ARIES-AT Nuclear Parameters, Radial Build, and Activation Analysis

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Web address:
http://fti.neep.wisc.edu/FTI/ARIES/DEC99/lae.pdf

ARIES Project Meeting
1-3 December 1999
UCSD

Design Parameters

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Fusion power	1737 MW
FW location at midplane – OB , IB	6.05 , 3.55 m
at top/bottom – OB , IB	~4.5 , 3.55 m
Γ : Peak OB , IB	6.1 , 4 MW/m^2
Average OB , IB	5.2 , 2.8 MW/m^2
FW poloidal length* – OB , IB	~5.5 , 4.5 m
SiC burnup limit	3%
FS dpa limit	200 dpa
Machine lifetime	40 FPY

HT magnet/cryostat composition from L. Bromberg

ARIES-RS' vacuum vessel configuration
(to be modified based on Clearance considerations)

* Between X points

Nuclear Parameters

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- Key features of FW/Blanket:
  - Self-cooled LiPb/SiC FW/blanket
  - Constant-flow, integral FW design (3.3 cm thick; 40% SiC, 60% LiPb)
  - IB and OB blankets only (no blanket behind divertor)
  - 90% enriched LiPb
  - 30 cm thick IB FW/blanket
  - 65 cm thick OB FW/blanket segmented into:
    - 30 cm FW/Blanket -I
    - 35 cm Blanket-II
  - 6 cm thick vertical stabilizing shell (90% W, 10% LiPb) at top/bottom:
    - Between blanket segments on OB
    - Between blanket and shield on IB
  - Penetrations:
    - 1.5 m^2 on OB for CD and plasma control, per TK
    - 2 cm radial gaps between 16 blanket modules

- Reference nuclear parameters:

Overall TBR	1.1
Overall Mn	1.1
SiC Burnup rate	1% per FPY*
FW EOL Fluence	18.5 MWy/m^2
FW Lifetime	3 FPY

- Comments:
  - Breeding is marginal
  - More SiC content in FW will degrade breeding
  - Thicker blanket will increase breeding
  - Higher enrichment (> 90%) is expensive and has insignificant impact on breeding

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* 0.7% Si , 0.3% C

TBR vs. FW SiC Content and Blanket Thickness

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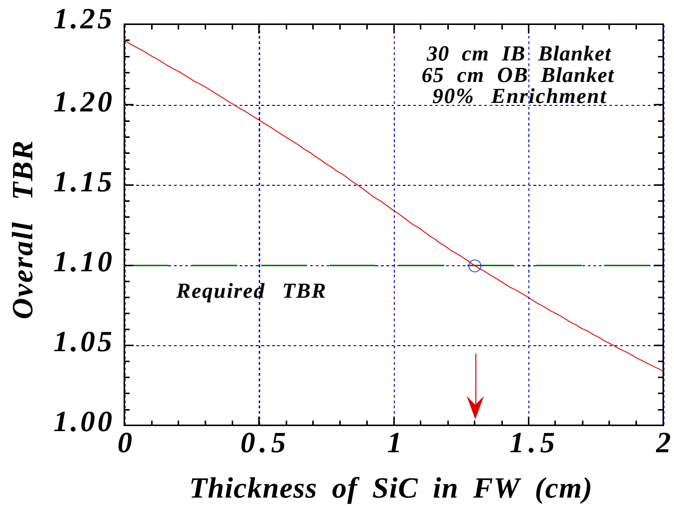
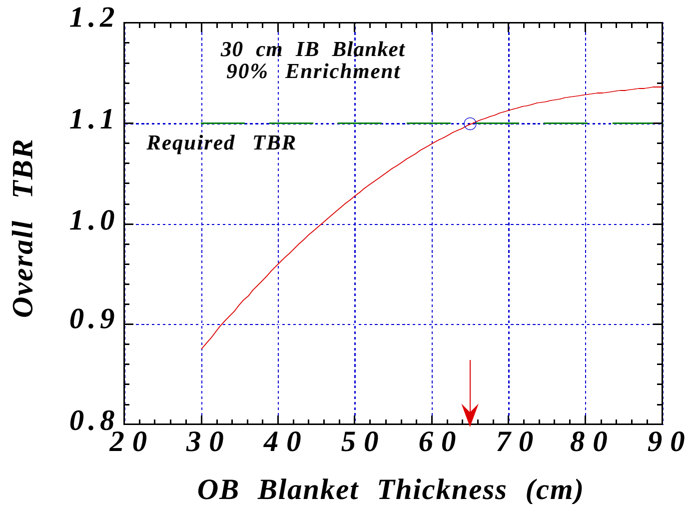


SiC content in FW has significant impact on breeding



Thicker OB blanket increases breeding slightly (~3%)

