ARIES-DB Design Issues and Activation of Divertor W Alloys

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Contents

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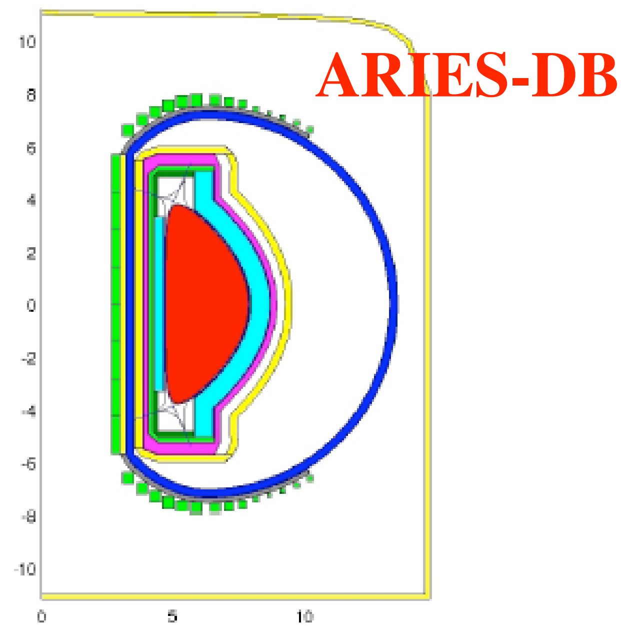
7/19/2009

- ARIES-DB design issues:
  - Recirculating power
  - New TF magnet dimension/composition
  - Divertor activation.

- Radial builds for two cases: with and without radial manifolds (<u>to be updated</u>).



- R = 6.3 m
- κ = 2.4
- COE = 106.56 mill/kWh (2008)
  (72 mills/kWh for ARIES-AT)

Ave. Γ @ plasma = 3.4 MW/m^2

ARIES-DB Recirculating Power is Excessive

As defined by ASC, ARIES-DB generates > 4500 MW_{th} with:

~2000 MW_e P_{gross}

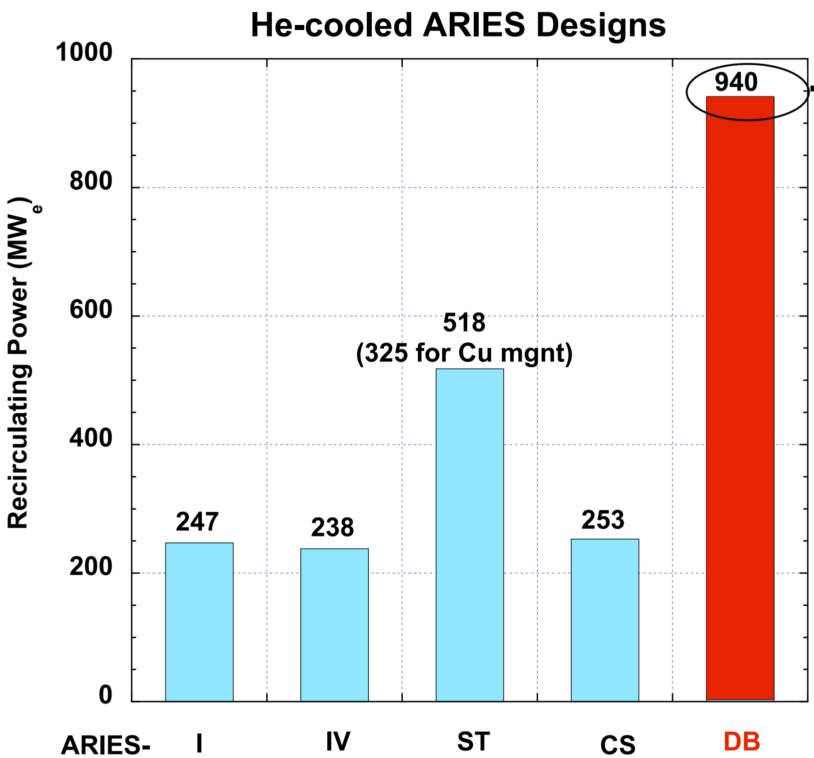
1000 MW_e P_e

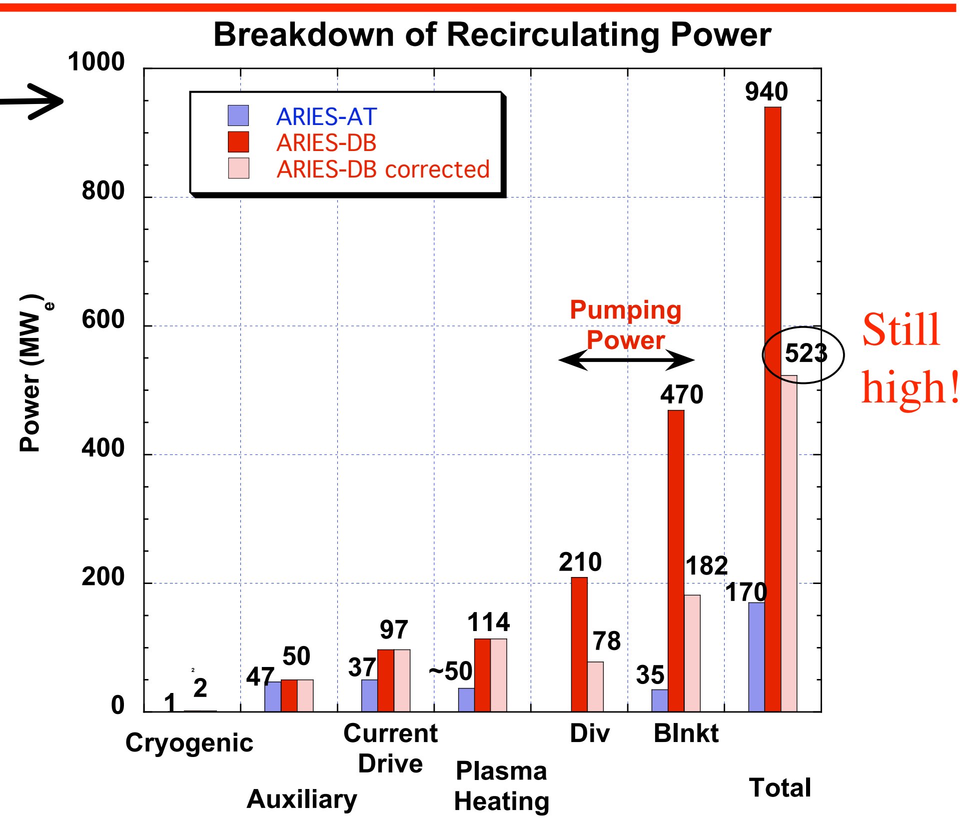
680 MW_e to pump helium (to be corrected)

210 MW_e to drive current and heat plasma

⇒ **Inefficient machine**

ARIES-DB Recirculating Power is Excessive (Cont.)



