PLASMA STABILIZATION CONDUCTING SHELLS AND THEIR IMPACT ON TBR AND ACTIVATION IN CLiFF DESIGN

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Background

- In the Advanced Power EXtraction (APEX) study, focus is placed on exploring innovative concepts for high power density application. Liquid Walls are among these concepts.
- In the thin Convective Liquid Flow First Wall (CLiFF) blanket concept, a 2 cm-thick liquid layer is flowing poloidally from top to bottom in front of a solid first wall.
- Plasma kink mode stabilization and plasma elongation can be achieved by introducing a conducting shell near the FW.
- The liquid layer in front of solid FW in CLiFF concept can in principle be used as a conducting shell but solid shells exhibit higher conductance.

Objectives

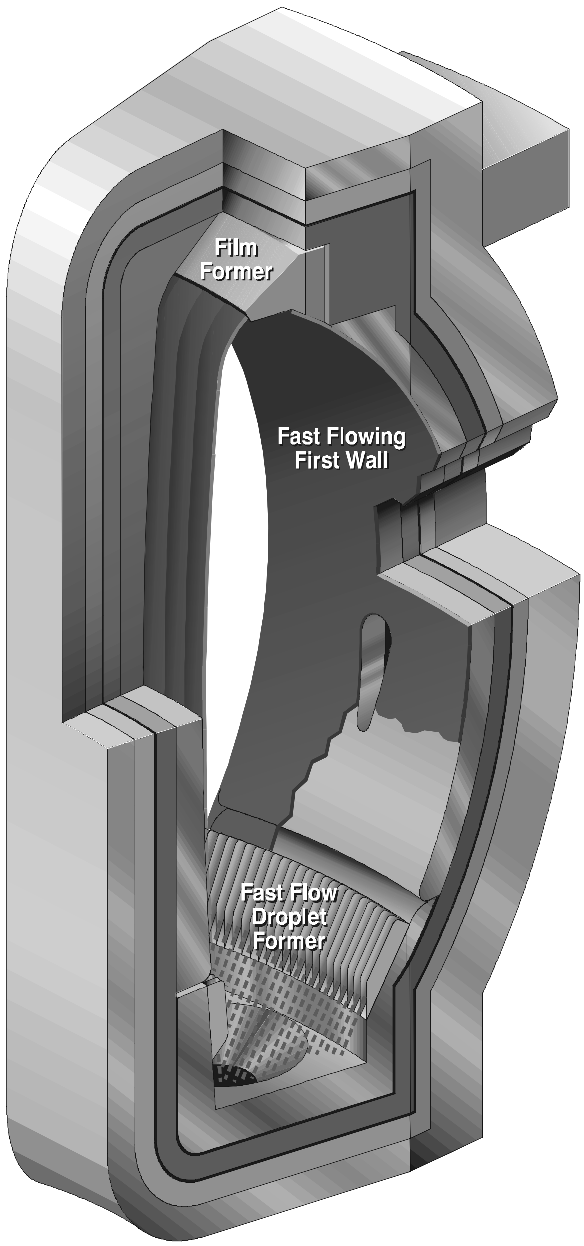
- Explore the impact of the conducting shell on the tritium production, particularly in systems that have marginal Tritium Breeding Ratio, TBR

- Assess the decay heat and waste disposal ratings (WDR) of the conducting shells that are made of solid alloys

