Neutronics Assessment of Molten Salt Breeding Blanket Design Options

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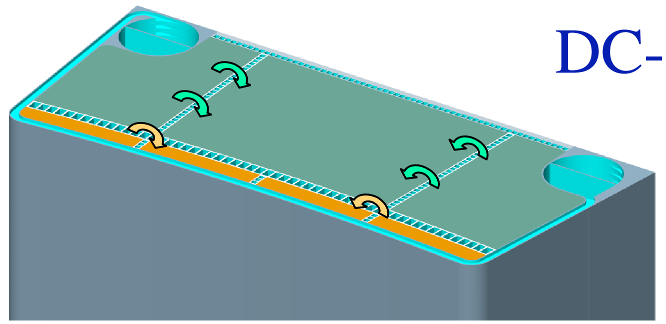
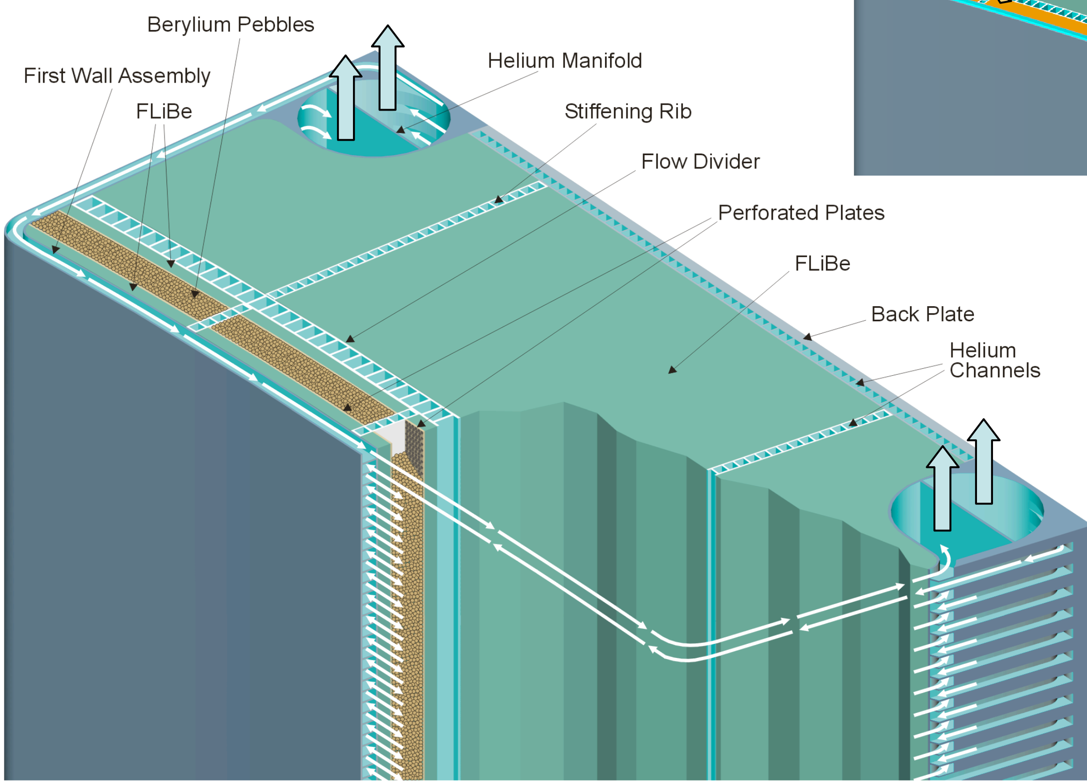
Neutronics Assessment

- Three blanket concepts analyzed
  1. Self-cooled Flinabe blanket (Flinabe/Be/FS)- [SC]
  2. Dual coolant blanket with Be (Flibe/He/Be/FS)- [DC-Be]
  3. Dual coolant blanket with Pb (Flibe/He/Pb/FS)- [DC-Pb]
- The RAFS alloy F82H used as structural material
- Same reactor configuration and power loadings used
- Water cooled steel VV and shield
- 1D calculations with IB and OB blankets modeled simultaneously
- Several iterations made to determine radial build that achieves adequate tritium breeding and shielding for VV and magnet
- Larger margins are considered to account for uncertainties resulting from approximations in modeling
- Multi-dimensional calculations are being performed to accurately model the blanket

