Shielding Recommendations for ARIES-ACT-1 and Activation of IB Components

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ARIES Project Meeting

September 26 - 27, 2012

Bethesda, MD

Contents

- Radial/vertical builds (same as presented at May 2012 meeting)

- Shielding options for maintenance ports

- Activation results:
  - WDR of IB SR and VV
  - IB and OB decay heats.

- Remaining tasks.

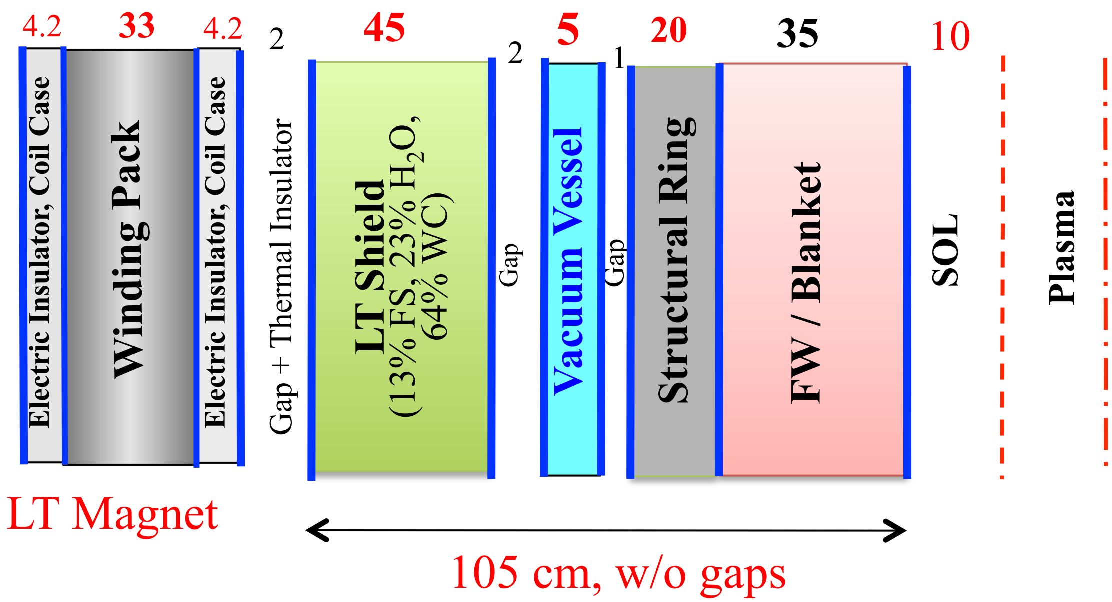
ARIES-ACT-1 Radiation Limits

Calculated Overall TBR	1.05	
Net TBR (for T self-sufficiency)	~1.01	
Damage to Structure (for structural integrity)	3%	Burn-up for SiC/SiC composites
	200	dpa for advanced FS
	???	W structure of divertor
Helium Production @ Structural Ring & VV	---	(not reweldable during operation)
	1	He appm if reweldable
LT S/C Magnets (@ 4 K):		
Peak fast n fluence to Nb_3Sn ($E_n > 0.1$ MeV)	10^{19}	n/cm^2
Peak nuclear heating	2	mW/cm^3
Peak dpa to Cu stabilizer	6×10^{-3}	dpa
Peak dose to GFF polyimide insulator	$< 10^{11}$	rads
Plant Lifetime	40	FPY
Availability	85%	
Operational Dose to Workers and Public	< 2.5	mrem/h

Radial / Vertical Builds

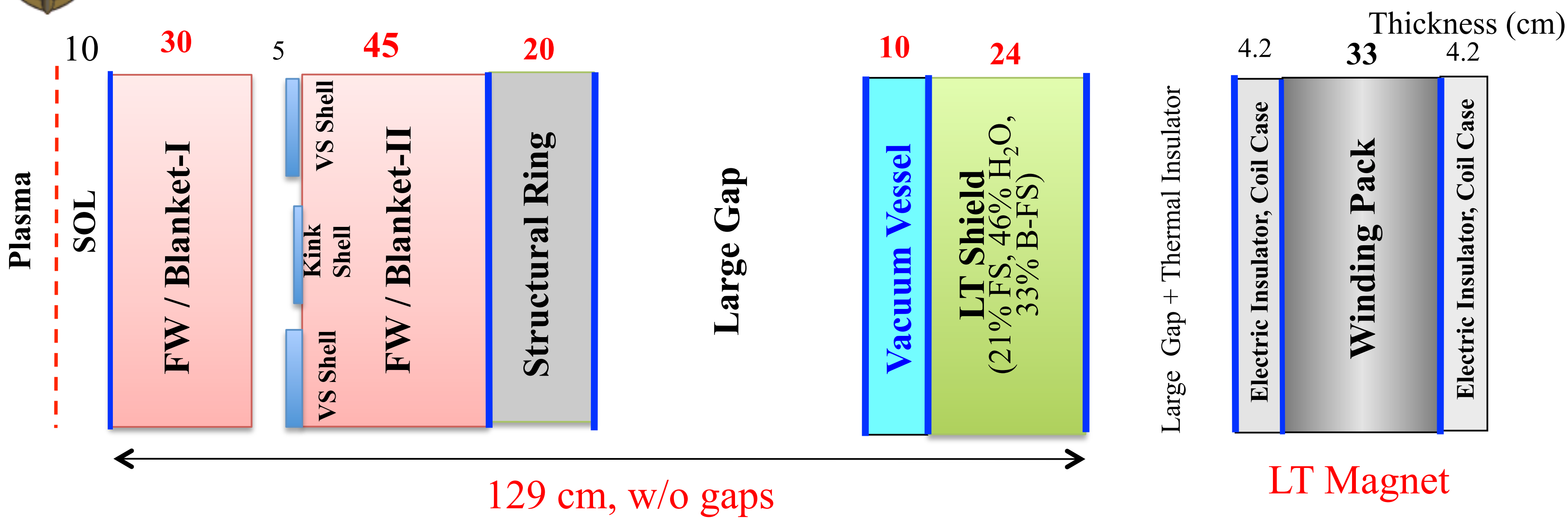
(incorporated in CAD Drawings and ARIES System Code)

