ARIES-CS Power Core Engineering: Updating Power Flow, Blanket and Divertor Parameters for New Reference Case ($R = 7.75$ m, $P_{fusion} = 2355$ MW)

Presented by

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ARIES Meeting

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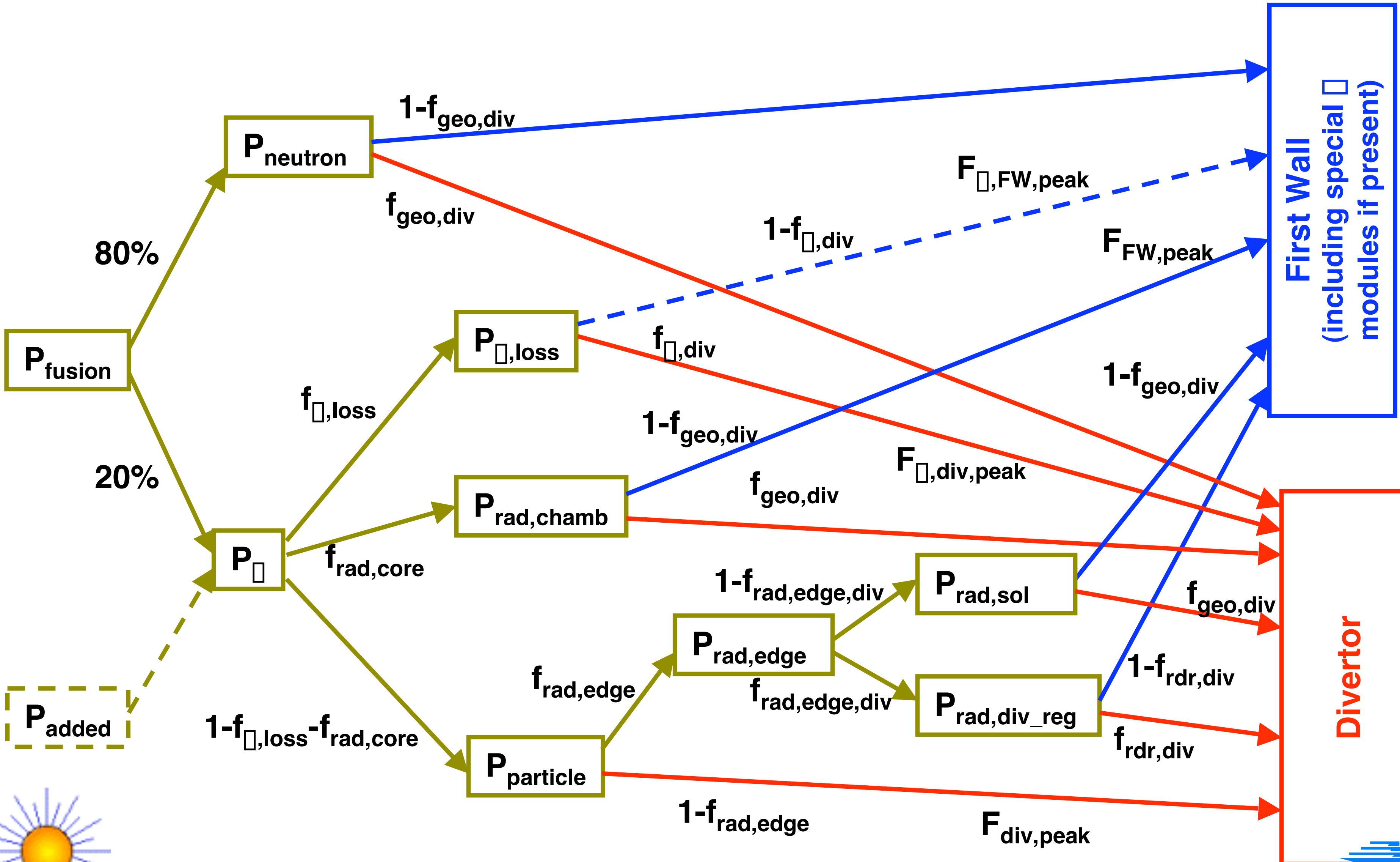
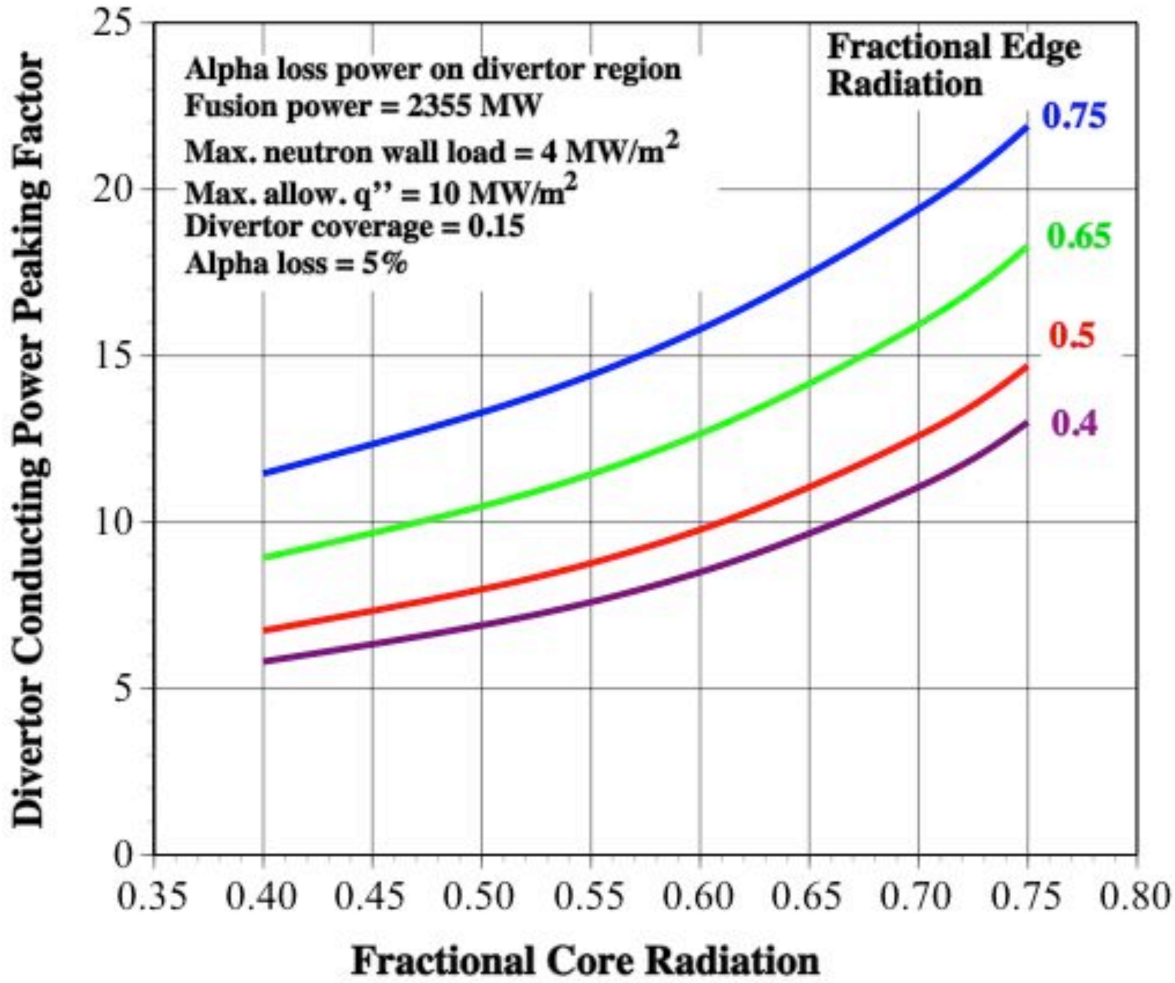
Comprehensive Power Flow Diagram Including Possibility of Added Power and Alpha Loss Flux Going to Both FW and Divertor (including J. Lyon's input, June 1, 2006)