TBR vs. Li Enrichment

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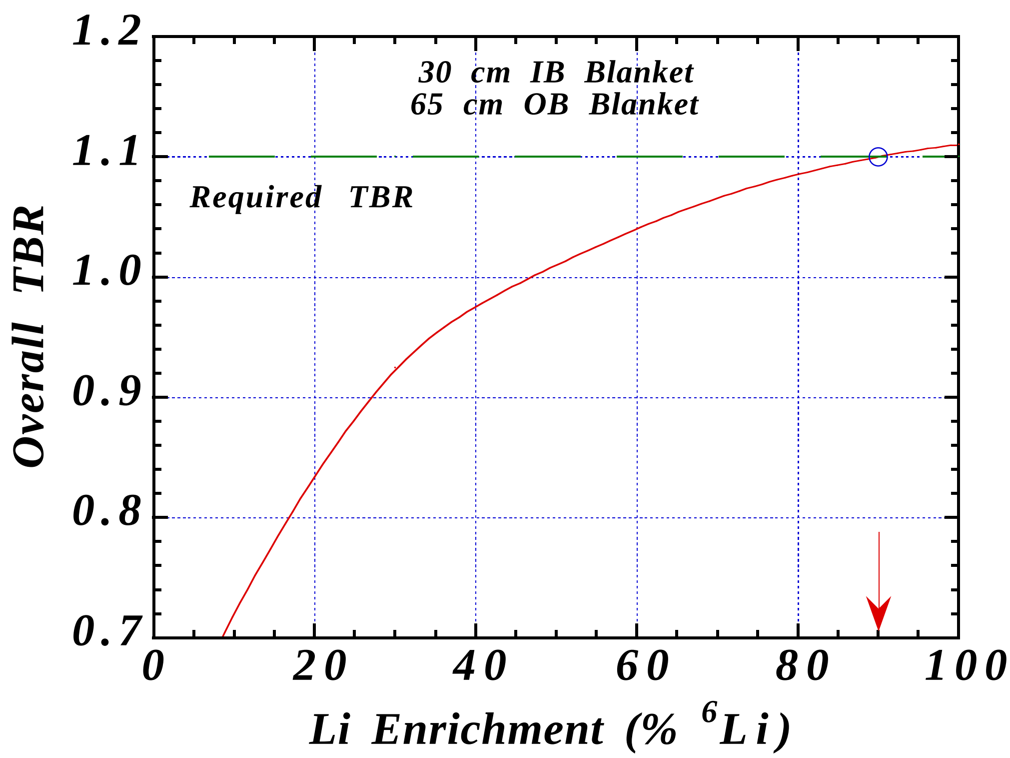

Blanket will not breed if enrichment drops below 90%

Impact of W Shell on Breeding

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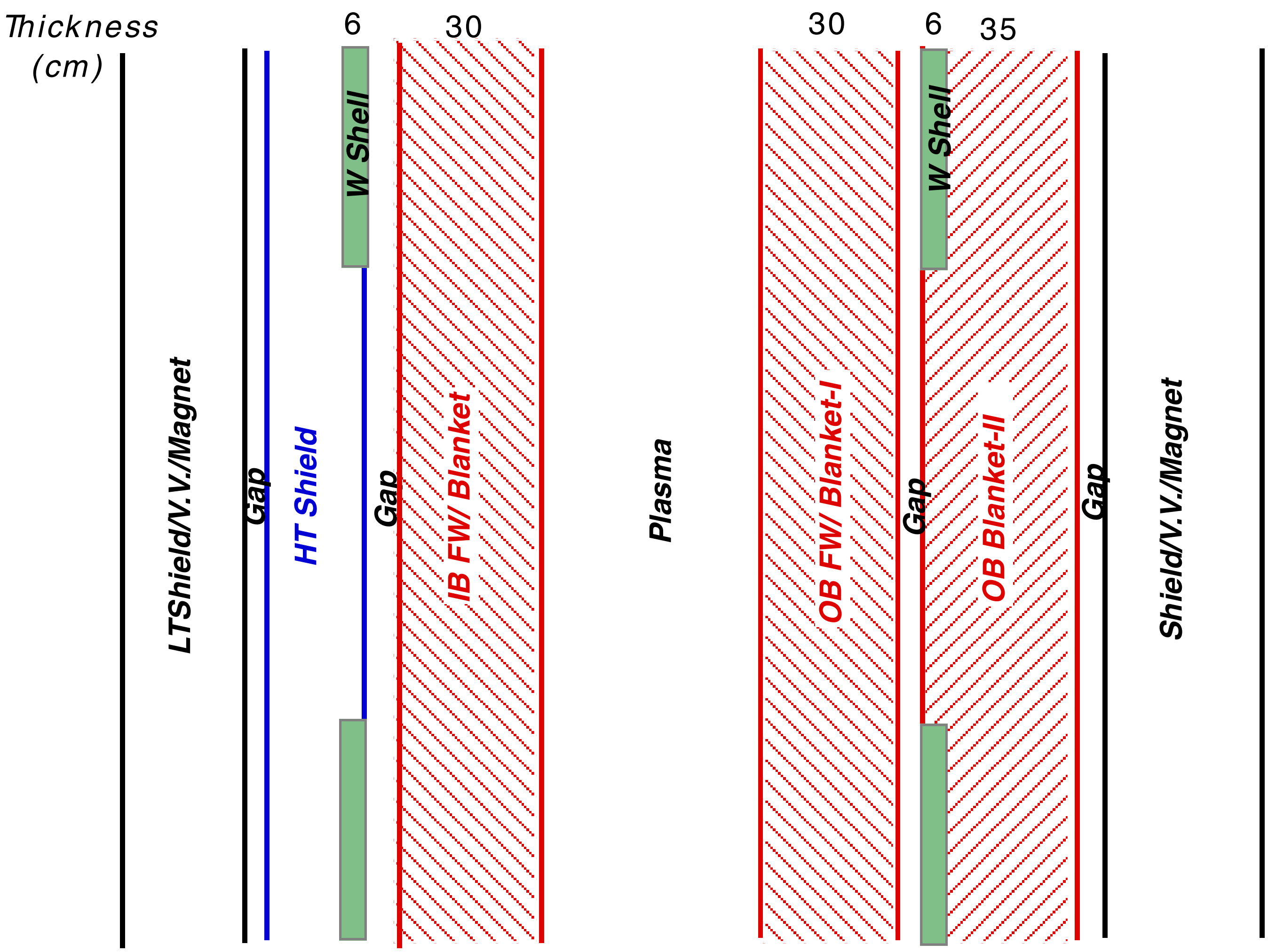