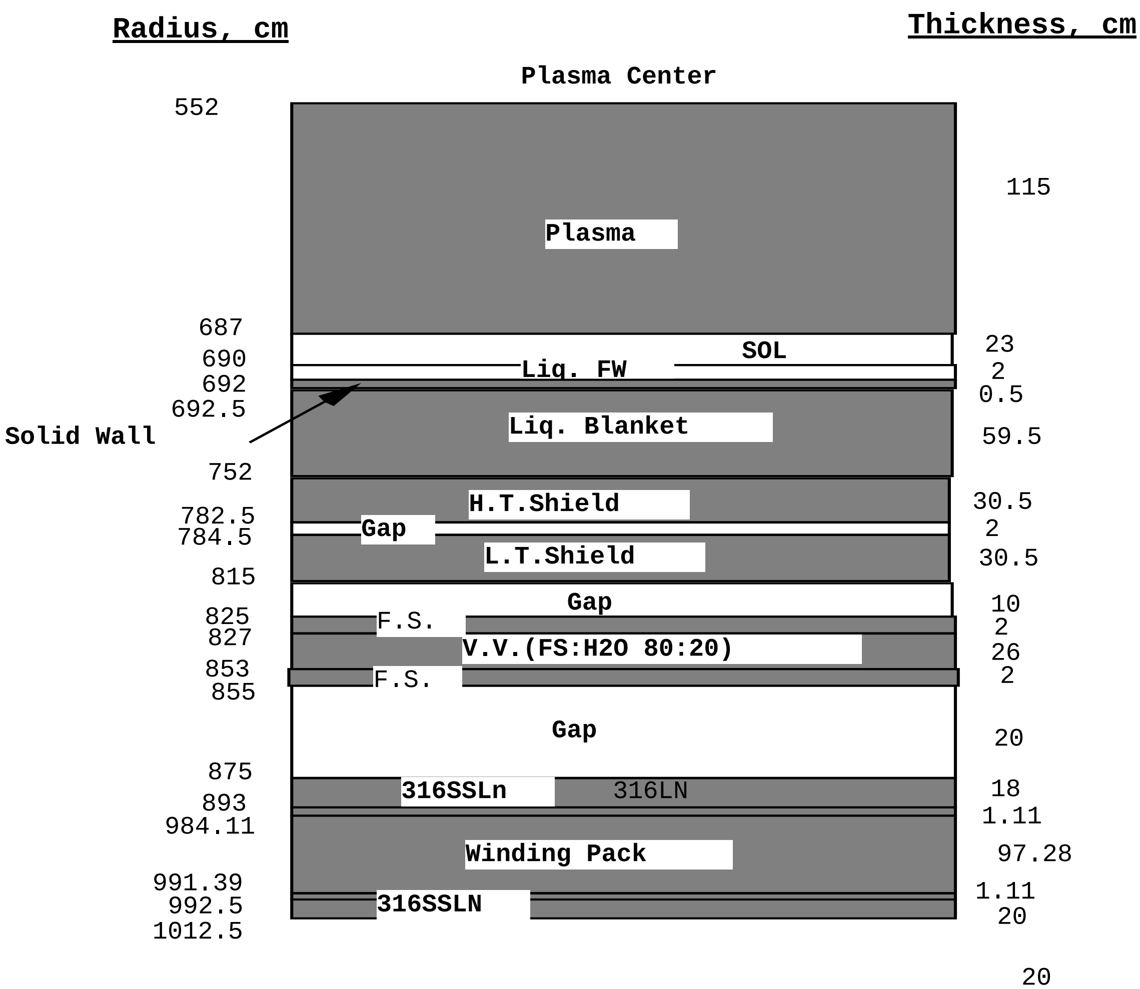
Decay heat ⇒ Safety concern

WDR ⇒ waste management concern

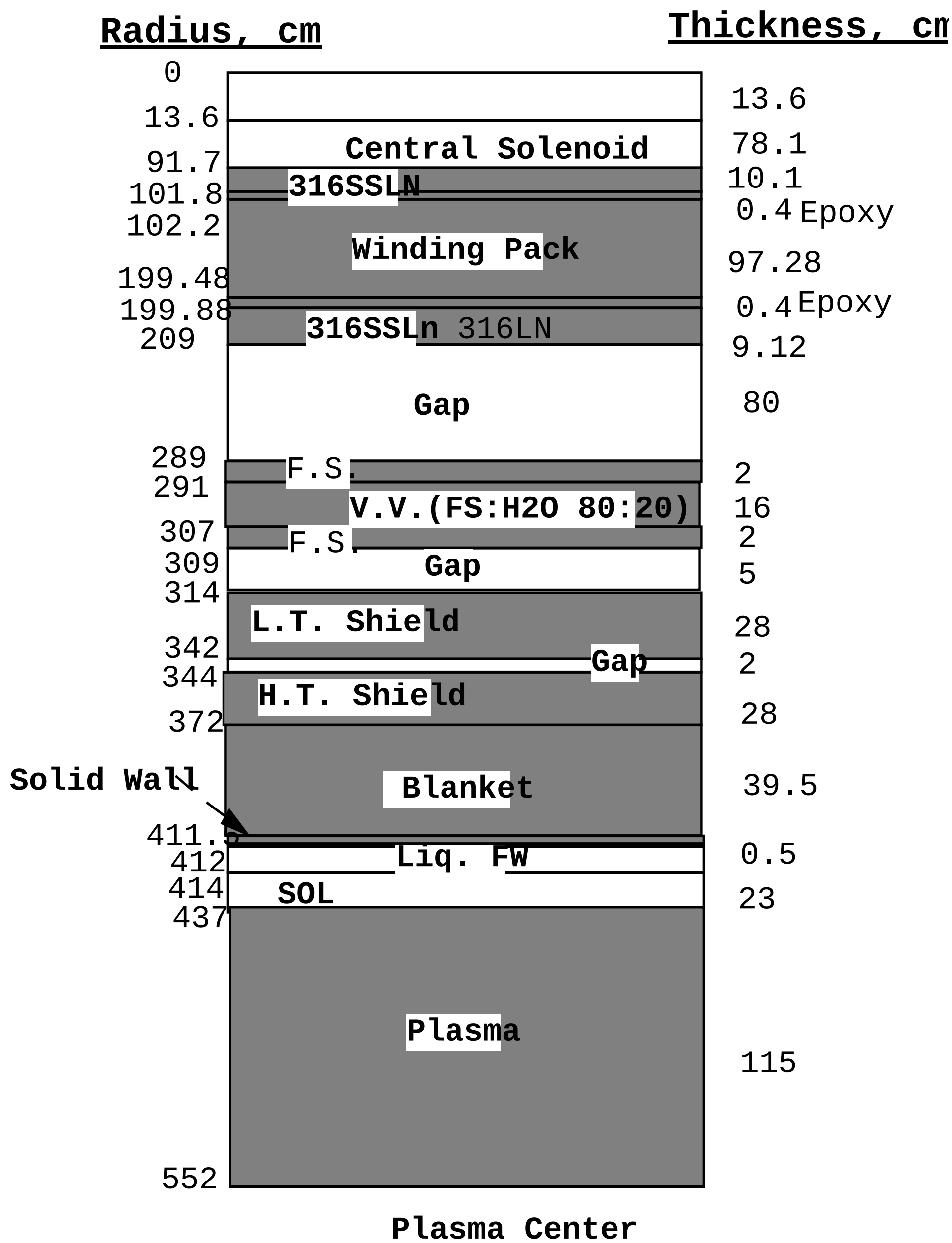
- Identify the best candidate material to be used as a stabilizing shell with the least impact on TBR and decay heat while having the lowest waste disposal rating.