Combination of Fractional Core Radiation, Edge Radiation and Divertor Peaking Factor for Maximum Divertor q''= 10 MW/m^2



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ARIES-CS Power Estimate for Reference Case with R = 7.75 m

Fusion power (MW)	2355
Neutron power (MW)	1884
Alpha power (MW)	471
FW surface area (m2)	727.7
Avg neutron wall load (MW/m2)	2.59
Wall load peaking factor	1.52
Max neutron wall load (MW/m2)	3.94
Alpha loss fraction	0.05
Alpha loss power (assumed to all go to to divertor) (MW)	23.55
Fraction of core power radiated (frad,core)	0.75
Radiated core power (MW)	353.25
Radiated core power to FW (MW)	314.4
Radiated core power to divertor (MW)	38.86
Particle power (MW)	94.2
Fraction of particle power radiated at edge (frad,edge)	0.75
Radiated edge power (MW)	70.65
Conducted power reaching divertor plates (MW)	23.55
Fraction of edge power radiated from divertor region, (frad,edge,div)	0.5
Edge power radiated in divertor region(MW)	35.33
Edge power radiated from SOL to all FW including divertor (MW)	35.33
Fraction of edge power radiated from divertor region going to divertor (frdr,div)	0.5
Edge power radiated from divertor region going to divertor (MW)	17.66
Edge power radiated from divertor region going to FW only (MW)	17.66

FIRST WALL

Total Surface Power to FW (MW)	363.5
Average first wall heat flux (MW/m2)	0.59
FW heat flux peaking factor for core and edge radiation on total area	1.52
Max. first wall heat flux on regular module (MW/m2)	0.81

DIVERTOR (INCLUDING ALPHA LOSS)

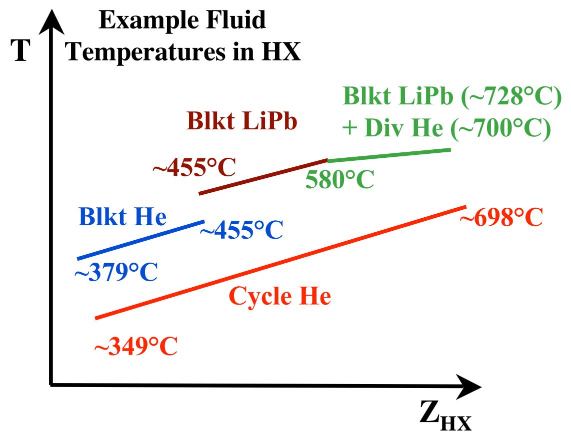
Conducted power peaking factor on divertor plates	21.9
Divertor fractional coverage	0.15
Eff. Div. coverage (accounting for geometry effect)	0.11
Divertor surface area (m2)	109.16
Surface power to the divertor including alpha loss component (MW)	107.51
Max. heat flux on divertor including alpha loss component (MW/m2)	10.0
Avg. heat flux on divertor including alpha loss component (MW/m2)	0.985