ARIES-ACT-1 Inboard Radial Build at Midplane (Peak IB Γ = 3.3 MW/m²)



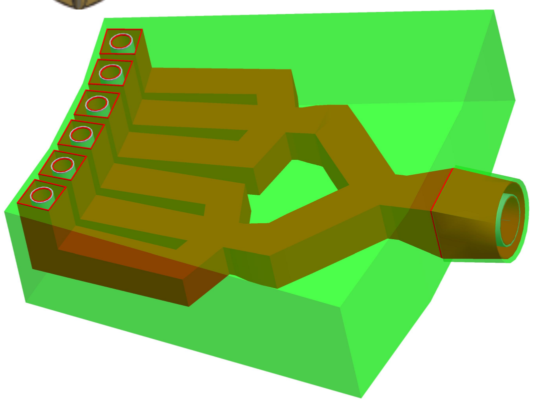
- LT shield thickness **and** composition optimized to protect magnet
- Structural Ring should be replaced every 10 FPY
- None of IB components is reweldable.
- VV, LT shield, and magnet are life-of-plant components
- Effect of neutron streaming through assembly gaps on damage and lifetimes of SR, VV, LT shield, and magnet will be assessed with 3-D analysis.

ARIES-ACT-SiC Outboard Radial Build at Midplane (Peak OB Γ = 4.7 MW/m^2)



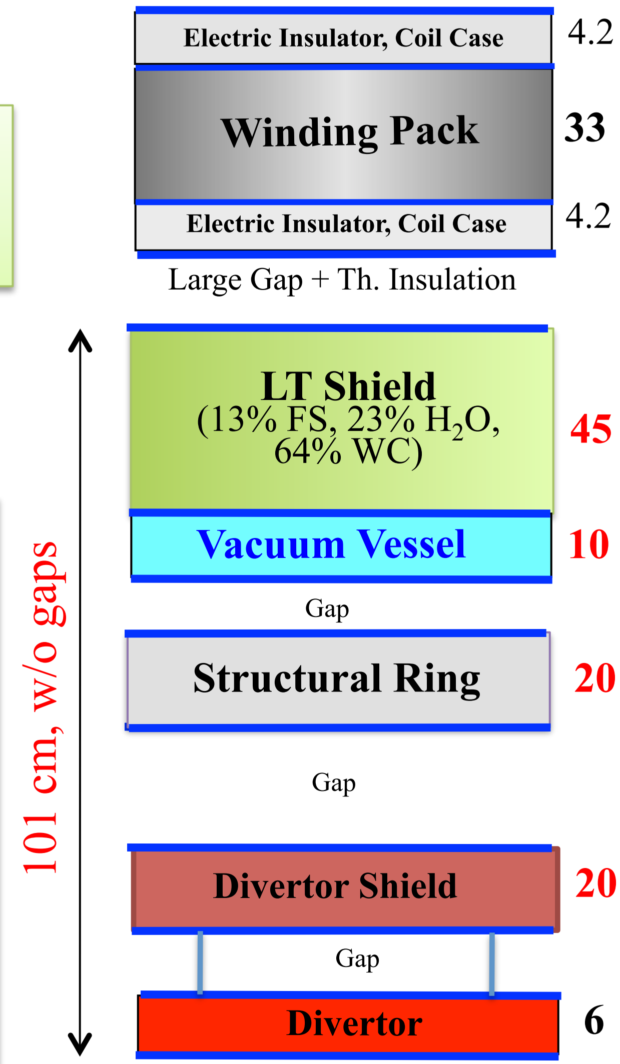
- LT shield thickness **and** composition optimized to protect magnet
- Structural Ring is not reweldable around midplane
- VV is reweldable away from gaps
- Without gaps, Structural Ring, VV, LT shield, and magnet are life-of-plant components.

ARIES-ACT-1 Vertical Build
(Peak div Γ = 2 MW/m^2)



Lower manifolds embedded in shield:
- Manifolds supply LiPb to IB blanket
- Located between divertor and SR
- Contains divertor pumping ducts.

- 10 cm thicker vertical build compared to ARIES-AT
- Same LT shield thickness **and** composition as for IB
- Lifetime of W-based divertor is unknown
- Steel Ring should be replaced every 20 FPY
- None of vertical components is reweldable
- Without gaps, VV, LT shield, and magnet are life-of-plant components
- Effect of neutron streaming through assembly gaps on damage and lifetimes of SR, VV, LT shield, and magnet should be assessed with 3-D analysis.