Conceptual sector schematic of CLiFF implementation in ARIES-RS scale reactor.



Radial Build of the O/B CLiFF Concept



High Temp. Shield:15% strc.(V),80%strc.(FS
Low Temp. Shield:95% strc.(FS),5%Liq.
Blanket :90%Liq.,10%strc.

Radial Build of the I/B CLiFF Concept

Factors Affecting TBR upon Inclusion of a Stabilizing Shell

(highly system-dependent)

- Location of the conducting shell (e.g. in front of the FW or deeper in the blanket).

- The type of breeder and structure

- The degree of lithium enrichment.

- The type and thickness of solid conducting shells (e.g. Cu, Al, FS, W, V alloy)

- Whether or not there is already a FW to act as a structural support and the conducting shell is placed in front of or near it.

- Whether or not there is a beryllium-multiplying zone in the blanket.

CLiFF Design with Flibe/Ferritic Steel (FS) Structure (No Beryllium Multiplying Zone)

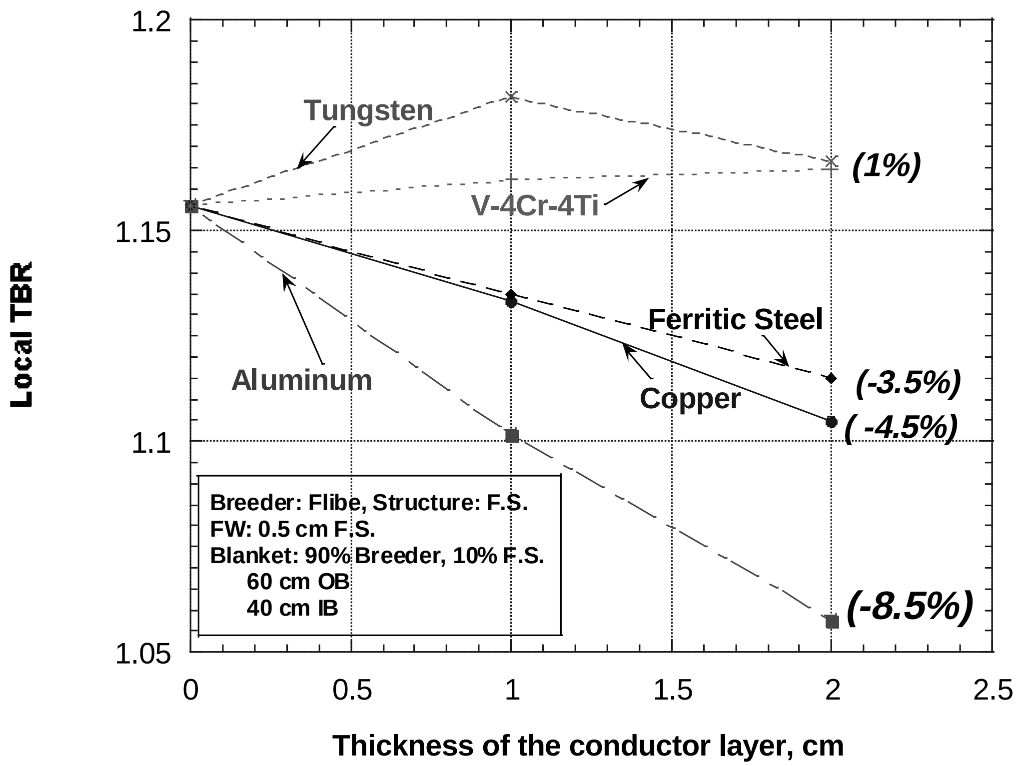
- This system is the initial CLiFF design concept.
- The blanket (60 cm OB, 40 cm IB) does not include a front Be multiplying zone
- Lithium enriched to 25% Li-6

TBR = 1.16 (with the liquid convective layer)
TBR = 1.156 (without the liquid convective layer) – less than 1% drop

TBR is marginal – There is a need to beryllium multiplying zone.

