



Re-Examination of Visions for Tokamak Power Plants – The ARIES-ACT Study

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ARIES Program Participants

Systems code: UC San Diego, PPPL

Plasma Physics: PPPL , GA, LLNL

Fusion Core Design & Analysis: UC San Diego, FNT Consulting

Nuclear Analysis: UW-Madison

Plasma Facing Components (Design & Analysis): UC San Diego, UW-Madison

Plasma Facing Components (experiments): Georgia Tech

Design Integration: UC San Diego, Boeing

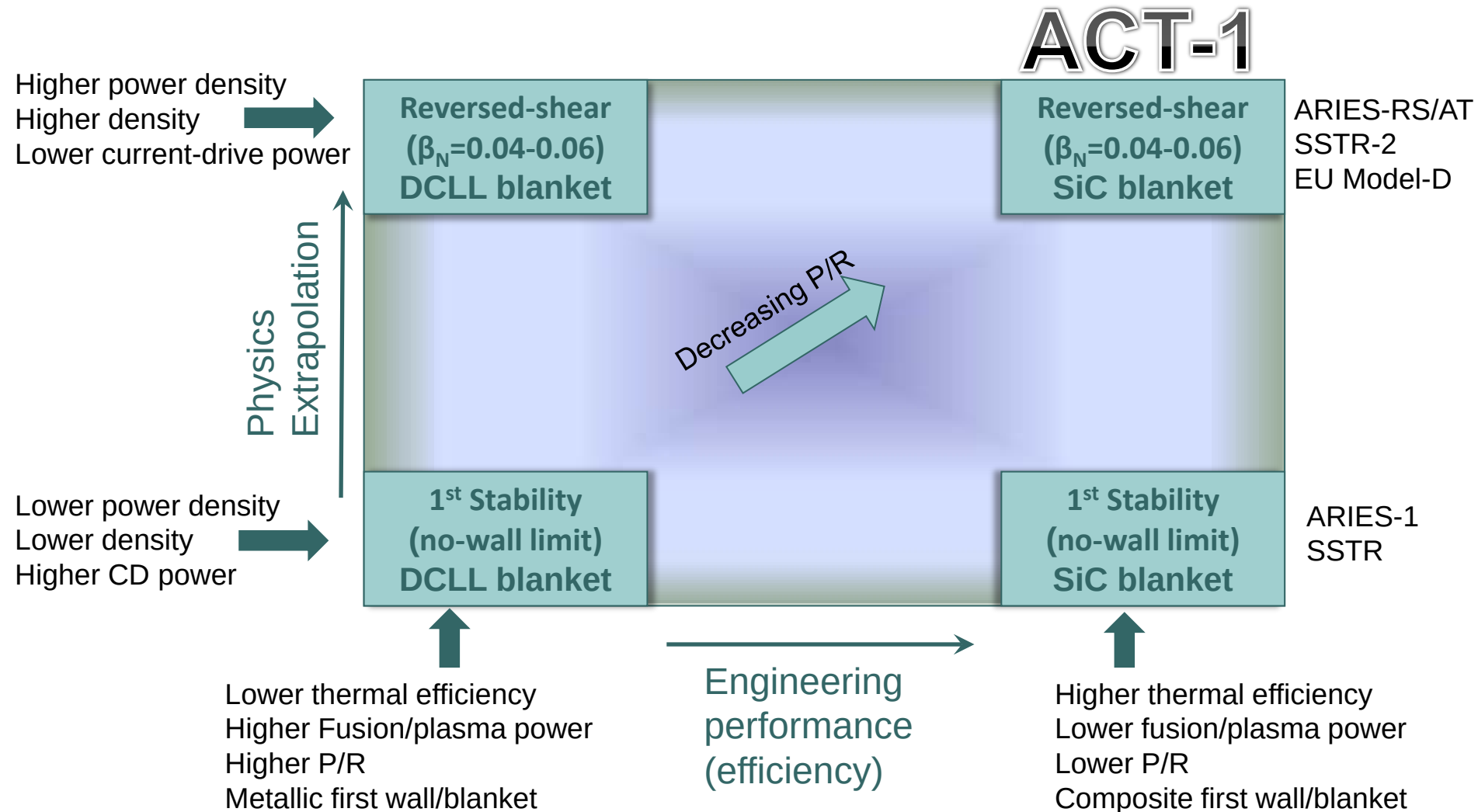
Safety: INEL

Contact to Material Community: ORNL

Goals of ARIES ACT Study

- Over a decade since last tokamak study : ARIES-1 (1990) through ARIES-AT(2000).
 - Substantial progress in understanding in many areas.
 - New issues have emerged: e.g., edge plasma physics, PMI, PFCs, and off-normal events.
 - What would be the maximum fluxes that can be handled by in-vessel components in a power plant?
 - What level of off-normal events are acceptable in a commercial power plant?
- Evolving needs in the ITER and FNSF/Demo era:
 - Risk/benefit analysis among extrapolation and attractiveness.
 - Detailed component designs is necessary to understand R&D requirements.

Frame the “parameter space for attractive power plants” by considering the “four corners” of parameter space



● ● ● Status of the ARIES ACT Study

➤ Project Goals:

- Detailed design of advanced physics, SiC blanket ACT-1 (ARIES-AT update).
- Detailed design of ACT-2 (conservative physics, DCLL blanket).
- System-level definitions for ACT-3 & ACT-4.