Blanket and Divertor Compositions

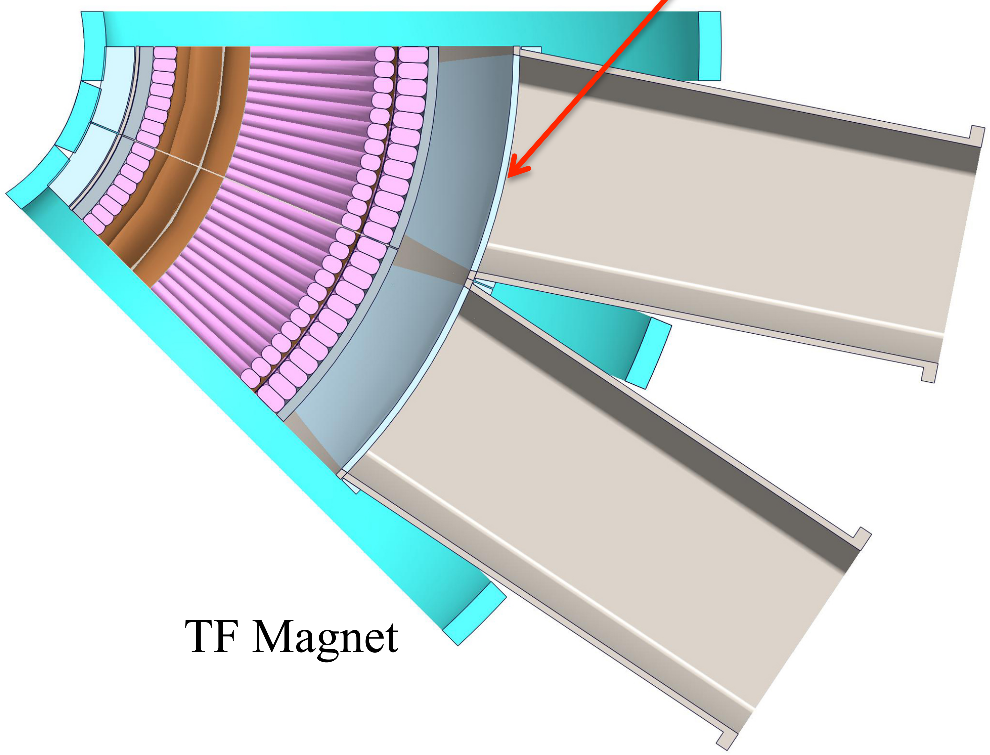
$Li_{15.7}Pb_{84.3}$ @ 700 ^oC; 8.8 g/cm^3 density; 60% enriched Li

	Thickness (cm)	Composition (volume %)
IB Blanket	35	18% SiC/SiC Composites 82% LiPb
OB Blanket-I	30	16% SiC/SiC Composites 84% LiPb
OB Blanket-II	45	19.3% SiC/SiC Composites 80.7% LiPb
Divertor Plates	6	9% W armor, 36% W alloy, 11% ODS-FS, 44% He coolant

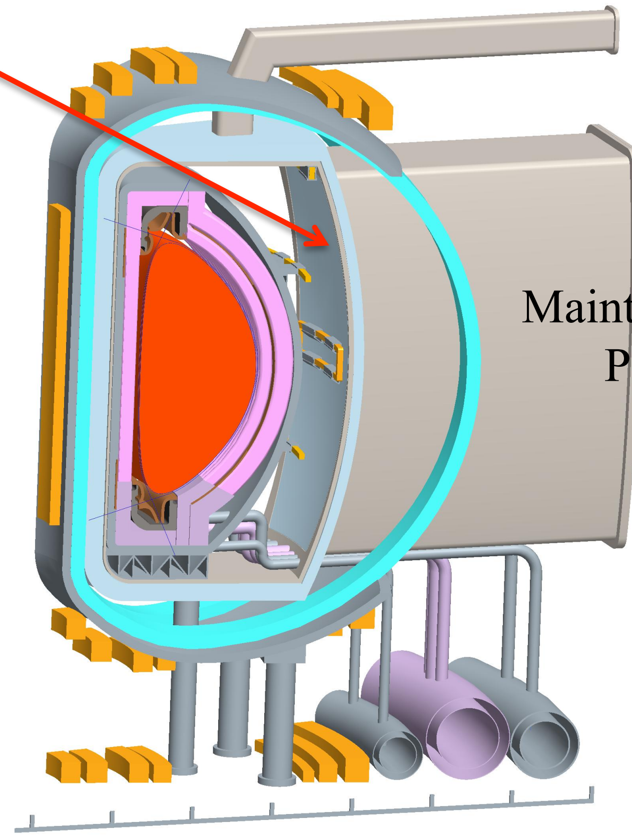
Shielding Options for Maintenance Ports

Maintenance Ports

Is Shielding Door needed?