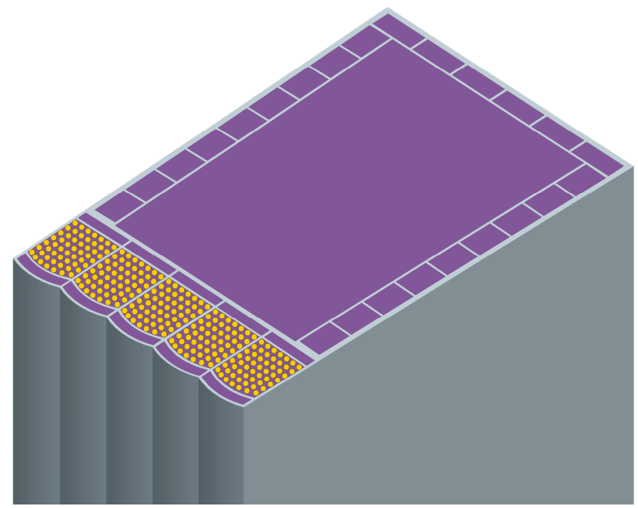
Molten Salt Blanket Options



DC-Pb



DC-Be



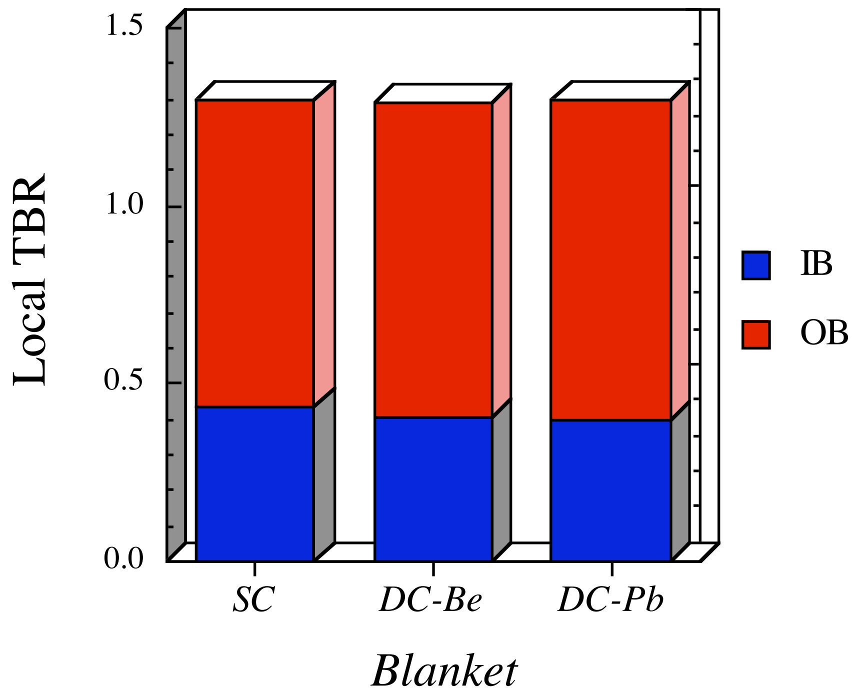
SC-Be

Blanket Radial Build

	SC Flinabe Be	*DC Flibe/He Be*	*DC Flibe/He Pb*
Blanket Thickness	50 cm OB 40 cm IB	65 cm OB 40 cm IB	65 cm OB 40 cm IB
Multiplier Zone	7 cm 60% Be	5 cm 60% Be	5 cm 87% Pb

- Same TBR can be achieved with a thinner SC OB blanket compared to the DC blanket with large He amount
- To achieve the same TBR a smaller Be zone thickness (5 cm) is required in the DC design with Flibe compared to the SC with Flinabe (7 cm)
- In the DC design more Pb is needed than Be although the Be is pushed farther from FW by the Flibe poloidal flow channel required to cool it