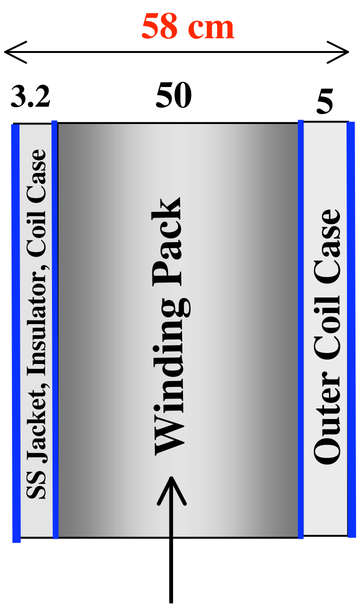


Need to reduce CD, heating, and He pumping powers

ARIES-DB TF Magnet

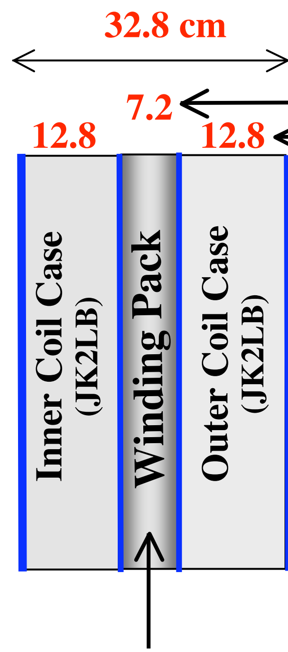
ARIES-RS

B/S/VV



18.5% 316 SS
48.2% Cu
12.8% Nb3Sn
10% GFF Polyimide
10.5% LHe

ARIES-DB



Too thin?
Too Thick?
(shield will be reoptimized to account for thick coil case)

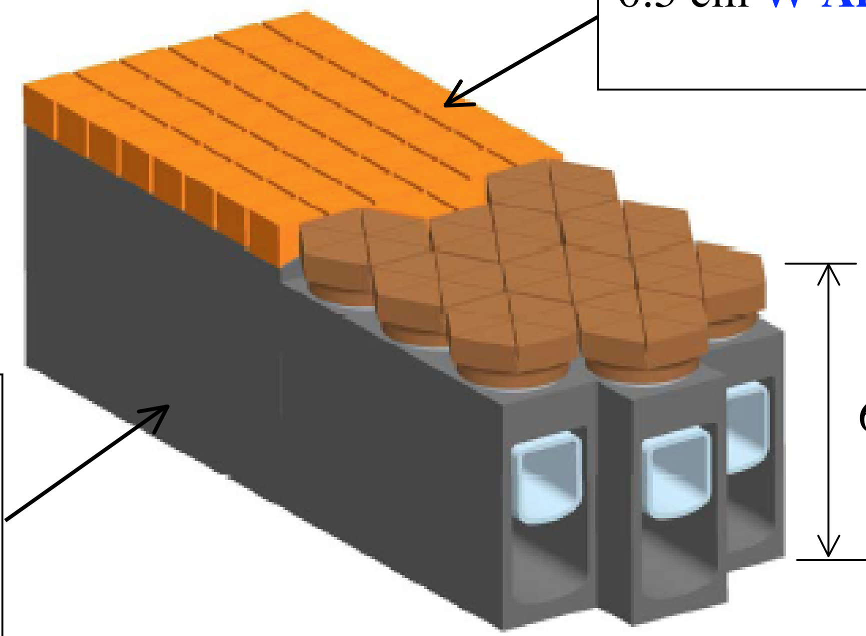
7.8% Inconel ← Why not JK2LB?
48.8% Cu
8.4% Nb_3Sn
10% Polyimide
25% He ← Too much He?

Check magnet algorithm in new ASC

ARIES-DB-DCLL Divertor

Two-Heat-Flux-Zone concept
(S. Malang and X. Wang)

0.5 cm **W Armor**: 90% W
10% void



5.5 cm **Cooling Channel**:
31.3% **W alloy**
1.7% W
13.7% ODS-FS
53.3% He

Concerns:

- Activation
- W decay heat and divertor temperature response during LOCA/LOFA. TBD
- Survivability of W armor (lifetime could be weeks if bombarded with 10^{20} He atoms/cm^2) (UW could simulate ARIES-DB divertor conditions using UW-IEC experiment).

Candidate W Alloys for Divertor

- **Pure W**
- **W with impurities** (99.99 / 0.01 wt%)
- **W-Re** (74 / 26 wt%)
- **W-Ni-Cu** (90 / 6 / 4 wt%)
- **W-Ni-Fe** (90 / 7 / 3 wt%)
- **W-La_2O_3** (99 / 1 wt%) - for EU divertor, per Rieth (FZK).

Structural W-alloys with W impurities

- Key **parameters** for activation analysis:
  - 1 MW/m^2 average NWL over divertor plates
  - 4 y irradiation period (3.4 FPY with 85% availability).

3.4 MWy/m^2

- Is divertor clearable? Recyclable? Disposable? Any high-level waste?

List of W Impurities
(M. Rieth - FZK)