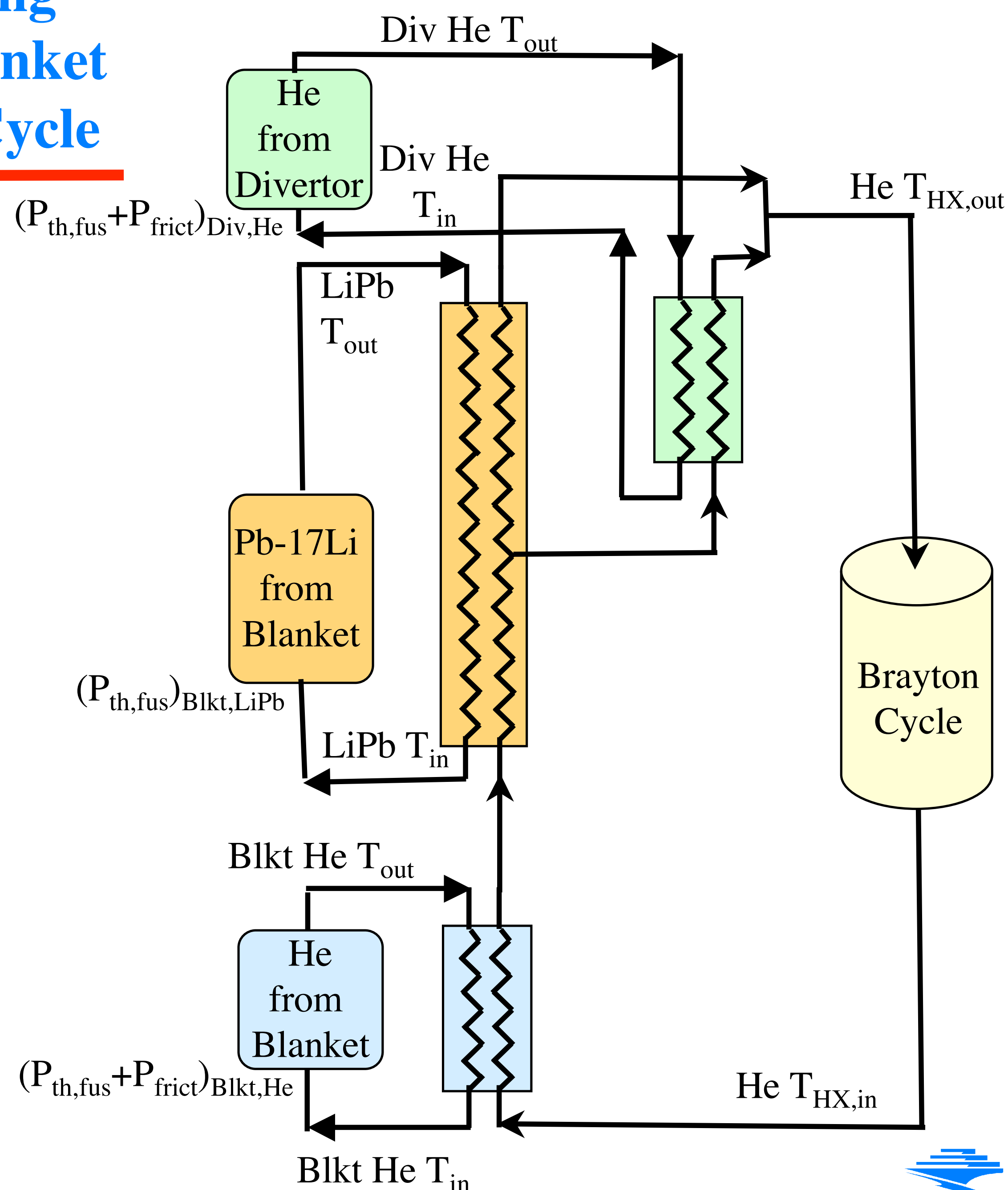
THERMAL POWER IN BLANKET AND DIVERTOR

Energy multiplication factor	1.15
Total fusion thermal power in reactor (MW)	2637.6
Neutron thermal power to blanket excluding (divertor+alpha loss) regions(MW)	1841.6
Thermal power to blanket excluding (divertor+alpha loss) regions(MW)	2205.1
Surface power to divertor region (MW)	107.5
Assumed fraction of neutron power to divertor in divertor region	0.287
Total thermal power to divertor region (including neutrons) (MW)	200.78
Thermal power to blanket behind divertor (MW)	231.7
Total thermal power to blanket (MW)	2436.8
Fractional thermal power to blanket	0.923
Fractional thermal power to divertor	0.076

Update of Coolant Routing Through HX Coupling Blanket and Divertor to Brayton Cycle

- Div He T_{out} ~ Blkt Pb-17Li T_{out}
- Min. DT_{HX} = 30°C
- $P_{Friction}$ ~ □$_{pump}$ x P_{pump}