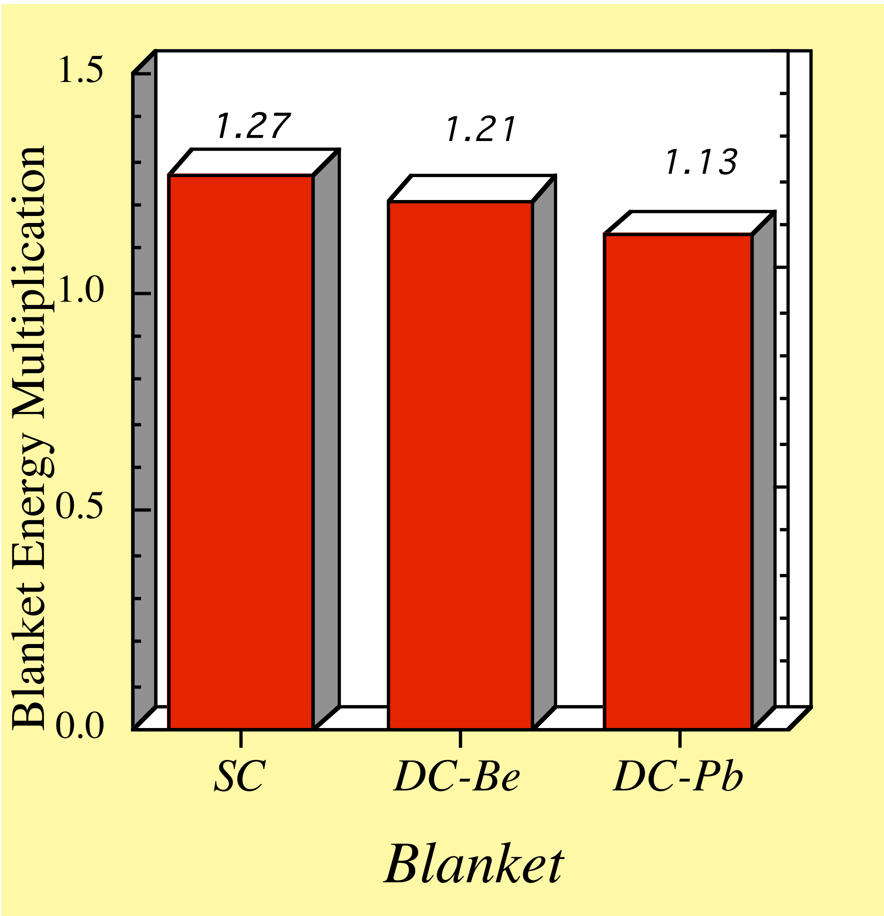
Tritium Breeding Potential



	SC	DC-Be	DC-Pb
IB	0.432	0.406	0.399
OB	0.867	0.882	0.897
Total	1.299	1.288	1.296

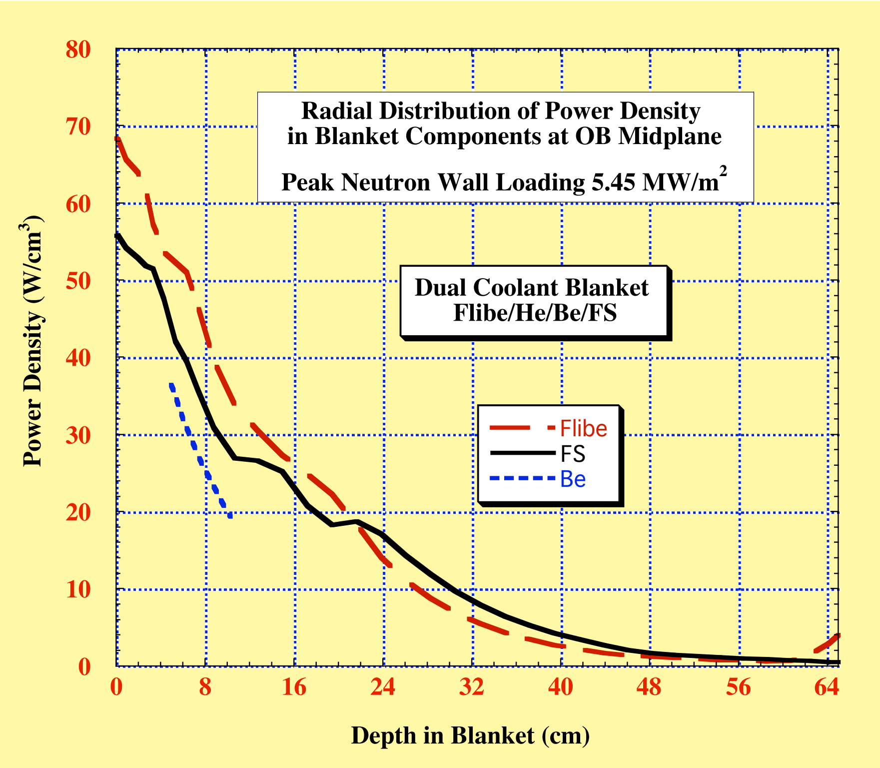
- If neutron coverage for double null divertor is 12% the overall TBR will be ~1.13 excluding breeding in divertor region. Breeding in divertor zone could add ~0.06
- The blanket design concepts have the potential for achieving tritium self-sufficiency. Some design parameters can be adjusted (e.g., multiplier thickness, blanket thickness, etc) to insure tritium self-suffiency if needed

