Nuclear Analysis for a Flowing Li_2O Particulate Blanket Without Structural First Wall

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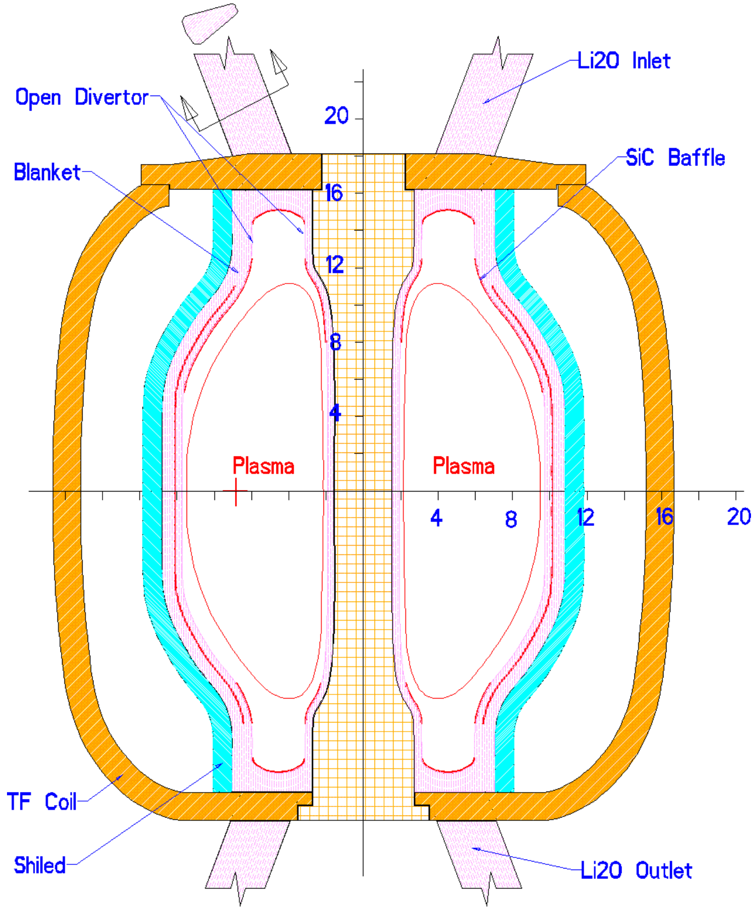
Background

- 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
- An innovative concept utilizes Li_2O granular particulates flowing down the reactor chamber
- This concept is referred to as the APPLE (Advanced Plasma-facing Particulate Li_2O Evaluation) concept



Schematic of the APPLE concept

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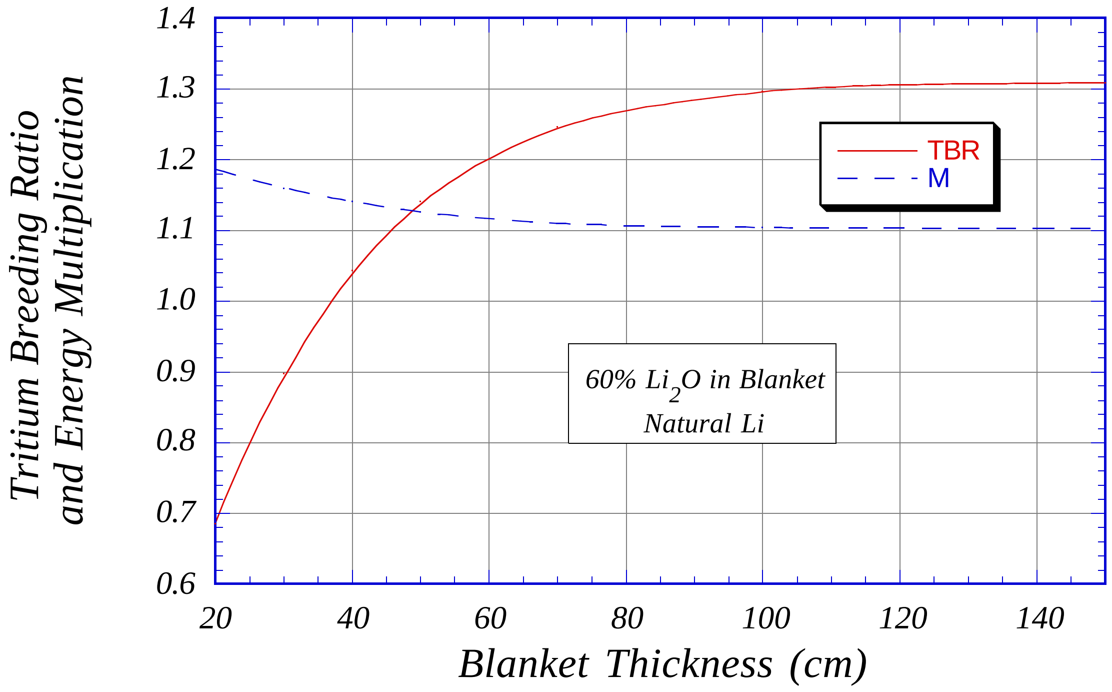
Calculational Procedure