- Two separate shells placed at top/bottom of IB and OB sides
- OB shells cover 50% of poloidal length
- Shell has no significant impact on breeding of FW/B-I
- 6 cm thick shell reduces breeding behind it by 50%
- Based on 3-D calculations, regions behind shells contribute 10% to TBR

  ⇒ Shell reduces breeding by ~0.05, resulting in overall TBR of 1.1

Components' Lifetimes

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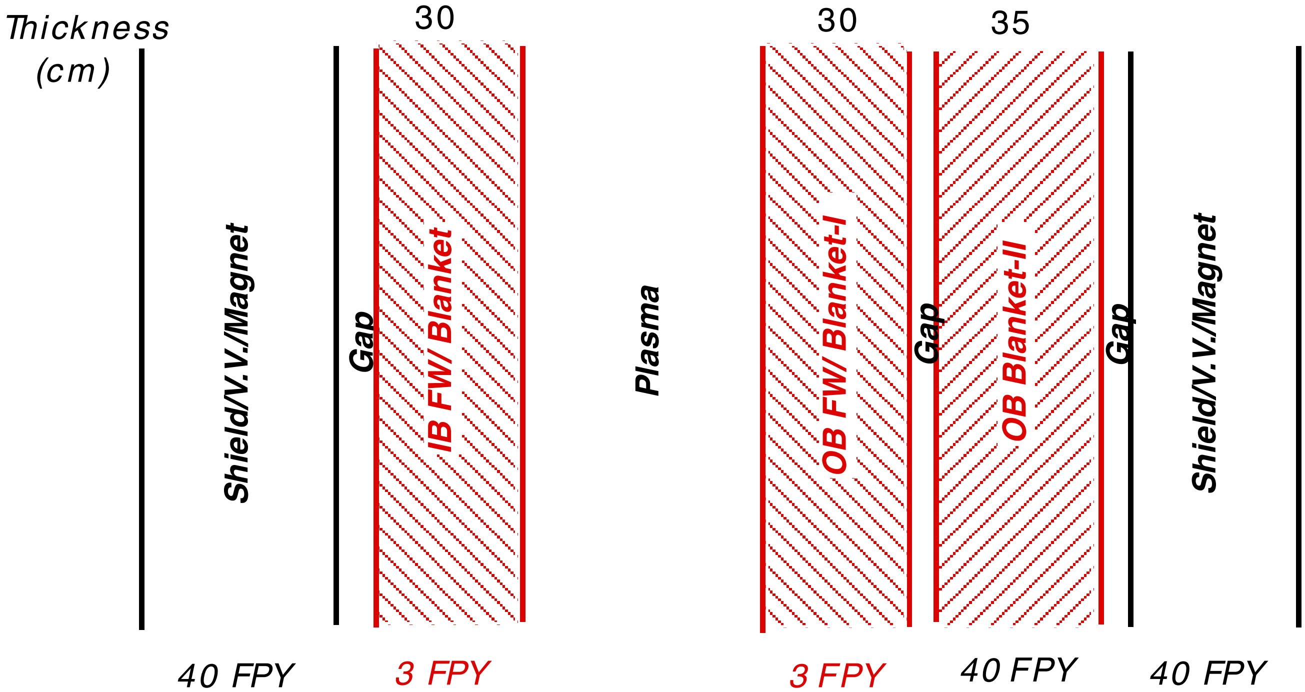
• Service lifetimes are based on:
  – 3% burnup limit for SiC structure of FW, blanket, HT shield
  – 200 dpa limit for FS structure of LT shield and V.V.