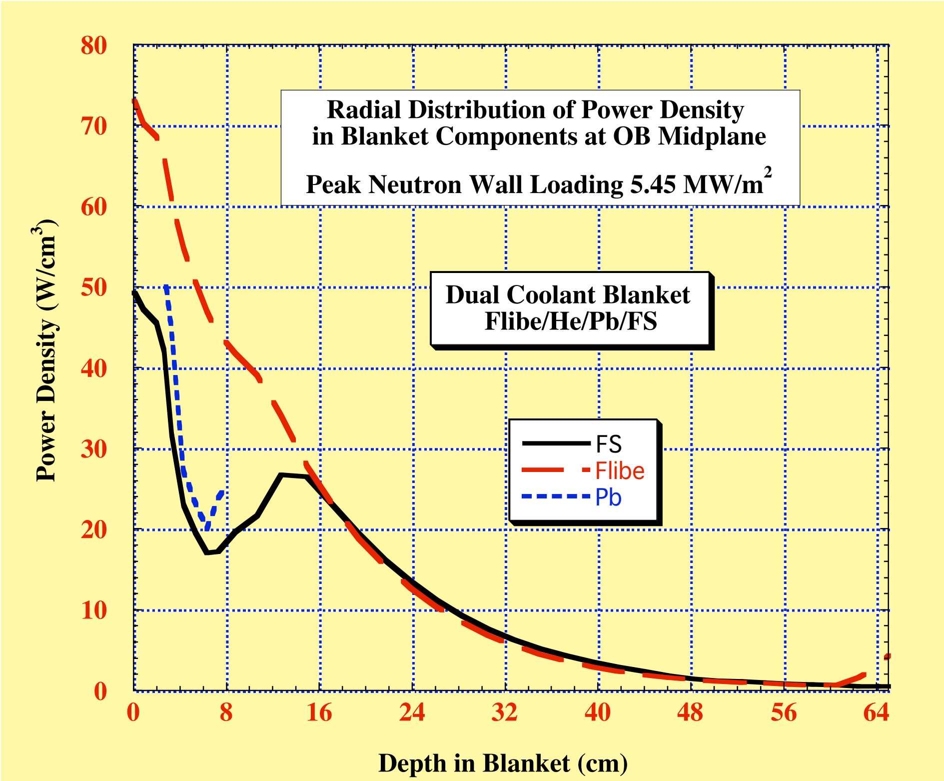
Blanket Energy Multiplication



- Using Be yields higher blanket energy multiplication
  - 1.27 for SC blanket with Be
  - 1.21 for DC blanket with Be
  - 1.13 for DC blanket with Pb

Nuclear Heating Determined in Blanket Components





- Peak nuclear heating values in OB blanket
  - FS 56 W/cm^3
  - Flibe 70 W/cm^3
  - Be 36 W/cm^3

- Peak nuclear heating values in OB blanket
  - FS 49 W/cm^3
  - Flibe 73 W/cm^3
  - Pb 50 W/cm^3

Peak Radiation Damage Parameters in FW Structure (OB Midplane)

	SC	DC-Be	DC-Pb
dpa/FPY	76.4	74.8	84.2
He appm/FPY	1005	983	922

- Based on 200 dpa damage limit blanket lifetime is ~2.4 FPY

Peak Radiation Damage Parameters in Shield (IB Midplane)

	SC	DC-Be	DC-Pb
dpa @30 FPY	18	33	41
He appm @30 FPY	100	183	213

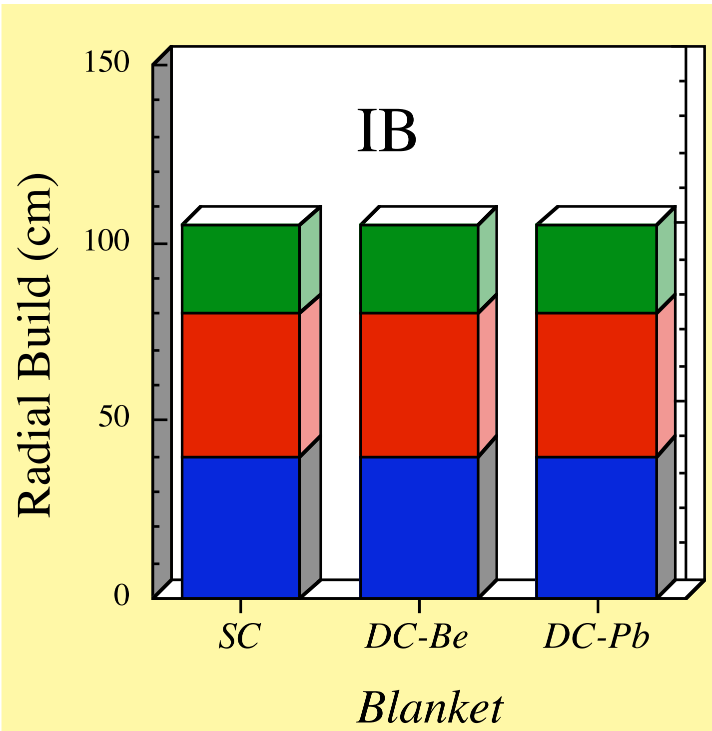
- Shield is expected to be lifetime component with a large margin

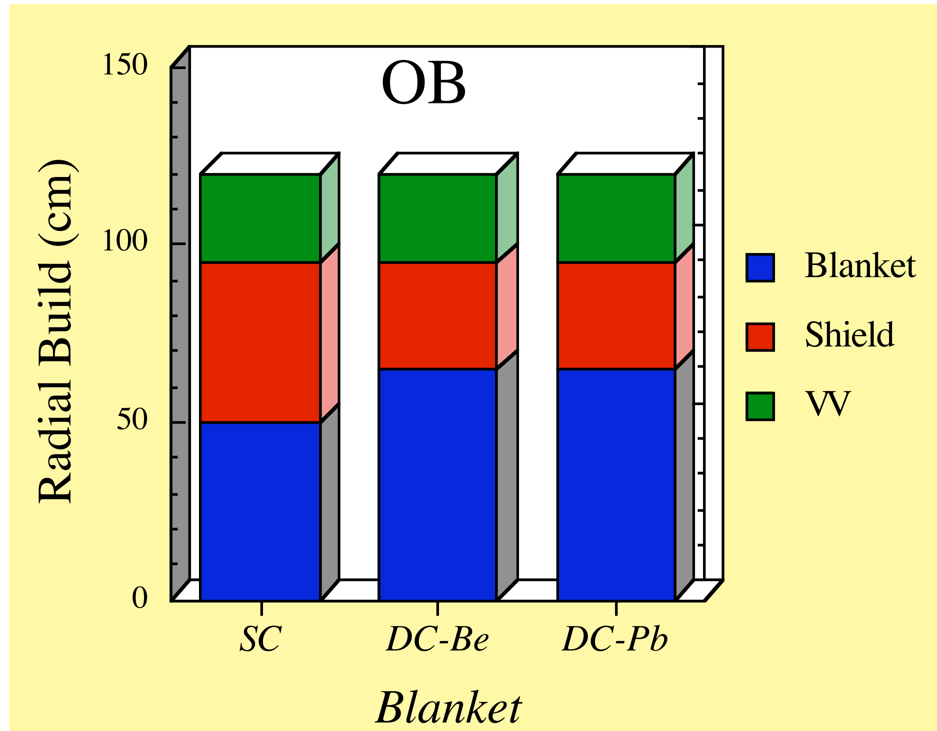
Total Tritium Production in Be (for 2.4 FPY blanket life)

