Neutronics Features of a High Power Density First Wall/Blanket with Lithium Evaporation Cooling

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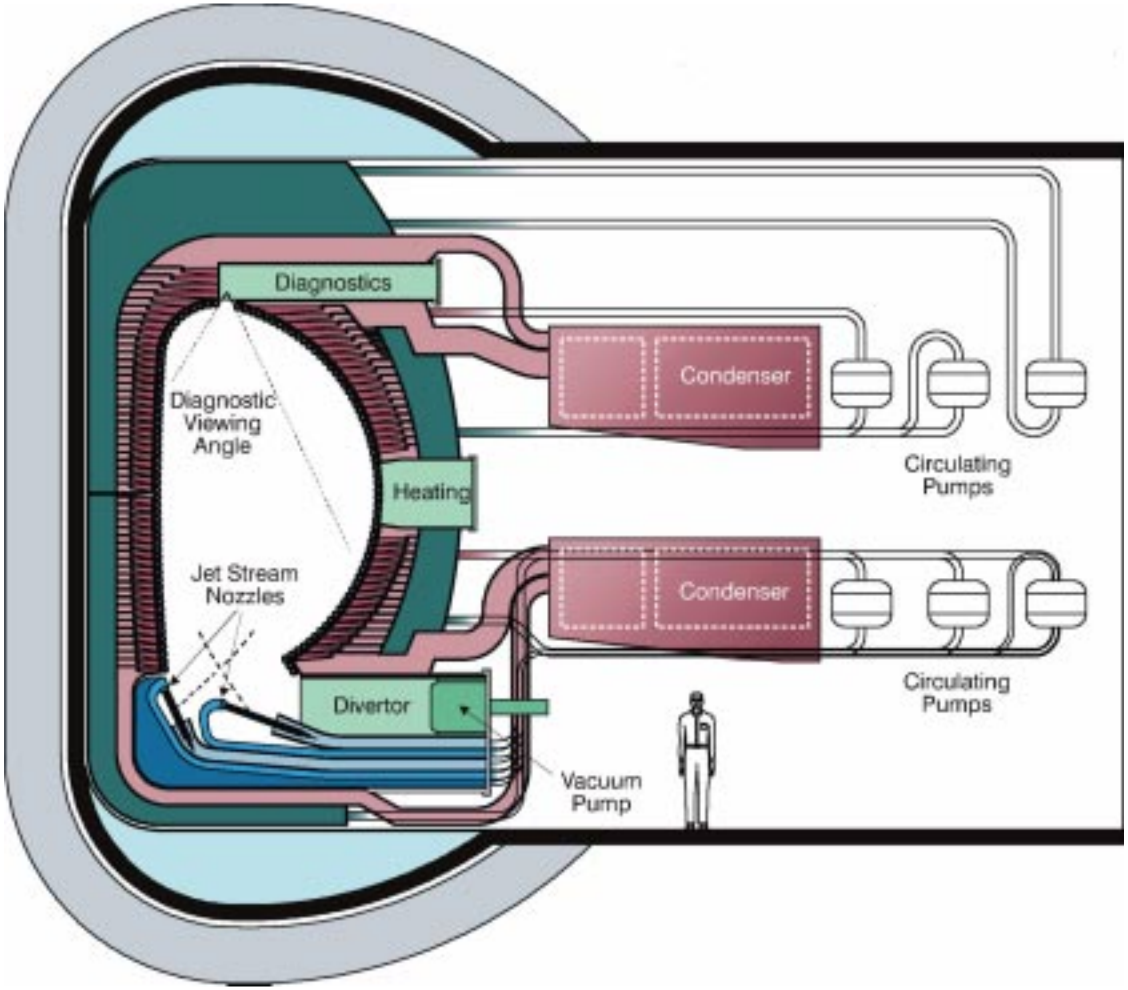
Background

- The APEX project was initiated to explore innovative concepts for blankets and other in-vessel components that can tremendously enhance the potential of fusion as an attractive and competitive energy source
- These concepts should have high power density handling capability, high power conversion efficiency, potential to achieve high availability, and safety and environmental attractiveness
- The EVOLVE (EVaporation Of Lithium and Vapor Extraction) concept utilizes the extremely high heat of evaporation of lithium to remove the entire heat deposited in FW/blanket