- 5 cm front blanket layer of Li_2O @30% packing fraction
- 0.5 cm SiC separation wall
- Li_2O blanket @60% packing fraction
- Shield consisting of 80% steel and 20% H_2O
- VV consists of two SS sheets each 5 cm thick sandwitching a 30-cm-thick shielding zone made of 80% steel and 20% H_2O
- 316SS and LA ferritic steel considered in activation analysis
- 1-D calculations for local nuclear parameters
- Both IB and OB regions modeled simultaneously
- Results normalized to OB and IB wall loadings of 10 and 7 MW/m^2
- Results coupled with coverage fractions to estimate overall parameters
- Neutron coverage fractions of 75% OB, 15% IB, 10% divertor

Impact of Blanket Thickness on Local TBR and Energy Multiplication



- Local TBR increases with blanket thickness reaching a maximum value of 1.3
- M decreases slightly with thickness increase

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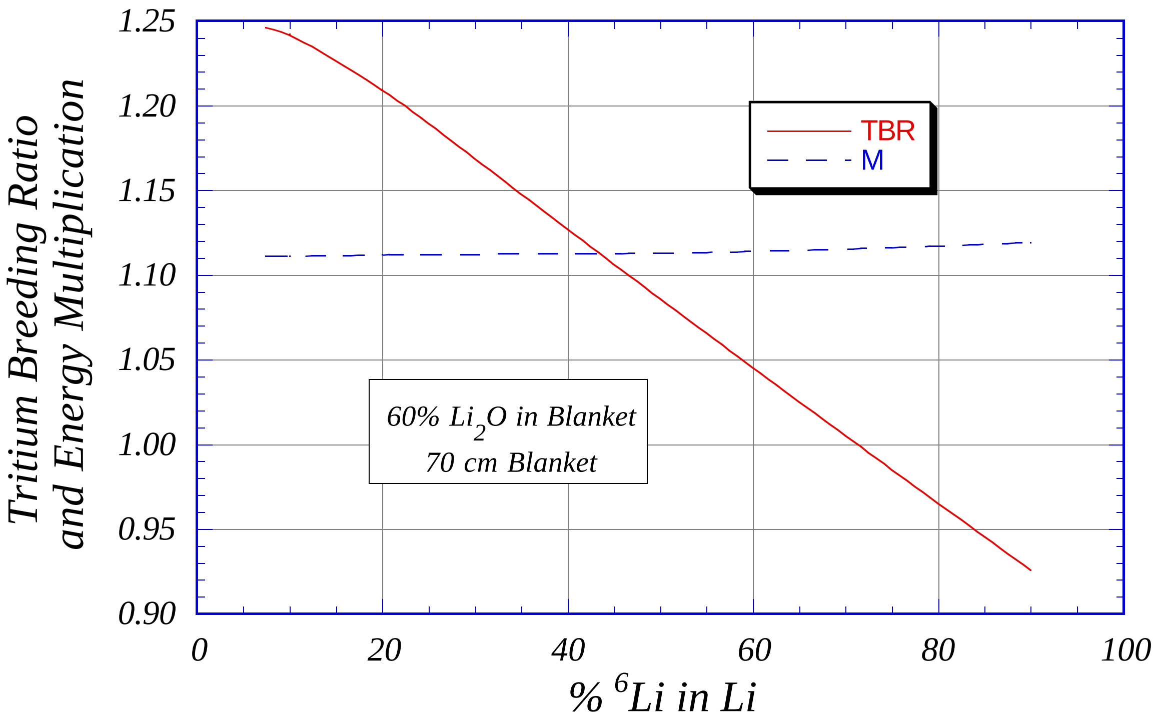
Effect of Li Enrichment