• Back wall of B-I is lifetime component. BW could be reused to reduce radwaste stream

• Ratio of replaceable component volume to total radwaste volume is 20-30% and drops to 10-20% if B-I back wall is reused

Nuclear Heat Load to In-vessel Components*

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(P_n= 1390 MW)

Nuclear Heating (MW)	Inboard	Outboard	Divertor	Total	
FW or DP	90	212	36**	**338**	(22%)
Blanket	230	708#	---	**938**	(61%)
HT Shield	60##	20	174	**254**	(17%)
Total	**380**	**940**	**210**	**1530**	
	(25%)	(61%)	(14%)		

Overall neutron energy multiplication is 1.1

* To be confirmed by 3-D analysis
** Assumed 5 cm thick SiC/LiPb (40/60) divertor plates
# 560 MW in B-I, 36 MW in W shells, 112 MW in B-11
15 MW in W shells, 45 MW in shield

Inboard Radial Build

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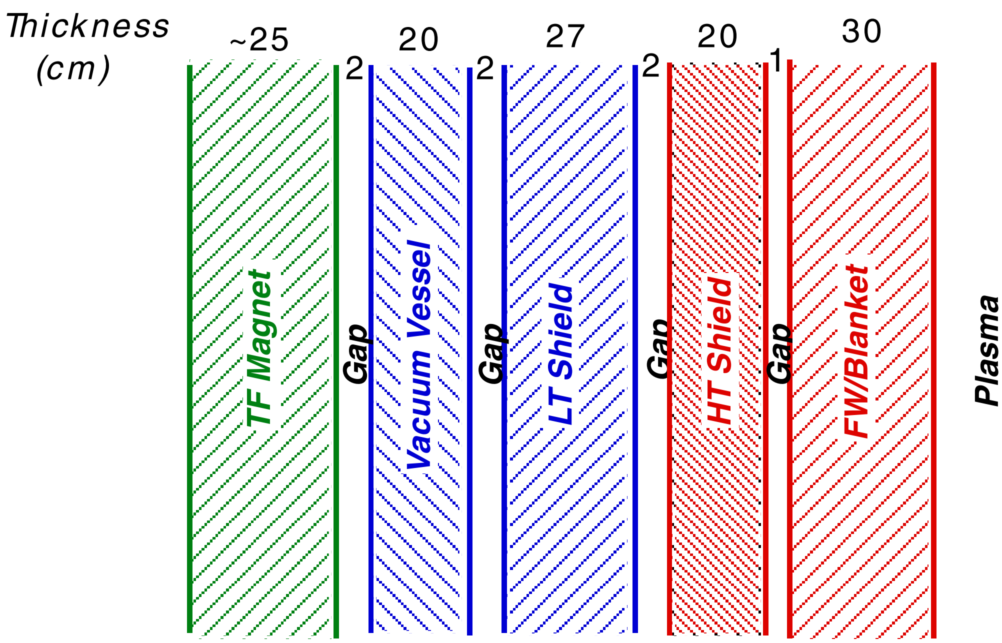

Component	Composition[#]
FW (3.3 cm)	40% SiC , 60% LiPb (90% Li-6)
Blanket (26.7 cm)	7% SiC , 93% LiPb (90% Li-6)
HT Shield	15% SiC, 10% LiPb , 75% B-FS
LT Shield	15% FS , 5% H_2O , 80% WC
Vacuum Vessel	35% FS , 40% H_2O , 25% WC
HT Magnet	87% SS, 10% LN, 2.5% $Y_1Ba_2Cu_3O_5$, 0.5% Ag

- V.V. and TF magnet radiation limits are all met[*] for peak Γ= 4 MW/m^2 (1 He appm at V.V and 10^{19} n/cm^2 at magnet @ EOL)

[#] SiC and WC are 95% dense
[*] Safety factor of 3 considered in all shielding calculations