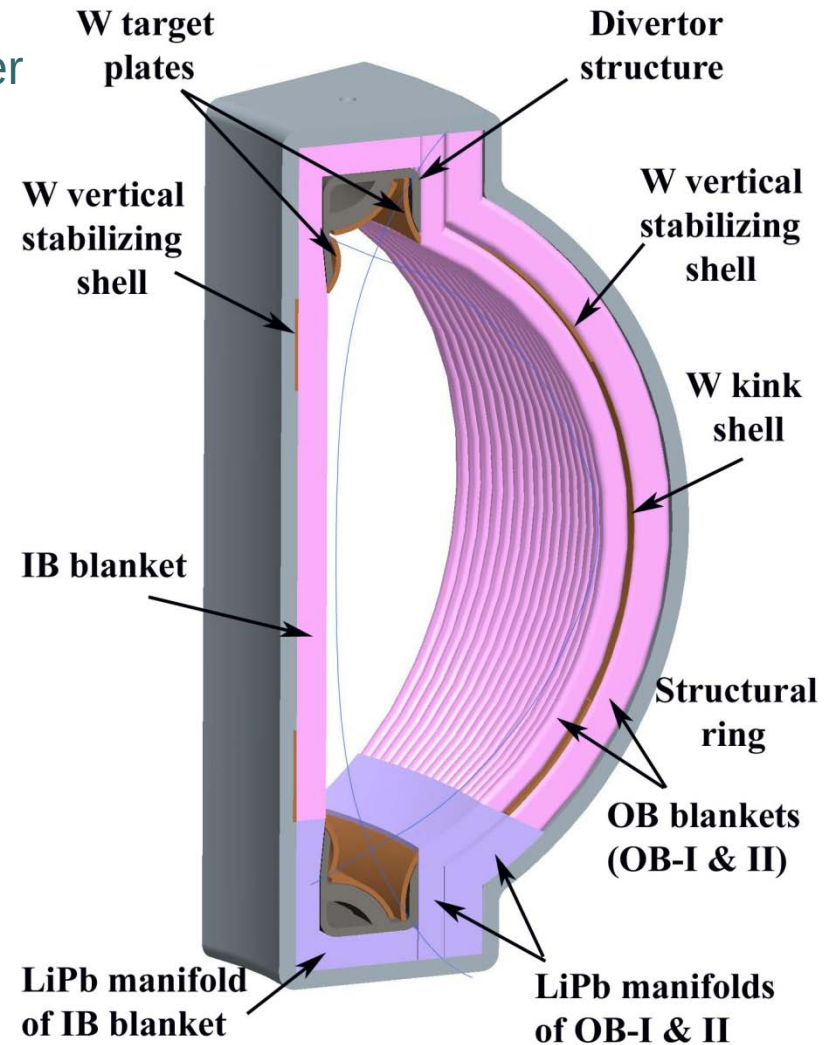
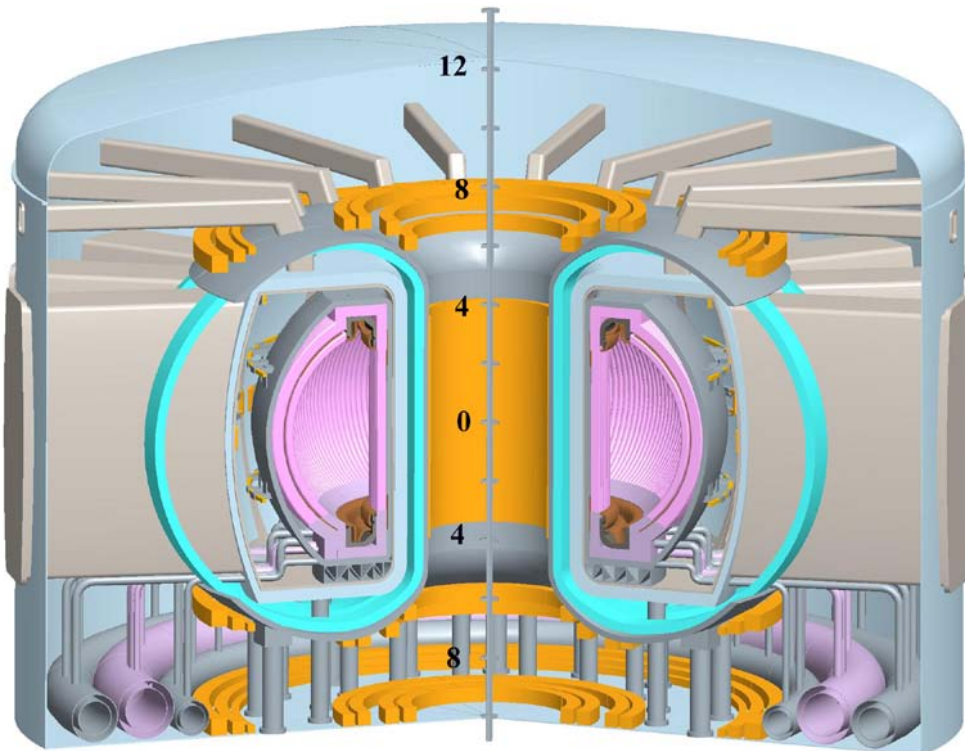
➤ ACT-1 research will be completed by Dec. 2012.

- First design iteration was completed for a 5.5 m Device.
- Updated design point at $R = 6.25$ m (detailed design on-going)
- 9 papers in this conference.

➤ ACT-2 Research will be completed by June 2013.

ARIES-ACT1 (ARIES-AT update)