TF Magnet

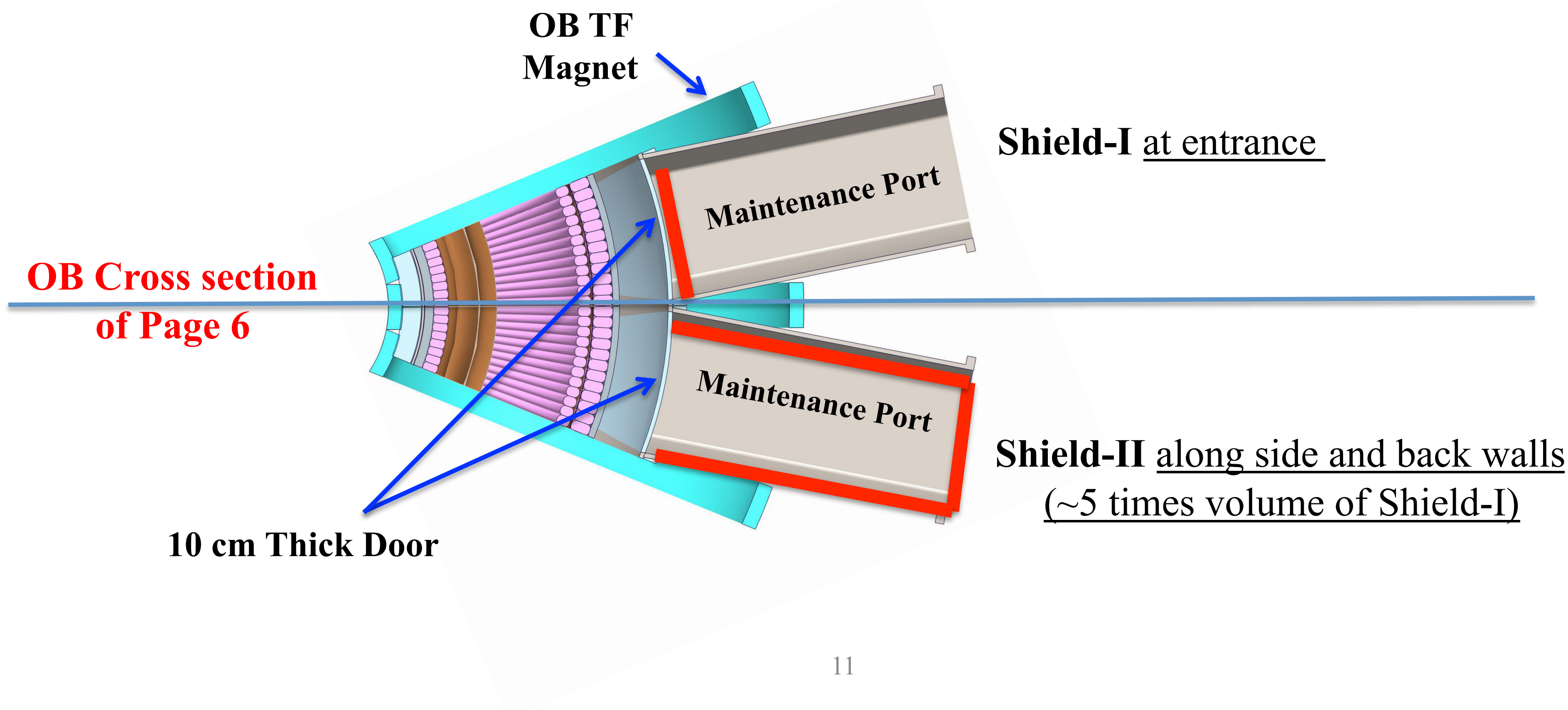


Maintenance Port

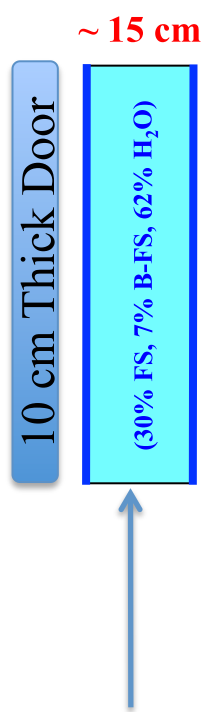
How to accommodate OB penetrations (ICRF, EC, LH, etc.)?

Shielding Concerns

– OB magnets are well shielded radially with stepped assembly gaps.
– Sides of magnets are not protected as 10 cm thick port walls are insufficient (refer to May 2012 presentation).
– Shield must be placed either at entrance or along side and back walls of each port.
– Thickness of shield depends on materials.



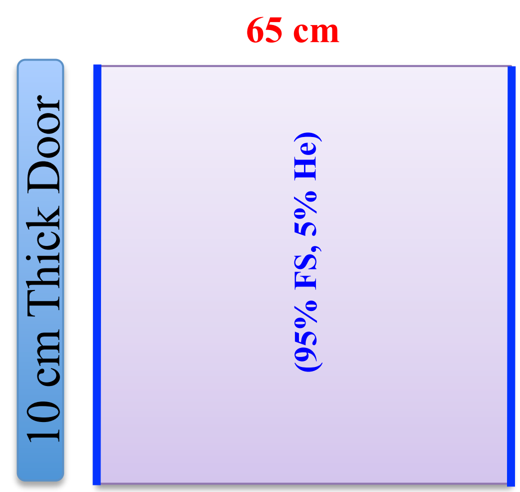
Options for Shield-I/II Composition/Thickness



