Preliminary ARIES-AT-DCLL Radial Build for ASC

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UCSD

Objectives

- Define preliminary radial builds for ARIES-AT-DCLL with:
  - Stabilizing shells
  - LiPb/He Manifolds (tentative composition/dimension/location).

- Highlight impact of DCLL system and stabilizing shells on ARIES-AT engineering and physics.

ARIES-AT Reference Design

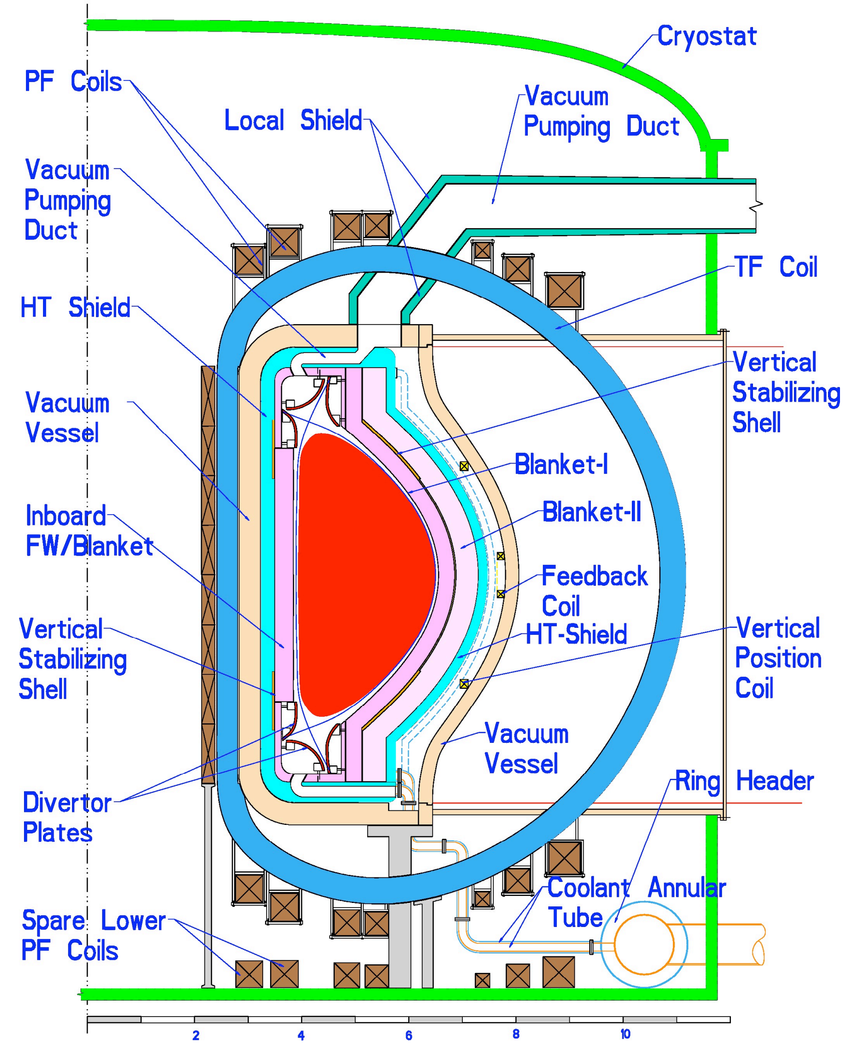
Fusion Power	1755 MW
Major Radius	5.2 m
Minor Radius	1.3 m
Peak Γ @ IB, OB, Div	3.1, 4.8, 2 MW/m^2

SiC/SiC Composite Structure
LiPb/SiC Blanket
Discrete LiPb Manifolds
HT S/C Magnet @ 70-80 K
No W on FW

