ARIES-CS Power Core Options for Phase II and Focus of Engineering Effort

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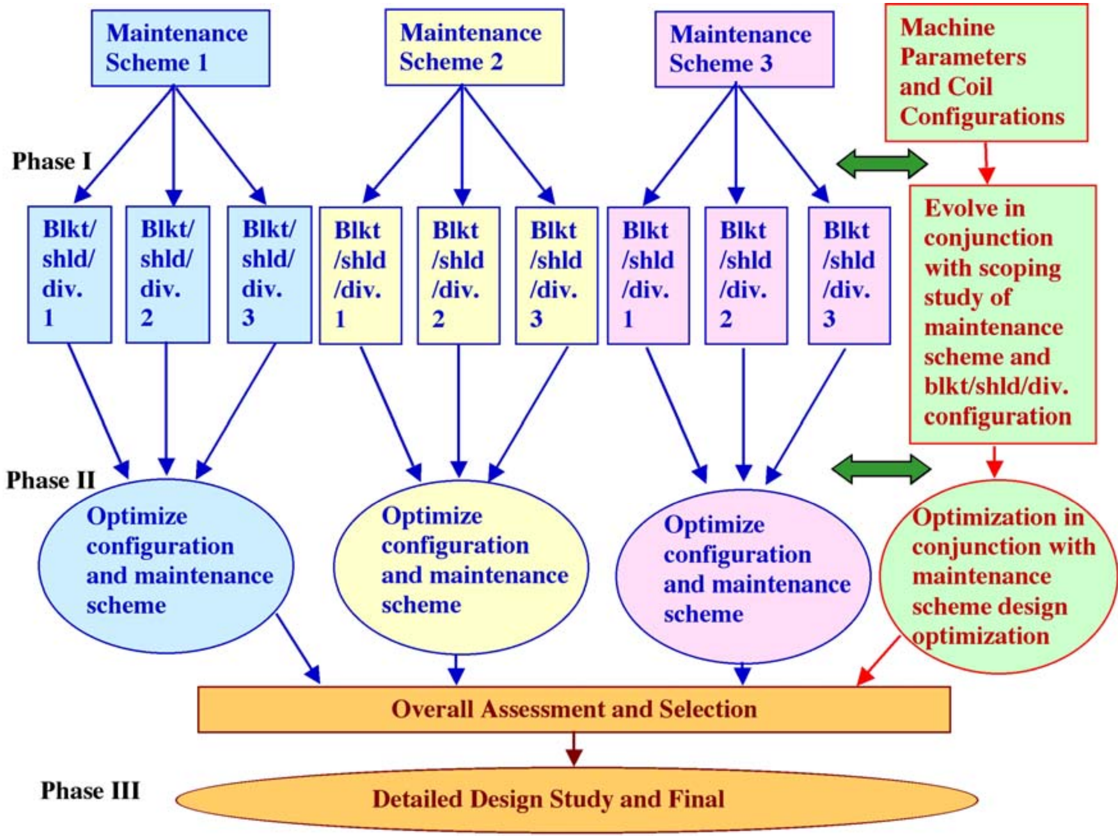
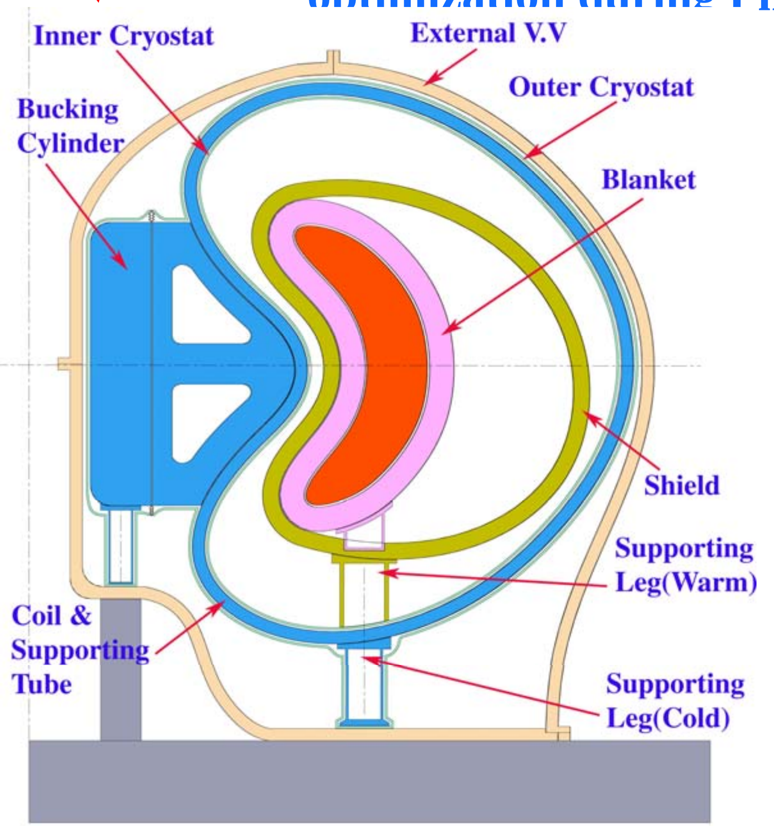
Engineering Activities During Phase I of ARIES-CS Study