Recommended

Water-cooled Shield
with B-FS filler

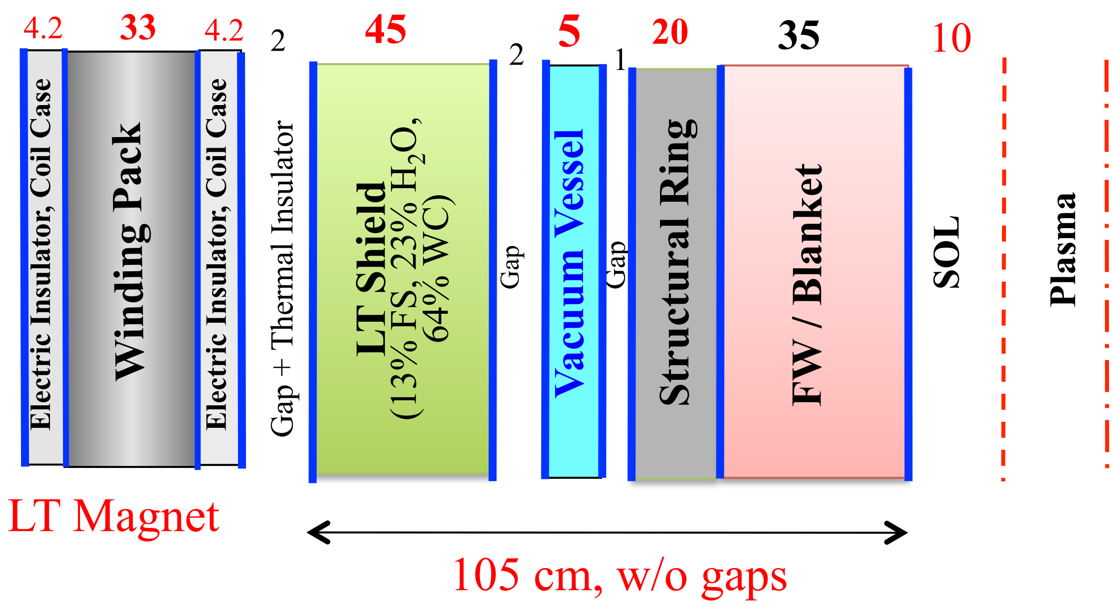
He-cooled Shield
with B-FS filler



He-cooled FS Shield
(blocks of steel)

Activation of IB VV and SR

WDR of FS-Based IB Components



SR (10 FPY):
80% ODS-FS, 20% He

VV (40 FPY):
90% 3Cr-3WV FS, 10% He

- **Problem**: SR and VV generate high-level waste (HLW).
- **Solution**: Reevaluate WDR with "Present Impurities".

“Present” Impurities

- To reduce long-term radioactivity, Klueh (ORNL) provided list of lowest 17 impurities (including 0.5 wppm Nb and 5 wppm Mo) that have ever been achieved in large-scale melting and fabrication practices of various steels.

- “Present” impurities are not specific to any particular steel composition and should be achievable at present with relatively modest effort and cost.

Reference: R. Klueh et al., Impurity effects on reduced-activation ferritic steels developed for fusion applications, *Journal of Nuclear Materials* 280 (2000) 353-359. Table 4, Page 357.

Compositions

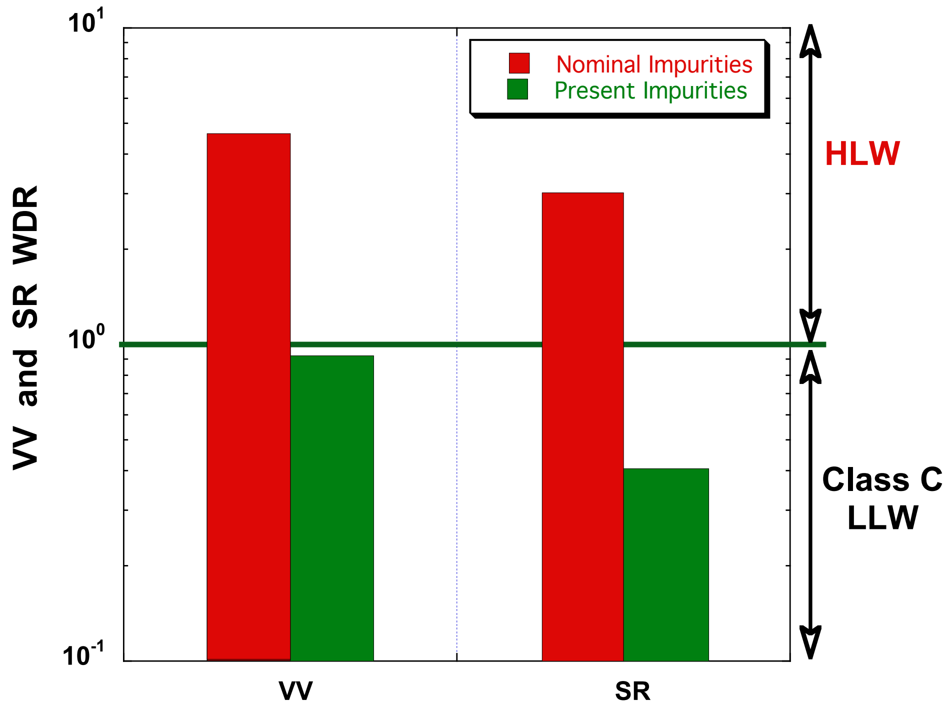
“Nominal” Impurities (from suppliers)

Alloy	MF82H	316_SS	ORNL-FS	RAAS	3Cr_3WV_FS	430_FS	Mn_AS
Density (g/cm^3)	7.89	7.966	7.78	7.966	7.89	7.7	7.82
B		0.001					0.0025
C	0.1	0.0225	0.1	0.1	0.1	0.12	0.1
N		0.07					0.19
O		0.002					
Al	1.40E-03	0.05		1.40E-03	1.40E-03	1.40E-03	5.0E-02
Si		0.5	0.25	0.5	0.14	1	0.55
P		0.025					0.016
S		0.0075					0.008
K		*5					
Ti		0.15		0.5			
V	0.2	0.004	0.025		0.25		0.02
Cr	7.5	17.5	9	15	3	17	10.1
Mn		1.8	0.5	1.7	0.5	1	17.5
Fe	90.11586	64.938	88.073862	64.883258	92.945858	80.815858	71.2434
Co	*28	0.05	*34	*28	*28	*28	
Ni	*474	12.25	*402	15	*474	*474	0.1
Cu	*100	0.1		1.00E-02	*100	*100	*600
Y				0.3			
Zr		0.002					
Nb	*3.3	0.01	*4	*3.3	*3.3	*3.3	
Mo	*21.0	2.5	*70	*21	*21	*21	*600
Pd	*0.05		*0.18	*0.05	*0.05	*0.05	
Ag	*0.1		*0.16	*0.1	*0.1	*0.1	
Cd	*0.4		*0.05	*0.4	*0.4	*0.4	
Sn		0.002					
Ta	0.02	0.01	*0.07				
W	2	*10	2	2	3		
Os	*0.05		*0.02	*0.05	*0.05	*0.05	
Ir	*0.05		*0.05	*0.05	*0.05	*0.05	
Pb		*8					*1
Bi	*0.02	*8	*0.05	*0.02	*0.02	*0.02	
Eu	*0.05		*0.05	*0.05	*0.05	*0.05	
Tb	*0.02			*0.02	*0.02	*0.02	
Dy	*0.05		*0.05	*0.05	*0.05	*0.05	
Ho	*0.05		*0.05	*0.05	*0.05	*0.05	
Er	*0.05		*0.05	*0.05	*0.05	*0.05	
U	*0.05		*0.6	*0.05	*0.05	*0.05	