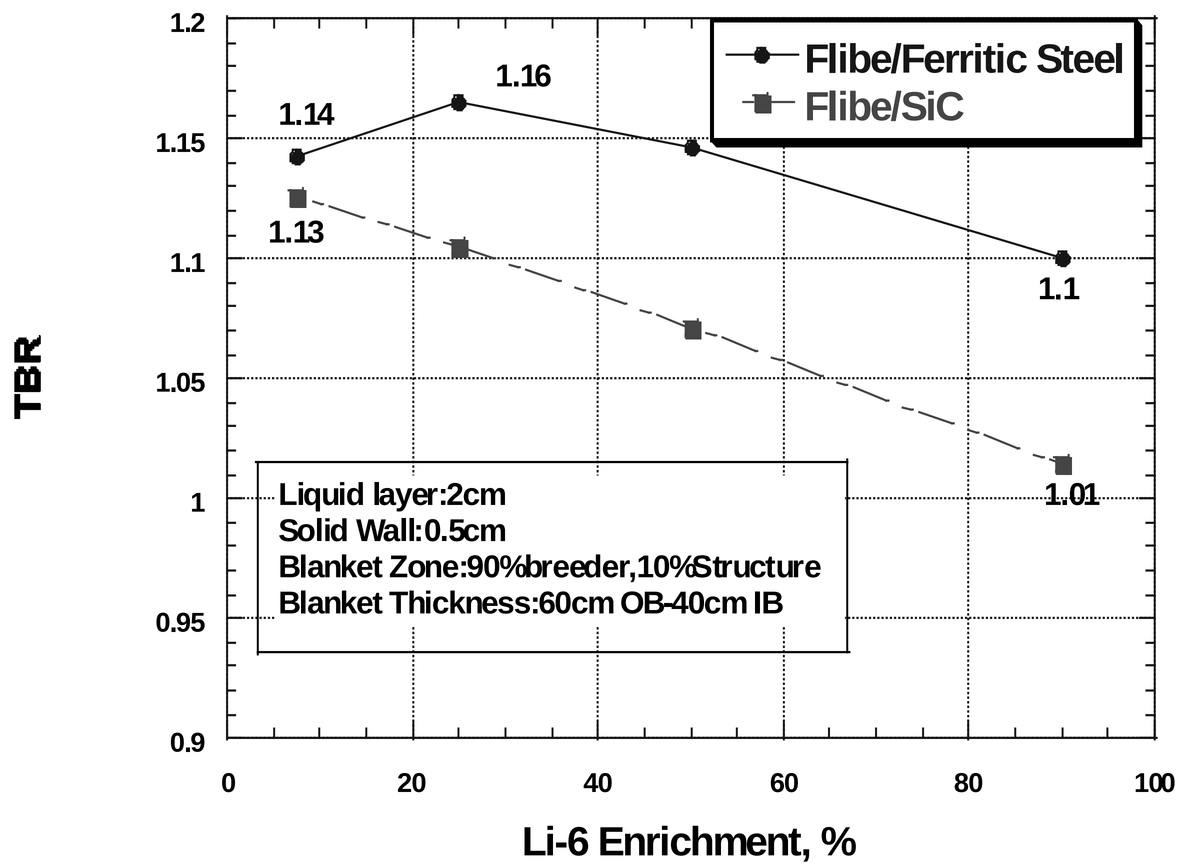
Effect Of Shell on TBR *(Flibe/FS-No Be)*

- The largest adverse effect on local TBR is with Aluminum (~ -8.5% at d=2 cm).
- The decrease in TBR upon including copper or ferritic steel conductors is comparable
- The inclusion of either tungsten or vanadium alloys improves local TBR due to neutron multiplication and enrichment to 25% Li-6.



Effect of Structure Type on TBR (No Be)

- Flibe/SiC combination gives lower TBR at all Li-6 enrichment than Flibe/FS combination
- Local TBR in the case of Flibe/SiC decreases with Li-6 enrichment whereas it peaks around 25% Li-6 enrichment in the case of Flibe/FS.
- Local TBR is still *marginal*



