (PKA) with energy T

ν(T) =Number of atoms subsequently displaced by the PKA

Swelling

- First discovered in 1986-UK

- Occurs when vacancies collect into clusters which grow and cause the material to expand

- Has been observed in many pure metals and alloys (Mg, Al, V, Fe, Co, Ni, Cu, Nb, Mo, Ta, W, Re, and Pt) and dozens of alloys.

- Generally occurs between 30 and 50% of the absolute melting point.

(Figures)

- Usually try to keep swelling <<10% (i.e., 1-2%)

- Limits the operating life to 2-3 FPY's in austenitic steels and 5-7 FPY's in ferritic steels.

Thermal Stress

$$\sigma_{th} = \frac{\alpha E}{2k(1-\nu)}\left[w_s t + 0.5 w_n t^2\right]$$

Material Related | **Reactor Related**

α = coefficient of thermal expansion
E = Modulus of Elasticity
k = thermal conductivity
ν = Poison Ratio
w_s = surface heat flux
w_n = nuclear heat rate
t = thickness

$$\text{Figure of Merit} = \frac{\sigma_{th}(T)}{\sigma_y(T)}$$

Compatibility Limits

Alloy	Coolant	Tmax °C
Al	Li	< 200
316 SS	Li	< 550
HT-9	Li	< 550
V	Li	< 800
Nb	Li	< 800
Mo	Li	< 1000
316 SS	Pb-Li	< 450
HT-9	Pb-Li	< 500
V	Pb-Li	????
Nb	Pb-Li	????
Mo	Pb-Li	????
316 SS/HT-9	Helium	< 600
V, Nb	Helium	< 600
Mo	Helium	< 1000