“Present” Impurities

Alloy	MF82H	316_SS	ORNL-FS	RAAS	3Cr_3WV_FS	430_FS	Mn_AS
Density (g/cm^3)	7.89	7.966	7.78	7.966	7.89	7.7	7.82
B		0.001					
C	0.1	0.0225	0.1	0.1	0.1	0.12	0.1
N		0.07					0.19
O		0.002					
Al	*30	*30	*30	*30	*30	*30	*30
Si		0.5	0.25	0.5	0.14	1	0.55
P		0.025					0.016
S							0.008
Ti		0.15		0.5			
V	0.2	0.004	0.025		0.25		
Cr	7.5	17.5	9	15	3	17	10.1
Mn		1.8	0.5	1.7	0.5	1	17.5
Fe	90.173301	65.060601	88.118301	64.894601	93.003301	80.873301	71.529295
Co	*8	*8	*8	*8	*8	*8	*8
Ni	*13	12.25	*13	15	*13	*13	*13
Cu	*10	0.1	*10	*10	*10	*10	*10
Y				0.3			
Nb	*0.5	*0.5	*0.5	*0.5	*0.5	*0.5	*0.5
Mo	*5	2.5	*5	*5	*5	*5	*5
Pd	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Ag	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Cd	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Ta	0.02	0.01					
W	2	*10	2	2	3		
Os	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Ir	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Bi	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Eu	*0.02	*0.02	*0.02	*0.02	*0.02	*0.02	*0.02
Tb	*0.02	*0.02	*0.02	*0.02	*0.02	*0.02	*0.02
Dy	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Ho	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05
Er	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05

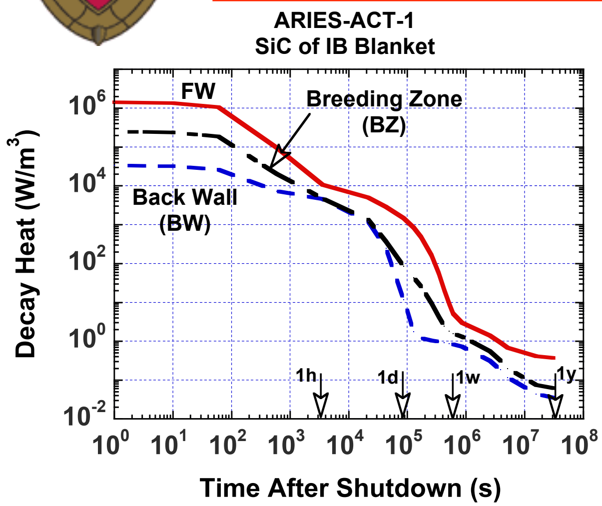
Class C Classification of VV and SR

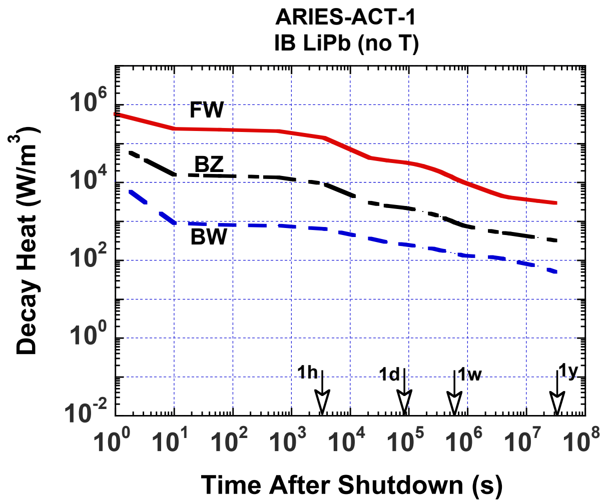


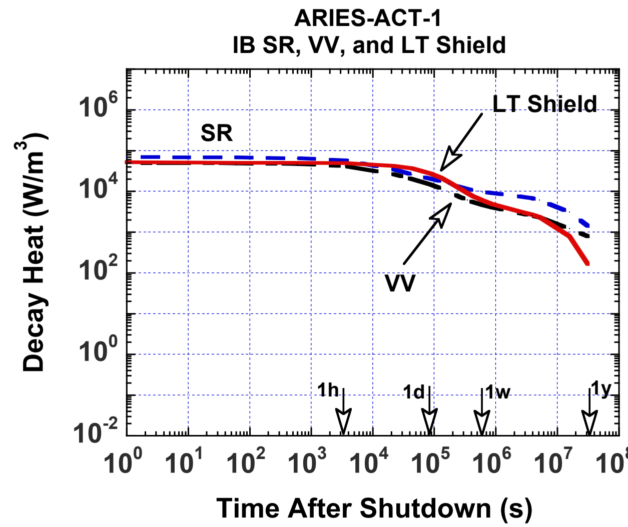
- Both VV and SR generate HLW using FS with "nominal" impurities.
- Both components qualify as LLW with "Present" Impurities.
- Unit costs of 3Cr-3WV and ODS ferritic steels should reflect cost of controlling 17 impurities, especially Nb and Mo.