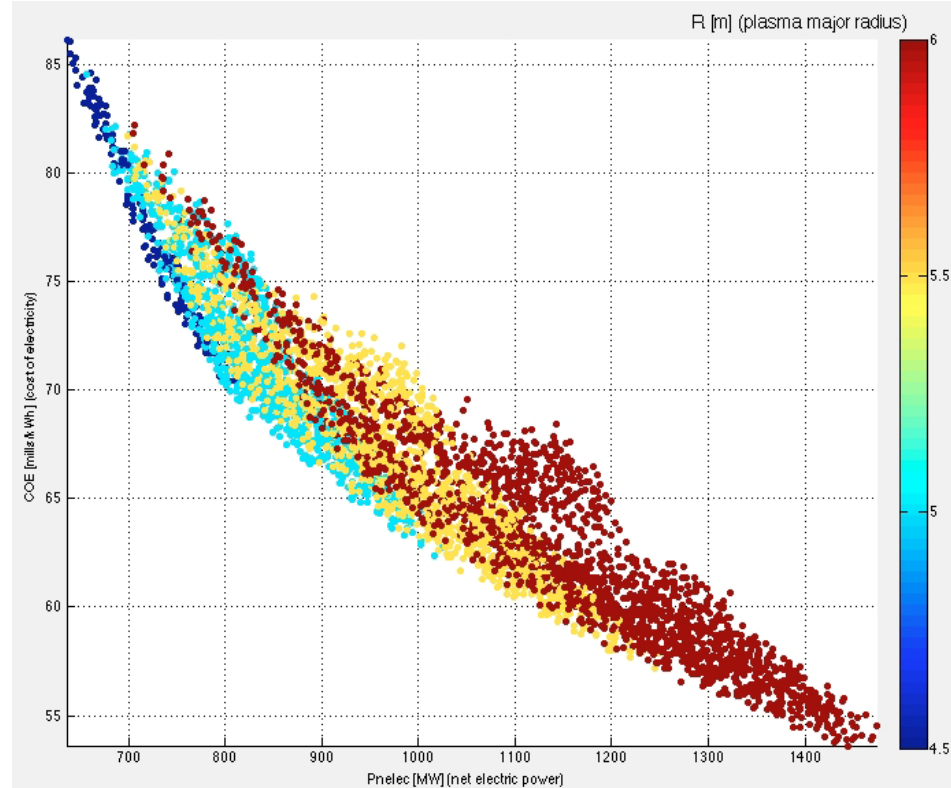
- Advance tokamak mode
- Blanket: SiC structure & LiPb Coolant/breeder (to achieve a high efficiency)



ARIES Systems Code – a new approach to finding operating points

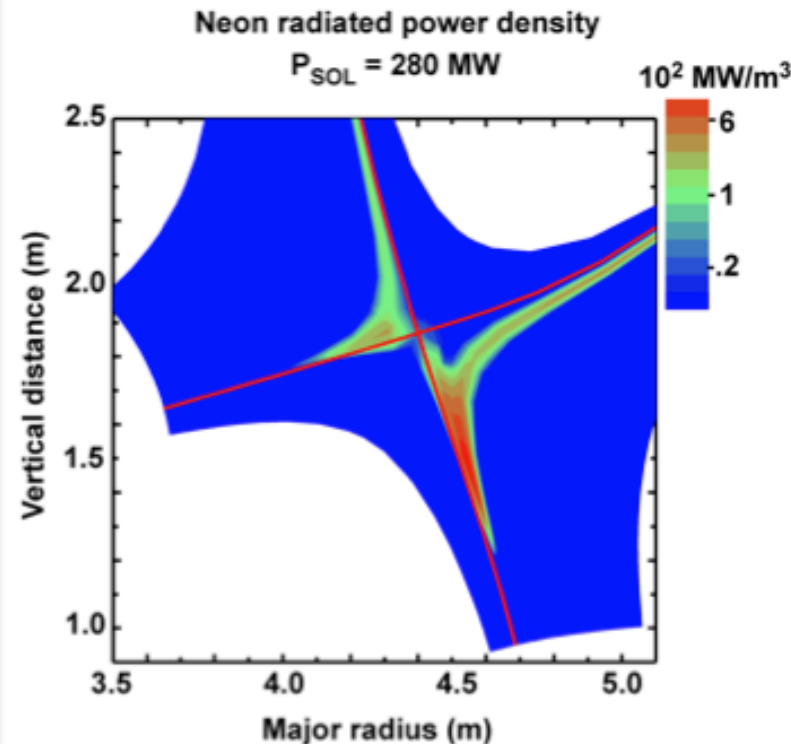
- Systems codes find a single operating point through a minimization of a figure of merit with certain constraints
 - Very difficult to see sensitivity to assumptions.
- Our new approach to systems analysis is based on surveying the design space and finding a large number of viable operating points.
- A GUI is developed to visualize the data. It can impose additional constraints to explore sensitivities

Example: Data base of operating points with $f_{bs} \leq 0.90$, $0.85 \leq f_{GW} \leq 1.0$, $H_{98} \leq 1.75$