	SC	DC-Be
IB	0.78 kg	0.46 kg
OB	2.19 kg	1.34 kg
Total	2.97 kg	1.80 kg

- Modest amount of tritium produced in Be
- Tritium inventory will be much smaller depending on temperatures

Shielding Requirement





- Radial build determined to insure that radiation limits are satisfied with adequate margins
  - Shield is lifetime component (<200 dpa)
  - VV is reweldable (<1 He appm)
  - Magnet adequately shielded (<10^{10} Rads)

Peak VV Damage Parameters

	SC		DC-Be		DC-Pb	
	IB	OB	IB	OB	IB	OB
Peak end-of-life dpa	0.035	0.007	0.065	0.029	0.07	0.03
Peak end-of-life He appm	0.21	0.04	0.38	0.16	0.45	0.17

Peak Magnet Damage Parameters (IB)

	SC	DC-Be	DC-Pb	Design Limit
Peak Nuclear Heating (mW/cm^3)	0.14	0.35	0.29	1
Peak end-of-life Fast Neutron Fluence (n/cm^2)	$1.3x10^{18}$	$2.8x10^{18}$	$2.8x10^{18}$	10^{19}
Peak end-of-life Dose to Insulator (Rads)	$3.1x10^9$	$7.6x10^9$	$6.6x10^9$	10^{10}
Peak end-of-life dpa to Cu Stabilizer	$9.0x10^{-4}$	$2.1x10^{-3}$	$2.0x10^{-3}$	$6x10^{-3}$

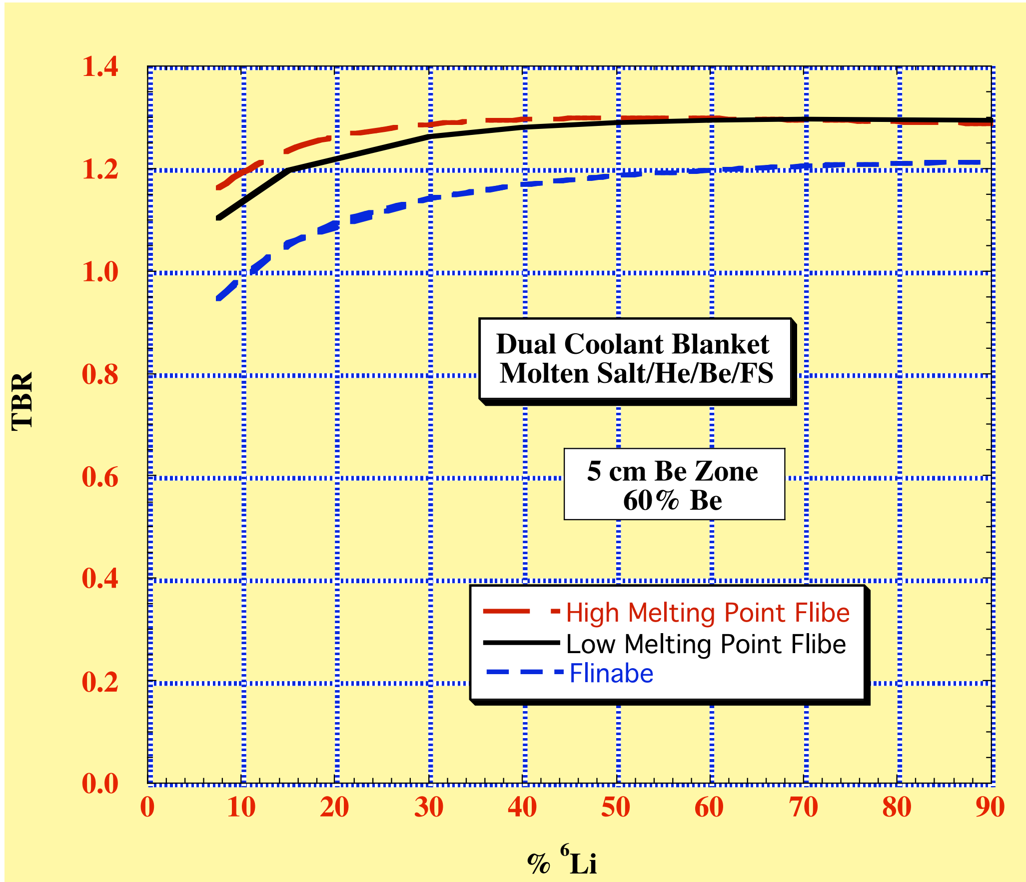
- Shielding effectiveness of DC blanket(with He) is lower than SC blanket
- With same IB radial build damage parameters in shield, VV, and magnet are a factor of ~2 lower with the SC blanket
- DC designs with Be and Pb result in comparable radiation damage parameters