1-D Decay Heat Analysis

IB Blanket Decay Heat

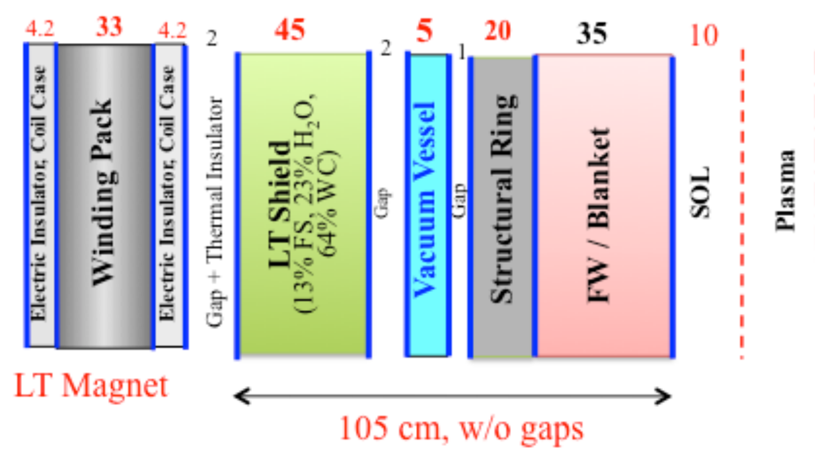




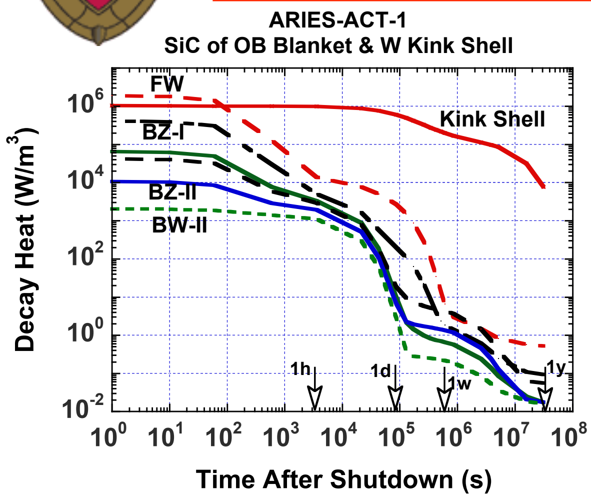


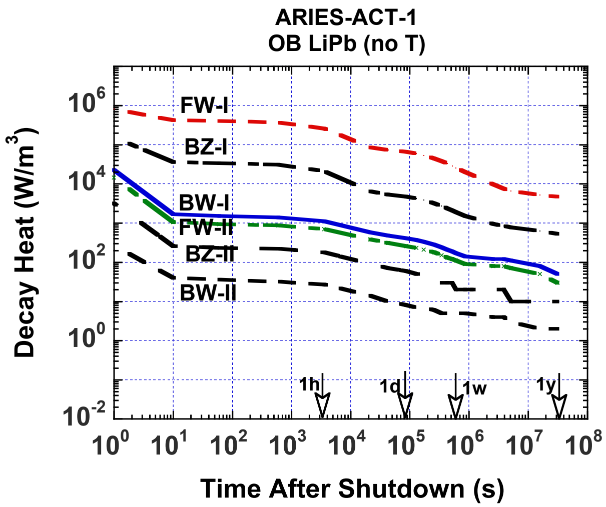
- LiPb, SR, and VV generate more decay heat than SiC structure of IB blanket.

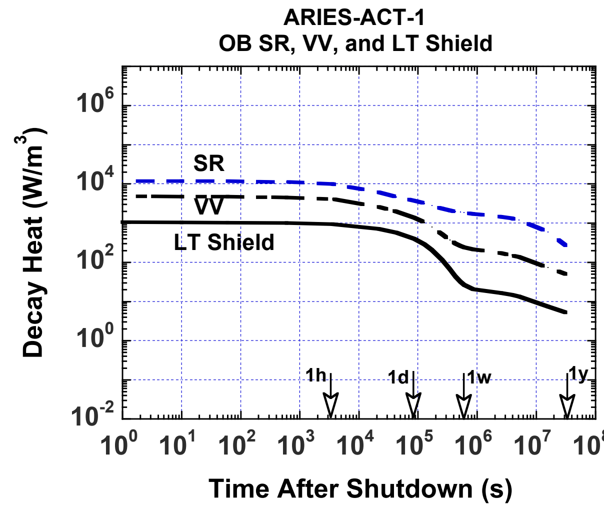
- WC filler of LT shield generates high decay heat.