- Enriching Li results in significant decrease in TBR and negligible increase in M
- Natural Li is used in the reference design

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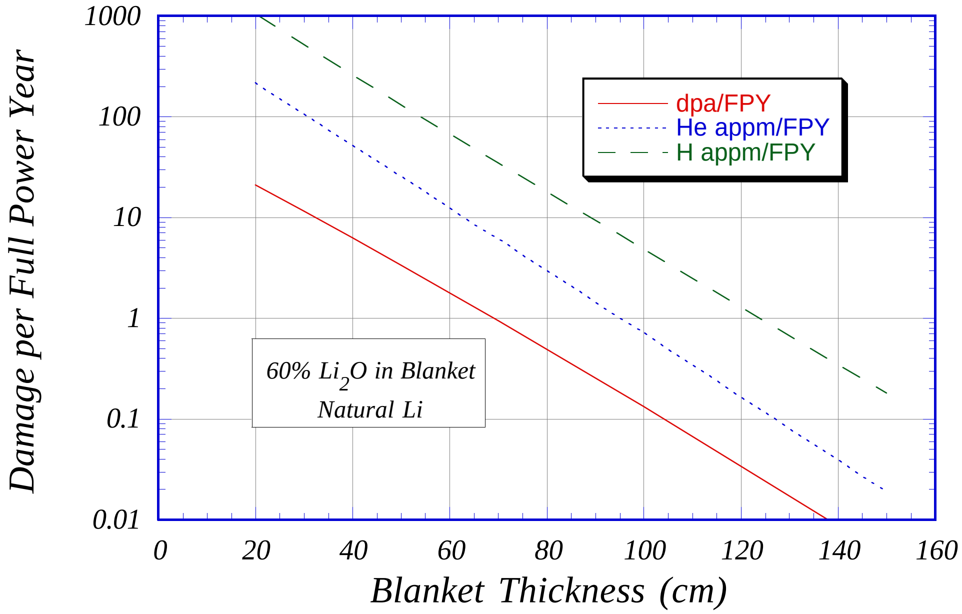
Impact of Blanket Thickness on Structure Damage and Gas Production



- Steel damage and gas production decrease by an order of magnitude in 35 cm
- A minimum blanket (Li_2O @ 60%) thickness of 40 cm is required for the structure to be lifetime component (200 dpa @ 30 FPY)
- A minimum blanket (Li_2O @ 60%) thickness of 145 cm is required in front of the SS VV to be reweldable (1 He appm @ 30 FPY)

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Local TBR and M

- Natural Li

- Total blanket thickness:

Outboard	75 cm	(for breeding)
Inboard	40 cm	(for structure shielding)

- Local TBR:

Outboard	1.233
Inboard	1.158

- Local M:

OB	1.099	(3.2% in shield/VV)
IB	1.166	(15.4% in shield/VV)

Estimated Overall TBR and Energy Multiplication

- The local TBR and M values were combined with neutron coverage fractions to determine the overall TBR
- We assume neutron coverage fractions of 75% OB, 15% IB, 10% divertor
- Blanket thickness in divertor region is 40 cm
- Overall TBR is 1.215

