APEX

Task III

Practical Engineering Issues Associated with the Design of a Liquid Wall

Status of Configuration Studies for CLiFF / Flibe System in ARIES - RS

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APEX Electronic Meeting
March 24, 2000

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Presentation Outline

- **Goals and Requirements**

- **Overall Configuration**

- **Components and systems**
  - Fast Flow
  - Blankets and piping
  - Divertor, Penetrations, and Pumping
  - Assembly and maintenance

Issues and Summary

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Why do we need a damage resistant blanket & first wall?

- **Goals for First Wall and Blanket design include:**

  - High power density
  - High tritium breeding ratio
  - High temperature for good power conversion efficiency
  - High availability (tolerant of some failures, long life, quick repair times, etc.)
  - Low activation

- **Conventional designs using solid walls do not presently meet *all* goals**

  - Power density may be too low or
  - Walls are too thin or
  - Refractory materials are not low activation

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”Bag” concept with thin liquid layer addresses most issues

First Wall:

- Thin layer of fast moving Flibe (~ 2 cm thick at 10 m/s)
- Temperature ~ 465 C to minimize vapor pressure

Blanket

- Thick zone of slower moving Flibe
- Flibe contained in flexible structure woven from SiC fibers (“bags”)
- Temperature ~ 600C, with multiple zones for better flow control
- Bags fed from bottom
- Any hot liquid that leaks from bag is cooled by fast liquid layer
- Bags expand to close sector to sector gaps
- No halo currents into structure (and minimal load asymmetry) with SiC Flibe system
- Extra beryllium included in 10 cm zone, 10 cm from front of bag to improve breeding
- Passive stabilizers woven into bag around Be zone

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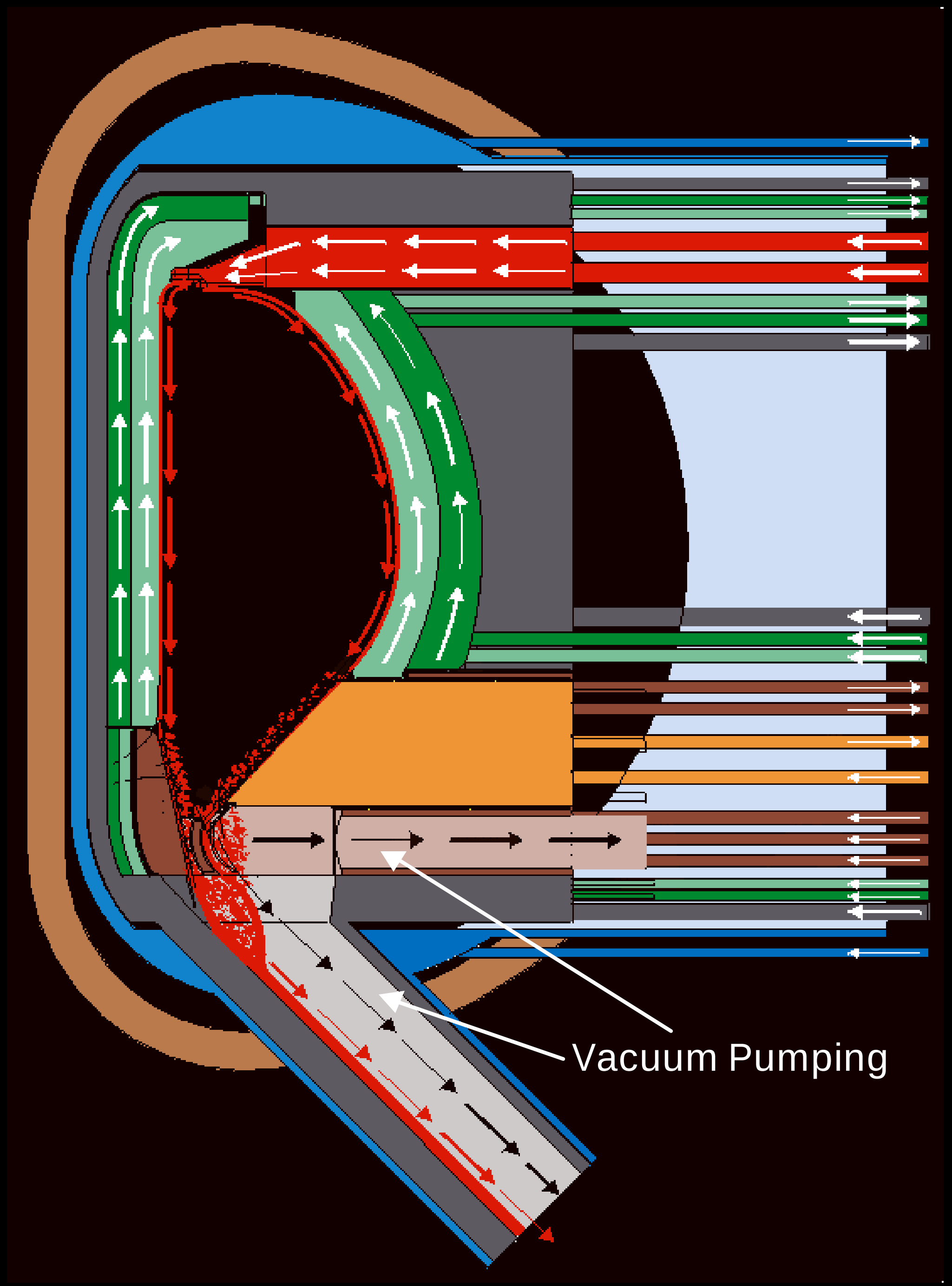
CLiFF Configuration showing coolant flows & vacuum pumping regions

- TF Coil
- Vacuum Vessel
- Shield
- Zone 2 Bags
- Zone 1 Bags
- Fast Flow First Wall
- Antenna
- Divertor