Dual-Coolant Concept has Attractive Features

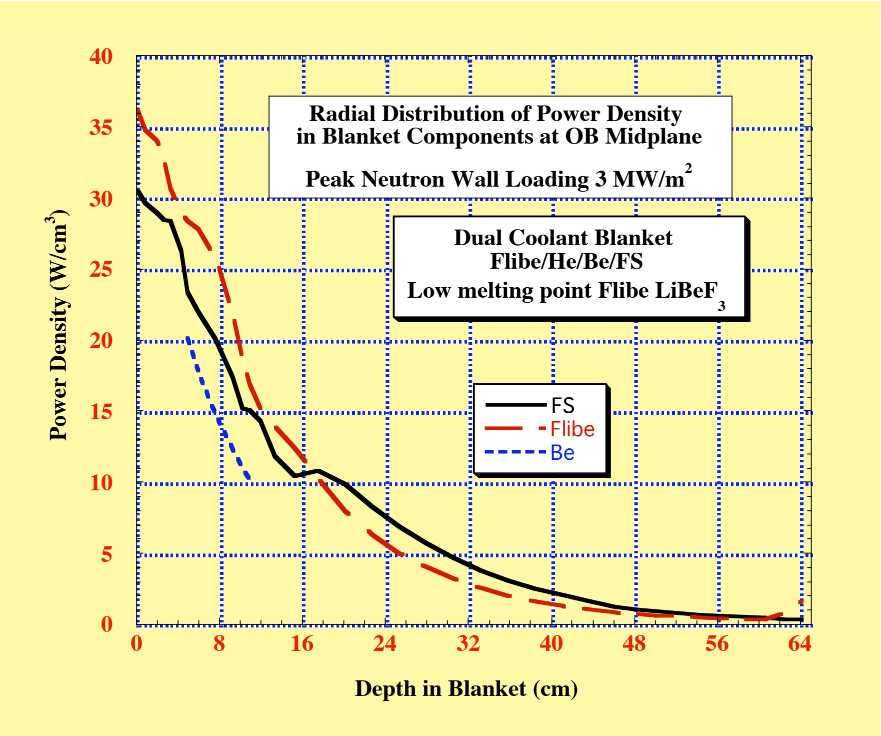
- Self-cooled concept have limited thermal capabilities restricting NWL that can be handled while meeting temperature limit of 550°C for RAFS. Advanced ODS ferritic steels (NCF) should be used to yield attractive performance with high thermal efficiency
- Dual-coolant concept allows for large exit coolant temperature while satisfying all temperature requirements for near term RAFS
- Performance of the dual-coolant concept with Be multiplier investigated further with low melting point Flibe ($LiBeF_3$) and Flinabe to avoid the need for ODS steel coating and eliminate molten salt freezing

Tritium Breeding Potential

- 50% Li-6 enrichment used for DC blanket with low melting point Flibe
- For similar TBR with Flinabe Be zone thickness increased to 8 cm and enrichment increased to 60% Li-6
- Local TBR for both designs is 1.287
- With 12% neutron coverage for double null divertor, overall TBR will be ~1.13 excluding breeding in divertor region that could add ~0.06