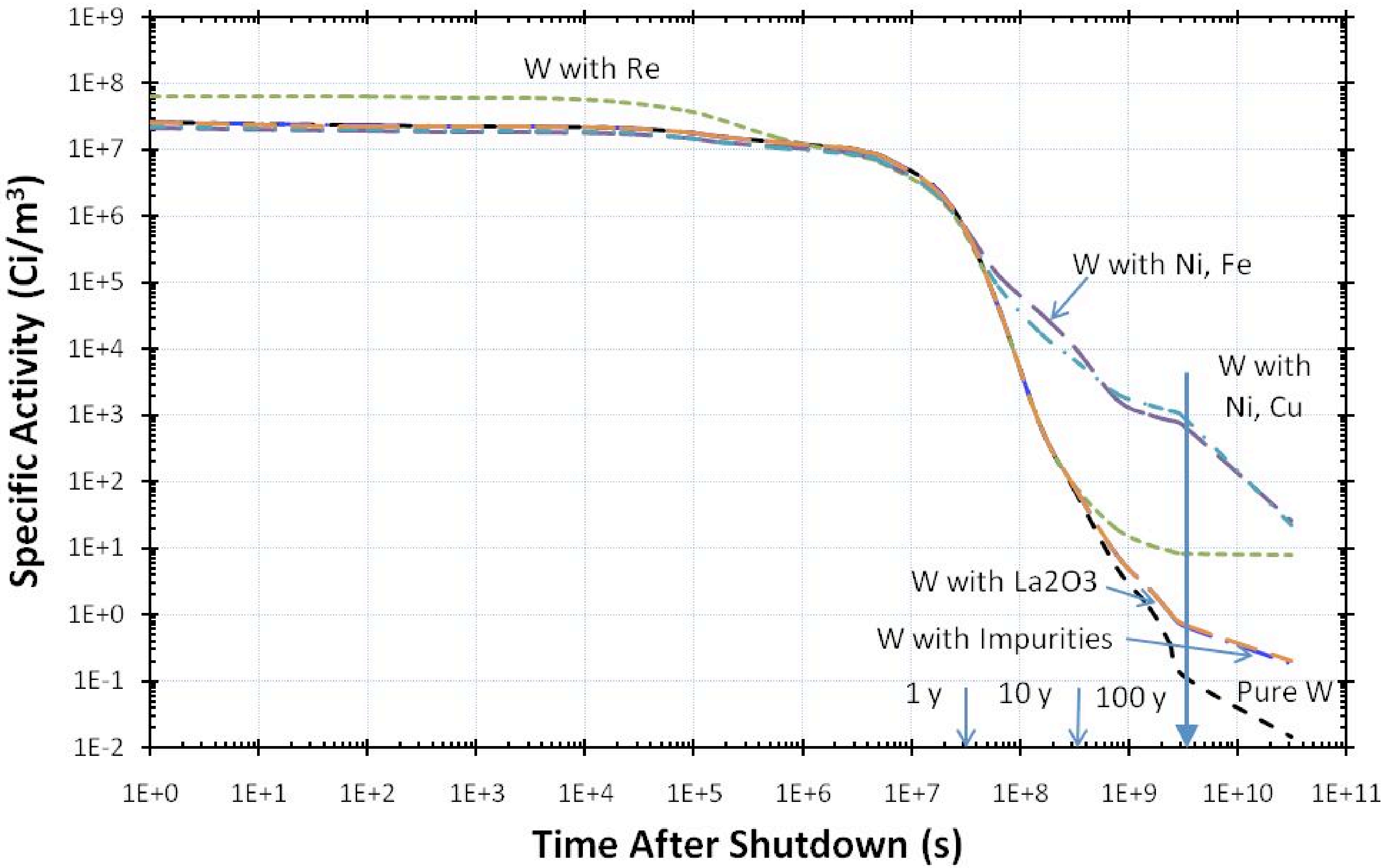
Chemical specification of solid metallic tungsten

Element Element	Garantierte Analyse max. [µg/g] Guaranteed analysis max. [µg/g]	Typische Analyse [µg/g] Typical analysis [µg/g]
Ag	10	< 5
Al	15	5
As	5	< 2
Ba	5	< 2
Ca	5	< 2
Cd	5	< 2
Co	10	< 2
Cr	20	< 5
Cu	10	< 5
Fe	30	10
K	10	5
Mg	5	< 2
Mn	5	< 2
Na	10	< 2
Nb	10	< 5
Ni	5	< 2
Pb	5	< 2
Ta	20	< 10
Ti	5	< 2
Zn	5	< 2
Zr	5	< 2
Mo	100	20
W	**min. 99.97 % *)**	**99.99 % *)**

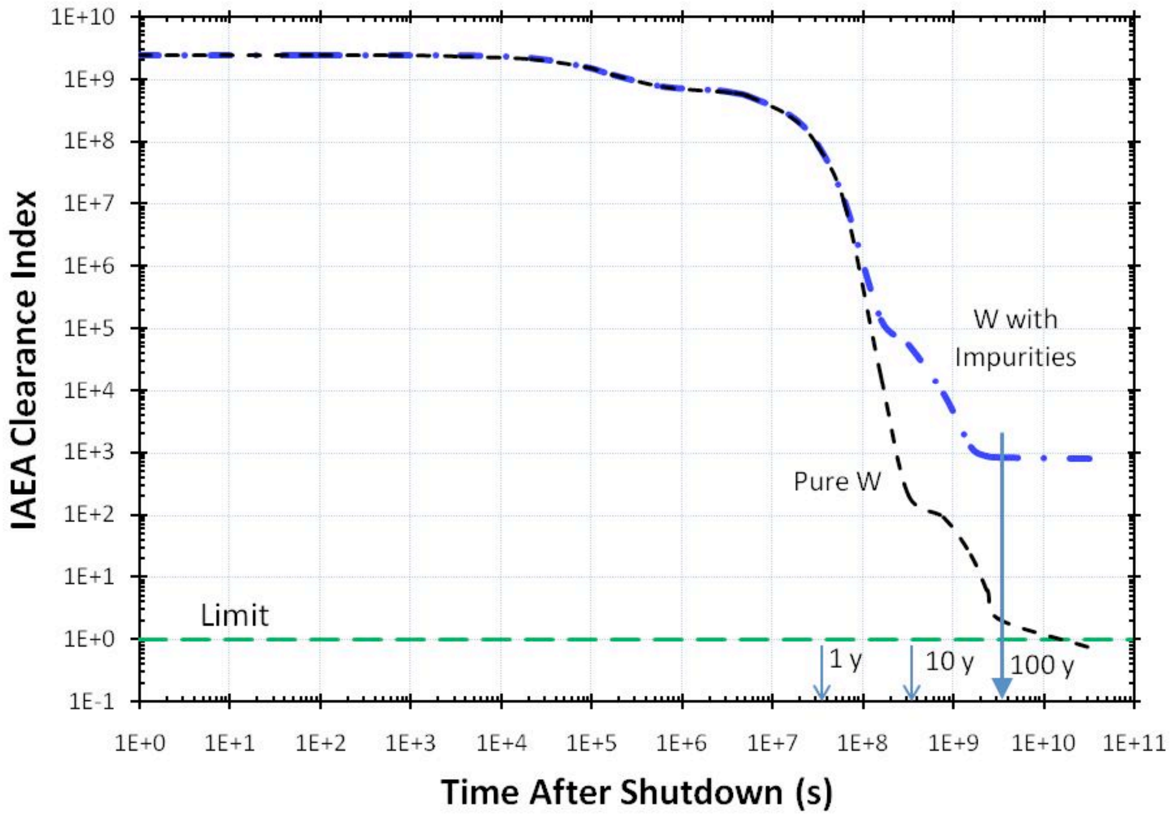
*) metallische Reinheit ohne Mo / metallic purity excluding Mo