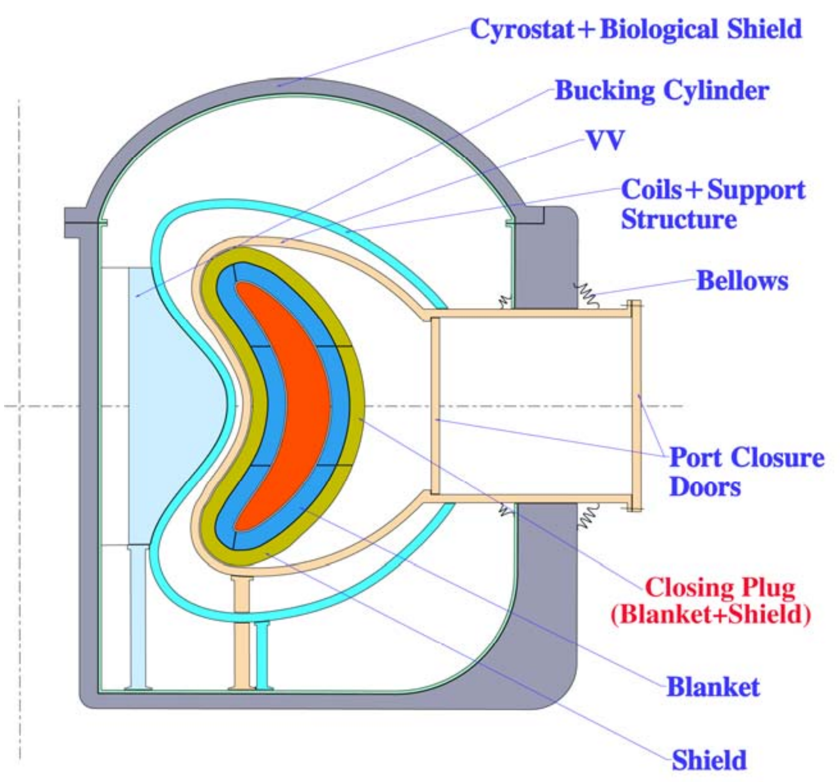
- **Perform Scoping Assessment of Different Maintenance Schemes and Blanket Concepts for Down Selection to a Couple of Combinations for Phase II**
- **Three Possible Maintenance Schemes:**
  1. **Field-period based replacement including disassembly of modular coil system (e.g. SPPS, ASRA-6C)**
  2. **Replacement of blanket modules through a few ports (using articulated boom)**
  3. **Replacement of blanket modules through ports arranged between each pair of adjacent modular coils (e.g. HSR)**
- **Different Blanket Classes**
  1. **Self-cooled Pb-17Li blanket with SiC_f/SiC as structural material**
  2. **Dual-Coolant blanket with He-cooled FS structure and self-cooled LM (Li or Pb-17Li)**
  3. **He-cooled CB blanket with FS structure**
  4. **Flibe blanket with advanced FS**