76.2%	OB
14.3%	IB
9.5%	Div

- Overall M is 1.116

93.6% deposited as high grade heat in the blanket

Peak Nuclear Heating and Radiation Damage Rate Values in Blanket

- SiC separation wall (not structure member) will require replacement

	IB	OB
Peak Nuclear Heating (W/cm^3)	54.9	75.0
Peak dpa Rate (dpa/FPY)	72.8	93.1
Peak He Prod. Rate (He appm/FPY)	7310	10438

- Steel structure at back of blanket is lifetime component

	IB	OB
Peak Nuclear Heating (W/cm^3)	14.9	4.3
Peak dpa rate (dpa/FPY)	5.54	0.87
Peak end-of-life dpa @ 30 FPY	166.2	25.9
Peak He Prod. Rate (He appm/FPY)	42.6	5.5
Peak end-of-life He appm @ 30 FPY	1277	163

VV and Magnet Shielding

- For reweldability, the peak helium production in the VV should not exceed 1 appm

- Adequate VV shielding is provided using
  40 cm SS/H_2O shield behind 75 cm OB blanket
  55 cm SS/H_2O shield behind 40 cm IB blanket

- End-of-life insulator dose in superconducting magnet should not exceed 10^9 Rads

- The 40-cm-thick VV provide additional shielding for the magnets

Peak VV and Magnet Neutronics Parameters

- 55 cm thick IB shield
- 40 cm thick OB shield
- 40 cm thick VV

Peak VV neutronics parameters

	IB	OB
Peak Nuclear Heating (mW/cm^3)	10	11
Peak end-of-life dpa	0.09	0.10
Peak end-of-life He appm	0.40	0.42

Peak magnet neutronics parameters

	IB	OB	Design Limit
Peak Nuclear Heating (mW/cm^3)	0.028	0.027	1
Peak end-of-life Fast Neutron Fluence (n/cm^2)	$8.5\text{x}10^{17}$	$8.0\text{x}10^{17}$	10^{19}
Peak end-of-life Dose to Epoxy Insulator (Rads)	$8.3\text{x}10^{8}$	$7.1\text{x}10^{8}$	10^{9}
Peak end-of-life dpa to Cu Stabilizer	$4.3\text{x}10^{-4}$	$4\text{x}10^{-4}$	$6\text{x}10^{-3}$

- All VV and magnet radiation limits are satisfied

Recommended Radial Build

- Radial build that satisfies requirements for structure lifetime, VV reweldability, and superconductor magnet shielding is

  Outboard: 155 cm total
    75 cm Blanket
    40 cm shield
    40 cm VV

  Inboard: 135 cm total
    40 cm Blanket,
    55 cm shield
    40 cm VV

Recommended Radial Build

Thick (cm)	Li_2O @ 30% p.f.	SiC wall	Li_2O @ 60% p.f.	Shield 80% Steel 20% H_2O	Steel	VV 80% Steel 20% H_2O	Steel
IB	5	.5	34.5	55	5	30	5
OB	5	.5	69.5	40	5	30	5

Activation Analysis

- Impact of replacing 316SS (20 appm Nb impurity) by low activation ferritic steel was assessed
- ORNL LAFS 9Cr-2WVTa with 0.5 wppm Nb is considered
- While nearly identical short-term activities are obtained in the two alloys, the long-term activity is reduced by more than two orders of magnitude when the LAFS is used
- The LAFS is used in the reference design

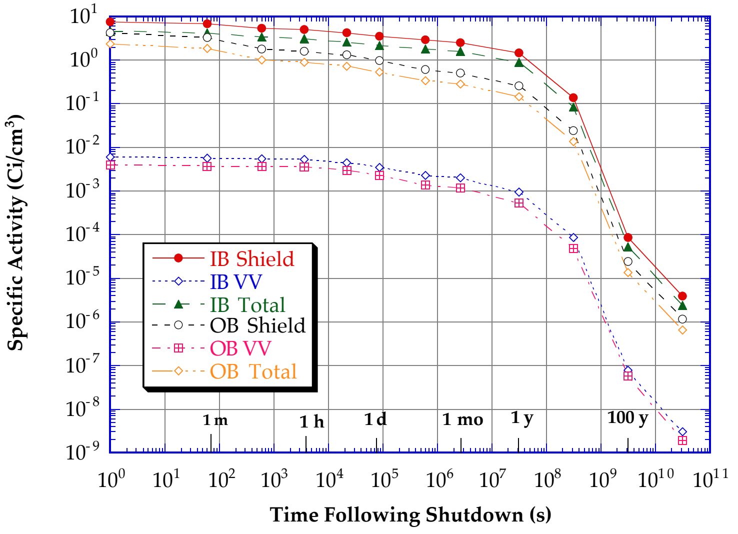
Impact of Particulate Blanket on Structure Activation