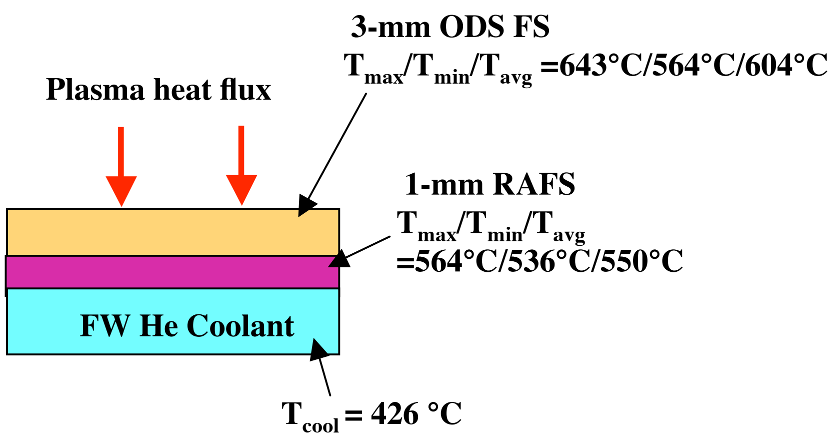


Power Parameters for Example Case

Fusion Thermal Power in Reactor Core	2637 MW
Fusion Thermal Power Removed by Pb-17Li	1414 MW
Fusion Thermal Power Removed by Blkt He	1024 MW
Friction Thermal Power Removed by Blkt He	107 MW
Fusion Thermal Power Removed by Div He	200 MW
Friction Thermal Power Removed by Div He	27-54 MW
Fusion + Friction Thermal Power in Reactor Core	2771-2798 MW

Updated DC Blanket Parameters for New Reference Case and Power Flow Assumptions from J. Lyon

- R = 7.75 m
- Fusion power = 2355 MW
- Avg/max. wall load = 2.59/3.94 MW/m^2
- Avg/max. plasma q'' = 0.59/0.81 MW/m^2



Blanket	**Updated Values**	***Previous Values***
Typical Module Dimensions	2m x 2m x 0.62 m	*2m x 2m x 0.62 m*
Tritium Breeding Ratio	1.1	*1.1*
Fusion Thermal Power in Blanket	2430 MW	*2367 MW*
Blanket Pb-17Li Coolant		
Pb-17Li Inlet Temperature	462°C	*500°C*
Pb-17Li Outlet Temperature	727°C	*710°C*
Pb-17Li Inlet Pressure	1 MPa	*1 MPa*
Typical Inner Channel Dimensions	0.26 m x 0.24 m	*0.26 m x 0.24 m*
Thickness of SiC Insulator in Inner Channel	5 mm	*5 mm*
Effective SiC Insulator Region Conductivity	200 W/m^2-K	*200 W/m^2-K*
Average Pb-17Li Velocity in Inner Channel	~0.04 m/s	*<~0.1 m/s*
Fusion Thermal Power removed by Pb-17Li	1410 MW	*1373 MW*
Pb-17Li Total Mass Flow Rate	28,500 kg/s	*35,100 kg/s*
Pb-17Li Pressure Drop	~0.4 kPa	*<~1 kPa*
Pb-17Li Pumping Power	~ 2 kW	*<~ 4.7 kW*
Maximum Pb-17Li/FS Temperature	474°C	*500°C*
Blanket He Coolant		
He Inlet Temperature	379°C	*368°C*
He Outlet Temperature	455°C	*486°C*
He Inlet Pressure	10 MPa	*10 MPa*
Typical FW Channel Dimensions (poloidal x radial)	2 cm x 3 cm	*2 cm x 3 cm*
He Velocity in First Wall Channel	46.4 m/s	*56.6 m/s*
Total Blanket He Pressure Drop	0.26 MPa	*0.34 MPa*
Fusion Thermal Power Removed by He	1020 MW	*994 MW*
Friction Thermal Power Removed by He	105 MW	*87 MW*
Total Mass Flow Rate	2980 kg/s	*1830 kg/s?*
Pumping Power	117 MW	*97 MW*
Maximum Local ODS/RAFS Temperature at FW	643/564°C	*654°C*
Radially Avg ODS/RAFS Temp. at T_{max} Location	604/550°C	*596°C*

Updated Divertor Parameters for New Reference Case and Power Flow Assumptions from J. Lyon