Outboard Radial Build

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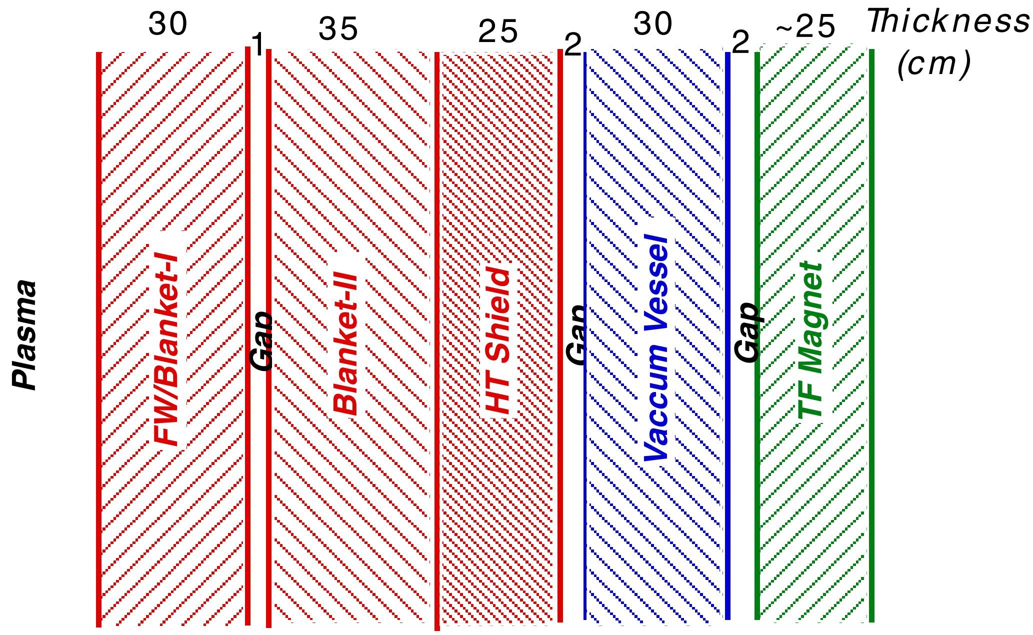

Component	**Composition**#
FW/Blanket-I:	
FW (3.3 cm)	40% SiC , 60% LiPb (90% Li-6)
B-I (26.7 cm)	7% SiC , 93% LiPb (90% Li-6)
Blanket-II	8% SiC , 92% LiPb
HT Shield	15% SiC, 10% LiPb , 75% B-FS
Vacuum Vessel	25% FS , 60% H_2O, 15% B-FS
HT Magnet	87% SS, 10% LN, 2.5% $Y_1Ba_2Cu_3O_5$, 0.5% Ag

- Blanket-II and HT shield could be combined in a single lifetime component
- V.V. and TF magnet radiation limits are all met* for peak Γ= 6 MW/m^2
  (1 He appm at V.V and 10^{19} n/cm^2 at magnet @ EOL)
- No need for separate LT shielding component

SiC and WC are 95% dense

* Safety factor of 3 considered in all shielding calculations

Optimum Water Content in IB LT Shield and V.V.

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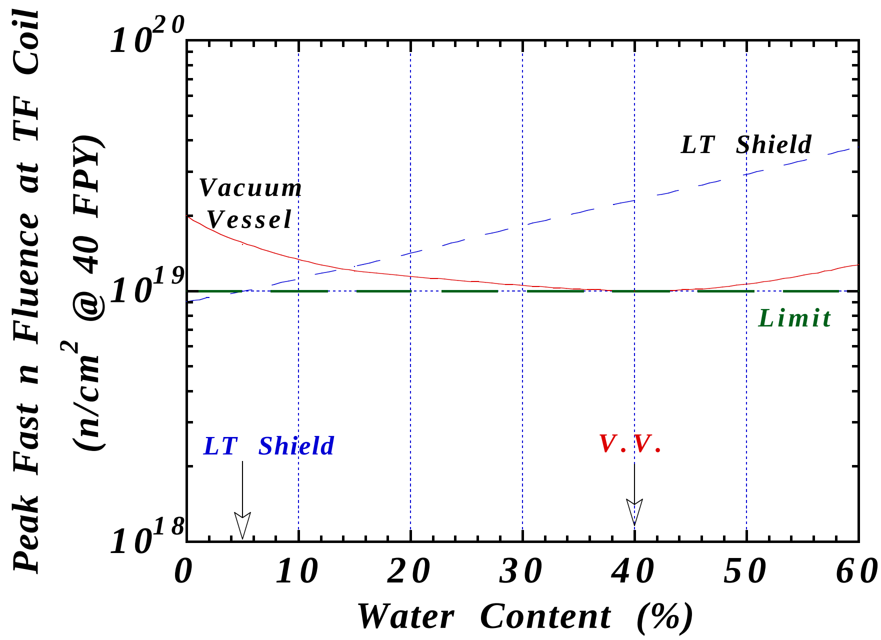

- Trading WC filler for water, optimum compositions are:

IB LT shield: 15% FS structure , 5% H_2O, 80% WC filler

IB V.V.: 35% FS structure , 40% H_2O, 25% WC filler

- Thinner V.V. could be cleared (to be confirmed by activation analysis)

Optimum Water Content in OB V.V.