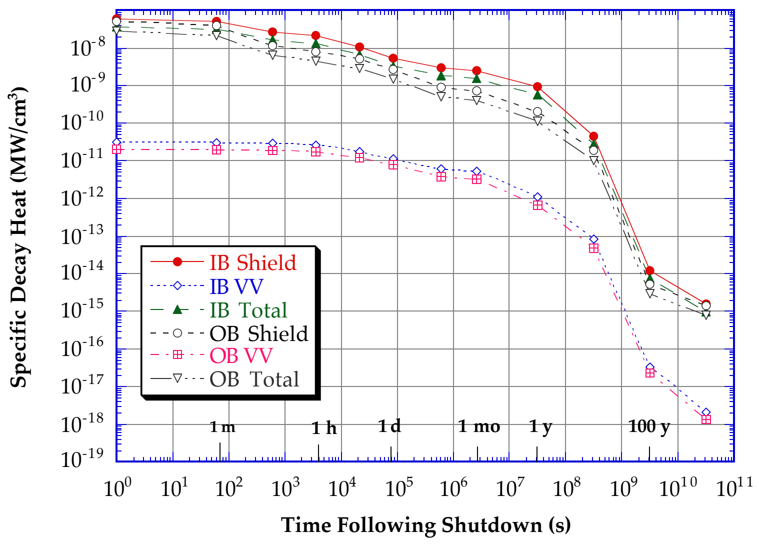
- Comparing the structure activity with and without the Li_2O particulate blanket indicates that
  - Short-term activity that affects decay heat and off-site dose from accidental release is reduced by a factor of ~40 due to the attenuation of the neutron flux in the blanket
  - Reduction in long-term activity that affects radwaste classification is not as significant since the structure is used for the whole reactor life (30 FPY) while in a conventional solid wall design, the FW/blanket structure is replaced after ~ 2 FPY

Activation for Reference Design

SiC baffles and separation walls replaced every 2 FPY

Shield and VV last for 30 FPY





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Waste disposal ratings

- Radwaste of different components of APPLE evaluated according to both NRC 10CFR61 and Fetter limits
- Results given for compacted wastes
- All components would qualify for disposal as low level Class C waste

Zone	Lifetime (FPY)	Class C WDR (Fetter)	Class C WDR (10CFR61)
SiC baffle/separation wall	2	0.275	0.02
IB shield	30	0.648	0.144
IB VV	30	4.54x10^{-3}	1.92x10^{--4}
OB Shield	30	0.46	0.057
OB VV	30	4.39x10^{-3}	1.86x10^{--4}

Summary

- The overall TBR is estimated to be 1.22 and the overall energy multiplication is 1.12
- 93.6% of nuclear heating deposited as high-grade heat in the front particulate blanket
- A minimum blanket thickness of 40 cm required for structure to be lifetime component
- The radial build required for VV reweldability and magnet shielding was determined
- More than an order of magnitude reduction in decay heat and activity results from placing the structure behind the Li_2O particulate blanket
- Using low activation ferritic steel structure behind the Li_2O particulate blanket allows for near surface burial of the radwaste
- The Li_2O particulate blanket concept without structural FW has the potential for achieving tritium self-sufficiency with lifetime structure and reweldable VV
- It has attractive safety features resulting from the significant reduction in radioactivity and decay heat generation in the structural material