C	30	10
H	5	2
N	5	< 2
O	20	5
P	20	< 10
S	5	< 2
Si	20	5

Specific Activity

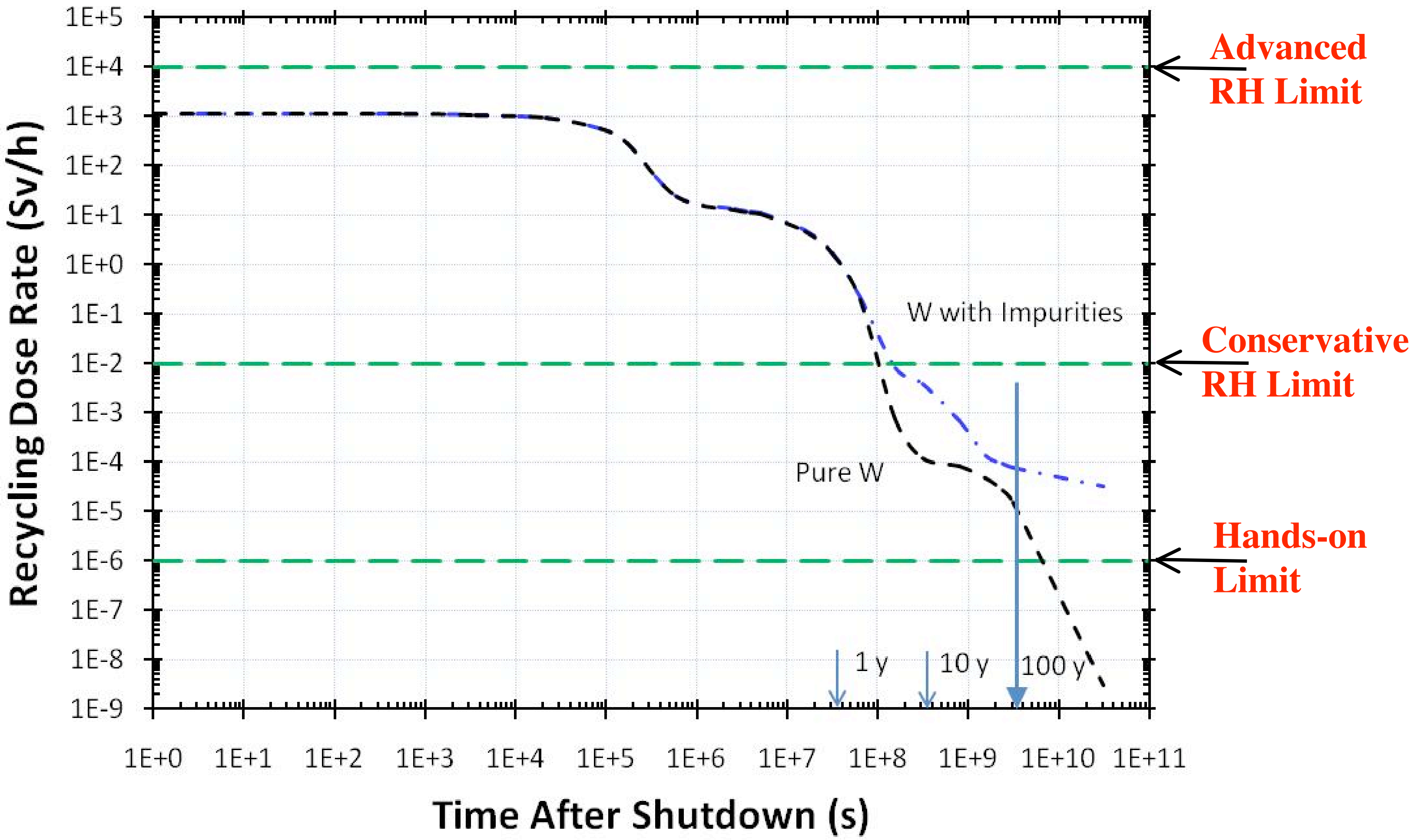


Divertor is Not Clearable

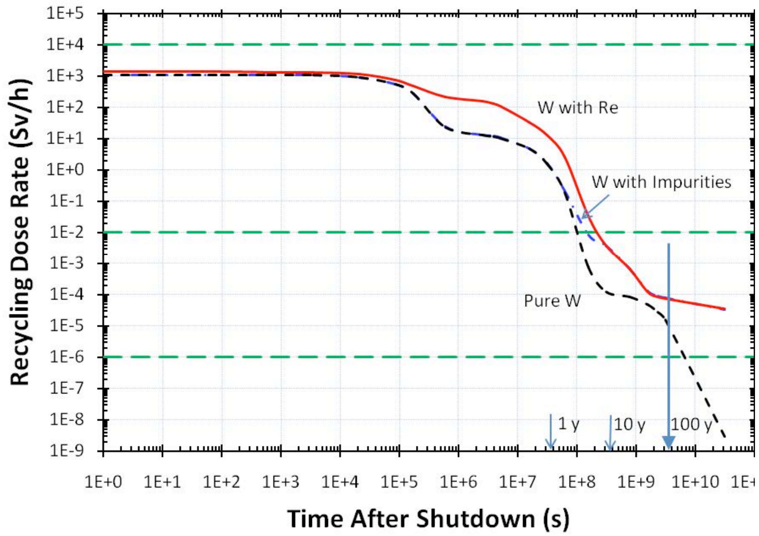


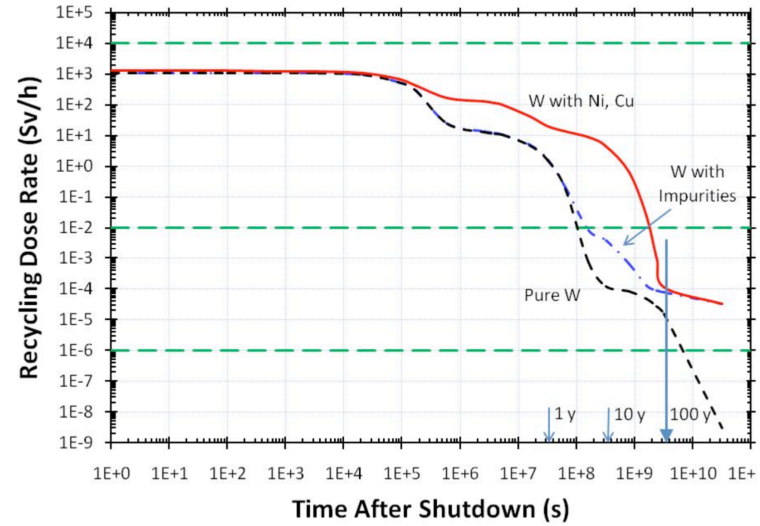
- Even highly pure W cannot be cleared after 100 y cooling period.
- Divertor should be recycled or disposed of.

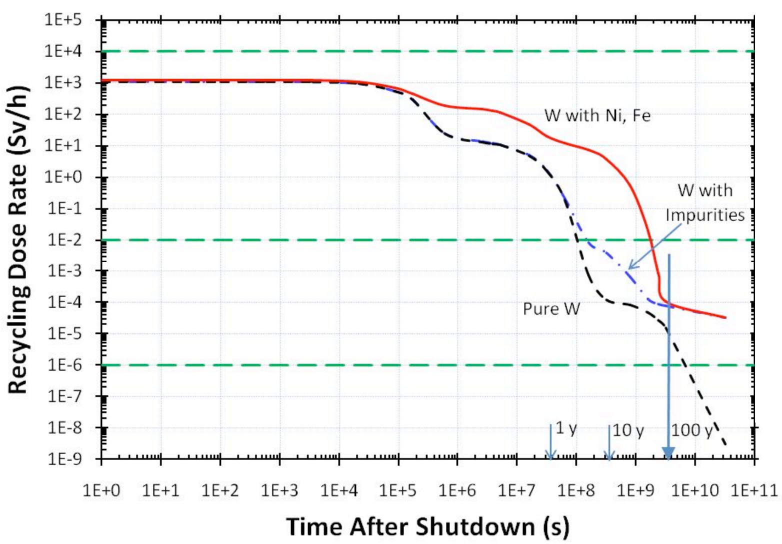
W Can be Recycled
(Cooling Channel)