Cross-sectional view of the EVOLVE first wall/blanket concept

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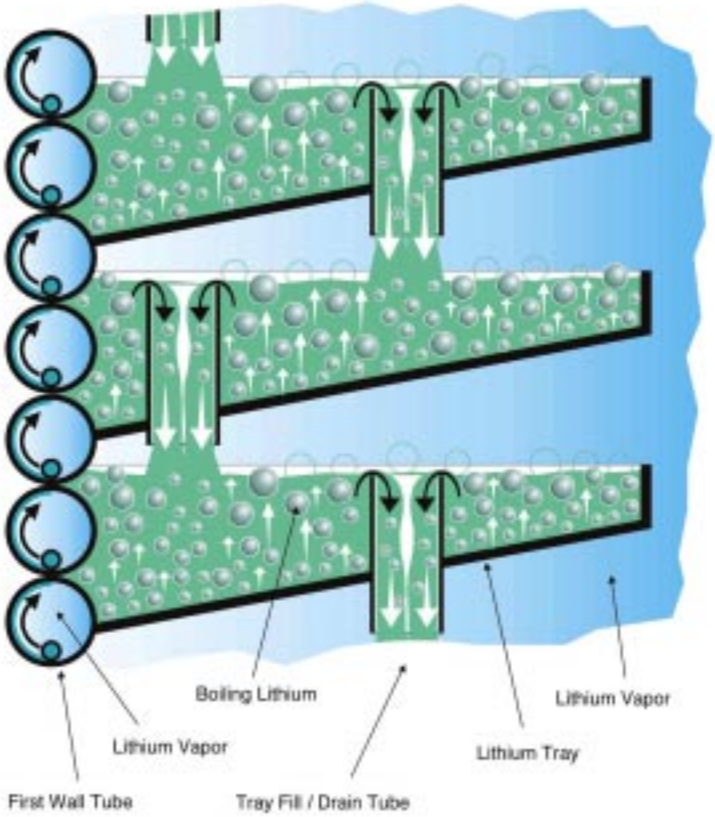

Schematic of EVOLVE first wall tubes and blanket trays containing Li

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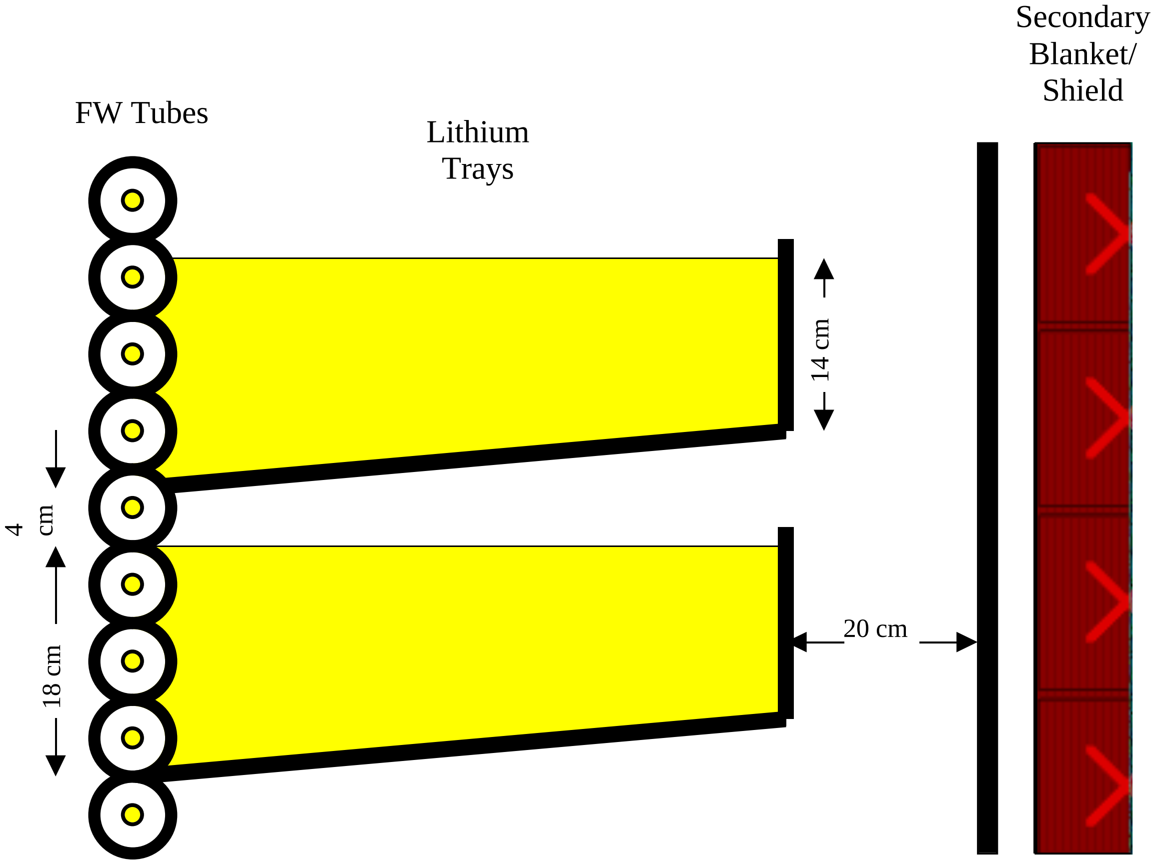
Configuration of the EVOLVE Concept