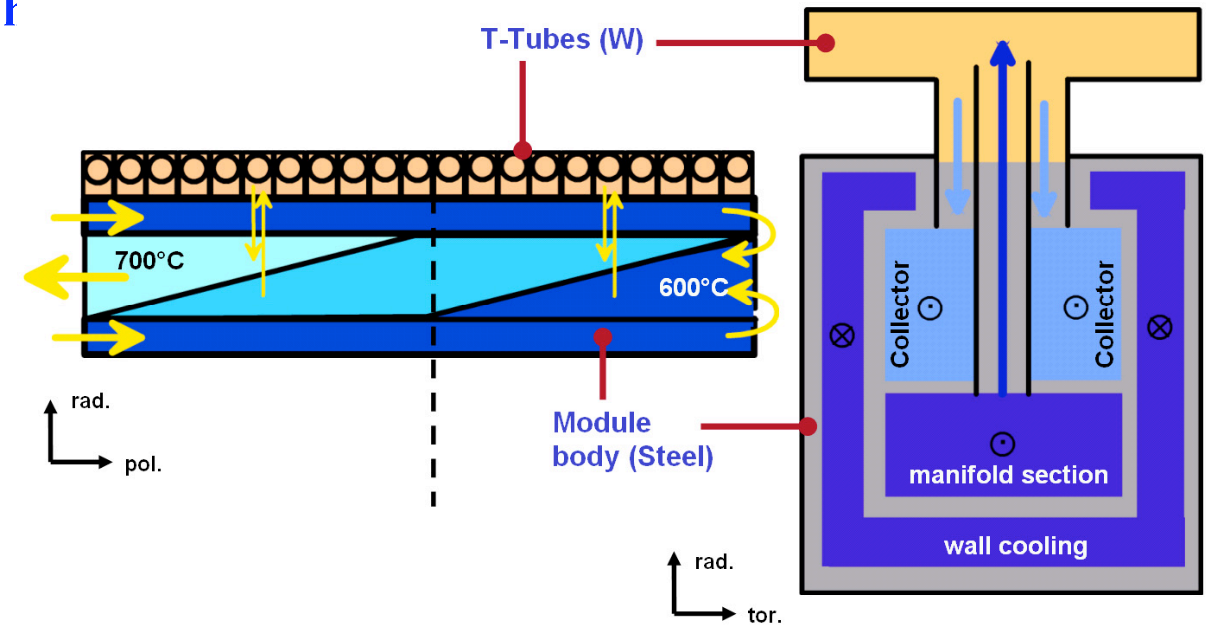
- **R = 7.75 m**
- **Fusion power = 2355 MW**
- **Max. wall load = 3.94 MW/m²**

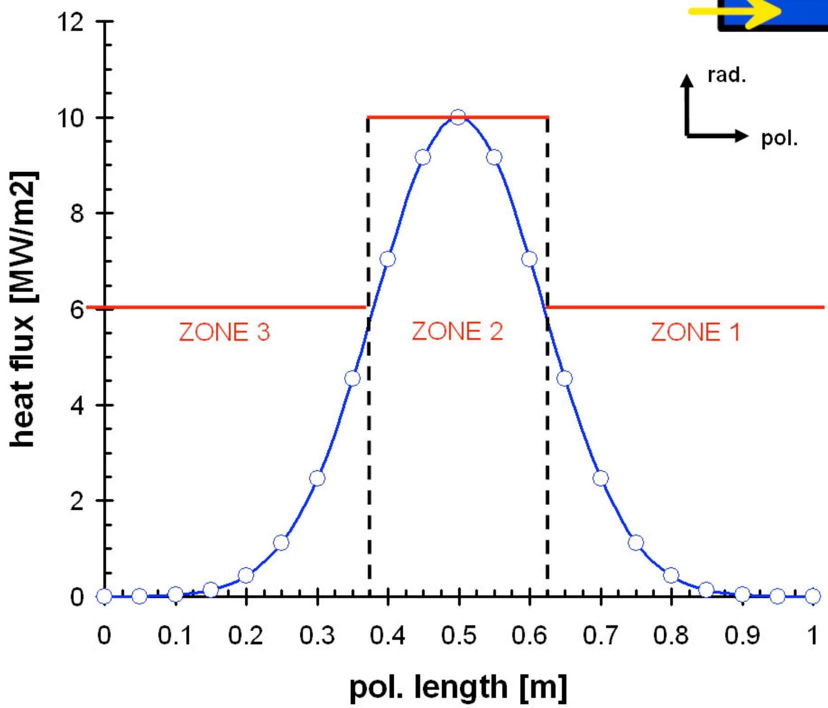
- **All alpha loss power on divertor**
- **Divertor coverage = 0.15**
- **Max. divertor q'' = 10 MW/m²**