Calculated Overall TBR	1.1
η_{th}	~ 60%
Availability	85%

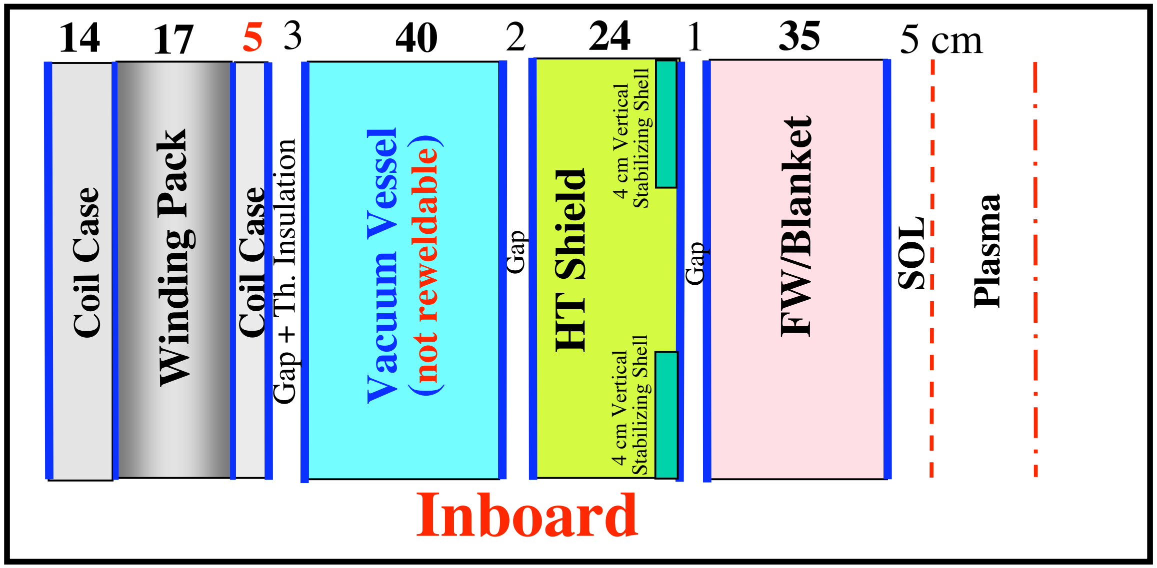
Plasma Control:

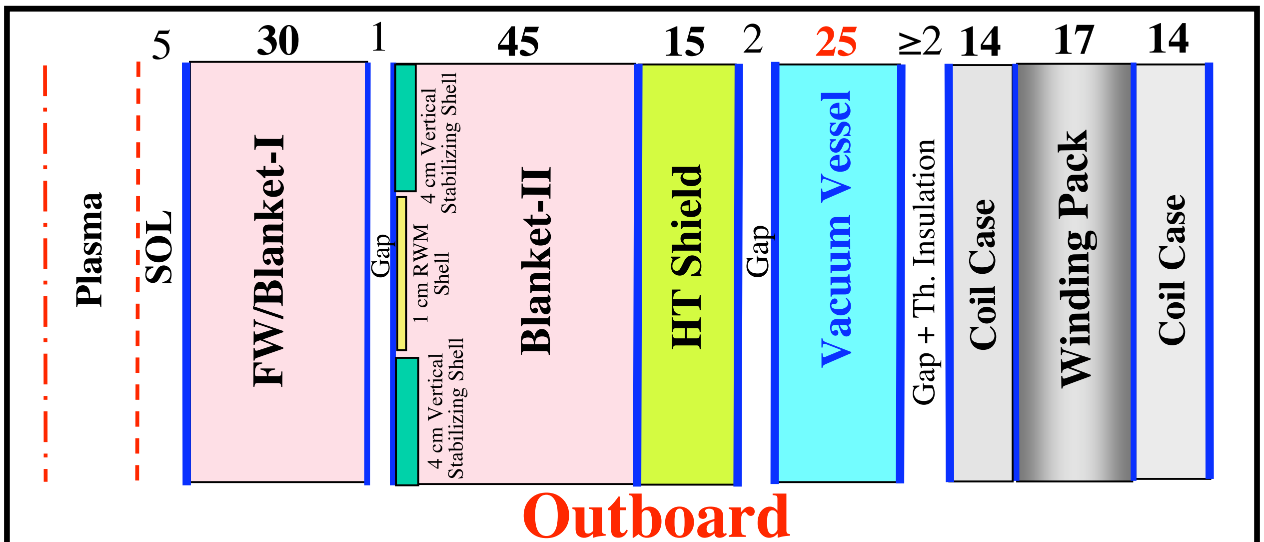
- 5 W Shells on IB and OB
- 2 Vertical Position Coils
- 2 Feedback Coils