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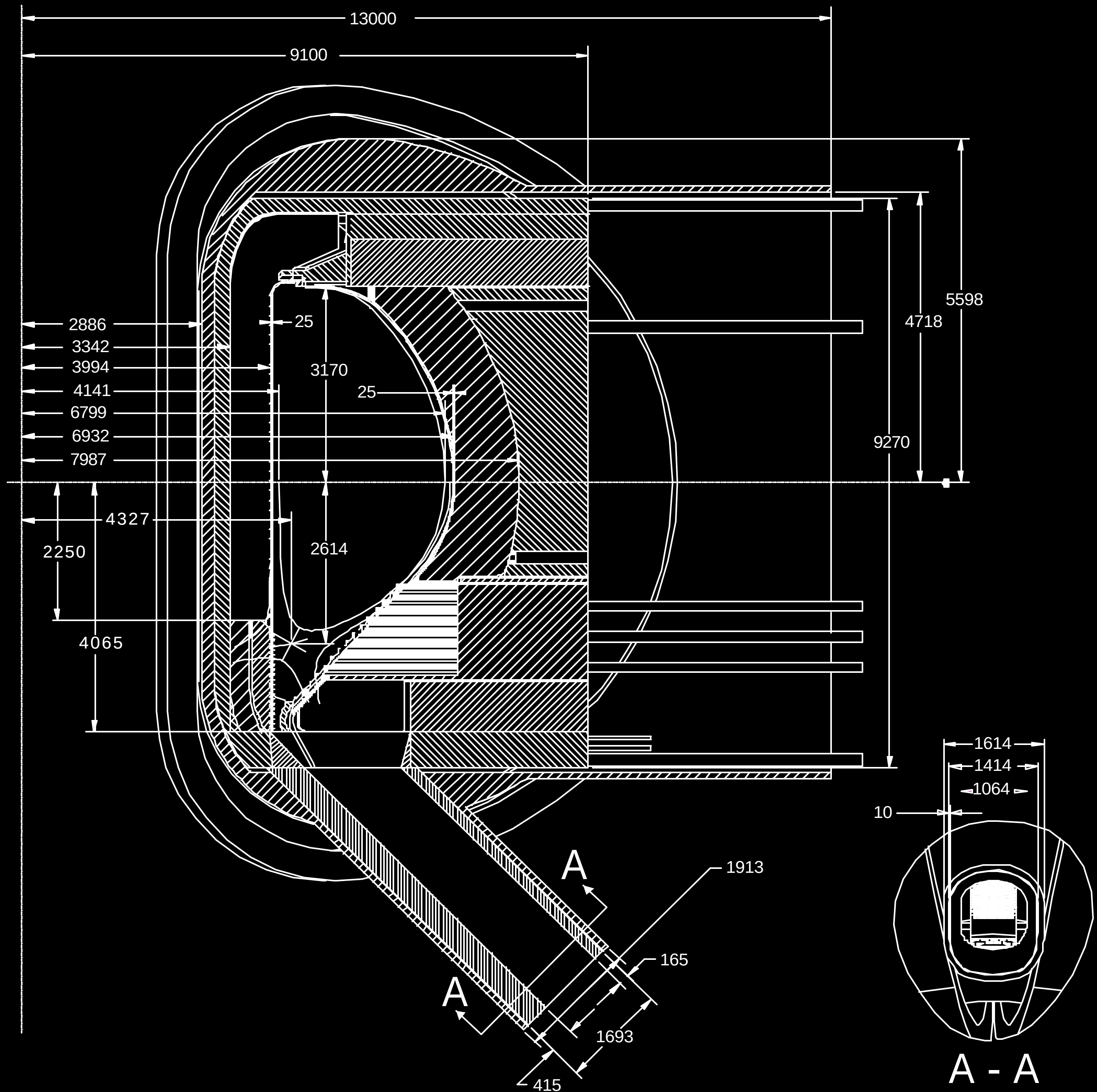
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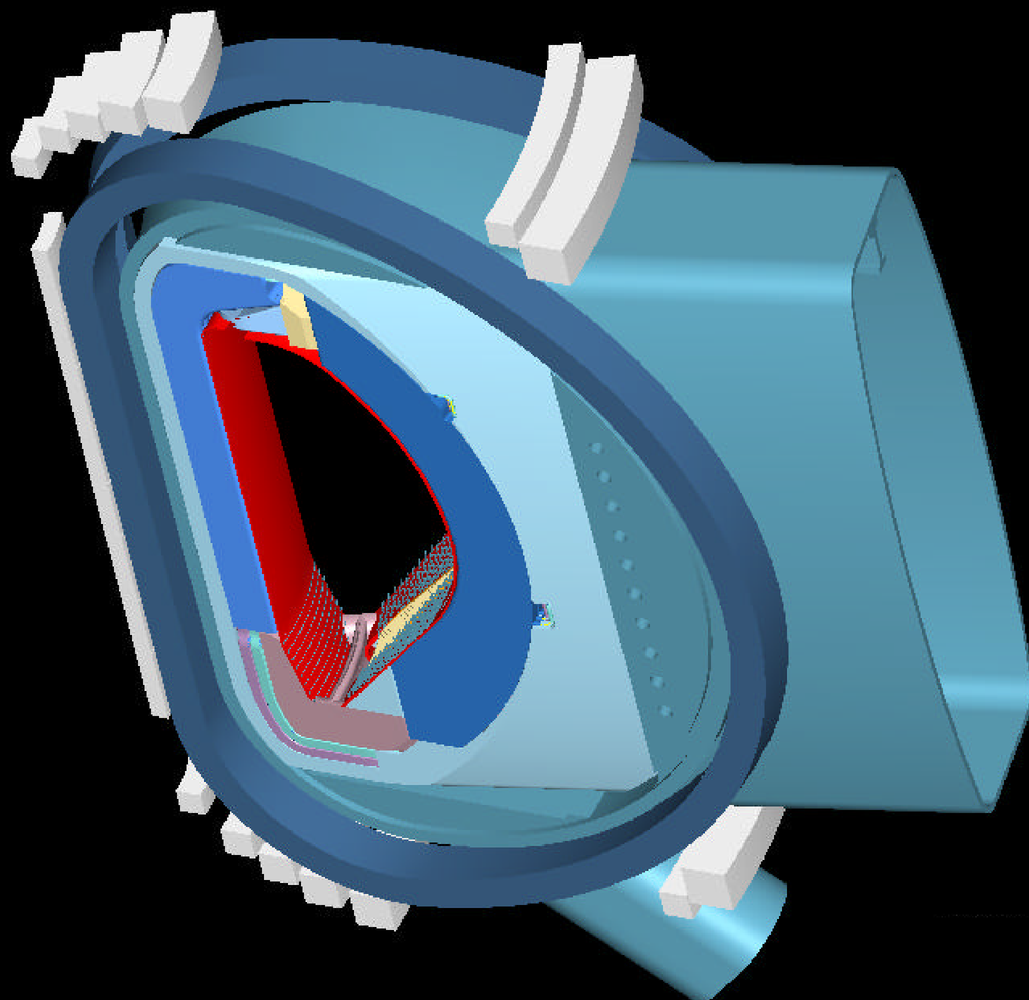
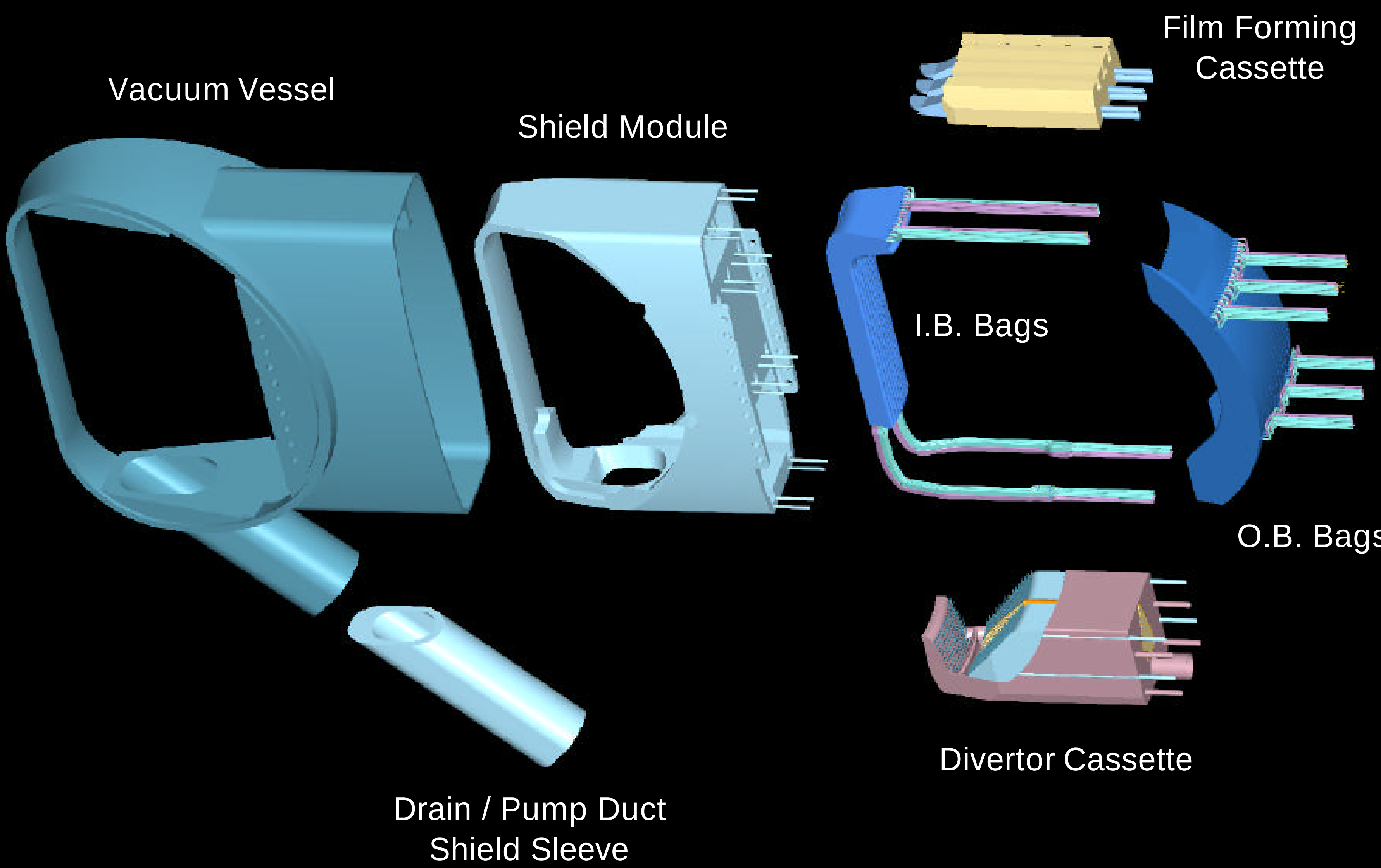
CLiFF "Bag" Concept Configuration and Assembly Sequence



Modular Components



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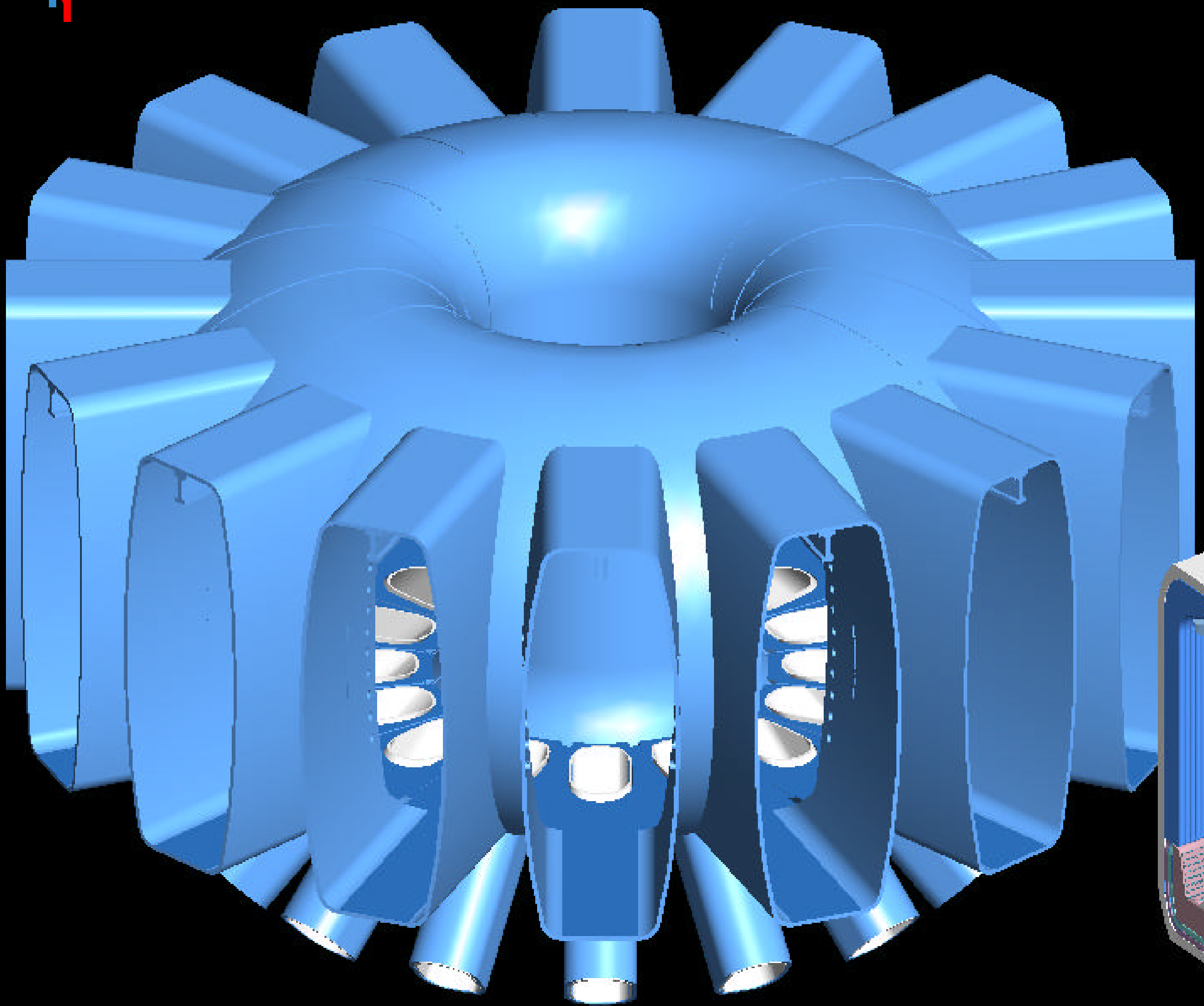
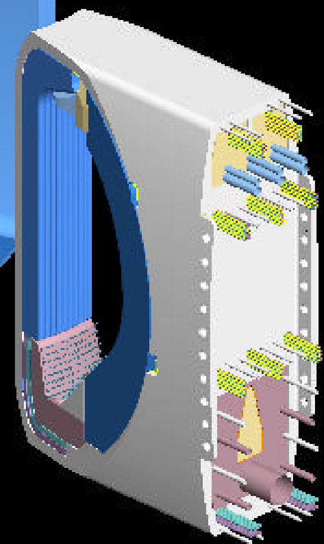
Sector Installation / Maintenance



Sector Module is shown withdrawn from its vacuum vessel port location

Except for removable divertor & film former cassettes, all other components are an integral part of the Shield Assembly