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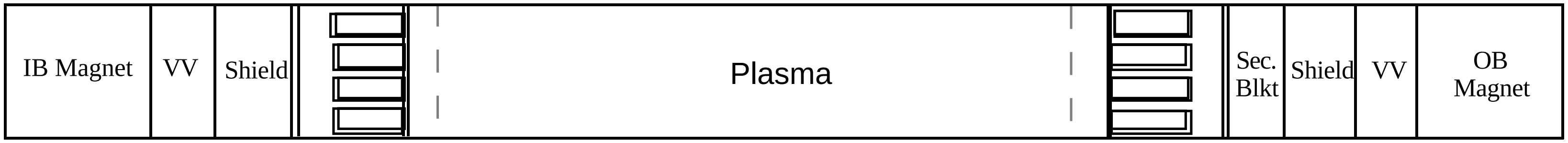
1-D Scoping Analysis

- Using W structure results in ~10% higher TBR compared to Ta
- A 40-cm-thick secondary breeding blanket utilized in OB side only
- Secondary breeding blanket made of W and self-cooled by Li
- Li enriched to 40% ^{6}Li to maximize TBR
- W structure used in shield with WC shielding material and Li cooling
- Tritium breeding, nuclear heating, and radiation damage in different components were calculated using 1-D calculations
- Radial build required for VV reweldability and magnet shielding determined

2-D Calculational Procedure

- TWODANT module of DANTSYS 3.0 utilized
- The ray tracing first collision source option used
- Both IB and OB regions modeled simultaneously
- Neutron coverage fractions of 75% OB, 15% IB, 10% divertor
- Made conservative assumption of no breeding in divertor region
- Li density in trays and FW is 0.35 g/cm^3
- Results normalized to OB and IB wall loadings of 10 and 7 MW/m^2



R-Z Two-Dimensional Model for EVOLVE

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Radial Build Used in Calculations

	IB	*OB*
FW	5 cm	5 cm
Li tray	40 cm	50 cm
Back wall of tray	0.5 cm	0.5 cm
Li vapor manifold	15 cm	20 cm
Manifold backplate	1 cm	1 cm
Clearance	2 cm	2 cm
Secondary blanket	0 cm	40 cm
Clearance	0 cm	2 cm
Shield	60 cm	50 cm
Clearance	2 cm	2 cm
VV front sheet	5 cm	5 cm
VV shielding zone	30 cm	30 cm
VV rear sheet	5 cm	5 cm
Total	165.5 cm	212.5 cm