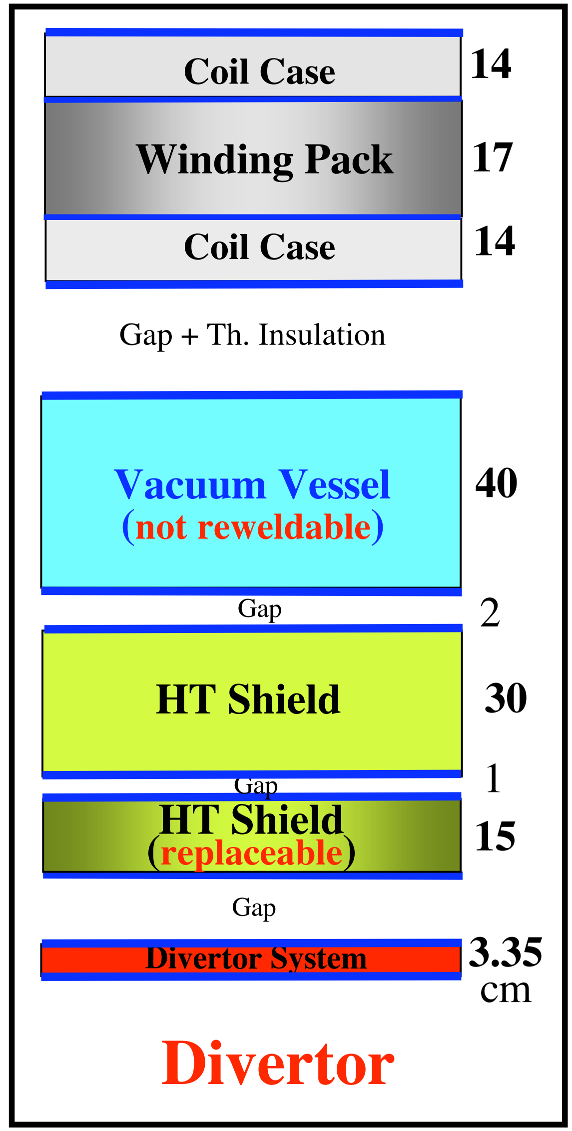


ARIES-AT Radial Builds: IB, OB, Div

(SiC Structure)