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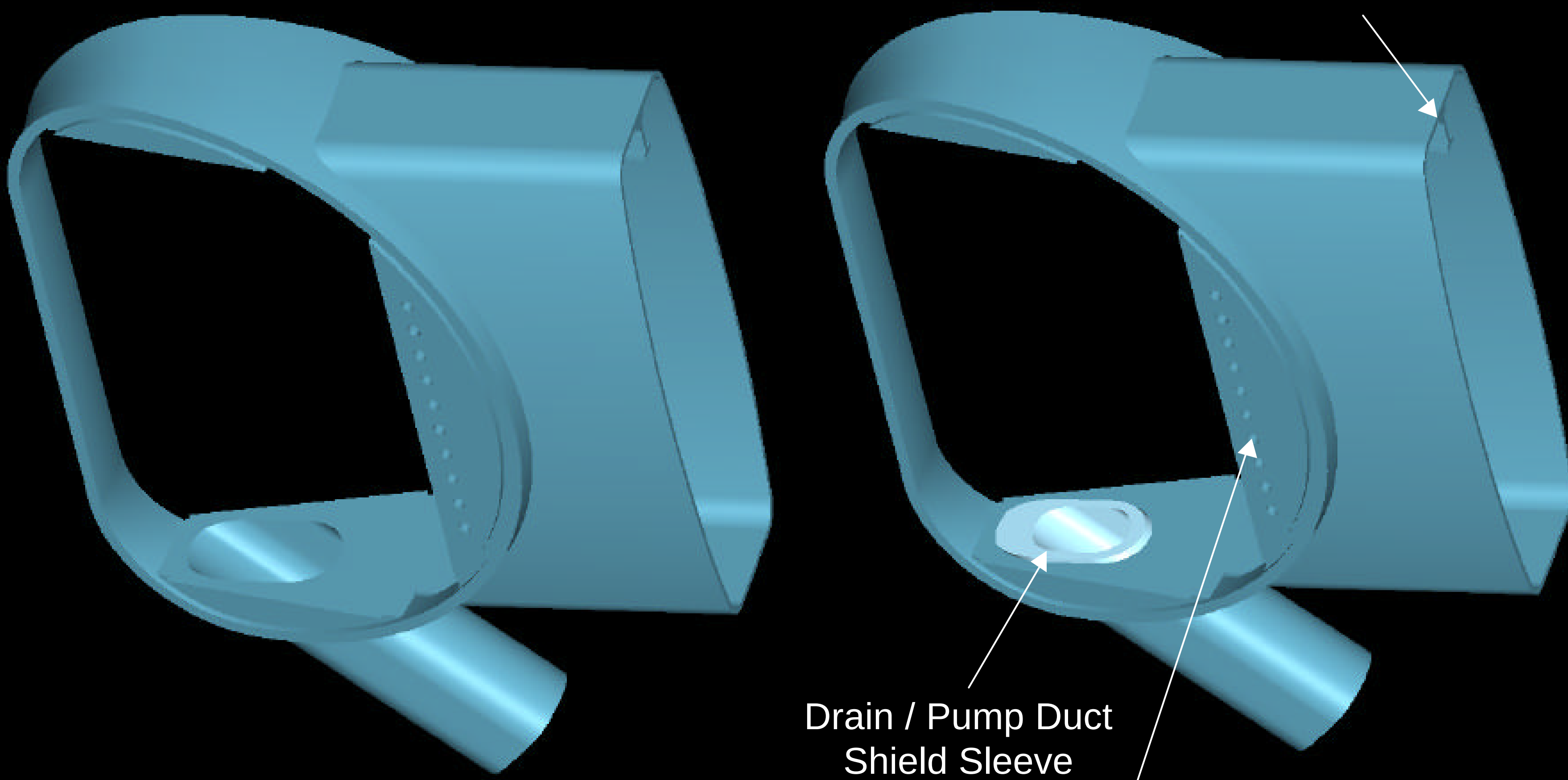
Vacuum Vessel



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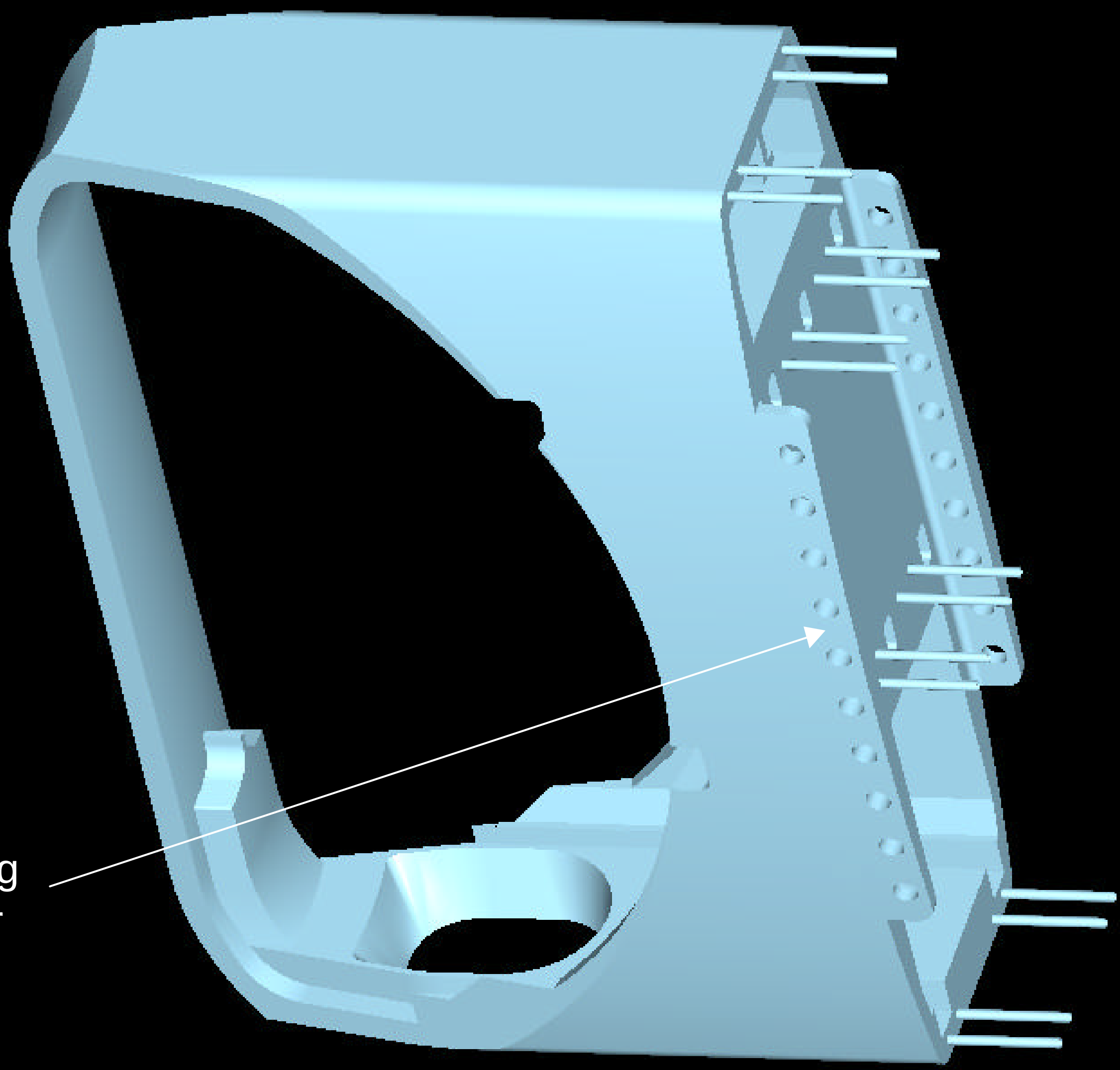
Assembly Sequence

Shield Module

Assembly Stage 1



Structural flange for attaching the Shield Modules together on the outboard side

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SiC "bag" is damage resistant and it has low activation

- Bag is woven from Sic fibers
  - Structure remains flexible, even though material is very brittle
  - No, or very minimal thermal stress
  - SiC fabric is commercially available
- Small leaks from bag should not be a fatal problem, since vapor pressure is suppressed by cooler flow over surface