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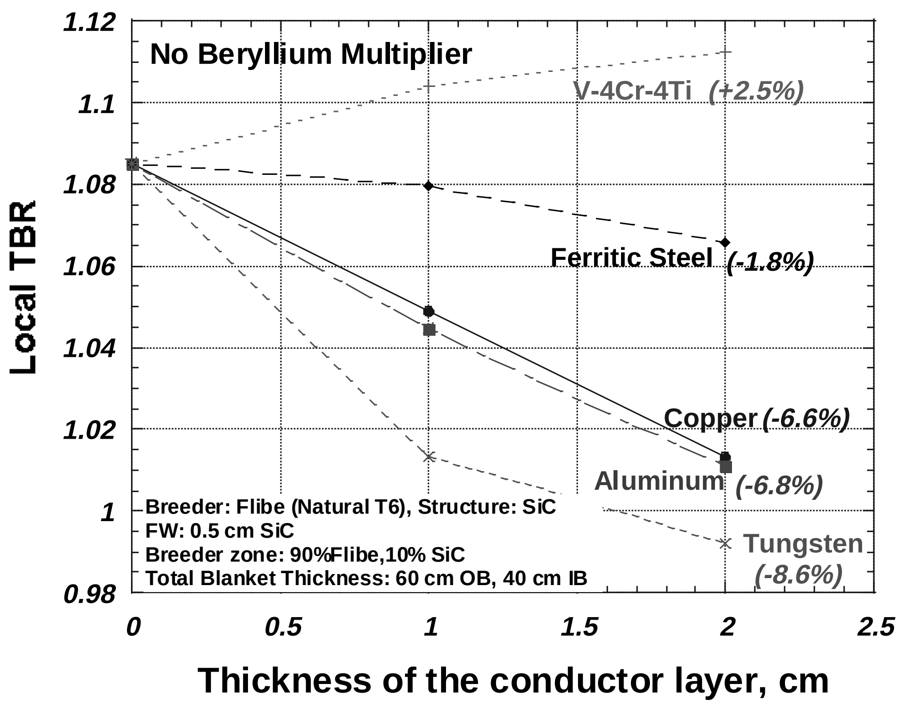
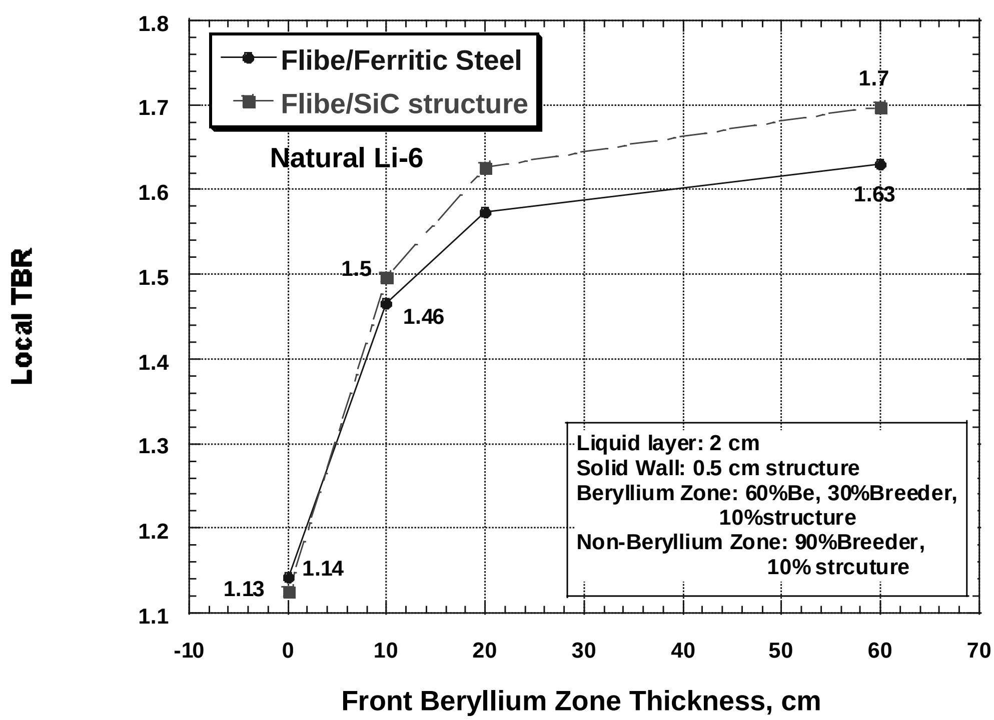
Effect Of Shell on TBR *(Flibe/SiC-No Be)*

- Removal of the liquid conductive shell itself (2m thick) leads to ~4% drop in TBR (from TBR=1.13 to TBR=1.09).
- Including a tungsten shell at the first wall has the worst impact on TBR. TBR drop by ~ 9% at d=2m. The absolute value for the TBR drops below unity (TBR=0.99)
- The inclusion of a vanadium shell improves TBR by +3% in this system (natural Li) at d=2cm.



Effect of Beryllium Multiplier on TBR

- With Beryllium multiplier zone and *natural Li-6*, local TBR increases drastically as the front Be zone thickness increases.
- Effect of Beryllium is more pronounced in the Flibe/SiC combination than in the Flibe/F.S. case. Local TBR can be larger in with Flibe/SiC than with Flibe/F.S. (Contrary to the no Be case).
- At front Be zone thickness of ~10 cm, local TBR seems adequate (TBR = 1.5 with SiC, 1.46 with Ferritic Steel).



Effect Of Shell on TBR *(Flibe/SiC-With Be)*

- Removal of the liquid convective layer itself (2m thick) leads to an increase in TBR by ~3% (from TBR=1.5 to 1.54).
- Placing W as a conducting shell at the FW in front of the beryllium multiplying zone gives the largest adverse impact on TBR (up to ~-30% for 2 cm shell). The least impact is with V and Al conductors (~-12% for 2 cm shell).