Secondary Blanket, Shield, and VV Design

- The composition of the secondary blanket is 90% Li, 10% W

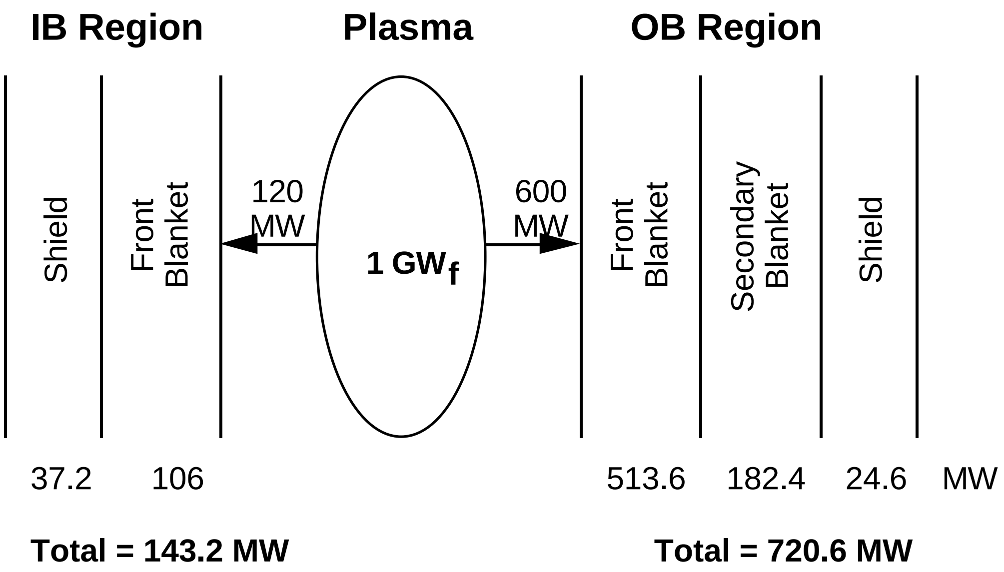
- The composition of shield is 20% Li, 10% W, 70% WC

- The VV is 40-cm-thick with a double wall structure of two SS sheets each 5 cm thick sandwiching a shielding zone of 80% WC and 20% He

Tritium Breeding Ratio in the Reference Design

- Overall TBR is 1.37 without divertor breeding
- 69.8% of breeding in the trays
    - 57.3% OB
    - 12.5% IB
- 27.7% of breeding in OB secondary blanket
    - 20.2% behind trays
    - 7.5% between trays
- 2.5% of breeding in shield
    - 1% OB
    - 1.5% IB
- Tritium breeding has a comfortable margin that gives design flexibility
- Overall TBR from 2-D calculation is slightly higher than that estimated from 1-D calculations coupled with coverage fractions (1.37 vs. 1.336)

Nuclear Heating Partitioning in the Reference Design



IB Region			**Plasma**		**OB Region**			
Shield	Front Blanket	120 MW	**1 GW$_f$**	600 MW	Front Blanket	Secondary Blanket	Shield	
37.2	106				513.6	182.4	24.6	MW

Total = 143.2 MW

Total = 720.6 MW

- Most of nuclear heating (~72%) deposited in high temperature front blanket
- Adding surface heat deposited in FW implies that ~76% of total IB and OB energy deposited as high grade heat in FW and trays

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Peak Nuclear Heating Values

- Peak W structure nuclear heating (W/cm^3) in blanket and shield components

	IB	OB
FW	85.0	105.8
Manifold Backplate	33.3	31.3
Secondary Blanket	NA	26.2
Shield	20.1	4.3

- No significant poloidal peaking is observed
- Peak heating in the manifold backplate, secondary blanket, and shield is a factor of 3-4 lower than predicted from 1-D calculations
- 1-D calculations were very conservative since the space between FW and secondary blanket was assumed to be completely empty
- Source is volumetrically distributed with most source neutrons being intercepted by the FW and trays
- The secondary neutrons and gamma rays which give large contribution to heating and damage tend to give nearly uniform profiles