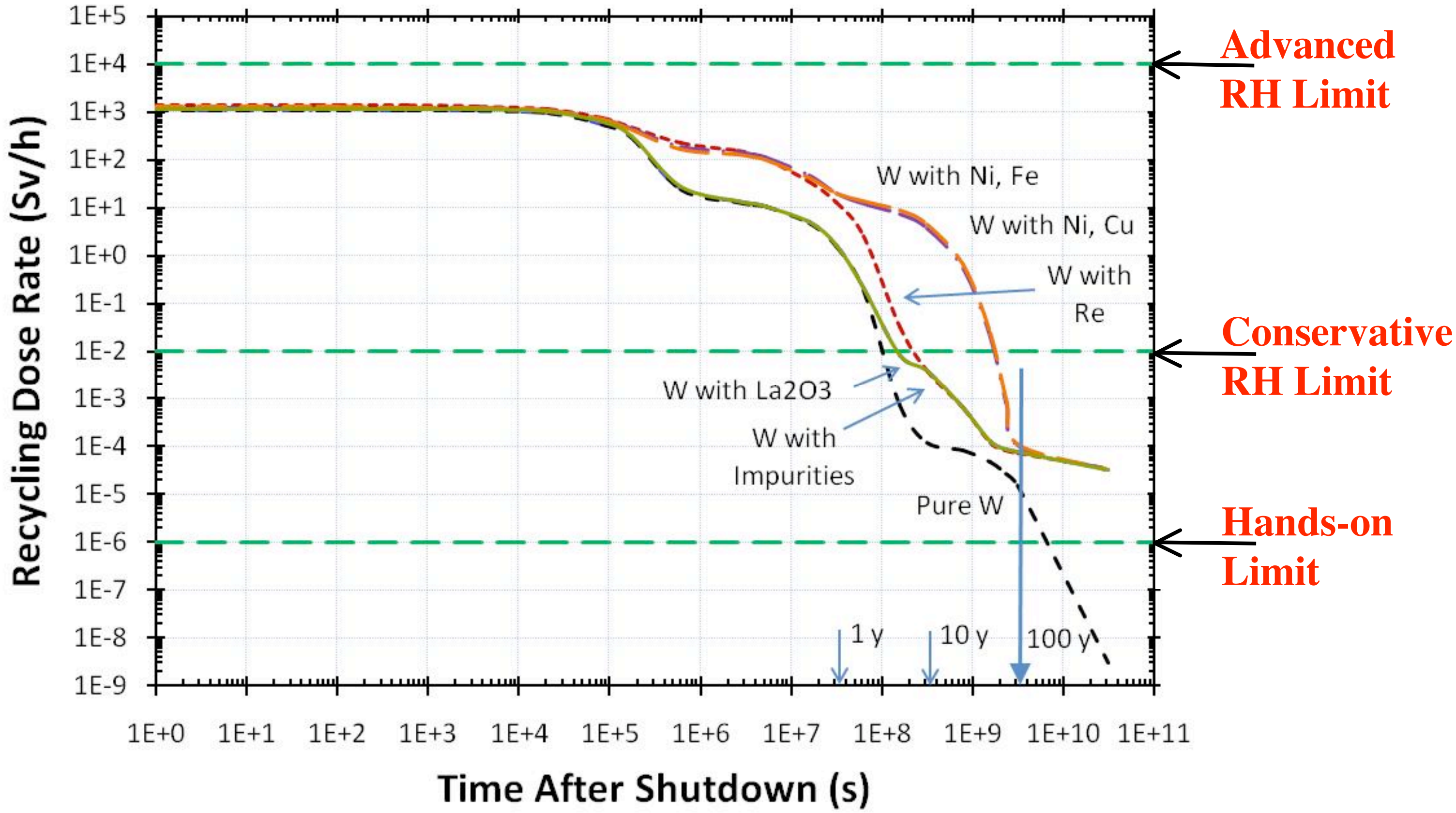
Candidate W Alloys Can be Recycled
(Cooling Channel)







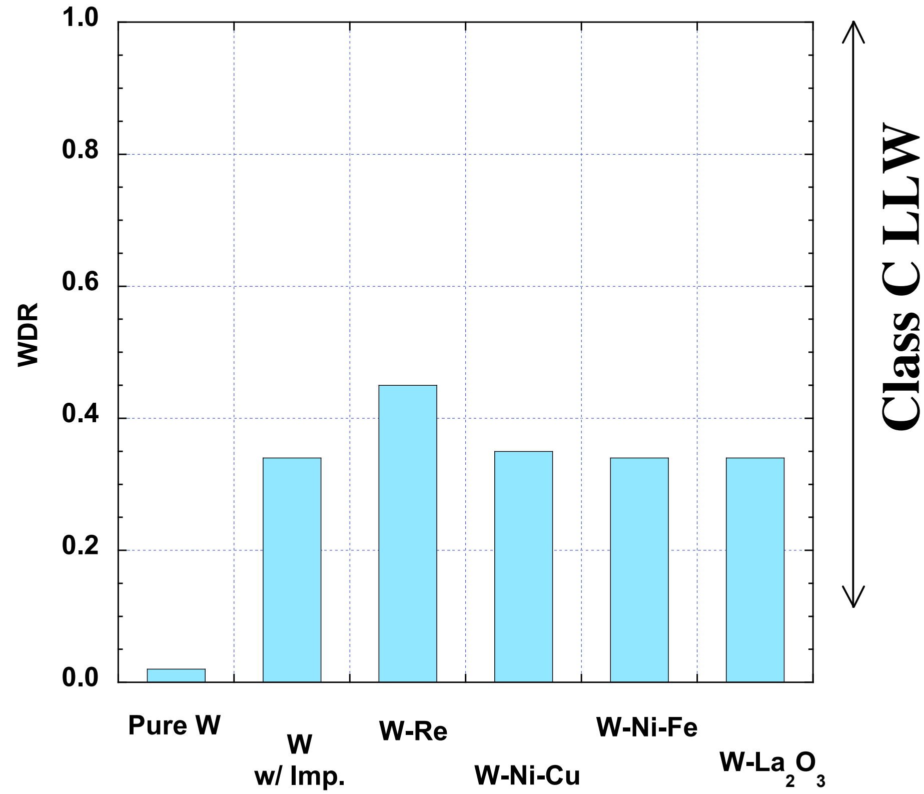
Candidate W Alloys Can be Recycled (Cont.)
(Cooling Channel)



- W-La_2O_3 alloy exhibits lowest recycling dose.
- All four W alloys can be recycled with advanced equipment immediately after divertor replacement
- Conventional remote handling equipment can be used after 6-65 y cooling period.