Impact of the Divertor Heat load

- Divertor design can handle $> 10 \text{ MW/m}^2$ peak load.
- UEDGE simulations (LLNL) showed detached divertor solution to reach high radiated powers in the divertor slot and a low peak heat flux on the divertor ($\sim 5 \text{ MW/m}^2$ peak).
 - Leads to ARIES-AT-size device at $R=5.5\text{m}$.
 - Control & sustaining a detached divertor?
- Using Fundamenski SOL estimates and 90% radiation in SOL+divertor leads to a 6.25-m device with only 4 mills cost penalty (current reference point).
 - Device size is set by the divertor heat flux



The new systems approach underlines robustness of the design point to physics achievements

Major radius (m)	6.25
Aspect ratio	4
Toroidal field on axis (T)	6
Peak field on the coil (T)	11.8
Normalized beta*	5.75%
Plasma current (MA)	10.9
H98	1.65
Fusion power (MW)	1813
Auxiliary power	154
Average n wall load (MW/m ²)	2.3
Peak divertor heat flux (MW/m ²)	10.6
Cost of Electricity (mills/kWh)	67.2

* Includes fast α contribution of $\sim 1\%$

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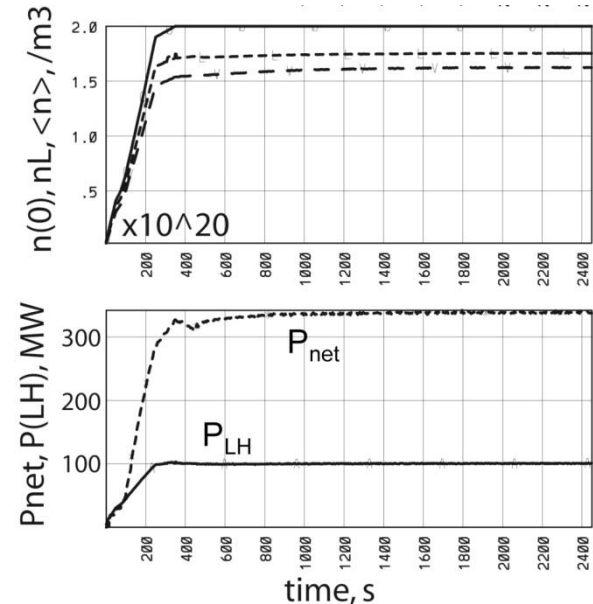
Major radius (m)	6.25	6.25
Aspect ratio	4	4
Toroidal field on axis (T)	6	7
Peak field on the coil (T)	11.8	12.9
Normalized beta*	<u>5.75%</u>	<u>4.75%</u>
Plasma current (MA)	10.9	10.9
H98	1.65	1.58
Fusion power (MW)	1813	1817
Auxiliary power	154	169
Average n wall load (MW/m ²)	2.3	2.3
Peak divertor heat flux (MW/m ²)	10.6	11.0
Cost of Electricity (mills/kWh)	67.2	68.9

* Includes fast α contribution of $\sim 1\%$

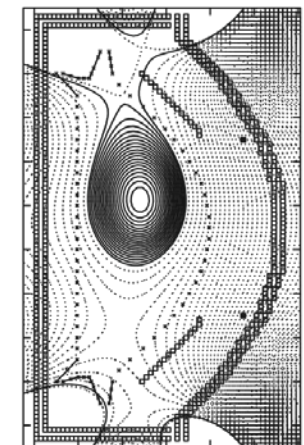
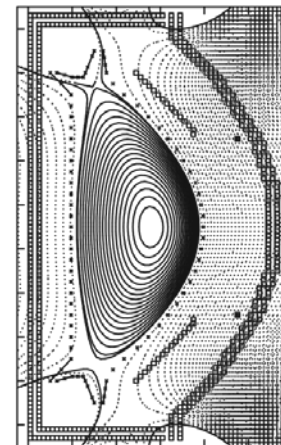
Detailed Physics analysis has been performed using the latest tools