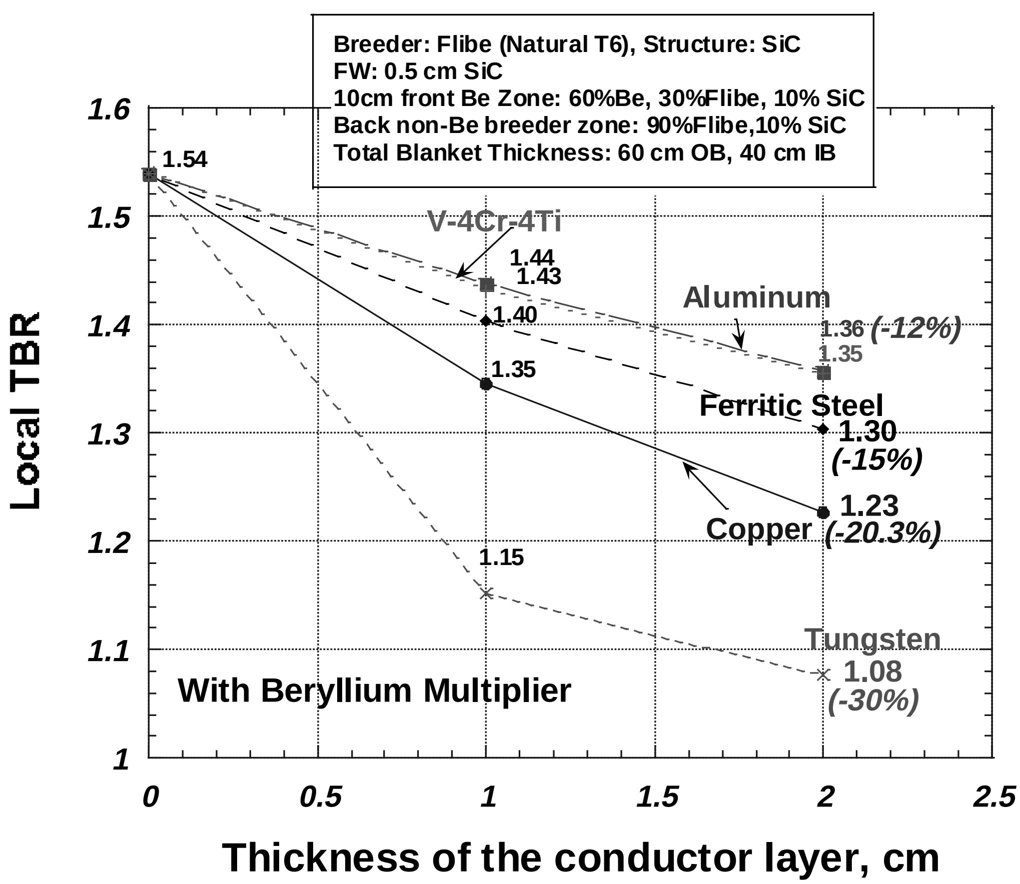


Table 1: The % change in TBR upon including a conducting shell of thickness d (Flibe with natural Li/SiC structure- no Be)

Material of Conducting shell	d= 1 cm	d=2 cm
Cu	-3.4%	-6.6%
Al	-3.7%	-6.8%
Ferritic Steel	-0.51%	-1.8%
W	-6.6%	-8.6%
V	+1.8%	+2.5%

Table 2: The % change in TBR upon including a conducting shell of thickness d (Flibe with natural Li/SiC structure- with 10 cm front Be multiplying zone)

Material of Conducting shell	d= 1 cm	d=2 cm
Cu	-12.6%	-20.3%
Al	-6.5%	-11.8%
Ferritic Steel	-8.8%	-15.3%
W	-25.2%	-30%
V	-6.9%	-11.9%

ACTIVATION ANALYSIS

Calculational Procedures

- Neutron wall loading of 7 and 10 MW/m^2 at the inboard and outboard first walls, respectively.
- DKR-PULSAR-2.0 activation code used along with FENDL/A.2.0 data
- The stabilizing shell is assumed to be 2-cm thick and placed immediately behind the liquid first wall or deep inside the blanket at 30 cm from the liquid first wall.
- The shell was assumed to survive for 3 FPY.
- The following five materials are analyzed for use as a stabilizing shell:

  - *The ORNL (9Cr-2WVTa) Low activation ferritic steel alloy.*
  - *The V-4Cr-4Ti alloy.*
  - *The W-5Re alloy.*
  - *The Al-6061 alloy.*
  - *The Glidcop-Al15-DS-Cu alloy.*

<u>Decay Heat in the Conducting Shell</u>

- The W-5Re alloy generates the highest amount of decay heat during the first year following shutdown.

  <u>Most of the decay heat is induced by</u>:
  ^{187}W ($T_{1/2}$ = 23.9 h),
  ^{185}W ($T_{1/2}$ = 74.8 d),
  ^{188}Re ($T_{1/2}$ = 16.94 h),
  ^{186}Re ($T_{1/2}$ = 3.77 d).

- The Al-6061 alloy is the second leading generator of decay heat during the first day following shutdown if the stabilizing shell is located immediately behind the first wall.

  <u>This is caused by the generation of</u>
  ^{24}Na ($T_{1/2}$ = 14.96 h) via the high-energy $^{27}Al(n,\alpha)$ reaction.

- The level of decay heat generated in the Al-6061 alloy drops in comparison to other alloys if the stabilizing shell is located at 30 cm from the liquid first wall due to the soften neutron spectrum.

Decay Heat in the Conducting Shell
(Cont'd)

- The copper alloy becomes the leading generator of decay heat at times exceeding one year following shutdown.