Divertor Qualifies for Class C LLW

	WDR*	LLW
Pure W	0.02	Class A
W w/ imp.	0.34	Class C
W-Re	0.45	Class C
W-Ni-Cu	0.35	Class C
W-Ni-Fe	0.34	Class C
W-La_2O_3	0.34	Class C

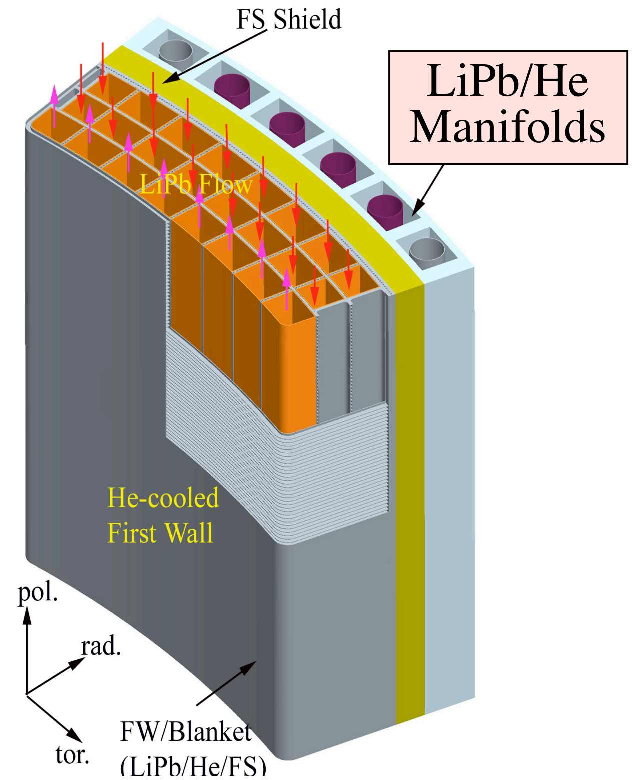


W-Re generates highest WDR, but still qualifies as LLW under ARIES-DB irradiation conditions (3.4 MWy/m^2)

* Evaluated at 100 y using NRC and/or Fetter's limits.

ARIES-DB-DCLL Radial Builds

- **DCLL blanket and shield**:
  - 0.5 cm low-density Ultramel SiC inserts
  - Calculated overall TBR = 1.1 with 70% Li enrichment
  - No stabilizing shells (to be added later)
  - Two cases:
    - With radial LiPb/He manifolds
    - Without radial LiPb/He manifolds (reference).



- Radial builds defined for **peak** NWL @ IB, OB, Div of 3.4, 4.8, 2 MW/m^2.

- Scaling laws for variation of shield with NWL provided to ASC.

ARIES-DB-DCLL Radiation Limits and Key Parameters

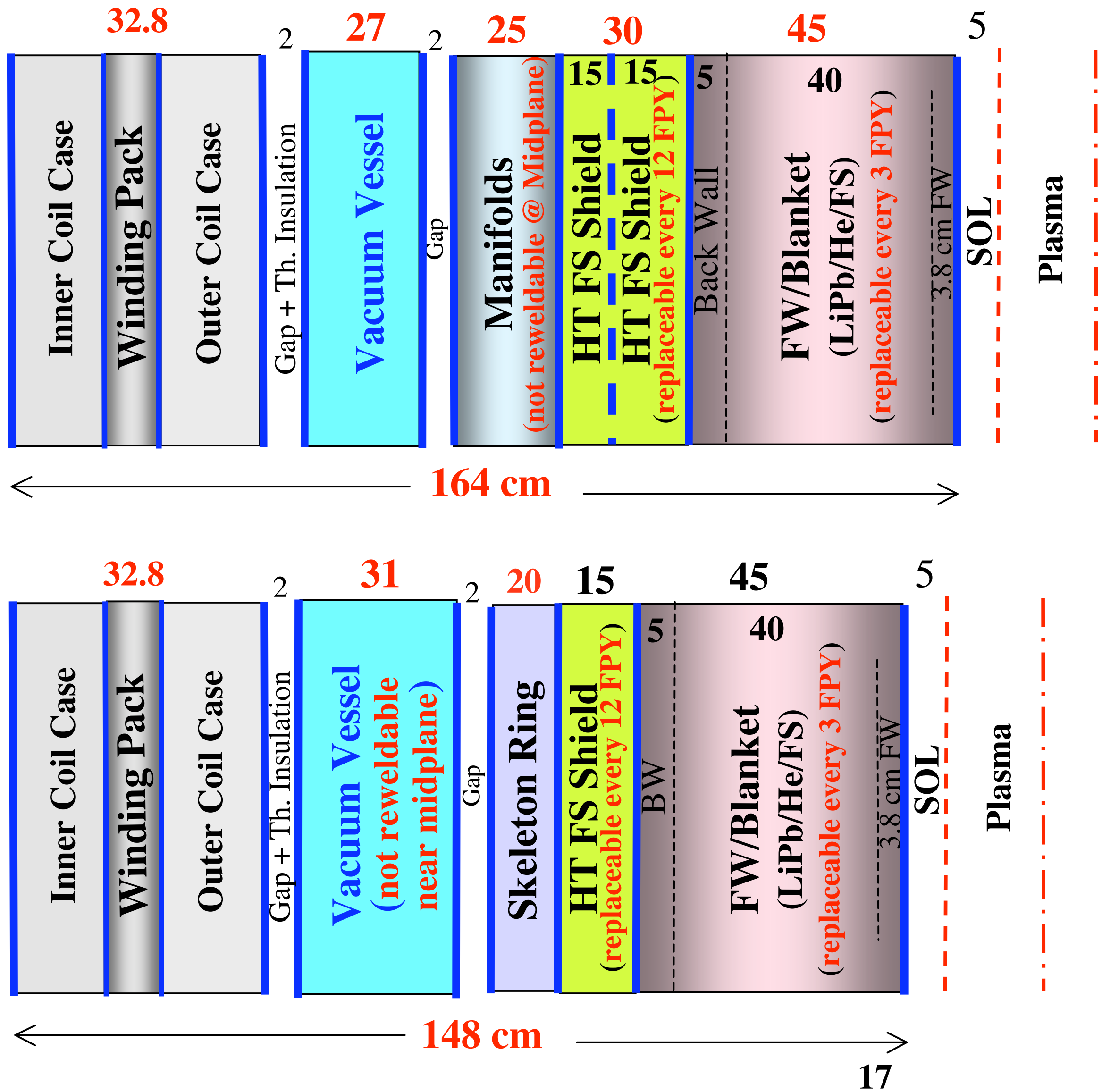
Calculated Overall TBR	1.1	
Net TBR (for T self-sufficiency)	~1.01	
Damage to Structure	200	dpa - advanced FS
(for structural integrity)	???	**W structure***
Helium Production @ Manifolds & VV#	1	He appm
(for reweldability of FS)		
LT S/C Magnets (@ 4 K):		
Peak fast n **fluence** to Nb_3Sn ($E_n > 0.1$ 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

* For divertor plates, W stabilizing shells, and W shield blocks behind assembly gaps, if needed.

