Nuclear Performance of EVOLVE

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Impact of Blanket Design on Nuclear Parameters

- Previously nuclear performance parameters determined assuming uniform vapor fraction of 17% in trays
- Up to 65% vapor fraction obtained using drift-flux model with churn-turbulent boiling regime and no MHD effects
- Preliminary analysis for flow pattern with triggered vapor channels indicate that vapor fractions below 8% are achievable
- Will assess impact of Li vapor fraction on nuclear parameters
- Will compare nuclear parameters for transpiration and boiling blankets using preliminary radial build and composition

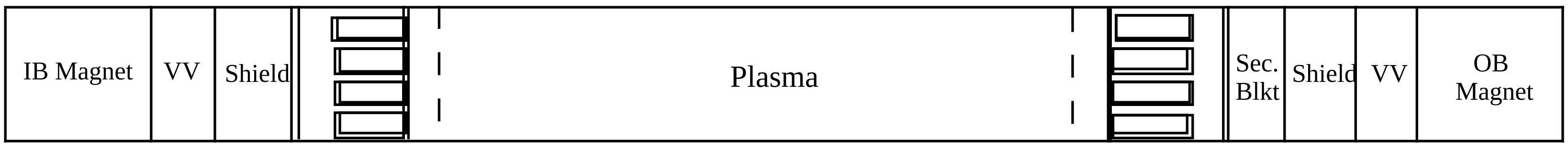
Secondary Blanket, Shield, and VV Design

- 40 cm thick secondary breeding blanket utilized in OB side
- Composition of secondary blanket is 90% Li, 10% W
- OB and IB shield thicknesses are 50 and 60 cm
- Composition of shield is 20% Li, 10% W, 70% WC
- 30 cm thick VV with two 5 cm thick SS sheets sandwiching He-cooled shielding zone of 80% WC

2-D Calculational Procedure

- TWODANT module of DANTSYS 3.0 utilized
- FW represented by 0.6 cm thick zone
- Li pool divided into 25 zones (5 radial x 5 vertical)
- Tray bottom and back W plates are 0.5 cm thick
- Both IB and OB regions modeled simultaneously
- Made conservative assumption of no divertor breeding
- Results normalized to peak OB wall loading of 10 MW/m^2

Two-Dimensional Model



R-Z Two-Dimensional Model for EVOLVE

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Iterations with Boiling Analysis

- Nuclear heating calculation iterated with lithium tray boiling analysis to determine a nuclear heating distribution that is *consistent* with vapor fraction distribution

Nuclear Heating (W/cm^3) Distribution in OB Tray
Using Initial Uniform Vapor Fraction of 17% in Li Pool

98.9						
99.4	28.3	22.1	17.6	14.5	12.6	40.4
100.7	28.2	21.9	17.4	14.2	12.2	39.2
101.7	28.2	21.8	17.4	14.2	12.1	38.1
102.5	28.4	21.9	17.4	14.2	12.0	37.1
104.6	28.7	22.2	17.5	14.3	12.2	36.3
103.2	90.3	72.0	58.4	48.2	40.3	34.4
104.0						

Vapor Fraction (%) Distribution in OB Tray from Third Li Boiling Analysis

65.1	64.2	63.4	62.8	63.3
64.5	63.3	62.6	61.9	62.3
63.6	62.2	61.4	60.5	60.9
62.1	60.5	59.4	58.4	58.5
30.5	29.7	29.1	28.5	28.5

- ***Iterations Converged***

	Average Vapor Fraction in Li Tray
Initial assumption	17%
First iteration	52.4%
Second iteration	55.6%
Third iteration	55.5%

Nuclear Heating (W/cm^3) Distribution in OB Tray Using Third Iteration Vapor Fraction Distribution