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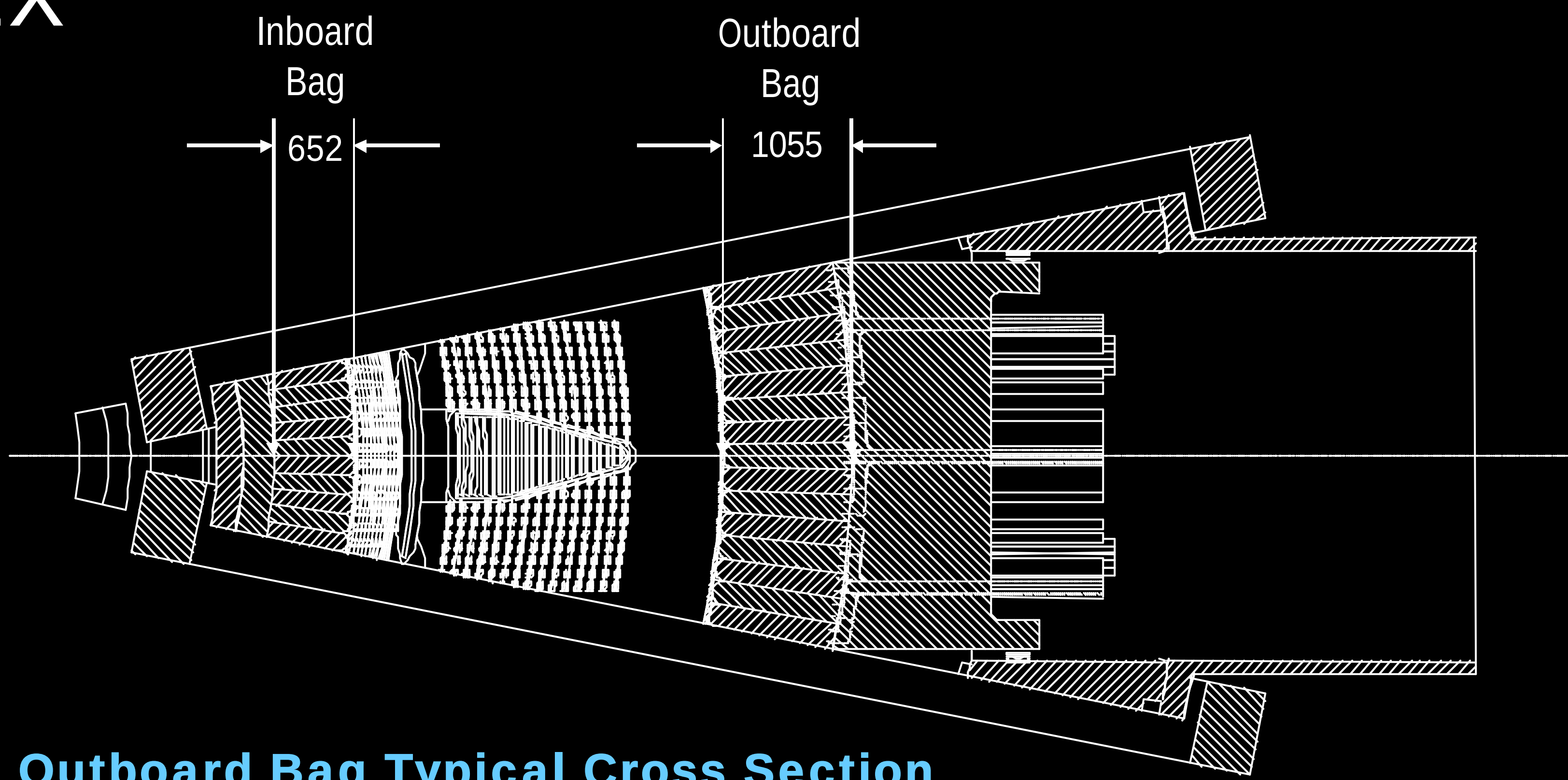
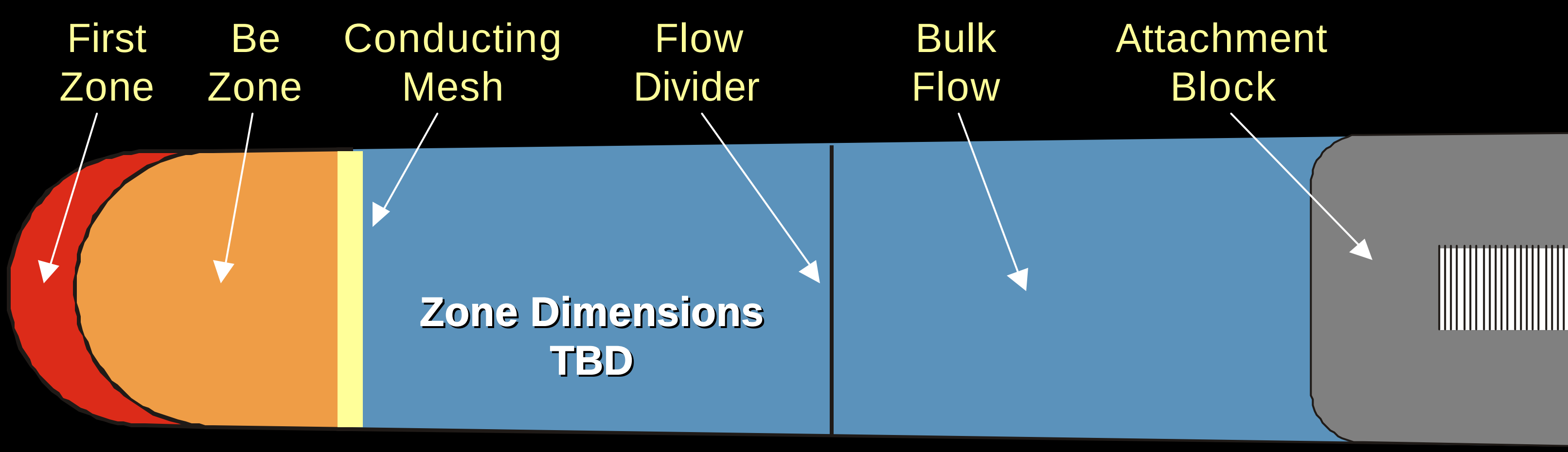


Outboard Bag Typical Cross Section



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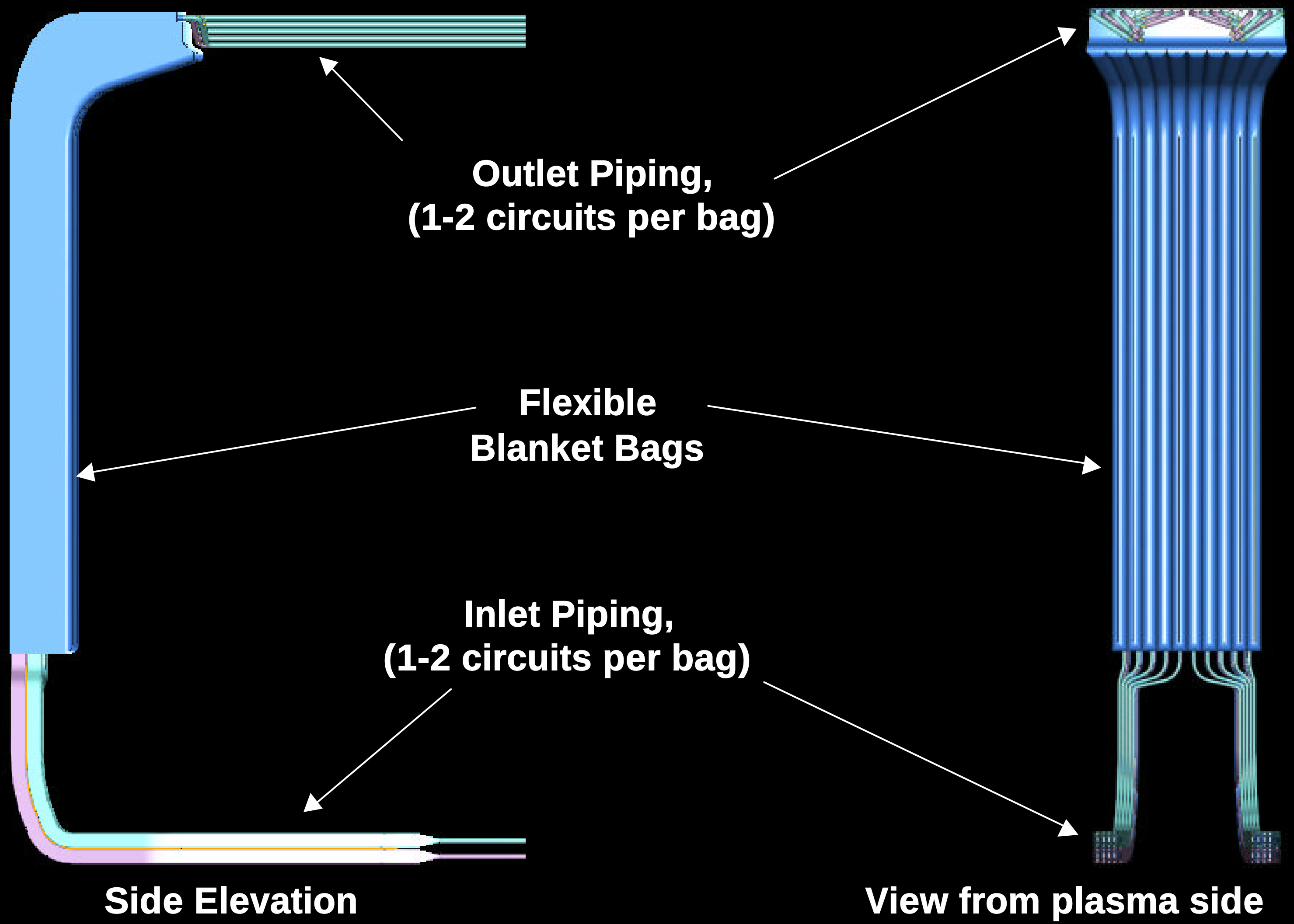
Inboard blanket array for one sector



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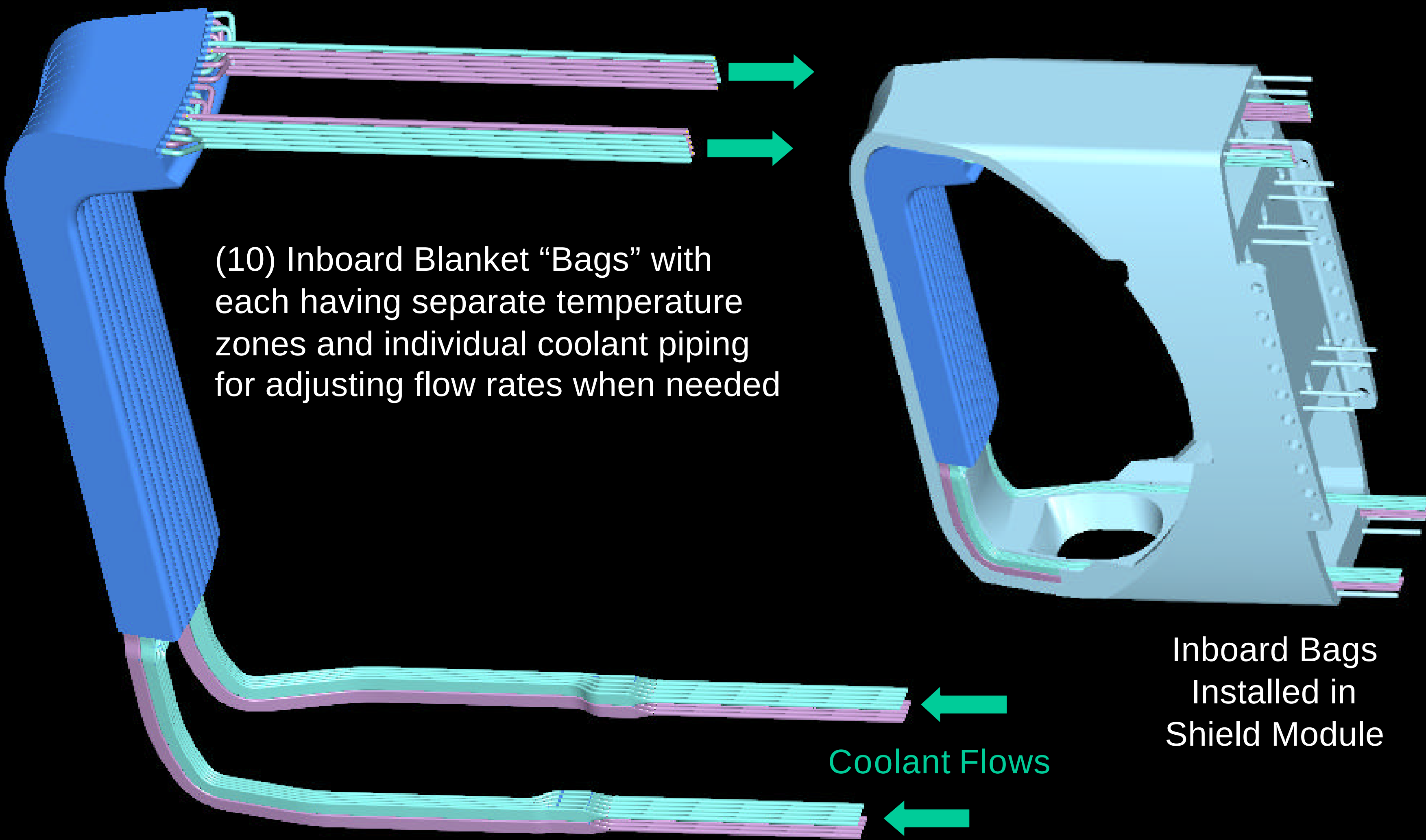
Inboard Bags