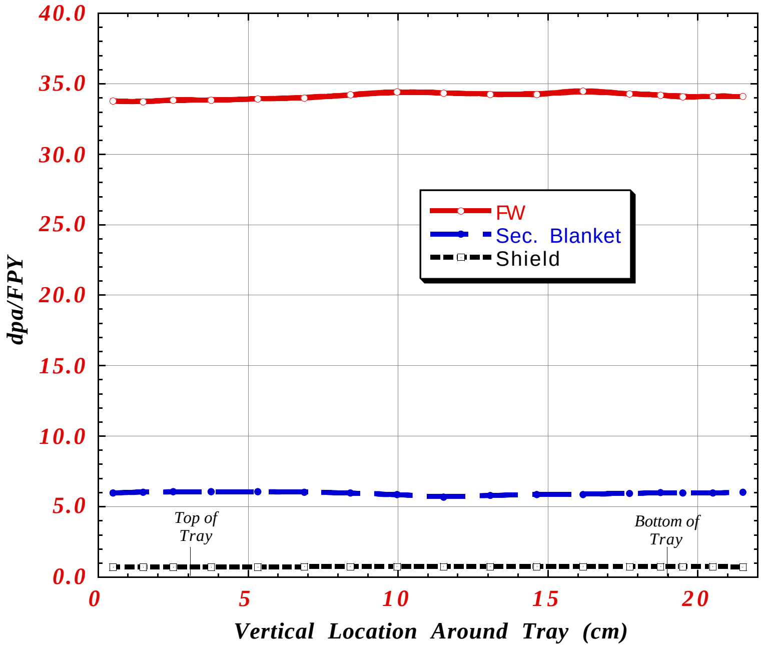
Peak Structure Damage Rate Values

- Peak dpa rate (dpa/FPY) and He production rate (He appm/FPY) in W structure

	dpa/FPY		He appm/FPY	
	IB	OB	IB	OB
FW	25.7	34.8	14.0	20.2
Manifold Backplate	7.0	7.0	2.0	2.0
Secondary Blanket	NA	6.1	NA	1.8
Shield	4.3	0.74	1.3	0.12

- No significant poloidal peaking is observed
- Peak dpa in manifold backplate, secondary blanket, and shield is factor of ~3-5 lower than predicted from 1-D calculations. He production is factor of ~6-10 lower
- Peak damage rate in OB secondary blanket and IB shield is factor of ~6 lower than in FW and they are expected to have factor of 6 longer lifetime than the FW and trays. Lifetime of OB shield is about an order of magnitude longer than for OB secondary blanket and IB shield making it lifetime component

Poloidal Damage Distribution Around OB Trays



- Slight damage peaking occurs in FW in front of trays due to increased reflection
- Damage is nearly poloidally uniform in the secondary blanket and shield

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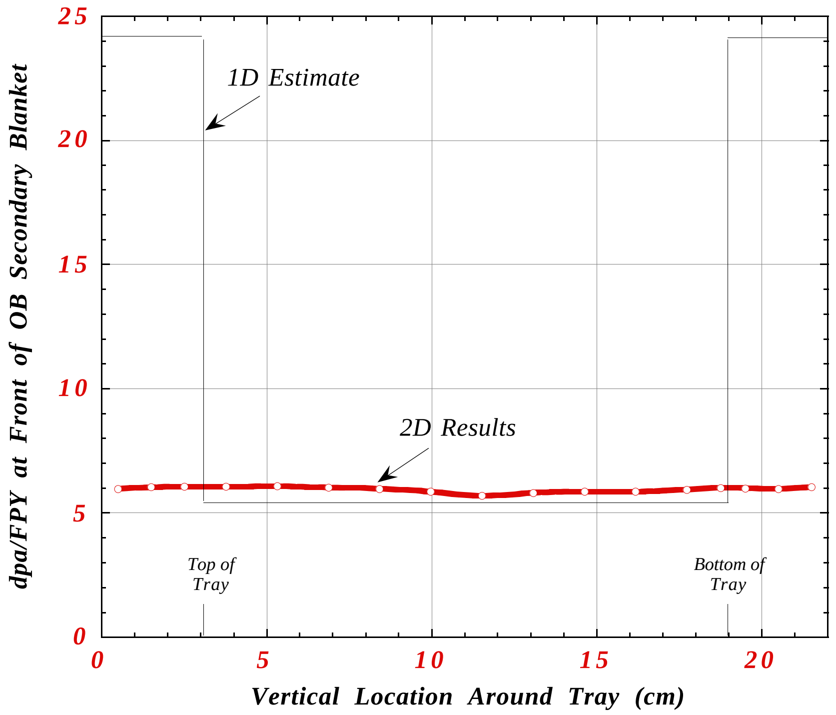
Poloidal Damage Distribution at Front Surface of OB Secondary Blanket