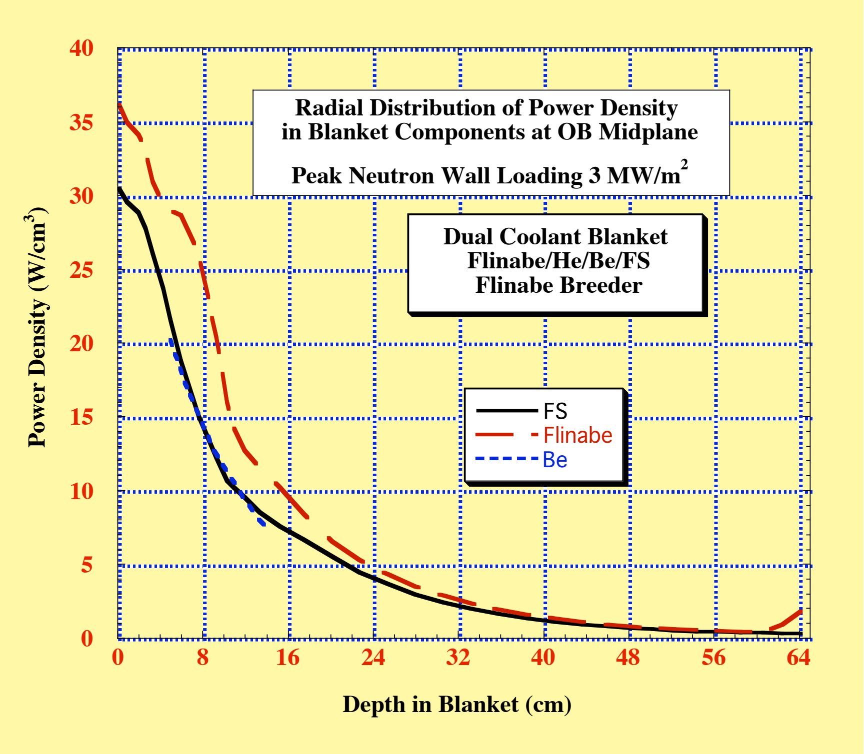


Nuclear Heating



Nuclear energy multiplication is 1.223 with $LiBeF_3$

Nuclear energy multiplication is 1.247 with Flinabe



Higher M in Flinabe blanket that uses more Be

Shield is lifetime component

- Peak cumulative end-of-life damage:
  - •17.2 dpa with $LiBeF_3$
  - •19.1 dpa with Flinabe
- Using Flinabe results in a slightly lower blanket shielding capability

VV is Reweldable

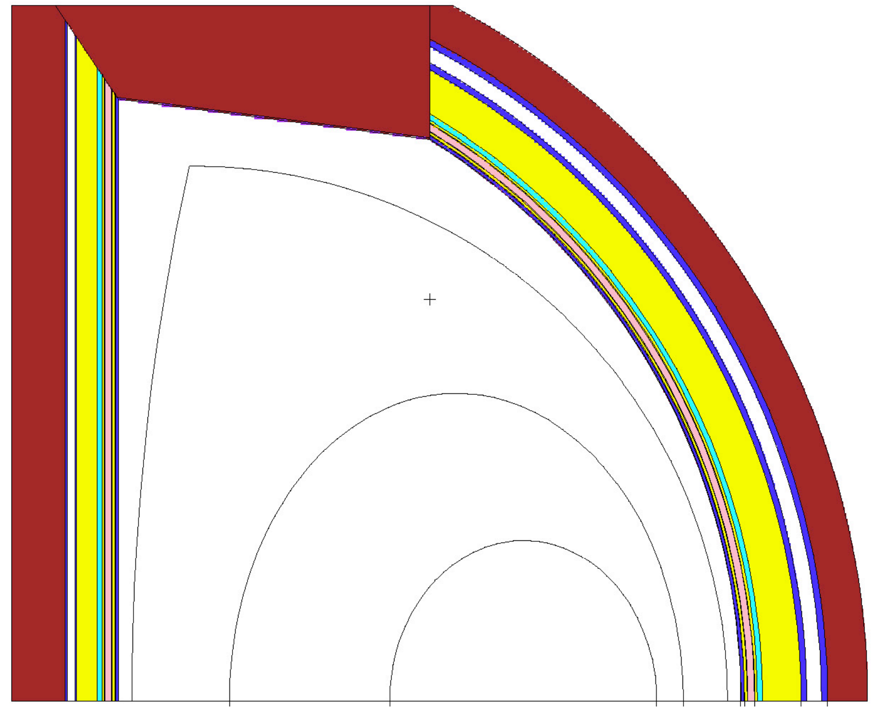
- Peak end-of-life He production in VV:
  - •0.21 appm with $LiBeF_3$
  - •0.23 appm with Flinabe

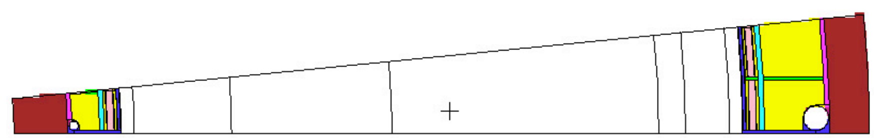
All Magnet Radiation Limits Satisfied

- Peak end-of-life magnet insulator dose:
  - •3.6×10^9 Rads with $LiBeF_3$
  - •3.9×10^9 Rads with Flinabe