Assembly Stage 2



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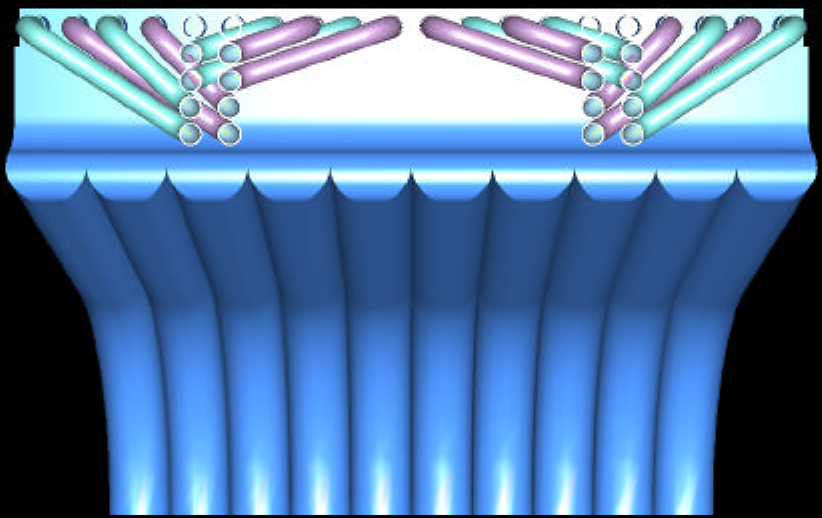
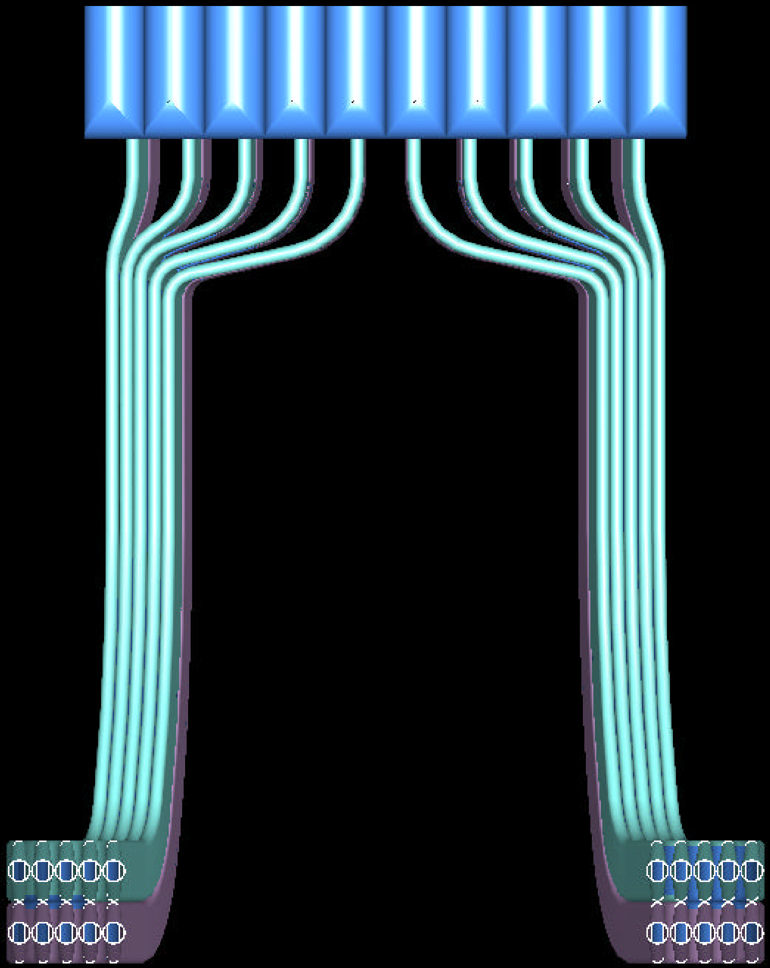
Inboard Bags

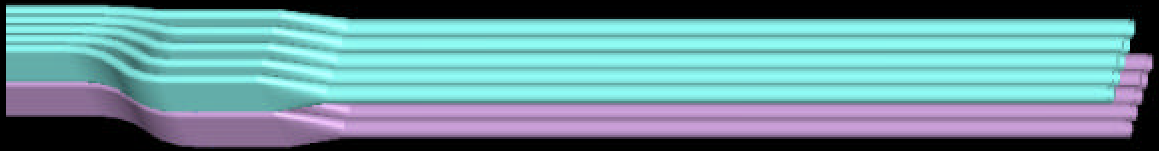
Detail Views



Inboard Upper Piping Configuration



Inboard Lower Piping Configuration



Flat to Round Piping Transition

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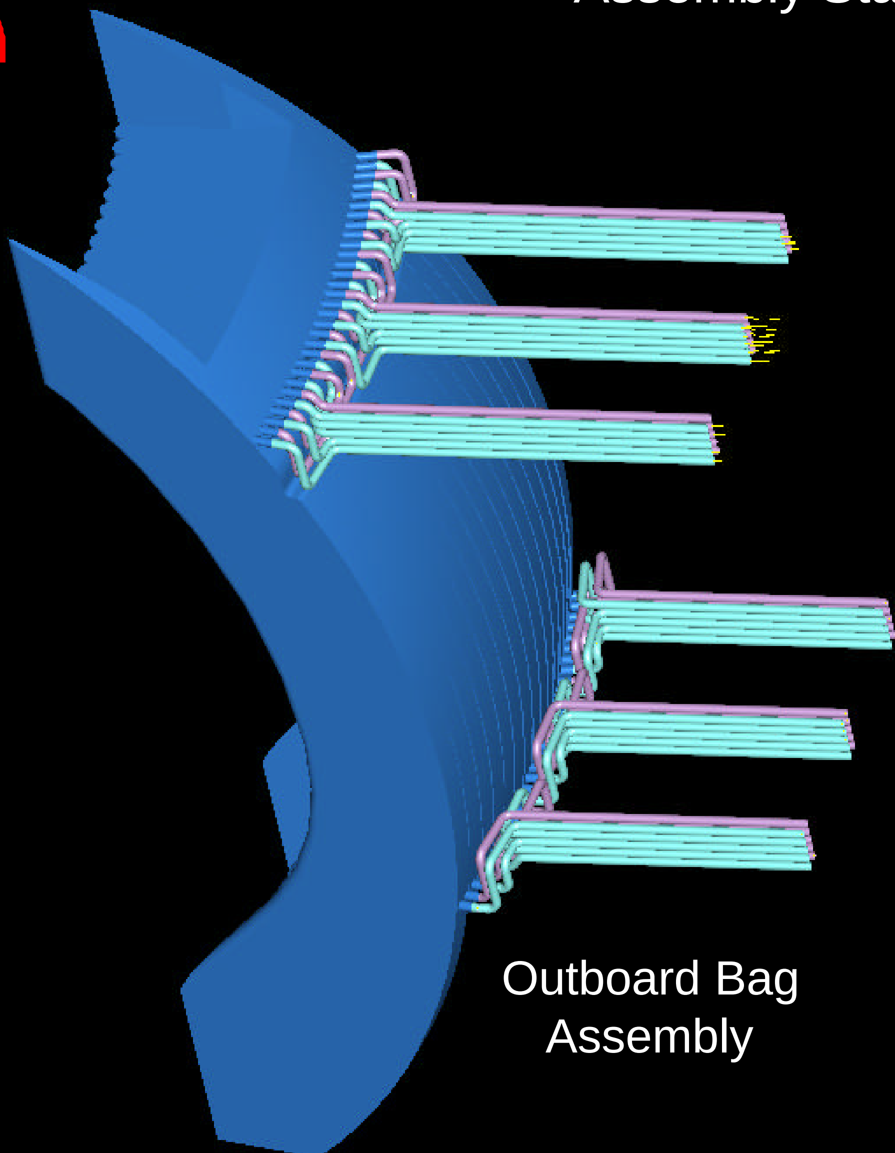
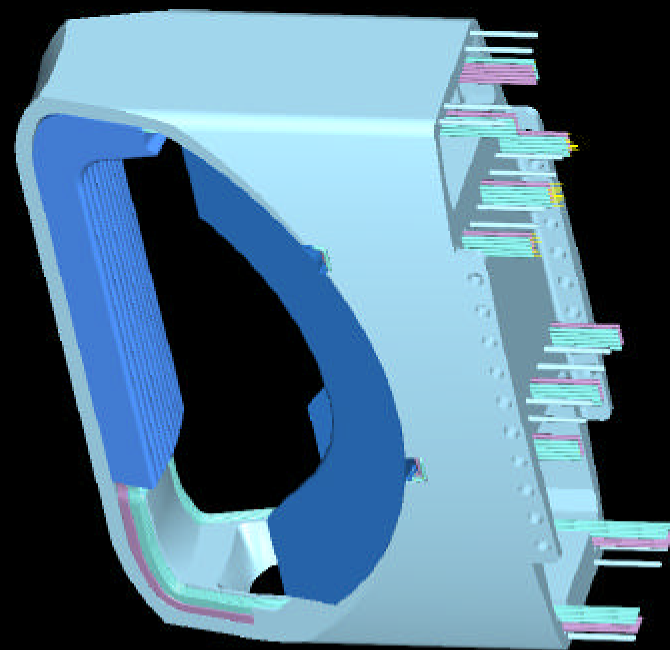
Outboard Bags