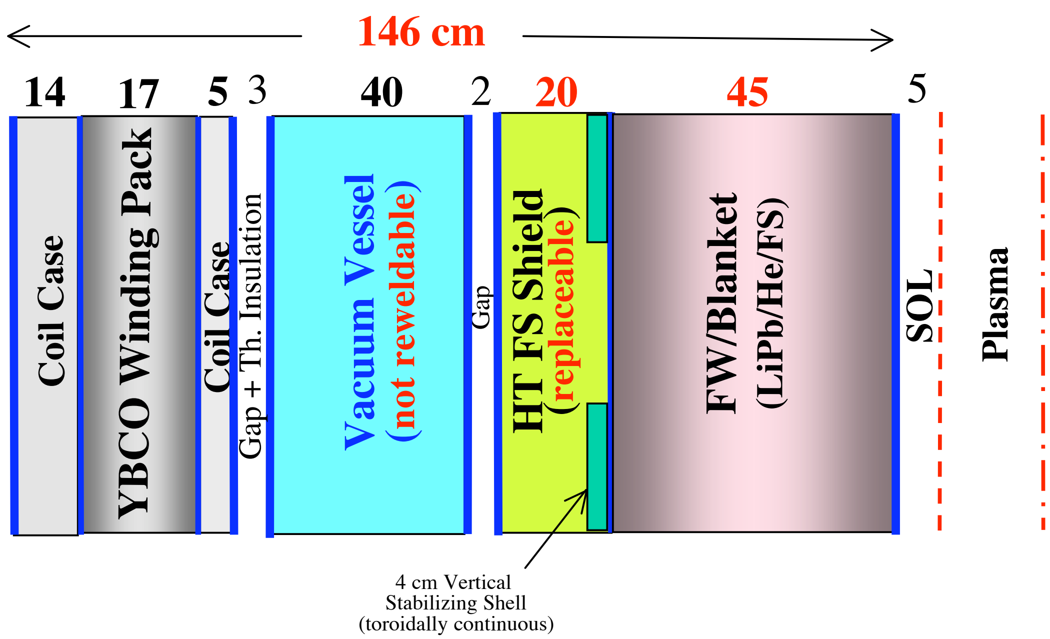




Changes, Updates, and Assumptions

	ARIES-AT-LiPb/SiC (Reference Design)	ARIES-AT-DCLL
Peak NWL @ IB, OB, Div	3.1, 4.8, 2 MW/m^2	3.1, 4.8, 2 MW/m^2 (to be updated)
FS structure	ORNL FS	MF82H FS
LiPb:		
Li enrichment	90%	90% or less
Average temp	700 °C	~580 °C
Density	8.8 g/cc	9 g/cc
OB blanket	Two segments	One segment
LiPb/He manifolds:	Discrete	Assumed toroidally continuous in OB and Div regions
W shells:		
Two 4-cm-thick VS shells on IB: (toroidally continuous)	Between IB blanket & shield	Between IB blanket & shield
Two 4-cm-thick VS shells on OB: (toroidally continuous)	Between OB blanket segments	Behind OB blanket (or use FS cooling channels of blanket)
1-cm-thick RWM shell on OB: (discrete)	Between OB blanket segments	FW could serve as RWM shell
Shield coolant	LiPb	He
IB Blanket-shield gap	1 cm	---
VV model	Homogeneous	Heterogeneous with 2-cm-thick plates
TF & PF magnets	YBCO HT S/C	Nb_3Sn LT S/C
Cross section data library	IAEA FENDL-2	IAEA FENDL-2.1

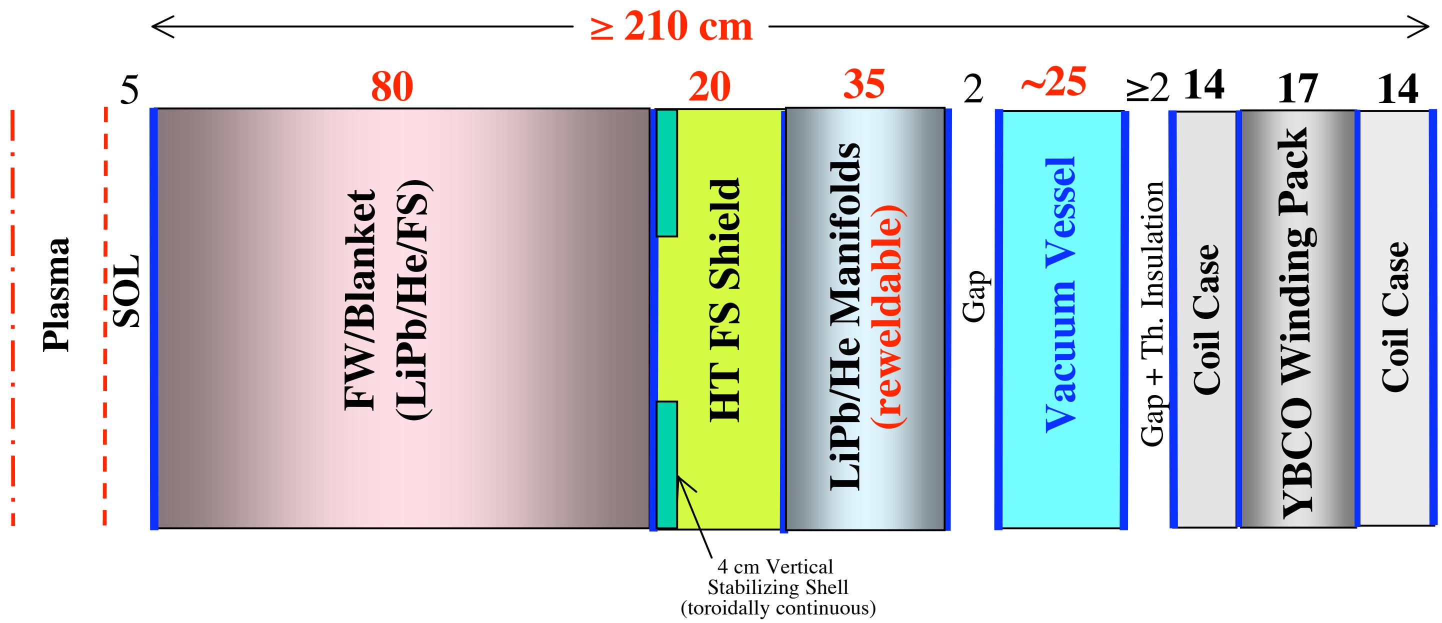
Recommended ARIES-AT-DCLL IB Radial Build



- No LiPb/He Manifolds on IB.
- Upper/lower W Shells located between Blanket & Shield.