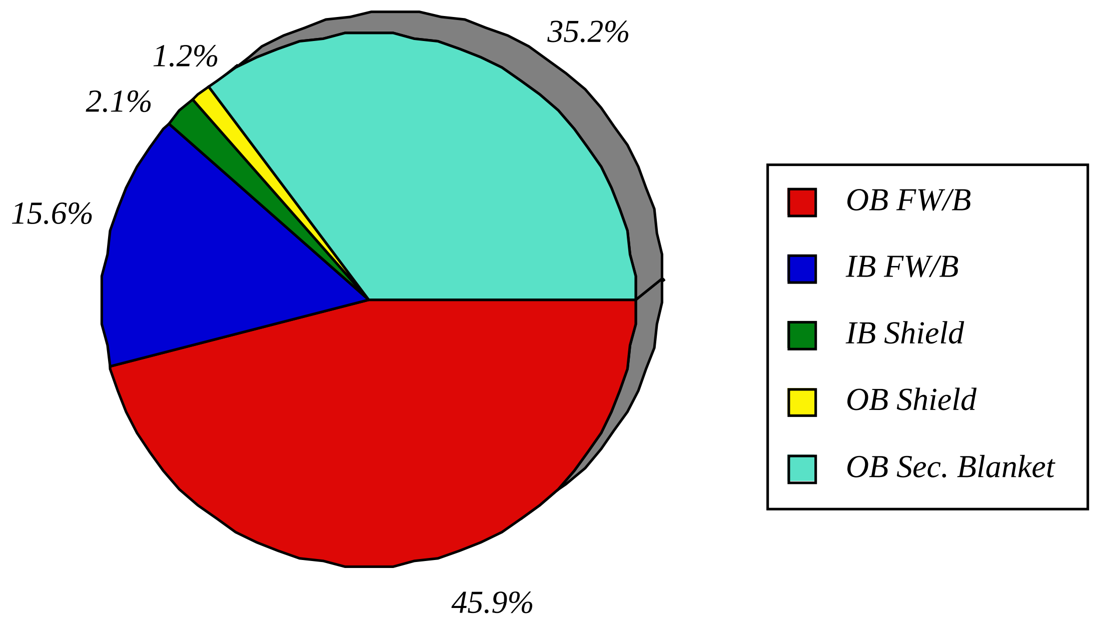
104.4						
104.5	13.5	11.9	10.4	9.3	8.4	56.7
105.5	13.7	12.1	10.6	9.5	8.5	55.8
106.4	14.1	12.3	10.9	9.8	8.8	54.8
107.2	14.6	12.6	11.5	10.3	9.3	53.8
109.0	27.0	23.1	20.0	17.7	16.0	52.7
109.0	98.0	84.2	72.9	64.1	56.8	50.5
110.0						

Two-dimensional neutronics with detailed vapor fraction distribution

- Iterated process between 2-D neutronics calculations and lithium tray boiling analysis with drift-flux model resulted in detailed vapor fraction profile in boiling lithium blanket

- 2-D calculations performed using this vapor fraction profile to determine nuclear performance parameters and compare them to those obtained in previous 2-D calculations with uniform 17% vapor fraction

Overall TBR 1.327



- Overall TBR lower by only 3%
- More breeding contributed by secondary blanket and shield

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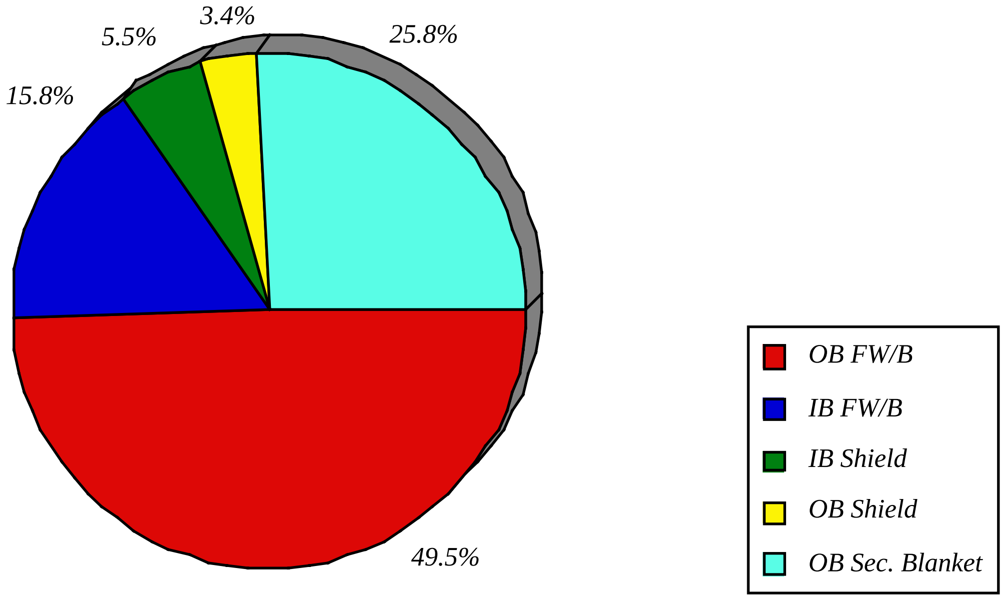
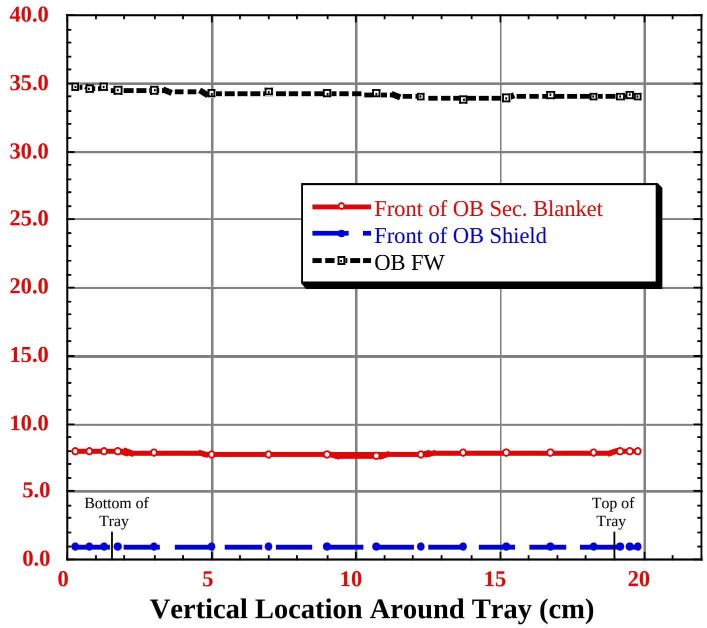
Overall Energy Multiplication 1.195