Assembly Stage 3



Outboard Bag Assembly



Outboard Bag Assembly Shown Installed

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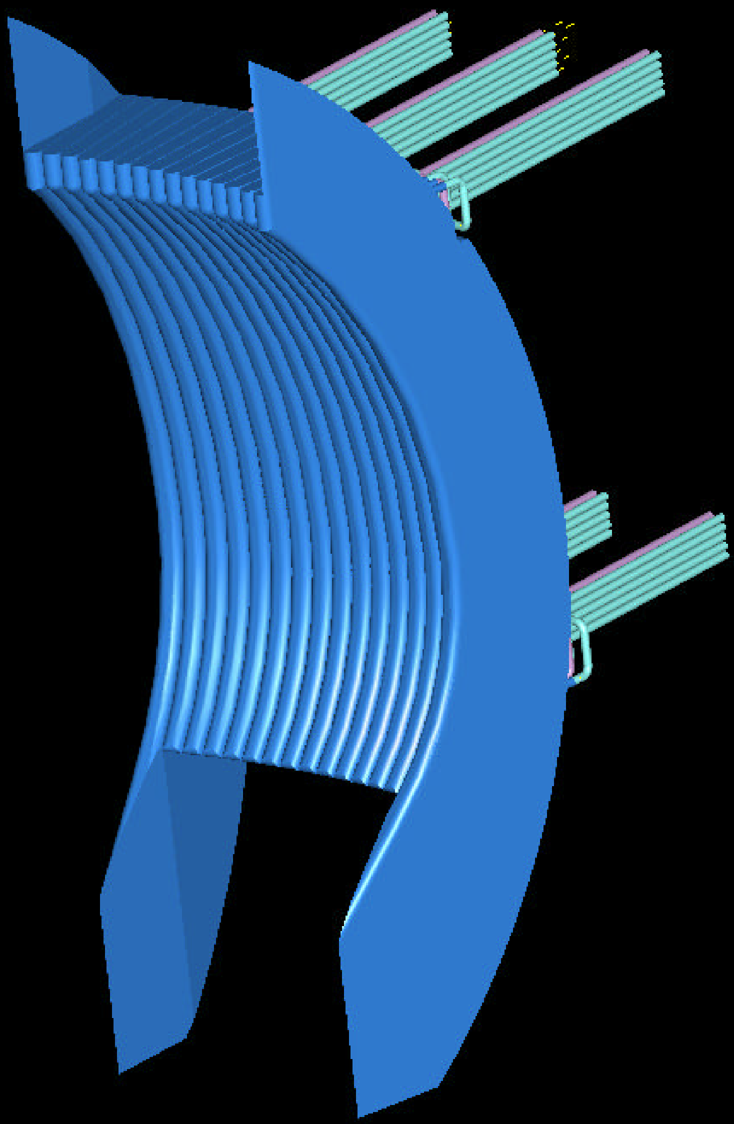
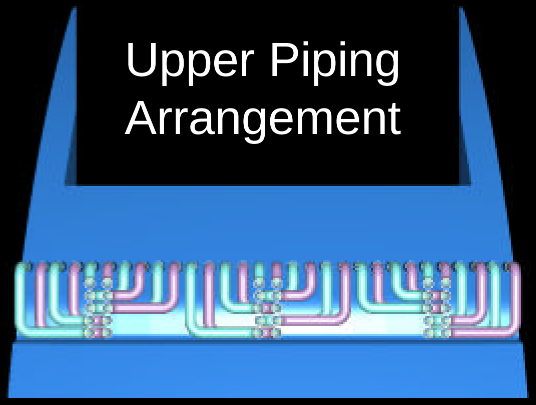
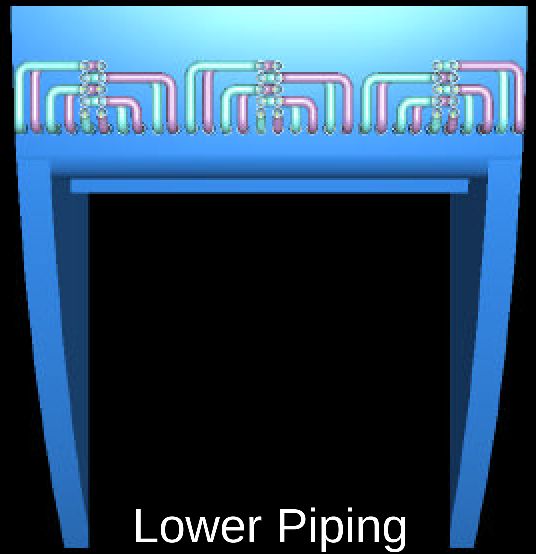
Outboard Bags

Detail Views



Plasma Facing View of Assembly





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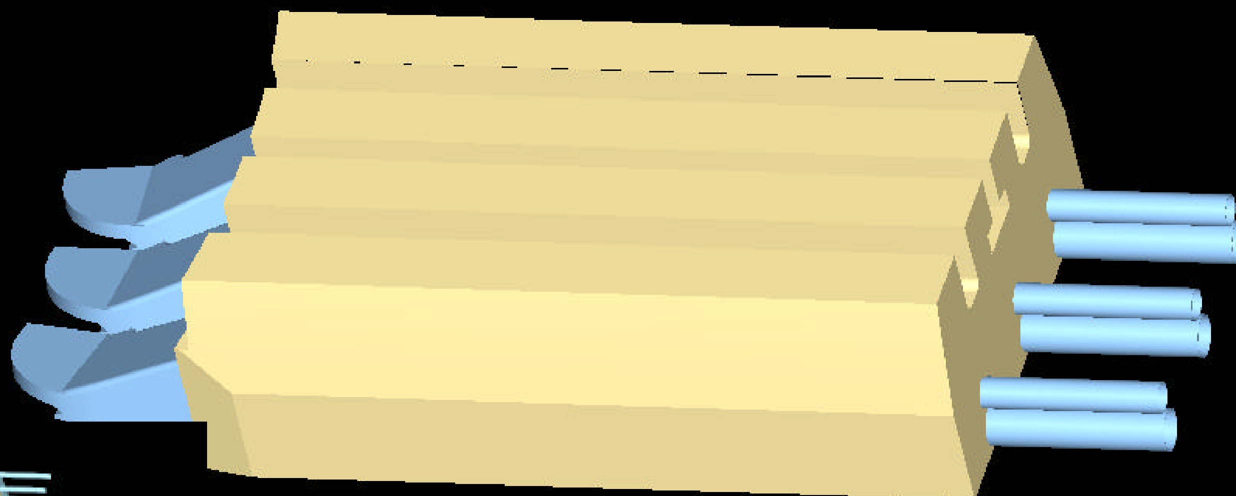
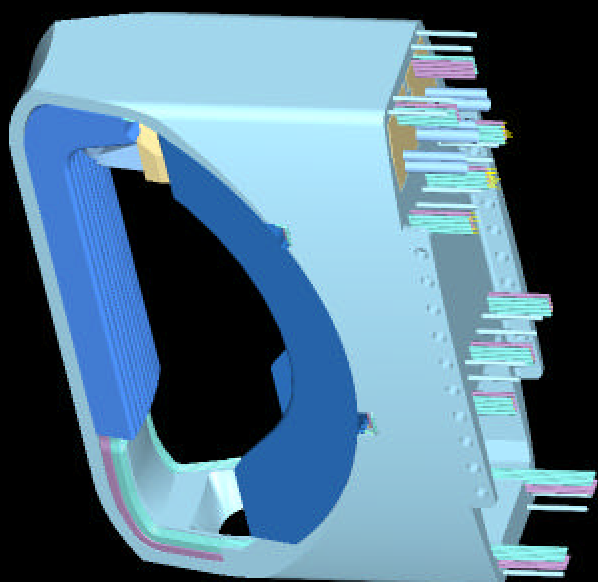
Film Forming Cassette

Assembly Stage 4



Film Forming Cassette Assembly



Film Forming Cassette
Shown Installed

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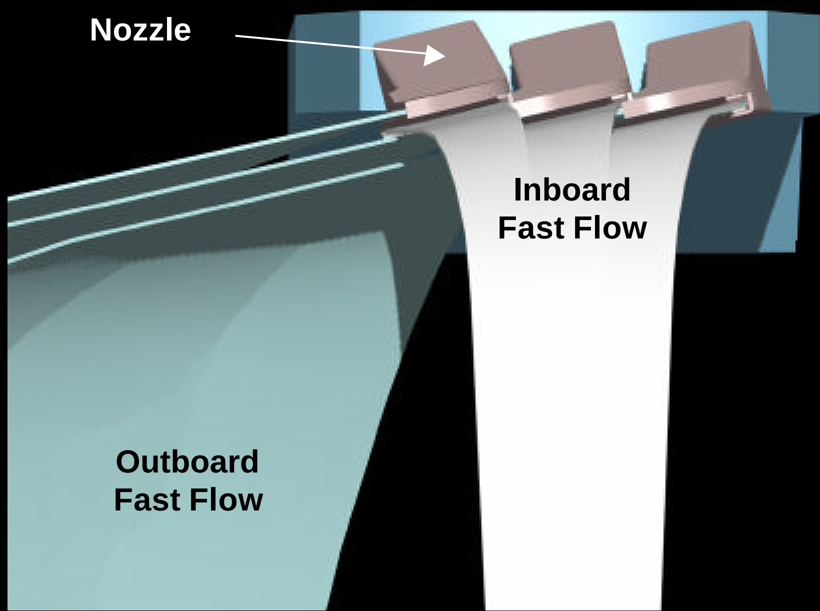
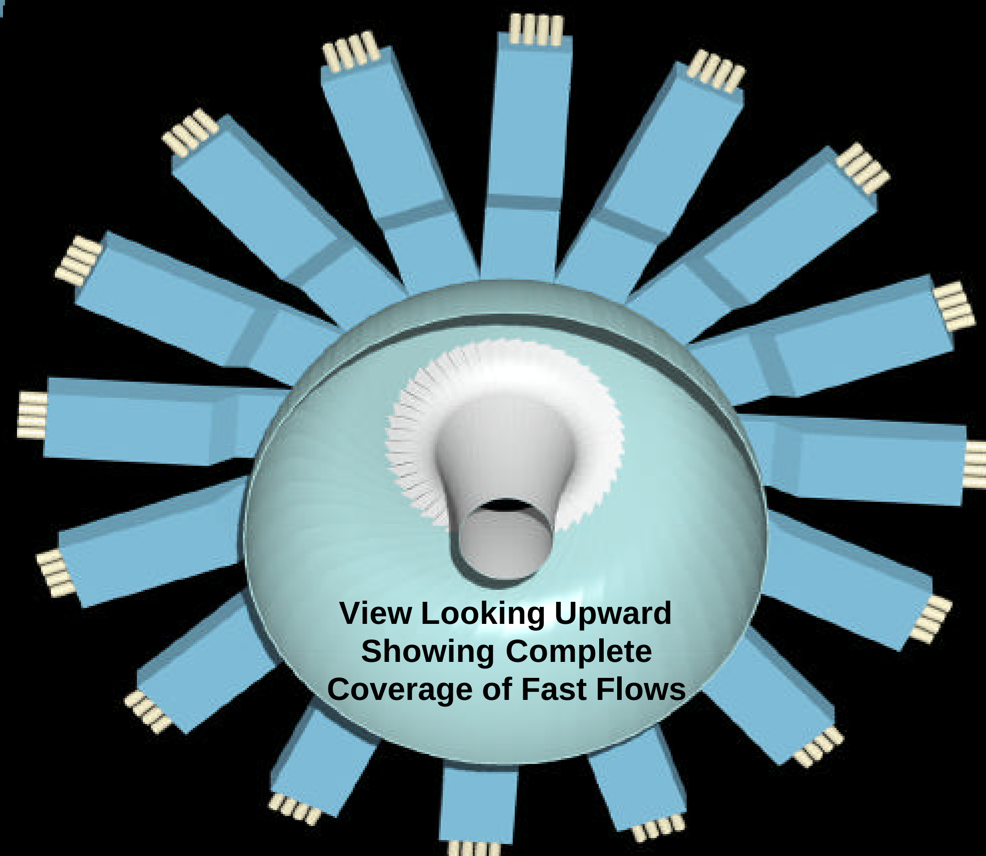
Film Forming Cassette