Recommended ARIES-AT-DCLL OB Radial Build

(Cross Section through Magnet*)

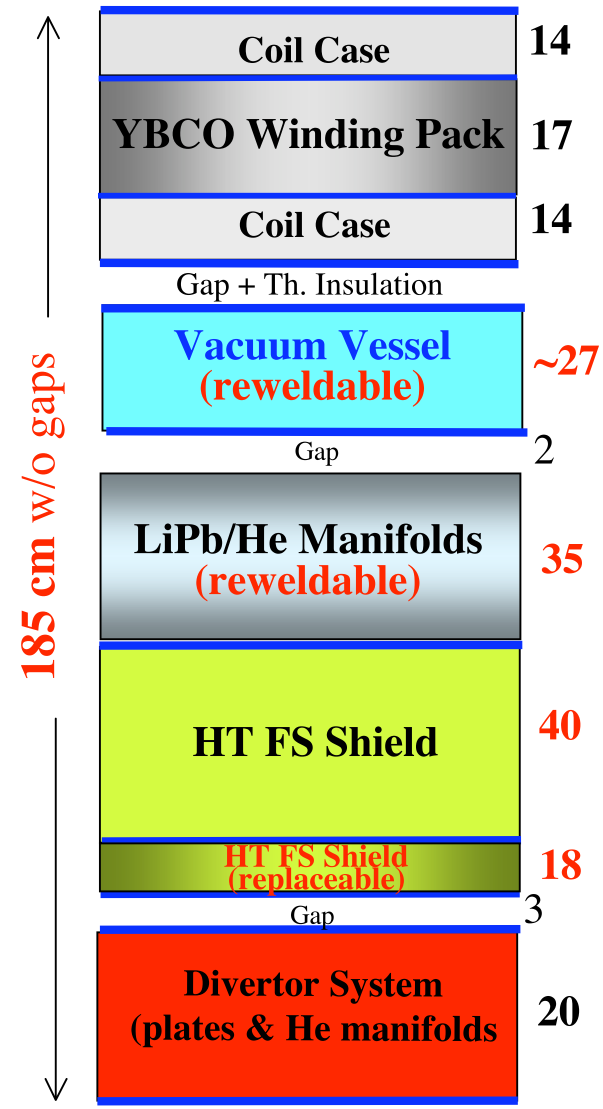


- 35 cm LiPb/He Manifolds placed behind shield (thickness/composition to be updated by Rene/Siegfried).
- Upper/lower W Shells located between Blanket & Shield.
- Could FW serve as RWM (kink) shell? Thickness? Impact on TBR?

* Cross section between magnet TBD.

Recommended ARIES-AT-DCLL Divertor Radial Build

35 cm LiPb/He Manifolds located behind shield (thickness/composition to be updated by Rene/Siegfried).



Impact of Stabilizing Shell Location on ARIES-AT Physics

- Preliminary assessment on stability and control without much detailed analysis.

- **For vertical stability,** parameters of interest is distance of stabilizing shell from plasma boundary normalized to minor radius (a=1.3 m), **and** growth rate of instability that must be restrained by feedback coils behind shield/manifolds.

- In reference **ARIES-AT**:
  - IB stabilizers d/a = 0.31
  - OB stabilizers d/a = 0.28

    ⇒ Plasma elongation = 2.2 and significant increase in beta

    ⇒ Feedback coils behind OB shield (@ 96 cm from plasma boundary)

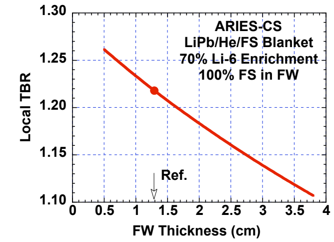
- In **ARIES-AT-DCLL** (assuming shells between blanket and Shield):
  - IB stabilizers d/a = 0.38
  - OB stabilizers **d/a = 0.65 <--- too high!**

    ⇒ Plasma elongation = 1.5 -1.6 – **unacceptable**

    Assuming feedback coils at same normalized location as in reference ARIES-AT (meaning coils embedded in shield!).
  - Impacts on physics and design of placing feedback coils outside manifolds (@ 140 cm from plasma) need to be assessed.

Impact of Stabilizing Shell Location on ARIES-AT Physics (Cont.)