- Energy multiplication lower by only 0.3%

- ~70% of total thermal power carried by vapor compared to 76% for 17% vapor fraction case

Peak Structure Damage Rate Values



- No significant poloidal peaking observed

- Peak damage rate in OB secondary blanket and IB shield factor of ~5 lower than in FW and expected to have a factor of 5 longer lifetime than FW and trays
- Lifetime of OB shield about an order of magnitude longer than for OB secondary blanket and IB shield making it lifetime component

Peak VV and Magnet Neutronics Parameters

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

Peak VV neutronics parameters

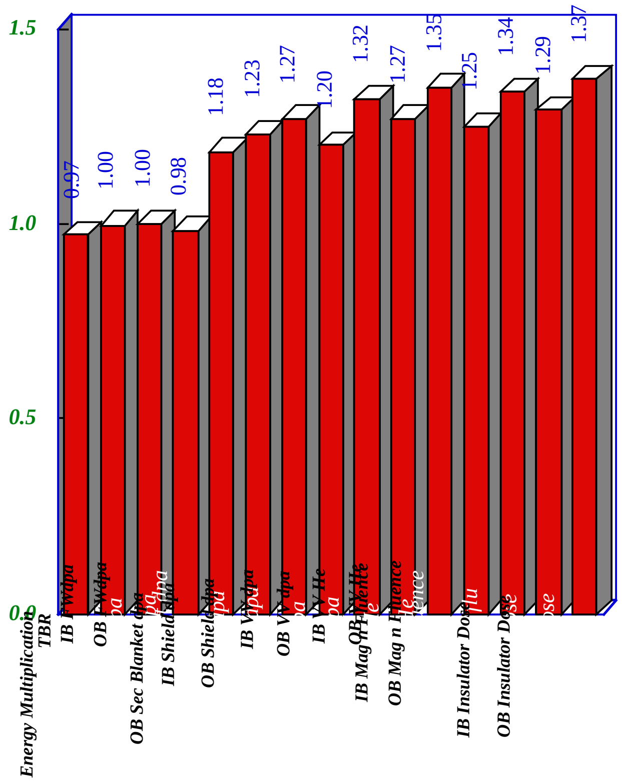
	IB	OB
Peak Nuclear Heating (mW/cm^3)	3.5	2.5
Peak end-of-life dpa	0.10	0.07
Peak end-of-life He appm	0.44	0.27

Peak magnet neutronics parameters

	IB	OB	Design Limit
Peak Nuclear Heating (mW/cm^3)	0.15	0.10	2
Peak end-of-life Fast Neutron Fluence (n/cm^2)	$4x10^{18}$	$2.7x10^{18}$	10^{19}
Peak end-of-life Dose to Insulator (Rads)	$4.3x10^{9}$	$2.7x10^{9}$	10^{11}
Peak end-of-life dpa to Cu Stabilizer	$1.9x10^{-3}$	$1.2x10^{-3}$	$6x10^{-3}$