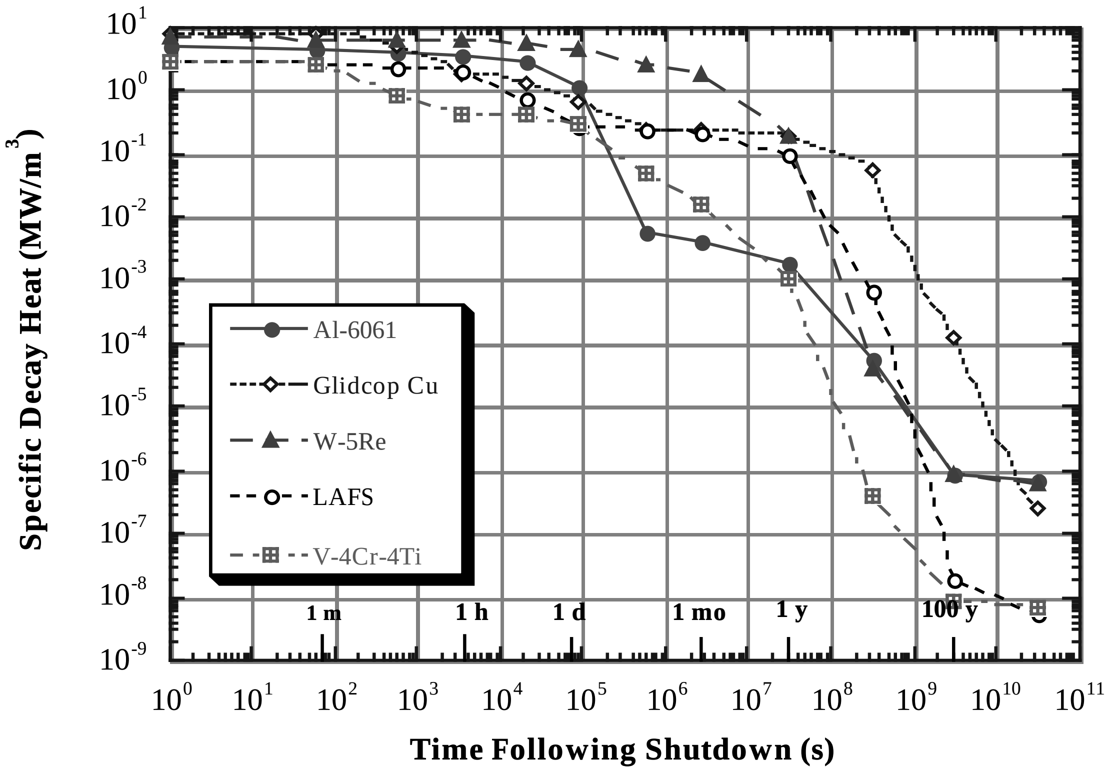
Most of the decay heat is dominated by:
^{66}Cu ($T_{1/2}$ = 5.1 min),
^{64}Cu ($T_{1/2}$ = 12.7 h).

- The low activation ferritic steel and vanadium alloys produce the least amount of decay heat, with the V-4Cr-4Ti alloy being the most attractive alloy.

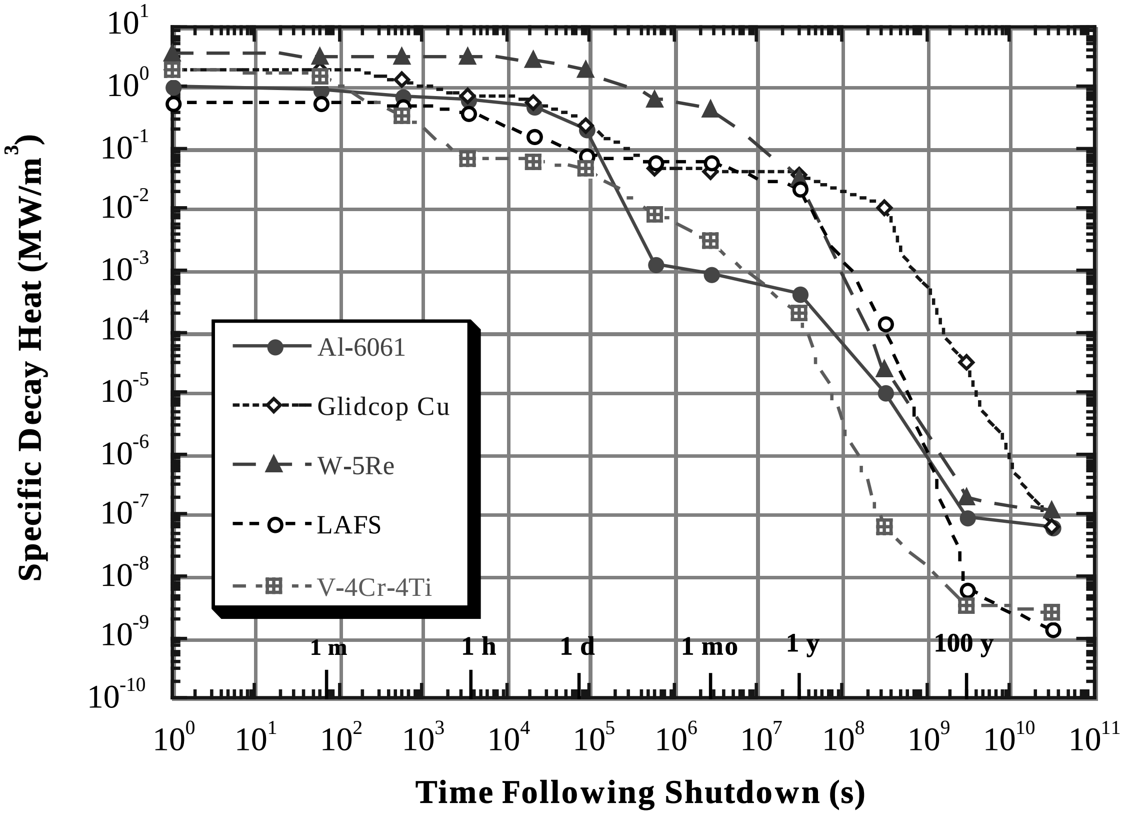
The decay heat is dominated by:
ORNL LAFS:
^{56}Mn ($T_{1/2}$ = 2.578 h)
^{54}Mn ($T_{1/2}$ = 312.2 d)

V-4Cr-4Ti:
^{51}Ti ($T_{1/2}$ = 5.76 min),
^{48}Sc ($T_{1/2}$ = 43.7 h).