New physics modeling

- Energy transport assessment: what is required and model predictions
- Pedestal treatment
- Time-dependent free boundary simulations of formation and operating point
- Edge plasma simulation (consistent divertor/edge, detachment, etc)
- Divertor/FW heat loading from experimental tokamaks for transient and off-normal*
- Disruption simulations*
- Fast particle MHD



$t = 1055 \text{ s}$



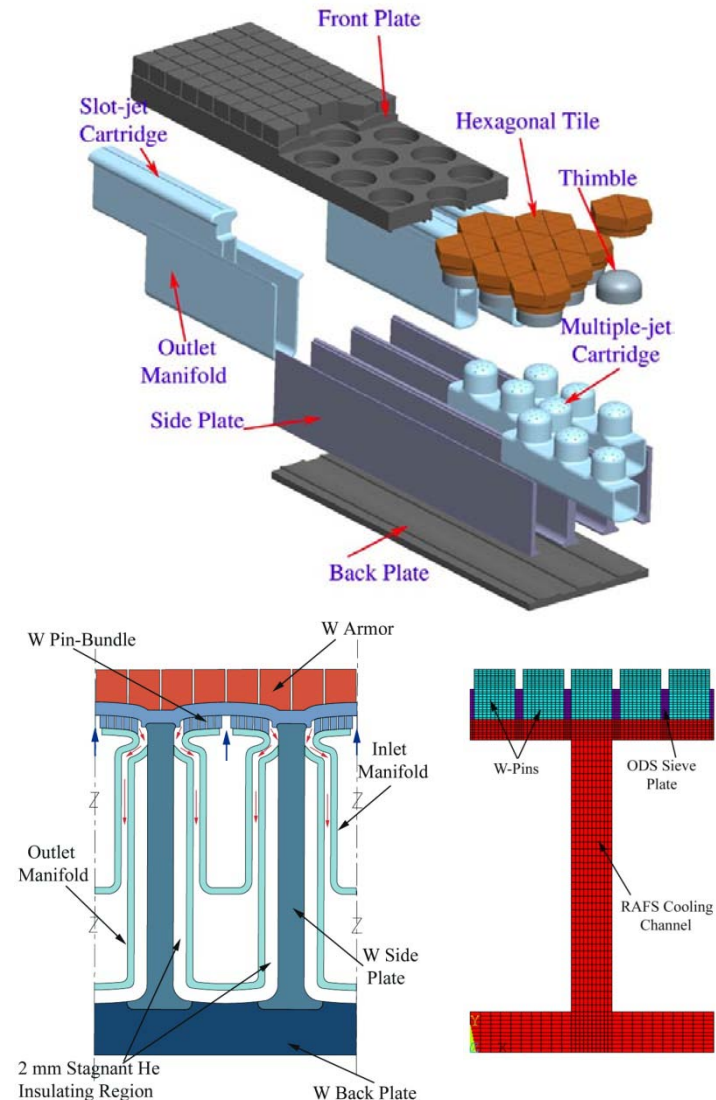
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* Discussed in the paper by C. Kessel, this session

Overview of engineering design:

1. High-heat flux components*

- Design of first wall and divertor options
 - High-performance He-cooled W-alloy divertor, external transition to steel
 - Robust FW concept (embedded W pins)
- Analysis of first wall and divertor options
 - Birth-to-death modeling
 - Yield, creep, fracture mechanics
 - Failure modes
- Helium heat transfer experiments
- ELM and disruption loading responses
 - Thermal, mechanical, EM & ferromagnetic