- **For RWM (kink stability),** 3.8 cm FS/He FW (containing 1.3 cm FS) will *probably* be adequate to slow the resistive wall mode down for feedback control.
  (Laila:scaling from 2 cm V kink shell of ARIES-RS ⇒ ~5 cm FS kink shell
  ⇒ Breeding problem)



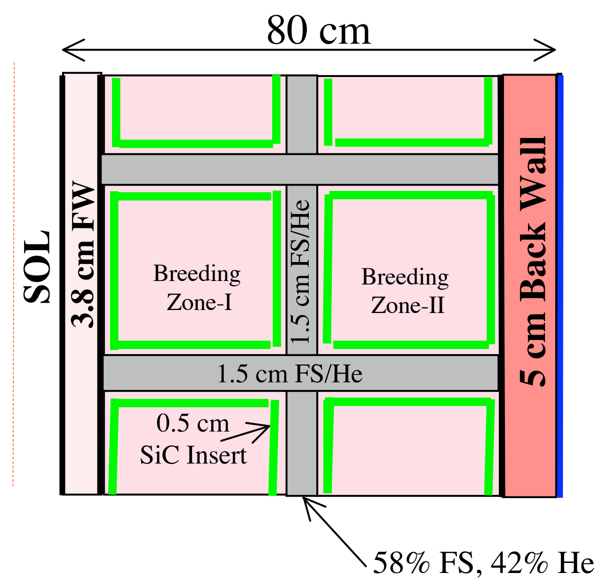
- **Steel vs Tungsten Kink Shell**:
  - Steels have resistivity ~12 times higher than W (and 50 times higher than Cu).
  - FS do **not** slow down plasma as efficiently as W.
  - This means voltage and power required for feedback system will be **360 MVA** (12 times higher than 30 MVA of reference ARIES-AT).
  - 360 MVA is very high regardless of the fact that it is mostly reactive power.

Overall conclusions:

- FS RWM (kink) shell requires very high voltage and power for feedback system (360 MVA).
- 5 cm thick FS RWM shell @ FW degrades TBR significantly. May examine Cu or W shell behind FW.
- Locating vertical stabilizing shell outside OB blanket results in major hit to plasma operating point and is probably unacceptable.
- This assessment assumes same geometry for plasma, which may not be the case.

Impact of Stabilizing Shell Location on ARIES-AT Physics (Cont.)

Feasibility of using FS Cooling Channels for Plasma Stabilization



Proposed ARIES-CS-DCLL Blanket

- Can central cooling channel be modified and connected from module to module (as in ARIES-AT) to create toroidally continuous stabilizing shell?
- If so, d/a = 0.35 for ARIES-CS-DCLL – much better than 0.65 for shell outside 80 cm blanket.
- Could modified cooling channel be moved 5 cm inward to attain d/a = 0.31?
- Thickness of steel shell >> thickness of W shell.
- Impact on TBR of modified cooling channel should be assessed.

Observations, Questions, Needed Info

Observations:

- LiPb/He manifolds increase radial standoff and should **not** be placed at IB.
- Initial assessment indicated unacceptable physics parameters for locating W stabilizing shells outside OB blanket.
- Steel RWM (kink) shell requires very high voltage/power (360 MVA) and fairly thick steel (~5 cm). This may not be economically acceptable and will degrade TBR significantly.

Questions:

- Could central 1.5 cm FS/He cooling channel within blanket be modified and connected toroidally to serve as vertical stabilizing shells?
- Does modified cooling channel call for more steel? If yes, more steel will degrade TBR.
- Could feedback coils be embedded in OB shield? If not, impacts on physics and design of placing coils outside manifolds should be assessed.
- Do W, Cu, and FS resistivities increase with neutron fluence? If so, assess impact on shell parameters.

To do:

- Replace HT YBCO TF/PF magnets by LT Nb_3Sn magnet.
- Breeding with < 90% enrichment (for larger breeding margin) will be assessed. It may require fairly thick IB and OB blankets. Impact on stabilizing shells and physics?
- OB radial build for Xn between magnets will be provided.
- IB replaceable shield will be divided into replaceable and permanent components to minimize radwaste stream.
- Boride material will be added to OB VV to reduce magnet heating and activation.
- Penetration shield should surround pumping ducts to limit radiation damage at VV and magnet.
- NWL distribution will be updated using actual neutron source profile within plasma, per Wilson (UW).

Needs:

- Practical solutions for RWM shells, vertical stabilizing shells, and feedback coils.
- Compositions of LT magnets **and** coil cases.
- Size, composition, and location of manifolds.