Shell Located Behind Liquid layer at the FW



Shell Located at depth 30 cm from FW



Waste Disposal Rating

- The waste disposal ratings are given following a cooling period of ten years.
- Only stabilizing shells made of ferritic steel and V-4Cr-4Ti alloys would qualify for disposal as low level waste according to the two waste disposal criteria. The WDR of both alloys are dominated by contribution from the niobium impurities in both alloys.
- The waste disposal ratings of the W-5Re alloy are also dominated by the niobium impurities. Limiting the level of niobium impurities in the W-5Re alloy to less than 1 wppm could reduce the alloy WDR below the Class C limits according to 10CFR61.
- The Al-6061 will also qualify for disposal as Class C waste according to the 10CFR61. The reason is that ^{26}Al, which has no limits in 10CFR61, dominates the WDR. On the other hand, due to the low limits allowed for ^{26}Al by Fetter, Al-6061 is the worst performing stabilizing shell.
- The WDR of the Glidcop Cu is too high. As shown in the table, the high 10CFR61 WDR limits are caused by ^{63}Ni produced by the ^{63}Cu (n,p) reaction. ^{63}Ni contribution to the Fetter waste disposal limits is minimal due to the fact that it is given higher allowable limits by Fetter. WDR at 30 cm depth are more moderate. The conclusions regarding alloys suitability are not changed.

Class C Waste Disposal Ratings behind the First Wall.

Alloy	Fetter	10CFR61
ORNL-FS	0.97 (^{94}Nb, ^{99}Tc)	0.42 (^{94}Nb)
V-4Cr-4Ti	0.4 (^{26}Al, ^{94}Nb)	0.47 (^{14}C, ^{94}Nb)
W-5Re	29.9 (^{94}Nb, ^{108m}Ag, ^{186m}Re)	11.6 (^{94}Nb)
Al-6061	412 (^{26}Al)	0.34 (^{63}Ni)
Glidcop Cu	23.3 (^{108m}Ag, ^{26}Al)	329 (^{63}Ni)

Class C Waste Disposal Ratings 30-cm Inside the Blanket.

Alloy	Fetter	10CFR61
ORNL-FS	0.46 (^{94}Nb, ^{99}Tc)	0.24 (^{94}Nb)
V-4Cr-4Ti	0.18 (^{94}Nb)	0.26 (^{94}Nb, ^{14}C)
W-5Re	13.7 (^{94}Nb, ^{108m}Ag, ^{186m}Re	9.7 (^{94}Nb)
Al-6061	33.4 (^{26}Al)	0.08 (^{63}Ni)
Glidcop Cu	4.7 (^{108m}Ag)	78.1 (^{63}Ni)

Concluding Remarks

Impact on TBR

- The impact of solid conducting shell on TBR is highly system-dependent. In Flibe/FS system with no beryllium multiplier and 25% Li-6 enrichment, Aluminum conductor at the FW has the largest adverse effect (-8.5% drop in TBR) while tungsten conductor improves TBR
- In Flibe/SiC system with no Be multiplier, placing tungsten as a conducting shell at the FW will have lesser adverse impact on TBR (~ -8-10%) if Flibe breeder uses natural lithium. However it improves TBR by ~+2-3% if 25%Li-6 enrichment is used.
- In Flibe/SiC system with beryllium multiplier, natural lithium gives the largest local TBR in this case (TBR=1.5). Using tungsten as the conducting shell gives the largest adverse impact on TBR (up to ~-30% for shell thickness d=2 cm) and the absolute value becomes TBR=1.08, which is not acceptable to meet tritium self-sufficiency condition.
- The least impact is with V and Al conductors (TBR drops by~-12% for 2 cm shell).

Concluding Remarks (Cont'd)

Decay Heat and WDR

- The tungsten alloy generates the highest amount of decay heat during the first year following shutdown.
- The Al-6061 alloy is the second leading generator of decay heat during the first day following shutdown if the stabilizing shell is located immediately behind the first wall.
- The low activation ferritic steel and vanadium alloys produce the least amount of decay heat. In addition, these two alloys also would qualify for disposal as low-level waste since their waste disposal ratings (WDR) are the least.
- The WDR of the W-5Re alloy are above unity based on both 10CFR61 and Fetter criteria but limiting the level of niobium impurities to less than 1 wppm could reduce the alloy WDR below the Class C limits according to 10CFR61.
- The Al-6061 will also qualify for disposal as Class C waste according to the 10CFR61 but according to Fetter's limits, Al-6061 is the worst performing stabilizing shell.
- The WDR of the Cu alloy is too high based on both 10CFR61 and Fetter's limits.