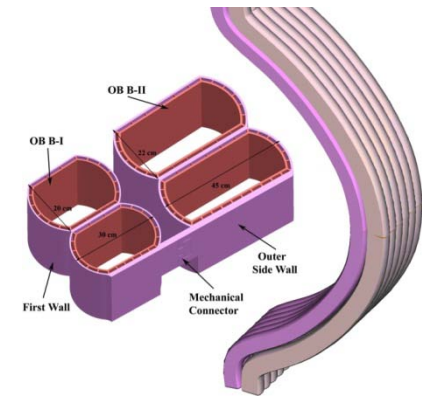
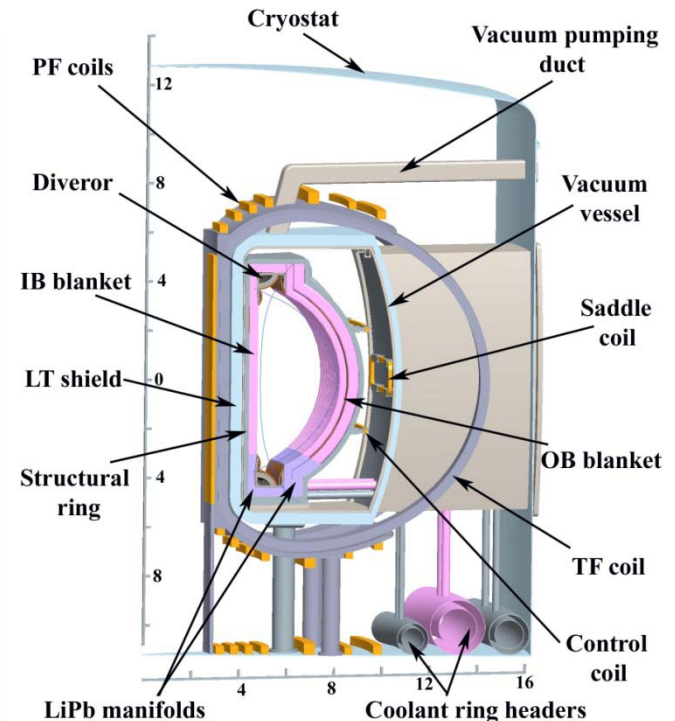


* Discussed in papers by M. Tillack and J. Blanchard, this session

Overview of engineering design*:

2. Fusion Core

- Features similar to ARIES-AT
 - PbLi self-cooled SiC/SiC breeding blanket with simple double-pipe construction
 - Brayton cycle with $\eta \sim 60\%$
- Many new features and improvements
 - He-cooled ferritic steel structural ring/shield
 - Detailed flow paths and manifolding for PbLi to reduce 3D MHD effects**
 - Elimination of water from the vacuum vessel, separation of vessel and shield
 - Identification of new material for the vacuum vessel***



* Discussed in the paper by M. Tillack, this session
** Discussed in the paper by X. Wang, this session
*** Discussed in the paper by L. El_Guebaly, this session



Detailed safety analysis has highlighted impact of tritium absorption and transport

- Detailed safety modeling of ARIES-AT (Petti et al) and ARIES-CS (Merrill et al, FS&T, 54, 2008) have shown a paradigm shift in safety issues:
 - Use of low-activation material and core design has limited temperature excursions and mobilization of radioactivity during accidents. Rather off-site dose is dominated by tritium.
 - For ARIES-CS worst-case accident, tritium release dose is 8.5 mSv (no-evacuation limit is 10 mSV)
- Major implications for material and component R&D:
 - Need to minimize tritium inventory (control of breeding, absorption and inventory in different material)
 - Design implications: material choices, in-vessel components, vacuum vessel, etc.



In summary ...

- ARIES-ACT study is re-examining the tokamak power plant space to understand risk and trade-offs of higher physics and engineering performance with special emphasis on PMI/PFC and off-normal events.
 - ARIES-ACT1 (updated ARIES-AT) is near completion.
 - Detailed physics analysis with modern computational tools are used. Many new physics issues are included.
 - The new system approach indicates a robust design window for this class of power plants.
 - Many engineering improvements: He-cooled ferritic steel structural ring/shield, Detailed flow paths and manifolding to reduce 3D MHD effects, Identification of new material for the vacuum vessel ...
 - In-elastic analysis of component including Birth-to-death modeling and fracture mechanics indicate a higher performance PFCs are possible. Many issues/properties for material development & optimization are identified.



Thank you!