Down Selection of Maintenance Schemes for Phase II

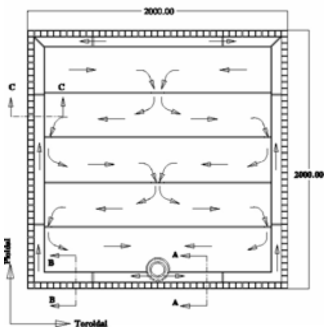
- **We are maintaining two options:**
  1. **Field period replacement**
  2. **Replacement of relatively small modules through a small number of ports (perhaps 1 or 2 per field period) with the use of articulated booms.**
     - More details of the procedures involved needed in both cases
     - Final selection of maintenance scheme will have to be compatible with the machine configuration based on our physics and system optimization during Phase II



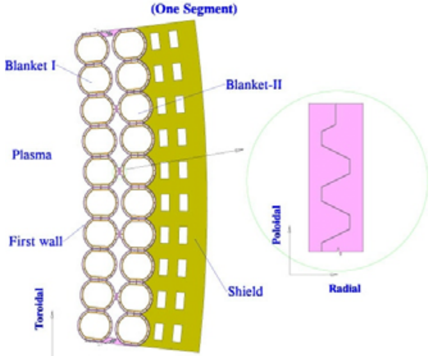


Major Parameters of Different Blanket Concepts

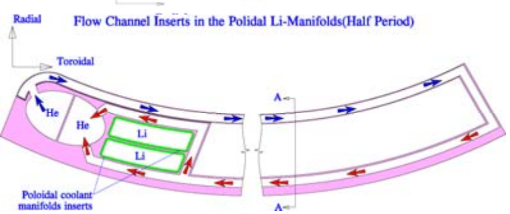
Cross-section of the Flibe Blanket Box (Front View)

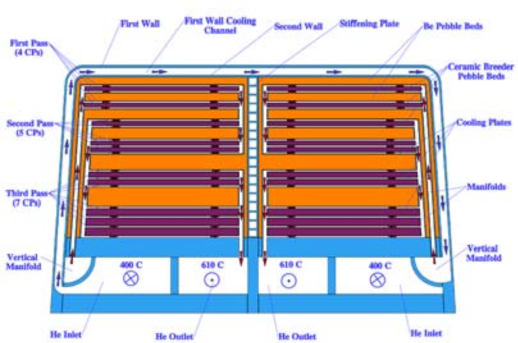


Cross Section of ARIES-CS Outboard Blanket/Shield (One Segment)



Flow Channel Inserts in the Polidal Li-Manifolds(Half Period)





Blanket Concepts Considered During Phase I of ARIES-CS	Self-Cooled Molten Salt	Self-Cooled Pb-17Li	Li Dual-Coolant Concept	Pb-17Li Dual-Coolant Concept	Ceramic Breeder
Breeder (form)	Flibe	Pb-17Li	Li	Pb-17Li	Li_4SiO_4 (pebble bed)
Multiplier (form)	Be(pebble bed)	None	None	None	Be(pebble bed)
Coolant	Flibe	Pb-17Li	He + self	He + self	He
Structure	ODS FS (nano-sized)	SiC_f/SiC	RAFS & ODS FS (+SiC insert if required)	RAFS & ODS FS	RAFS & ODS FS
Struct. T_{max} (°C)	700	1000	550 (RAFS) 700 (ODS FS)	550	550 (RAFS) 700 (ODS FS)
Breeder T_{max} (°C)	700	1100	800	700	950
Breeder T_{min} (°C)	550	650	500	460	
Multiplier T_{max} (°C)	750				750
Multiplier T_{min} (°C)					
Coolant T_{out} (°C)			He : 500	He : 480	610
Coolant T_{in} (°C)			He: 400	He : 300	400
Coolant P (MPa)	<0.5 (FLIBE)	2 (Pb-17Li)	He : 8	He : 14	8
Blanket thickness (m)	0.33	0.5	0.67-0.75	0.52-0.6	0.65
Avg./peak neutron wall load for analysis (MW/m^2)	2/3	2/3	2/3	2/3	3/4.5
Upper limit on neutron wall Load (MW/m^2)	3	4-5 (TBD)	4-5 (TBD)	4-5 (TBD)	~5
Surf. Heat Flux (MW/m^2)	0.5	0.5	0.5	0.5	0.5
TBR	▯ 1.1	▯ 1.1	▯ 1.1	▯ 1.1	▯ 1.1
Cycle η (%)	~45	~58%	>45	~45	~42
Structural material lifetime and criteria	20 MW-a/m^2 200 dpa swelling?	18 MW-a/m^2 assuming 3% SiC burnup?	21 MW-a/m^2 200 dpa swelling?	15 MW-a/m^2 200 dpa swelling?	20 MW-a/m^2 200 dpa swelling?