\# Reweldability not required near IB midplane.
Only top/bottom interface between manifolds and shield needs to be reweldable for "without radial manifolds" case.

ARIES-DB-DCLL IB Radial Build

(midplane cross section - to be updated)



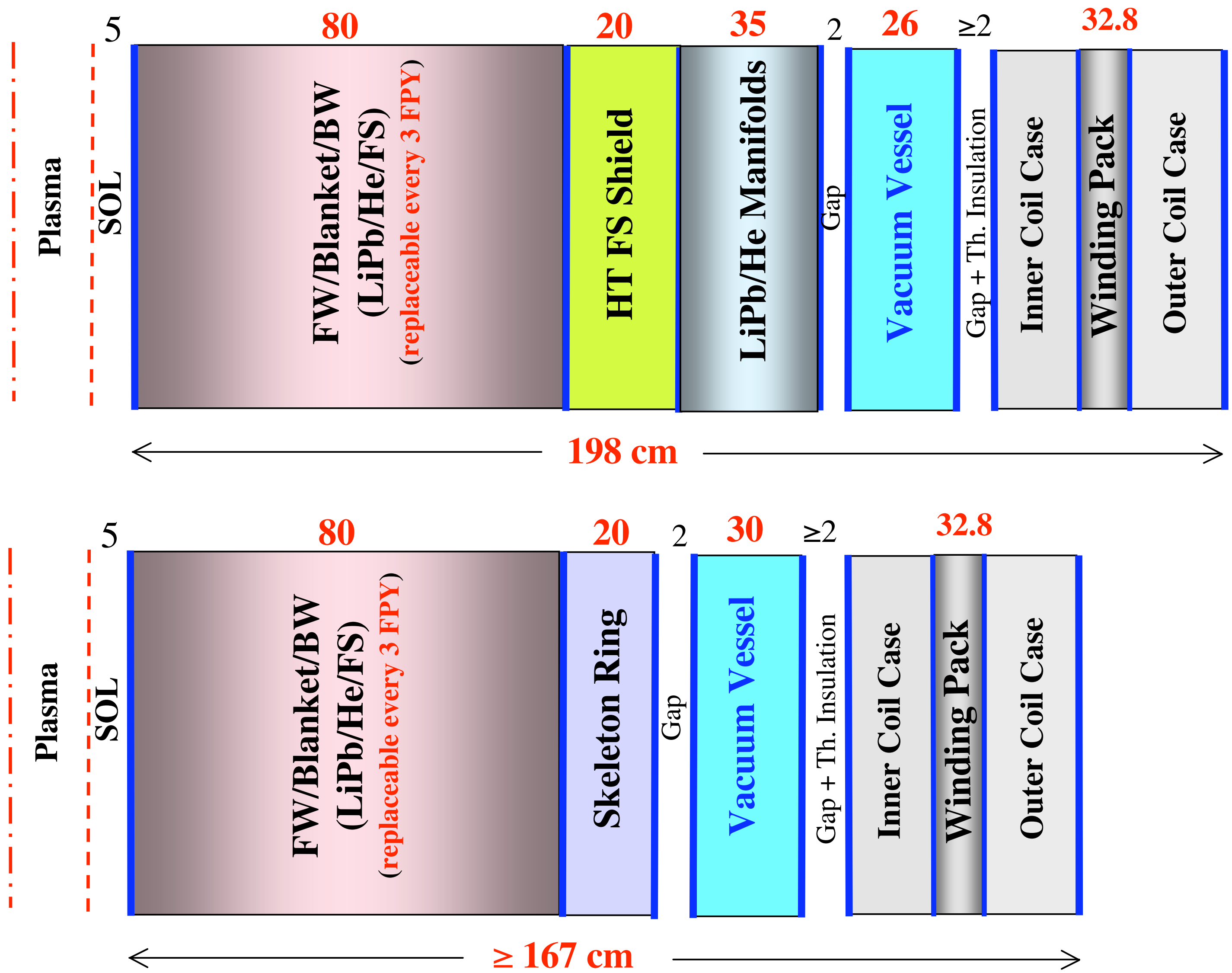
with
Radial Manifolds

Δ = 16 cm

without
Radial Manifolds
(reference)

ARIES-DB-DCLL OB Radial Build

(Radial Xn Underneath Magnet - to be updated)



No Shells

(to be added)

with Radial Manifolds

Δ = 31 cm

without Radial Manifolds

(reference)

ARIES-DB-DCLL Upper/Lower Radial Build

Most challenging case due to:

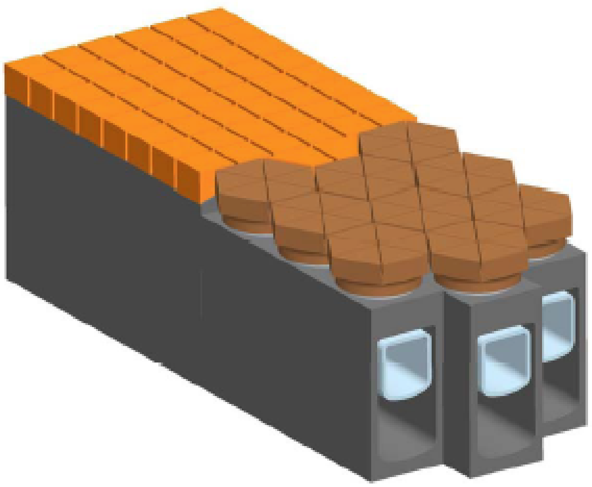
– Neutron streaming through large vacuum pumping ducts

– High W decay heat (may require active cooling system during LOCA/LOFA).