- All VV and magnet radiation limits satisfied with comfortable margin

Nuclear parameters relative to values with 17% vapor fraction



2-D neutronics calculations for worst case conditions imply that *all nuclear parameters are acceptable* with a comfortable margin

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EVOLVE *boiling blanket* expected to *perform adequately* from the *neutronics* point of view for *any of the boiling regimes* considered

- *Small impact* of high void fraction

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Nuclear parameters for transpiration and boiling blankets

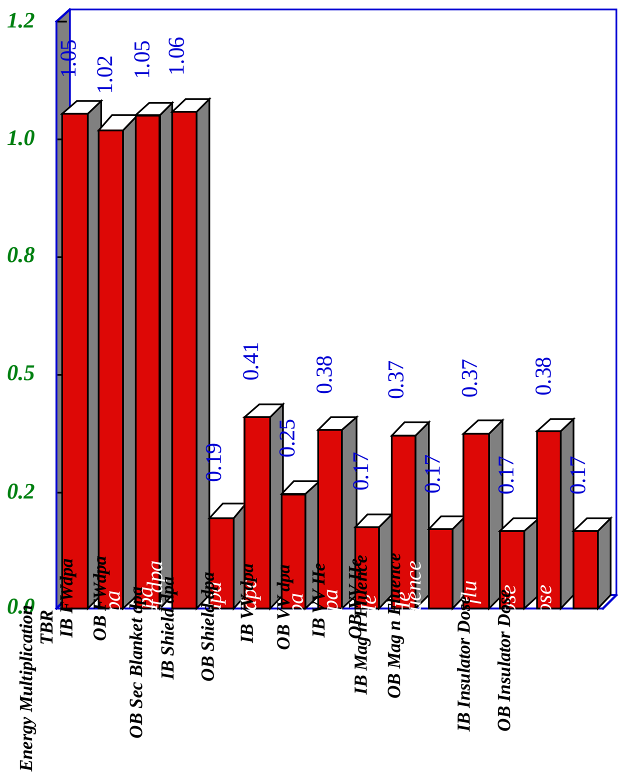
- Preliminary radial build and material composition for transpiration blanket used to compare nuclear parameters for EVOLVE boiling and transpiration design options

Overall Material Fractions in FW/B

	Inboard		Outboard	
	Boiling	Transpiration	Boiling	Transpiration
Thickness (cm)	42.6	42.85	52.6	60.3
% Li	43.4	80.5	43.6	83
% W	2.6	6.7	2.1	6.7
% Vapor	54	12.8	54.3	10.3

- With these assumptions *boiling blanket more transparent* for neutrons and gamma
- Relative results depend on assumptions made for material composition

Nuclear parameters for transpiration blanket relative to boiling blanket



- Slightly higher TBR and M in transpiration design due to lower vapor fraction and larger content of Li and W
- About 10% higher nuclear heating and damage in FW of transpiration design due to larger reflection
- Nuclear heating and damage in OB components behind transpiration blanket a factor of 4-6 lower due to thicker and more dense transpiration blanket
- Nuclear heating and damage in IB components behind transpiration blanket a factor of 2-3 lower due to more dense transpiration blanket

Conclusions

- Higher vapor fraction in boiling blanket has minimal impact on nuclear performance parameters
- Based on 2-D neutronics calculations for worst case conditions with highest predicted vapor fraction distribution all nuclear performance parameters acceptable with a comfortable margin
    - Overall TBR 1.37 without divertor breeding
    - ~70% of thermal power carried by Li vapor as high-grade heat
    - OB secondary blanket and IB shield have a factor of 5 longer lifetime than FW
    - OB shield expected to be a lifetime component
    - VV is reweldable and all magnet radiation limits are satisfied
- EVOLVE boiling blanket expected to perform adequately from the neutronics point of view for any of the boiling regimes considered

Conclusions

- Based on preliminary composition assumptions the transpiration blanket has larger Li and structure content resulting in slightly higher TBR and a factor of 2-5 better shielding performance
- Differences between nuclear parameters of two concepts are not inherent but caused by composition assumptions which need to be verified by more analysis and experiments
- Nuclear performance parameters for both designs are acceptable with large margin implying that choice between two options should not be driven by differences in nuclear performance