What Kind of Criteria for Assessment?

From Les Waganer (for illustration purposes):

		Poor	Adequate	Good	Excellent	Option A		Option B		Option C		Option D1		Option D2A		Option D2B		Option E	
						Self Cld, Flibe, FS, Be, Intnl VV		Self Cld, LiPb, SiC, Intl VV		Dual Cooled, He, Li, FS, Ext VV		Dual Cooled, He, LiPb, FS, Intl VV		Dual Cooled, He, LiPb, FS, Ext VV, He-Cld Shld		Dual Cooled, He, LiPb, FS, Ext VV, He/H2O Shld		He, FS, Be, Cerm Brdr Ext VV	
Evaluation Parameter	**Wt**	**1**	**2**	**3**	**4**	**UnWtd**	**Wtd**	**UnWtd**	**Wtd**	**UnWtd**	**Wtd**	**UnWtd**	**Wtd**	**UnWtd**	**Wtd**	**UnWtd**	**Wtd**	**UnWtd**	**Wtd**
Tritium Breeding Ratio	**2**	Needs Be Multiplier	90% Enrch Lithium	30% Enrch Lithium	Natural Lithium	1	**2**	2	**4**	4	**8**	2	**4**	2	**4**	2	**4**	1	**2**
Operating Temperature, °C	**4**	>600	600-750	750-900	1000-1200	1	**4**	4	**16**	2	**8**	2	**8**	2	**8**	2	**8**	2	**8**
Complexity, Technical Maturity	**3**	Very Cmpx, Immature	Cmpx, Low Mat	Cmpx, Mod Mat	Low Cmpx, Good Mat	3	**9**	3	**9**	2	**6**	2	**6**	2	**6**	2	**6**	1	**3**
Inherent Safety	**2**	Poor	Adequate	Good	Excellent	2	**4**	2	**4**	4	**8**	4	**8**	4	**8**	4	**8**	4	**8**
Pumping Power	**1**	High	Moderate	Mod. Low	Low	1	**1**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	4	**4**
Thickness of Breeding Zone, m	**2**	>1.3	1.2 - 1.3	1.1 - 1.2	< 1.1	2	**4**	3	**6**	3	**6**	3	**6**	3	**6**	3	**6**	4	**8**
Radioactive Waste Products	**2**	Poor	Adequate	Good	Excellent	2	**4**	2	**4**	3	**6**	2	**4**	2	**4**	2	**4**	4	**8**
Sum	*16*	*16*	*32*	*48*	*64*		**28**		**46**		**45**		**39**		**39**		**39**		**41**

Down-Selection of Blanket Concepts

- **Ceramic Breeder Concepts**
  - Requires large heat transfer surfaces (impact on complexity, fabrication, cost)
  - Relatively thick breeding zone
  - Modest cycle efficiency
- **Molten salts**
  - In general, poor heat transfer performance
  - Limits q'' and wall load that could be accommodated for self-cooled concept
  - Self-cooled flibe blanket only feasible with advanced ODS FS.
  - DC concept with He as FW coolant preferable
- **DC Concepts (He/Liquid Breeder)**
  - He cooling needed most probably for ARIES-CS divertor (to be fully studied as part of Phase II).
  - Additional use of this coolant for the FW/structure of blankets facilitates pre-heating of blankets, serves as guard heating, and provides independent and redundant afterheat removal
  - Generally good combination of design simplicity and performance
- **Reasonable to maintain a higher pay-off, higher risk option in Phase II mix (e.g. high temperature option with SiC_f/SiC)**

Selection of Blanket Concepts for Phase II

1. **Dual Coolant concept with a self-cooled liquid breeder zone and He-cooled RAFS structure:**
   1(a) Pb-17Li with SiC-composite as electrical (and thermal) insulator between flowing LM and steel structure.
   1(b) Molten salt (possibly FLINABE with lower melting point) with the possibility of Be or lead as neutron multiplier as back-up option (lower priority).