Divertor	f_{target}=1	f_{target}=0.75	f_{target}=0.5	***Previous Values***
Divertor T-Tube Unit Cell Dimensions	9 cm (tor.) x 1.6 cm (pol.)	9 cm (tor.) x 1. 6 cm (pol.)	9 cm (tor.) x 1. 6 cm (pol.)	*9 cm (tor.) x 1.6 cm (pol.)*
He Inlet Temperature	625°C	605°C	566°C	*580°C*
He Outlet Temperature	700°C	700°C	700°C	*730°C*
He Inlet Pressure	10 MPa	10 MPa	10 MPa	*10 MPa*
Typical FW Channel Dimensions	0.5 mm	0.5 mm	0.5 mm	*0.5 mm*
He Jet Velocity	200 m/s	200 m/s	200 m/s	*200 m/s*
Average Jet Flow h	~ 17,000 W/m²-K	~ 17,000 W/m²-K	~ 17,000 W/m²-K	*~ 17,000 W/m²-K*
He Pressure Drop	0.43 MPa	0.43 MPa	0.43 MPa	*0.4 MPa*
Fusion Thermal Power in Divertor	200 MW	200 MW	200 MW	*237 MW*
Divertor He Friction Power	53 MW	40 MW	27 MW	*26 MW*
Total Mass Flow Rate	655 kg/s	491 kg/s	327 kg/s	*338 kg/s*
Pumping Power	60 MW	45 MW	30 MW	*28 MW*
Maximum W Alloy Temperature	<1300°C	<1300°C	<1300°C	*<1300°C*
Maximum Primary + Secondary stresses	<370 MPa	<370 MPa	<370 MPa	*<370 MPa*

Assumed Divertor Target Heat Load Distribution and Manifolding Scheme (from T. Ihli)

- He mass flow = 12 kg/s and □P ~ 0. 34 MPa per 2m x 1 plate under the assumed heat flux profile
- For our large divertor coverage, what fraction of the divertor (f_{target}) should we assume under such a "target plate" h





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Updated Data for System Code Based on New Power Flow Assumptions from J. Lyon

Dual Coolant Blanket Pumping Power

(Previously, divertor pumping power ~28 MW)

Max. Neutron Wall Load	**Cycle Efficiency (Updated)**	**Blanket Pumping Power (MW) (Updated)**	**Divertor Pumping Power (MW) (Updated) f_{target}=1**	**Divertor Pumping Power (MW) (Updated) f_{target}=0.5**	***Cycle Efficiency (Old)***	***Blanket Pumping Power (MW) (Old)***
1.5 MW/m^2					*0.441*	*48*
2 MW/m^2	0.448	66	118	59	*0.436*	*53*
3 MW/m^2	0.442	102	78	9	*0.432*	*74*
4 MW/m^2	0.424	118	60	30	*0.423*	*85*
5 MW/m^2	0.405	138	47	23.5	*0.414*	*97*

ARIES-CS Abstracts Submitted for Presentation at 17th TOFE

1. F. Najmabadi, "The ARIES-CS Study? "(abstract?)

2. L. P. Ku and the ARIES Team, "Configuration Optimization and Physics Basis of ARIES-CS"

3. J. F. Lyon, L.P. Ku, L. El-Guebaly, L. Bromberg and the ARIES Team, "Optimization of the ARIES-CS Compact Stellarator Power Plant Parameters"

4. A. R. Raffray, L. El-Guebaly, T. Ihli, S. Malang, X. Wang and the ARIES-CS Team, "Engineering Design and Analysis of the ARIES-CS Power Plant"