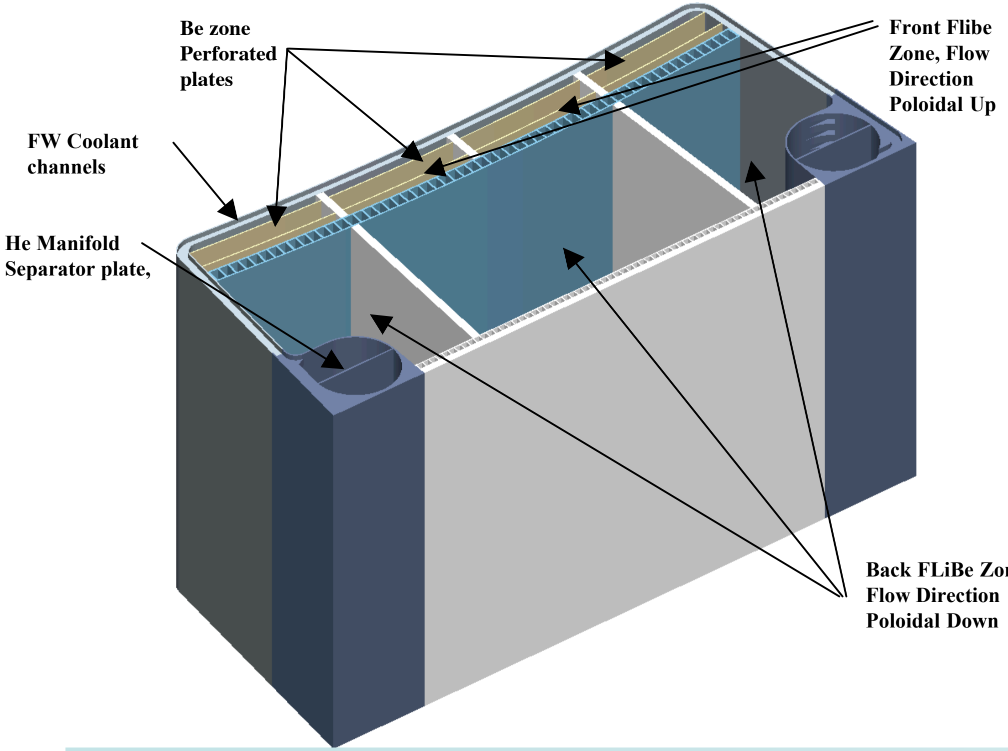
3-D Neutronics Modeling

- 3-D neutronics performed for the DC blanket with $LiBeF_3$ to check impact of 3-D geometrical effects and blanket heterogeneity on overall TBR
- Neutron source sampled from D-shaped plasma using a peaked distribution at magnetic axis
- The model includes detailed heterogeneous geometrical configuration of IB and OB blanket sectors
- 3-D model used a conservative assumption by including water-cooled steel with 1 cm tungsten armor in the double null divertor region

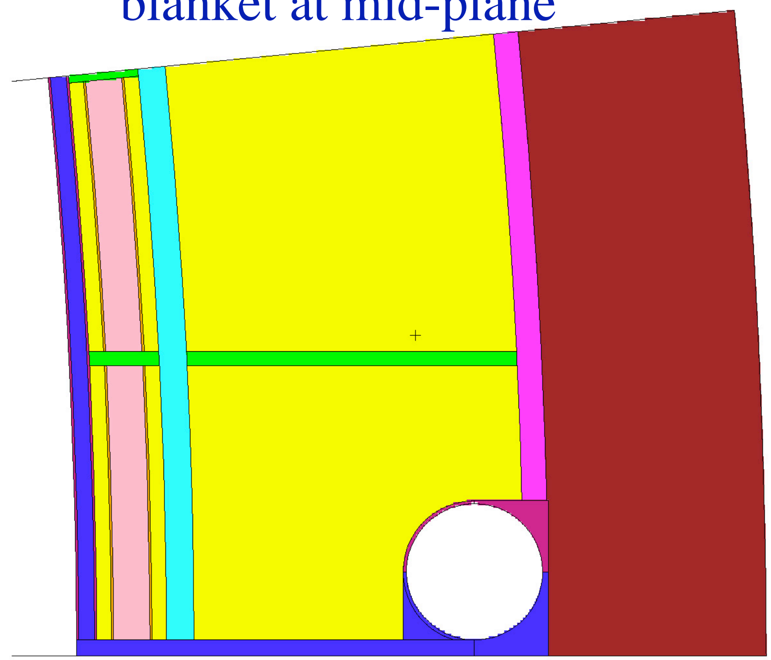




3-D TBR Calculation



Cross section in OB blanket at mid-plane



- Total TBR is 1.07 (0.85 OB, 0.22 IB). This is conservative estimate (no breeding in double null divertor covering 12%)
- Minor design modifications such as increasing Be zone and/or blanket thickness can be made to enhance TBR if needed to ensure tritium self-sufficiency. Increasing Be zone from 5 to 6 cm increases TBR to 1.09
- 3-D modeling and heterogeneity effects resulted in ~6% lower TBR compared to estimate based on 1-D calculations

Summary

- The overall TBR for dual-coolant blanket with 5 cm Be zone and no divertor breeding will be ~1.07 based on 3-D calculations
- Minor design modifications can be made to enhance the TBR if needed to ensure tritium self-sufficiency
- Be yields higher blanket energy multiplication compared to Pb
- Modest amount of tritium is produced in the Be (~3 kg) over the blanket lifetime of ~3 FPY
- Using He gas in the dual-coolant blanket results in about a factor of 2 lower blanket shielding effectiveness compared to SC blanket
- With total blanket/shield/VV radial build of 105 cm in IB and 120 cm in OB it is possible to ensure that shield is lifetime component, VV is reweldable, and magnets are adequately shielded
- We conclude that molten salt blankets can be designed for fusion power plants with neutronics requirements such as adequate tritium breeding and shielding being satisfied