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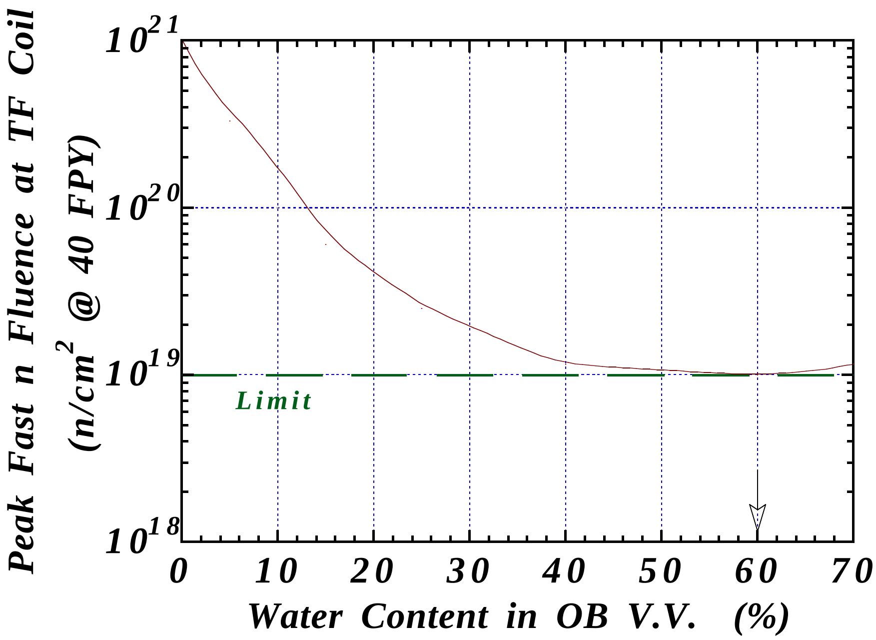

- Trading B-FS filler for water, optimum V.V. composition is:

  25% FS structure , 60% H_2O, 15% B-FS filler

- Thinner V.V. could be cleared (to be confirmed by activation analysis)

Impact of WC filler on IB Shield Size

- Low-cost manufacturing technique could only be applicable to metallic structural components (without filler)
- WC filler of both IB LT shield and V.V. was replaced by FS structure
- FS shield/V.V. will increase radial build by 15 cm
- Thicker IB components result in larger machine
- Impact on COE of thicker but cheaper IB shield/V.V. needs to be assessed by ASC

Comparison Between ARIES-AT and ARIES-RS Radial Builds

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	Inboard		Outboard	
ARIES design	**AT**	**RS**	**AT**	**RS**
Thickness (cm):				
FW/Blanket-I	30	20	30	20
Blanket-II	---	---	35	30
Replaceable Shield	---	20	---	7
HT shield	20	26	25	28
LT shield	27	28	---	40
Vacuum vessel	20	20	30	30
Subtotal	**97**	**114**	**120**	**155**
Magnet & cryostat	25	55	25	55
Total	**122**	**169**	**145**	**210**
Net reduction in thickness	**47**	**0**	**65**	**0**

- Thinner ARIES-AT radial builds are due to:
  - better LiPb shielding performance compared to Li
  - use of water in LT shield and V.V. instead of He
  - compact HT magnet

Activation Analysis

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- Codes and model:
  - Activation: ALARA code; FENDL-2 activation library
  - Flux: 1-D DANTSYS code; FENDL-1 Xn data
  - 175 n and 42 g group structure
  - 3-D neutron flux used to re-normalize 1-D flux for all components
  - Average OB and IB Γ are 5.2 and 2.8 MW/m^2, respectively
  - Operation time: 3 FPY for FW/B-I, 40 FPY for all other components

- Activity, decay heat, WDR, and clearance index depend strongly on material, flux level, neutron spectrum, operation time, and cooling period

- Results reported here are for:
  - OB side only, as defined by OB radial build.
    (IB side exhibits similar behavior at reduced level)
  - SiC and FS materials with impurities
  - 100% dense compact waste (coolants and void excluded)

- Results include:
  - Activity and decay heat as function of time after shutdown
  - Fetter's and NRC (10CFR61) waste disposal ratings for individual components at end of service lifetime
  - Dominant radionuclides at various times after shutdown

- Clearance calculations are underway

- Benchmarking of ALARA (activity, decay heat, and WDR) with DKR-Pulsar code showed excellent agreement

Activity
OB FW/Blanket-I
(3 FPY)