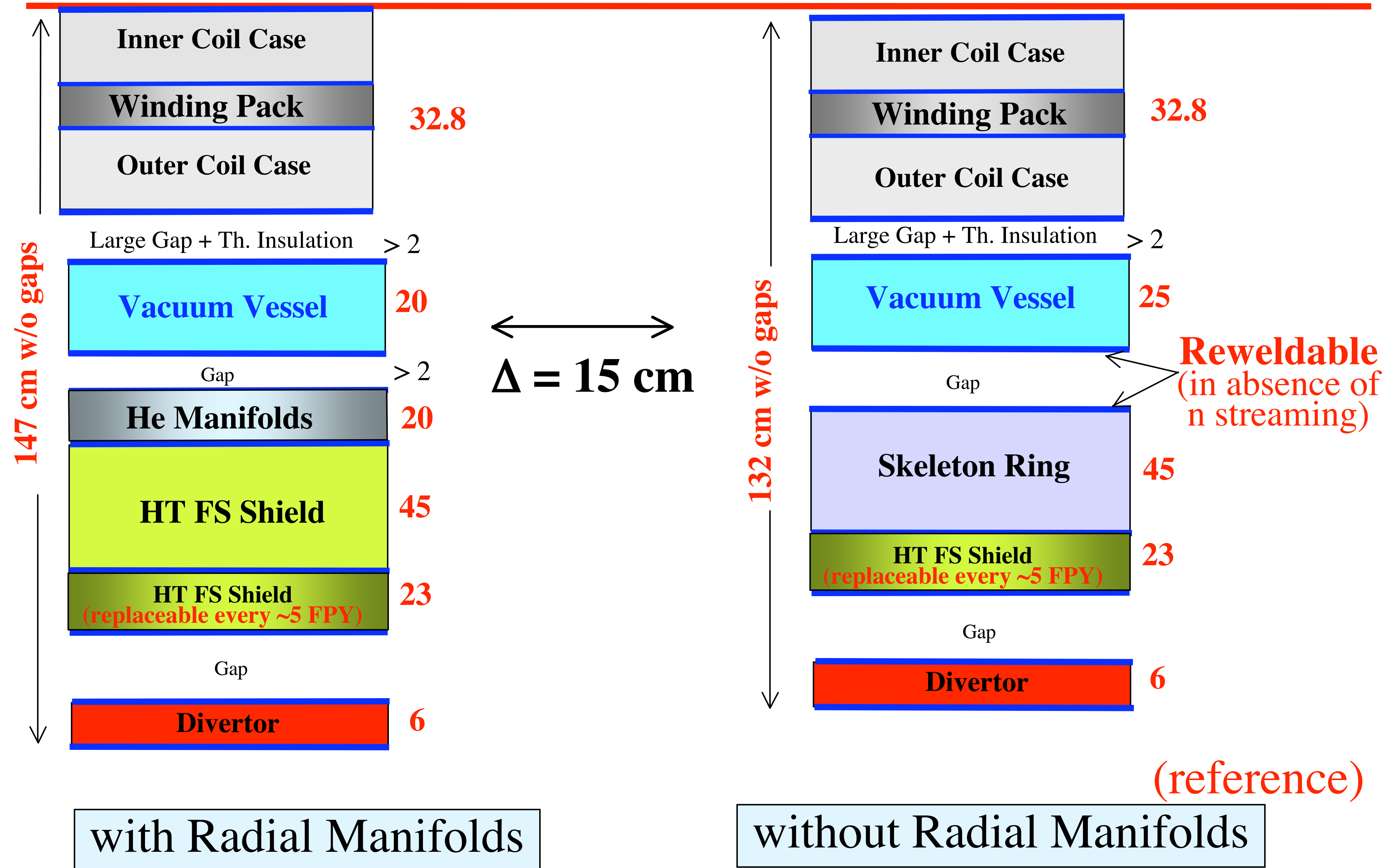
6 cm Thick Divertor

Two-Heat-Flux-Zone concept

(S. Malang and X. Wang)



ARIES-DB-DCLL Div Radial Build
(to be updated)



Compositions

	ARIES-DB-DCLL with Manifolds		ARIES-DB-DCLL* without Manifolds
Inboard:			
FW		34% FS, 66% He	
Blanket		76% LiPb, 13% He/void, 7% FS, 4%SiC	
Back Wall		80% FS, 20% He	
HT Shield / Skeleton Ring		15%FS, 10% He, 75% B-FS Filler	
Manifolds	50% FS, 25% He, 24% LiPb, 1%SiC		---
VV	17% FS, 34% H_2O, 49% WC		15% FS, 35% H_2O, 50% WC
Outboard:			
FW		34% FS, 66% He	
Blanket		77% LiPb, 12% He/void, 7% FS, 4%SiC	
Back Wall		80% FS, 20% He	
HT Shield / Skeleton Ring		15%FS, 10% He, 75% B-FS Filler	
Manifolds	50% FS, 25% He, 24% LiPb, 1%SiC		---
VV	30% FS, 50% H_2O, 20% B-FS		28% FS, 52% H_2O, 20% B-FS
Top/Bottom:			
Divertor		29% W alloy, 9% W, 13% ODS-FS, 50% He	
Replaceable HT Shield		15%FS, 10% He, 75% B-FS Filler	
Permanent HT Shield / Skeleton Ring		15%FS, 10% He, 75% B-FS Filler	
Manifolds	50% FS, 25% He, 24% LiPb, 1%SiC		---
VV	22% FS, 48% H_2O, 30% B-FS		19% FS, 50% H_2O, 31% B-FS

Comparison Between ARIES-AT and ARIES-DB

	ARIES-AT (LiPb/SiC)	ARIES-DB-DCLL (LiPb/He/FS)	Cost of ARIES-DB-DCLL
Physics		Several changes	
IB, OB, Div radial standoff*	135, 160, 133 cm	< 144, < 163, < 132 cm	
Limit on max. NWL (MW/m^2)	~ 6	< 5.5	
Major radius	5.2 m	6.3 m	↑
Calculated overall **TBR**	1.1 w/ 90% ^{6}Li enrichment	~1.1 w/o shells w/ 70% ^{6}Li enrichment	
FW/blanket **lifetime**	~4 FPY ⇒ 18 MWy/m^2	~2.8 FPY ⇒ 13 MWy/m^2	↑
Overall **energy multiplication**	1.1	~1.15	↓
Structure unit cost#	~ 620 $/kg	~ 95 $/kg	↓
η_{th}	~ 60%	~ 40%	↑
Cost of **heat transfer/transport system#**	~ $200M	~ $700M	↑
He pumping power	---	~260 ~~680~~ MW_e	↑
Level of Safety Assurance (**LSA**) factor	1	2	↑
COE#	**72 mills/kWh**	**< 105 mills/kWh**	

* Excluding gaps.
\# in 2008$.

Observations and Recommendations

Observations:

- ARIES-DB and ARIES-AT have comparable radial standoff
- Four candidate W alloys have acceptable activation characteristics
- Divertor pumping ducts will increase radiation level behind divertor shield where reweldability of coolant pipes is essential
- Elements that tend to degrade TBR:
  - Thick FW (to withstand disruption)
  - More structure within blanket
  - W armor on FW
  - Stabilizing shells.

Recommendations:

- Check/confirm TF magnet composition/dimension
- Reduce recirculating power
- Segment OB blanket to reduce replacement cost and radwaste stream.

Qs and needs:

- FW/Blanket composition and dimension (to assure TBR ≥ 1.1)
  - Any W armor on FW?
  - Any change to FW materials? Any need for refractory alloys (W, Ti, Mo, or Nb) to handle high heat flux?
- Locations of kink shells, vertical stabilizing shells, and feedback coils. Impact on TBR?
- Divertor pumping ducts: size and location.
- VV design and FS content.

To be done/considered :

- W decay heat and divertor temperature response during LOCA/LOFA
- Change of SiC electric conductivity with neutron irradiation.
- Change of electric conductivity of stabilizing shells with neutron irradiation.