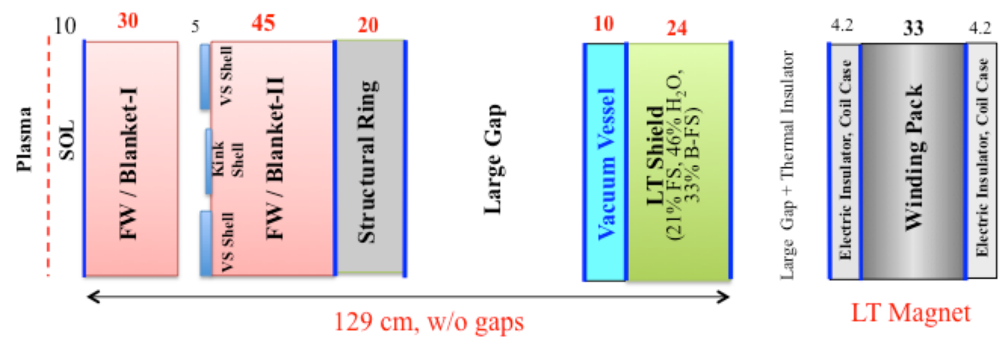
OB Blanket Decay Heat







- LiPb generates more decay heat than SiC structure of OB blanket.
- W stabilizing shells generate highest decay heat in ARIES-ACT-1.
- <u>Worst case accident scenario </u>would be loss of LiPb flow (LOFA in blanket) and loss of He **and** water coolants (LOCA in other components).



TBD

By Dec 2012:

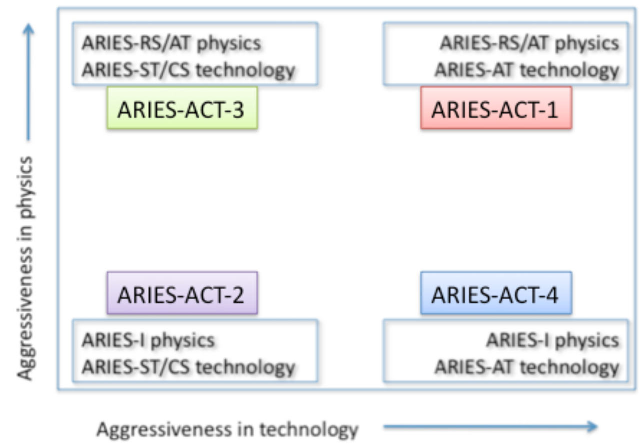
ARIES-ACT-1:

- Document nuclear analysis:

  NWL, TBR, nuclear heating, activation.

ARIES-ACT-2 parameters:

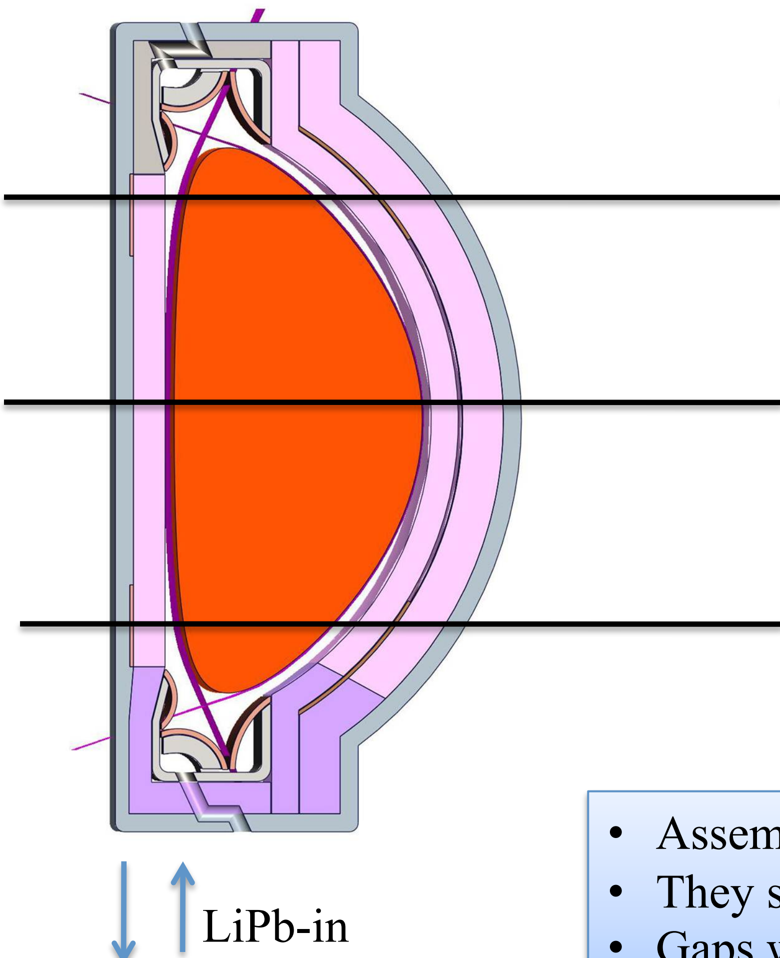
- Radial/vertical build definition with thin VV:
  - Check 3-D TBR and determine blanket thickness
  - Define thicknesses and composition of all components.
  - Any special requirements regarding:
    - Reweldability of components, especially IB LiPb/He manifolds
    - Lifetimes of IB Structural Ring, and manifolds?
- Nuclear heat loads to all components.
- 1-D decay heat for the LOCA/LOFA assessment.



By June 2013:

- 3-D activation analysis (first ever for ARIES project) for ARIES-ACT-1,2 (decay heat, WDR, recycling, and clearance).
- 2- or 3-D temperature response during LOCA/LOFA.
- Peak damage to IB and OB components with straight and zigzagged gaps.

Evolution of Assembly Gaps during Operation



Relative Change	Temperature	Neutron-induced Swelling at EOL
Top	High	Low
Middle	Medium	High
Bottom	Low	Low

- Assembly gaps will not completely close during operation.
- They should not be closed to allow removal of components.
- Gaps will close non-uniformly in all directions.