- Negligible damage peaking occurs in the secondary blanket between trays

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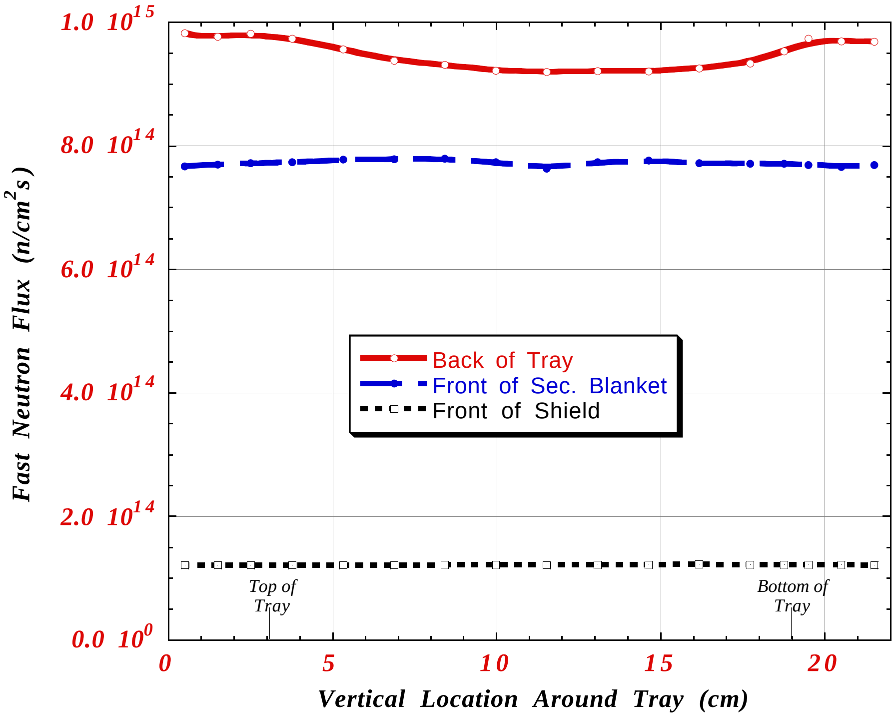
Poloidal Distribution of Fast Neutron Flux



- Largest peaking between trays occurs at the back of the trays and decreases rapidly as one moves away from them

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Peak VV and Magnet Neutronics Parameters

- 60 cm thick IB shield
- 50 cm thick OB shield
- 40 cm thick VV

Peak VV neutronics parameters

	IB	OB
Peak Nuclear Heating (mW/cm^3)	2.8	2.0
Peak end-of-life dpa	0.08	0.05
Peak end-of-life He appm	0.30	0.21

Peak magnet neutronics parameters

	IB	OB	Design Limit
Peak Nuclear Heating (mW/cm^3)	0.039	0.023	1
Peak end-of-life Fast Neutron Fluence (n/cm^2)	8.4×10^{17}	5.4×10^{17}	10^{19}
Peak end-of-life Dose to Epoxy Insulator (Rads)	1.0×10^{9}	6.4×10^{8}	10^{9}
Peak end-of-life dpa to Cu Stabilizer	4.8×10^{-4}	2.7×10^{-4}	6×10^{-3}

- All VV and magnet radiation limits are satisfied

Conclusions

- Adequate tritium breeding is achievable for the EVOLVE concept if Li is enriched to 40% ^{6}Li and a secondary breeding blanket is used in OB region
- The overall TBR is 1.37 assuming no breeding in the divertor region
- Surface heat and 72% of nuclear heating are deposited as high-grade heat in the front evaporation-cooling zone
- No significant peaking in nuclear heating and damage occurs behind the trays
- OB secondary blanket and IB shield are expected to have a factor of 6 longer lifetime than the FW and trays. The OB shield is expected to be a lifetime component
  - The VV is reweldable and all magnet radiation limits are satisfied