2. **Self-cooled Pb-17Li blanket with SiC-composite as structural material.**

- **In principle, these concepts could all be developed in combination with either a field-period-based maintenance scheme or a port-based maintenance scheme.**

Major Focus of Engineering Effort During Phase II

1. **Divertor design and analysis**

2. **Detailed design and analysis of dual coolant concept with a self-cooled Pb-17Li zone and He-cooled RAFS structure:**
   - **Modular concept first (port-based maintenance)**
   - **Field-period based maintenance concept next**

3. **Coil cross-section (including insulation + structural support)**
   - **Do we need to do structural analysis?**

4. **Integration with credible details about design of different components, maintenance and ancillary equipment for both maintenance schemes.**

Note that much of the effort on the modular concept is compatible with either 3-field period or 2-field period configurations. For simplicity we should focus on one configuration and flag any potential issue if applied to the other configuration.

Divertor Design and Analysis

- **Focus on He-cooled divertor**

- **Thomas Ihli from FZK will be joining us as a visiting scholar from January to July 2005. His tasks will include:**
  - **Scoping study of heat transfer enhancement mechanisms for He-cooled divertor**
  - **Design and analysis of most promising configuration to show that design can accommodate all constraints and that a credible fabrication method exists**
  - **Integration of divertor design within the overall compact stellarator power plant to show the compatibility of the divertor design, materials and coolant with those of other components (including the blanket/shield coolant(s) and power cycle), and to show a credible installation/maintenance scheme.**

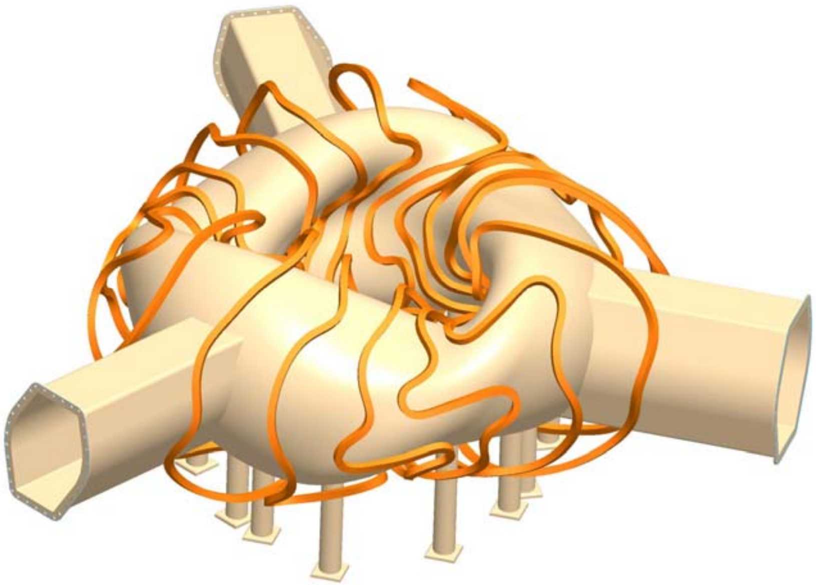
- **Key precursor and parallel activity**
  - **Physics modeling to provide a better idea of the divertor location and of the design heat flux**
  - **Hayden McGuinness, Arthur Grossman and T. K. Mau are coordinating this activity**
  - **Install/update/develop/run MFBE, GOURDON and GEOM codes**

Detailed Design and Analysis of Dual Coolant Concept with a Self-Cooled Pb-17Li Zone and He-Cooled RAFS Structure

- **Modular concept first (port-based maintenance)**

- **Design and analysis to show in sufficient and credible details:**

  - Module attachment and replacement
  - Port maintenance including all pipes and lines
  - Coolant lines coupling to the heat exchanger (choice of material)
  - Tritium extraction system for Pb-17Li
  - Interface Pb-17Li/FS temperature and compatibility with corrosion limits
  - Analysis of assumed LOCA/LOFA accident scenarios
  - Effect of FS on confinement



Engineering group discussion today or tomorrow on these to agree on plan of action for Phase II