Detail Views





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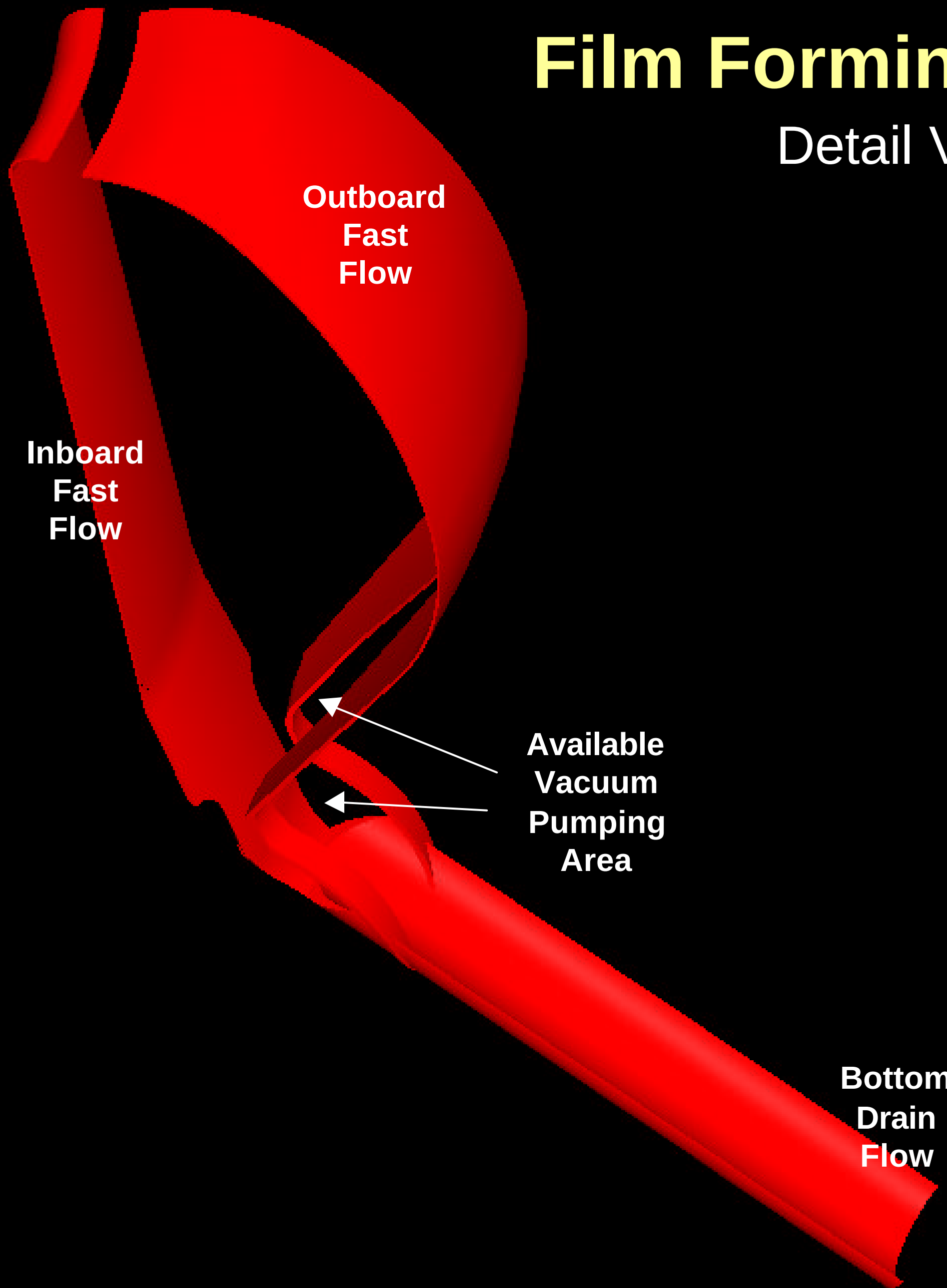
Film Forming Cassette

Detail Views



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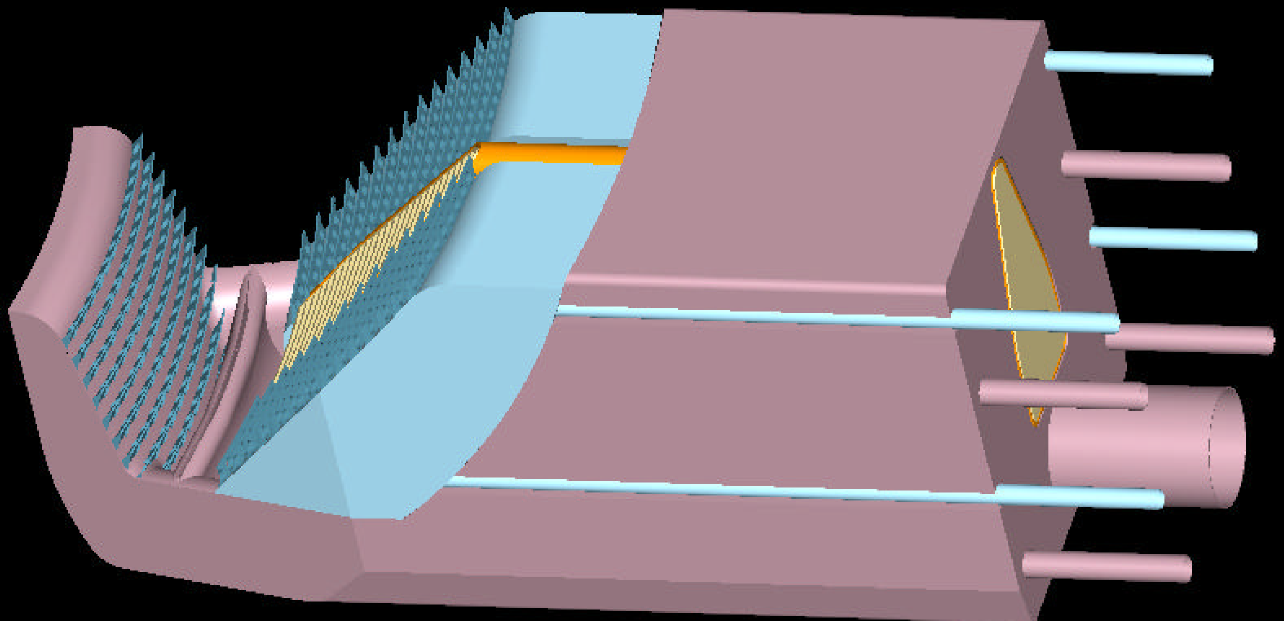
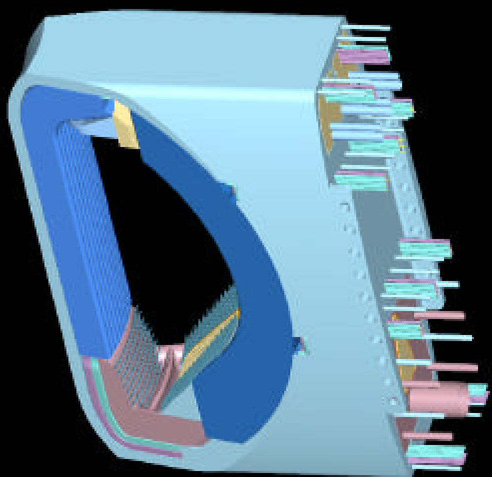
Divertor Cassette

Assembly Stage 5



Divertor Cassette Assembly



Divertor Cassette
Shown Installed

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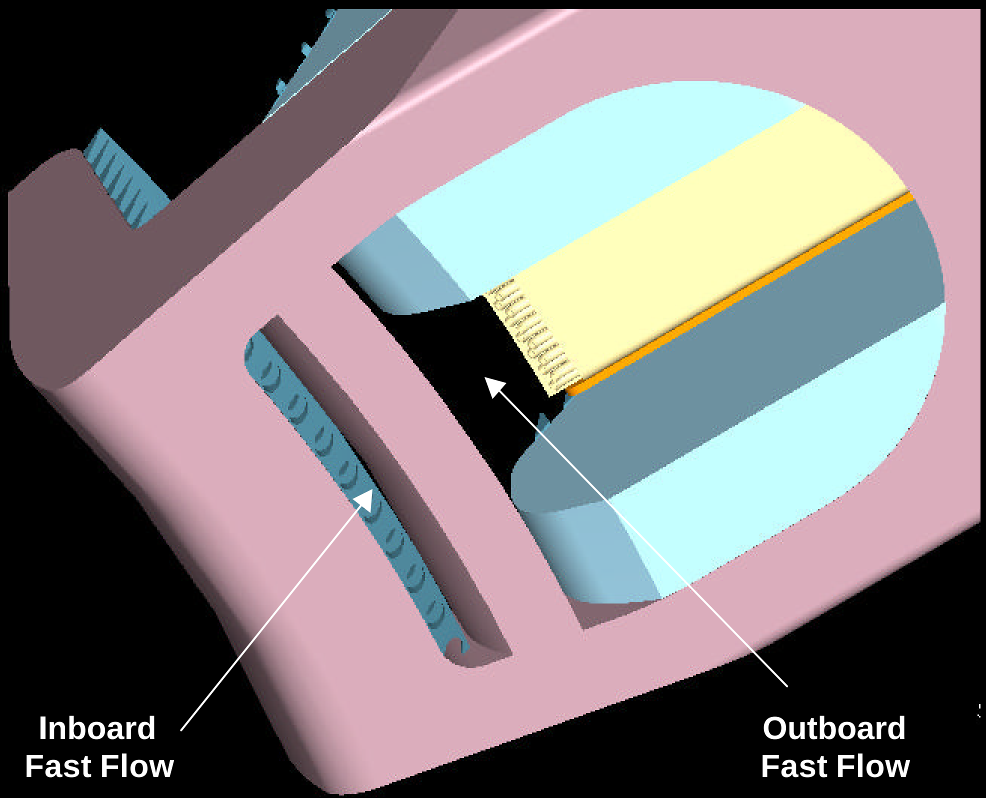
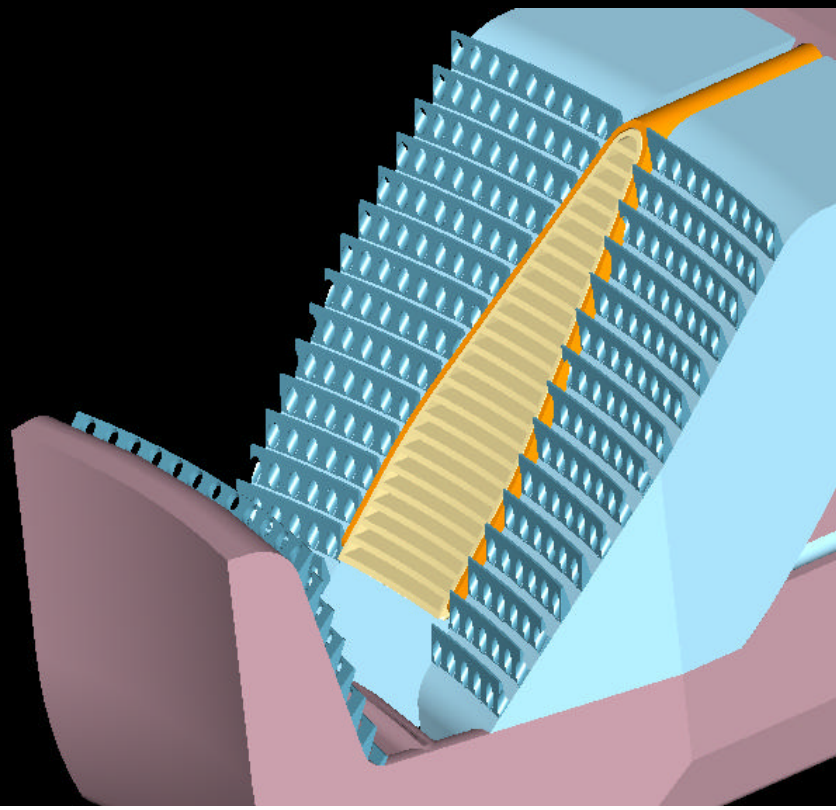
Divertor Cassette