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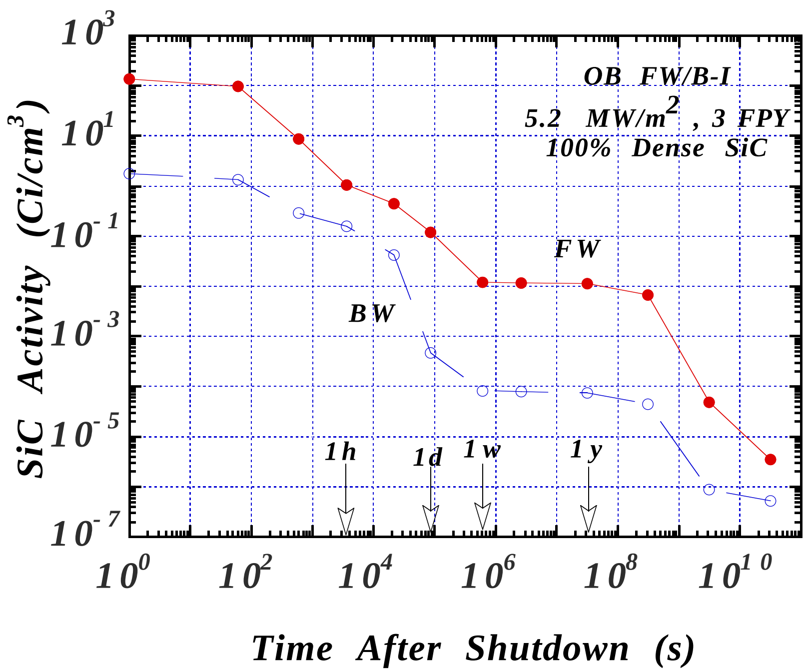

- OB FW contains highest activity among all SiC structures
- Compared to FW, activity generated in back wall (BW) is lower by factor of 10 or more
- Radial SiC structural ribs of B-I contain intermediate activity

Decay Heat
OB FW/Blanket-I
(3 FPY)

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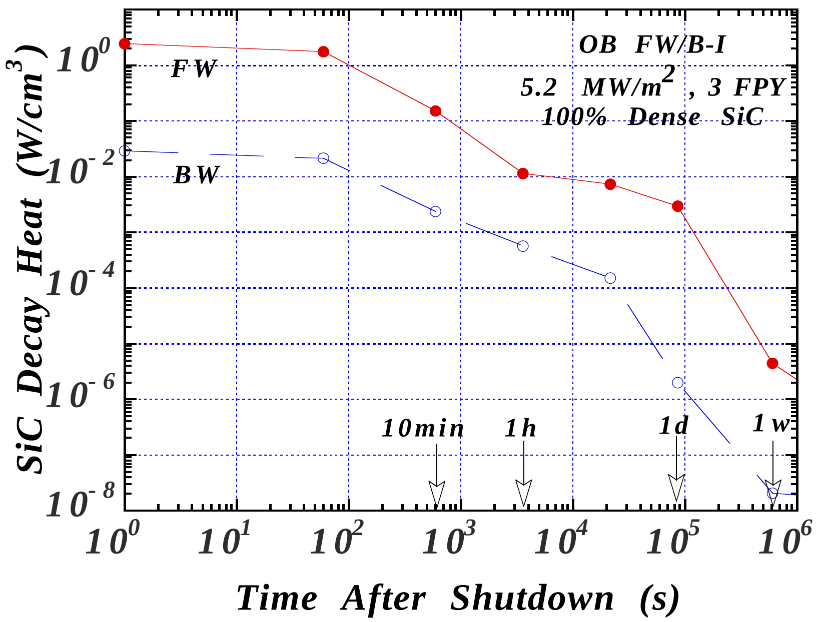

- OB FW contains highest decay heat among all SiC structures
- LiPb may contain higher decay heat than SiC. Coolant activation will be assessed for LOFA analysis

Class C Waste Disposal Rating
OB FW/Blanket-I
(3 FPY)

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	Fetter's WDR	**NRC WDR**
FW	0.3	0.04
Cell	0.006	0.01
BW	0.0002	0.007
Average	**0.1**	**0.02**

- WDR is for compact waste (void excluded)
- WDR < 1 means component qualifies as Class C low level waste
- Al^{26} is dominant nuclide for Fetter's WDR
  Si^{28} (n , np) Al^{27} (n , 2n) Al^{26}
- C^{14} is dominant nuclide for NRC WDR
  C^{12} (n , γ) C^{13} (n, γ) C^{14}
- BW could last for 40 FPY and qualifies as Class C LLW
  (Fetter's and NRC WDR_{BW} are 0.01 and 0.1 @ 40 FPY, respectively)

OB FW/Blanket-I qualify easily as Class C LLW after 3 FPY

Activity and Decay Heat
OB Blanket-II, HT Shield, V.V., and Magnet
(40 FPY, 5.2 MW/m^2, 100% Dense Composition)

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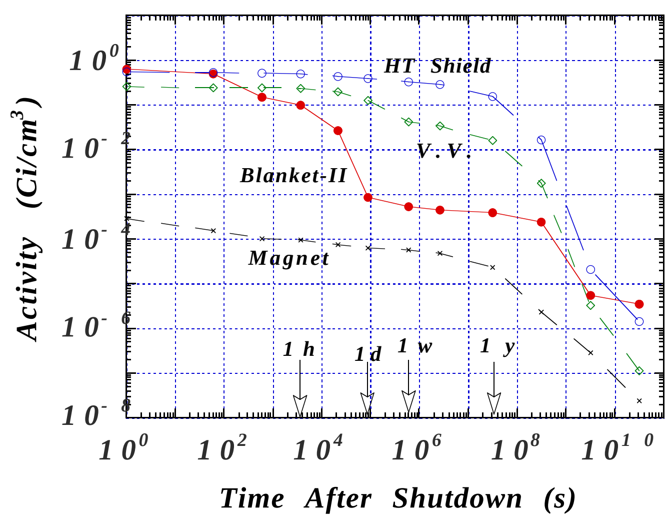