5. L. El-Guebaly, R. Raffray, S. Malang. J. Lyon, L.P. Ku, X. Wang, P. Wilson, D. Henderson, T. Tautges, M. Sawan, G. Sviatoslvsky, B. Kiedrowski, M. Wang, C. Martin, B. Merrill, and the ARIES Team, "Overview of ARIES-CS In-vessel Components: Integration of Nuclear, Economic, and Safety Constraints in Compact Stellarator Design"

6. Lester M. Waganer and the ARIES Team, "Design Approach for ARIES Compact Stellarator"

7. X.R. Wang, L.A. El-Guebaly, S. Malang, A. R. Raffray[1]and The ARIES Team, I"ntegration of the Modular Dual Coolant Pb-17Li Blanket Concept in the ARIES-CS Power Plant"

8. X.R Wang, S. Malang, A.R. Raffray and The ARIES Team, "Configuration Design and Maintenance Approach for the ARIES-CS Stellarator Power Plant"

9. X.R. Wang, S. Malang, C. Martin, A. R. Raffray and The ARIES Team, "Coil Structural Design and Magnetic-Structural Analysis of the AIRIES-CS Coil System"

10. B. J. Merrill, L. El-Guebaly, C. Martin, R. L. Moore, R. Raffray, and the ARIES Team, "Safety Assessment of the ARIES Compact Stellarator Design"

11. L. Crosatti, D. L. Sadowski, J. B. Weathers, S. I. Abdel-Khalik, M. Yoda, and the ARIES Team, "Experimental and Numerical Investigation of the Thermal Performance of Gas-Cooled T-Tube Divertor Modules"

12. C. Mistrangelo, A. R. Raffray, and the ARIES Team, "MHD Analysis of Dual Coolant Pb-17Li Blanket for ARIES-CS"

13. L. Bromberg, "Coil material assessment?"

14. P. Wilson, et al., "3-D Neutron transport for ARIES-CS"

15. T. K. Mau, "Divertor physics?"

OTHERS???

Suggested Papers for FS&T Special Issue on ARIES-CS (draft)

1. F. Najmabadi, “The ARIES-CS Study “
2. L. P. Ku, “Physics Basis of ARIES-CS”
3. J. F. Lyon,, “System Optimization of ARIES-CS”
4. A. R. Raffray, “Engineering Design and Analysis of Power Core Components (Coupled to Power Cycle)”
5. L. El-Guebaly, “Nuclear Design and analysis”
6. Lester M. Waganer, “Manufacturing and out of reactor component design …
7. X.R. Wang: “Design Layout and Maintenance Schemes”
8. X.R Wang, L. Bromberg… “Coil material, design and structural analysis”
9. B. Merrill, L. El-Guebaly…’ “Safety analysis”
10. T. K. Mau, “Divertor and alpha loss physics”
11. **OTHERS???**

Action Items (partial list)

- **Divertor and alpha loss physics modeling (T.K. Mau)**
  - Plan for next month, including back up, to have enough basis for review meeting
- **Coil and Structure Analysis**
  - Analyze effect of penetration and rib requirement (X. Wang)
- **CAD Drawing**
  - Update CAD drawings for our final design choices (X. Wang)
  - Include enough space for pumping; local increase in SOL (F. Najmabadi, X. Wang)
  - Add ECH port (1 or 3?); can also be used to help maintenance (X. Wang)
- **Pumping (F. Najmabadi, M. Zarnstorff, A. Turnbull)**
  - Base pressure 10^{-8}, 10^{-9} torr?
  - Cryopump or turbo pump or both
  - Can we use steady state pump for initial pumping?
- **Availability (L. Waganer)**
  - Include complete module removal procedure in estimating maintenance time and availability
- **System runs (J. Lyon)**
  - For both blanket designs (reference and advanced)
  - Assume ECH
  - Sensitivity analysis (effect of lower coil manufacturing cost,
- **Cryostat**
  - Size and attachment to concrete wall (L. El-Guebaly, R. Raffray, L. Waganer)