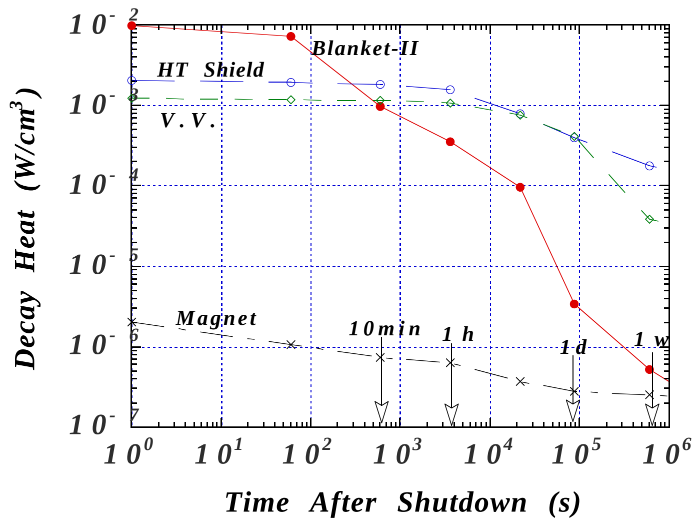

Class C Waste Disposal Rating
OB Blanket-II, HT Shield, V.V., and Magnet
(40 FPY, 5.2 MW/m^2, Compact Waste)

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	Fetter's WDR	NRC WDR
Blanket-II	0.002 (Al^{26})	0.05 (C^{14})
HT Shield	0.17 (Nb^{94},Tc^{99},Ho^{166m})	0.1 (Nb^{94},$Ni^{63,59}$)
V.V.	0.05 (Nb^{94},Ho^{166m})	0.03 (Nb^{94})
Magnet	0.01 (Ag^{108m},Nb^{94})	0.004 (Nb^{94})

All OB permanent components qualify as Class C LLW after 40 FPY

Dominant Radionuclides for OB Components @ Various Time After Shutdown (in descending order)

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Activity:

	SiC FW	HT Shield	V.V.	Magnet
Shutdown	$Al^{28,29,30}$	Fe^{55},$W^{185,187}$, Mn^{56},Cr^{51},Re^{186}	W^{187},Re^{188},Mn^{56}, Cr^{51},Fe^{55}	Ag^{110},Mn^{56}, Ag^{108},Fe^{55}
t < 1 d	Na^{24},Si^{31}	Fe^{55},$W^{185,187}$, Mn^{56},Cr^{51},Re^{186}	W^{187},Fe^{55}, W^{185},Cr^{51}, Re^{188}	Mn^{55},Fe^{55},Co^{58}, Ag^{110},Cr^{51}
1d < t > 1w	Na^{24},T,P^{32}	Fe^{55},W^{185},Cr^{51}, Fe^{59},Mn^{54},Re^{186}	Fe^{55},W^{185},Cr^{51} Re^{186},W^{187},Fe^{59}	Fe^{55},Co^{58}, Ag^{110},Cr^{51},Mn^{54}
1w < t > 1y	T	Fe^{55},W^{185},Mn^{54}	Fe^{55},W^{185},Co^{60}	Fe^{55},Co^{58},Ag^{110m}, Mn^{54}
1y < t > 10y	T,C^{14}	Fe^{55},T,Co^{60}	Fe^{55},Co^{60},T	Fe^{55},Ni^{63},Co^{60}
> 10 y	C^{14},Be^{10}	Ni^{63},T,Mo^{93}, Nb^{93m},Ni^{59}	Ni^{63},T,Ni^{59} Mo^{93},Nb^{93m}	Ni^{63},Ag^{108m},Ni^{59}, C^{14},Mo^{93},Nb^{93m}

Decay Heat:

	SiC FW	HT Shield	V.V.	Magnet
Shutdown	$Al^{28,29,30}$	Mn^{56},$W^{187,185}$	W^{187},Mn^{56},Re^{188}	Ag^{110},Mn^{56}
t < 1 d	Na^{24},Si^{31}	Mn^{56},$W^{187,185}$	W^{187}, Mn^{56},Re^{188}	Mn^{55},Ag^{110},Co^{58}
1d < t > 1w	Na^{24},Si^{31},P^{32}	W^{185},Fe^{59}, Mn^{54}	Co^{60},Fe^{59},$W^{185,187}$	Ag^{110m},Co^{58}, Mn^{54}