Detail Views

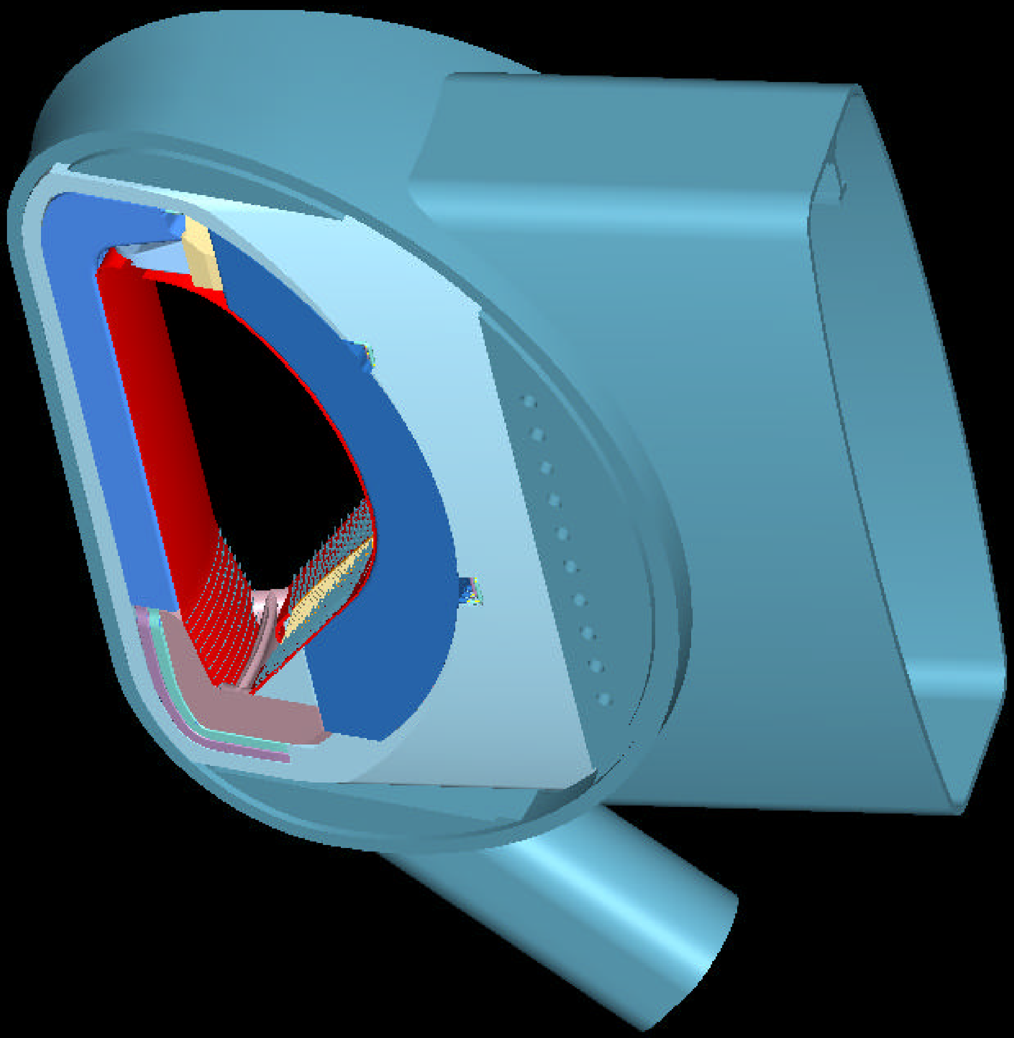


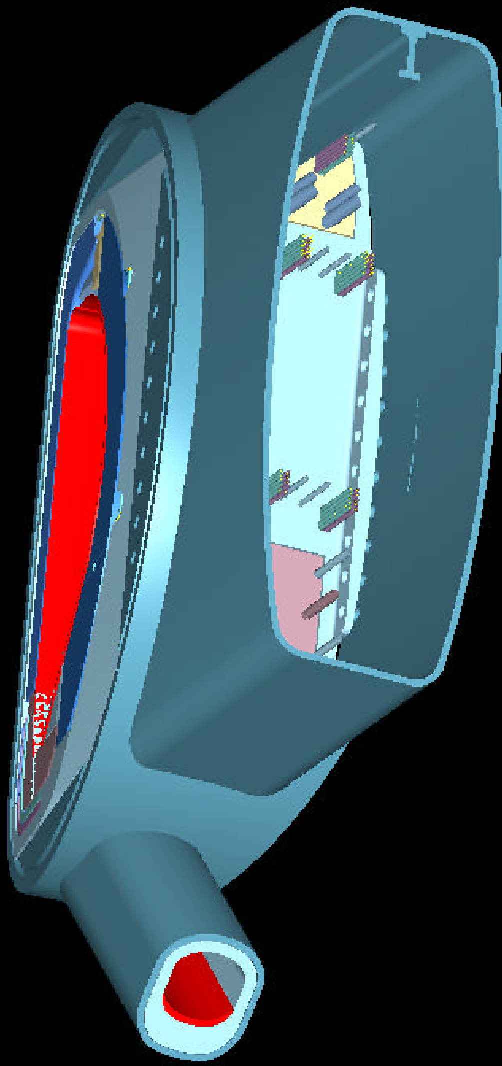
Bottom View
Showing Exit Channels

Close-up of Flow
Baffling / Disruption Fins

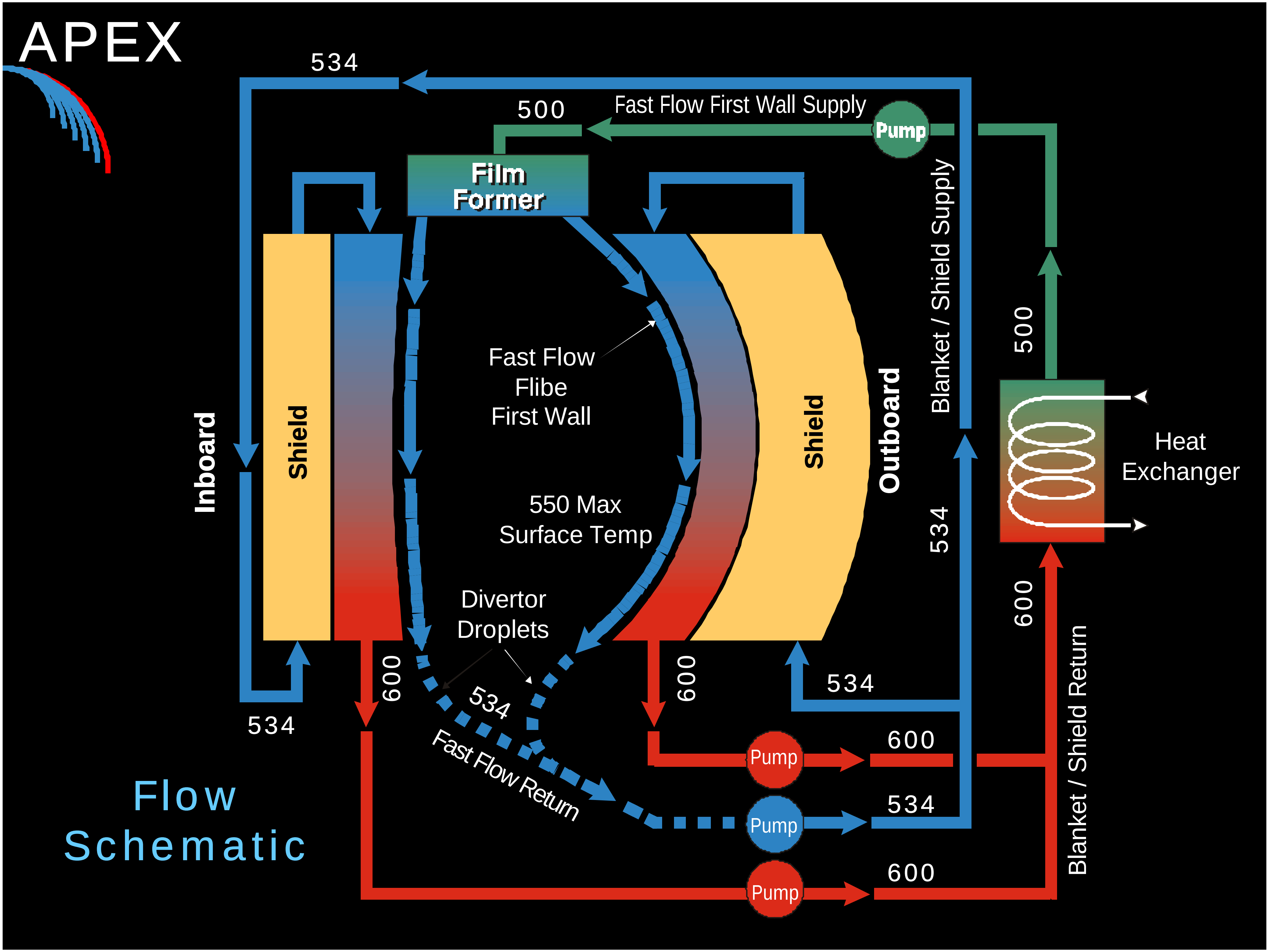


Complete Segment Assembly





Underneath View Showing
Drain / Vacuum Pumping Duct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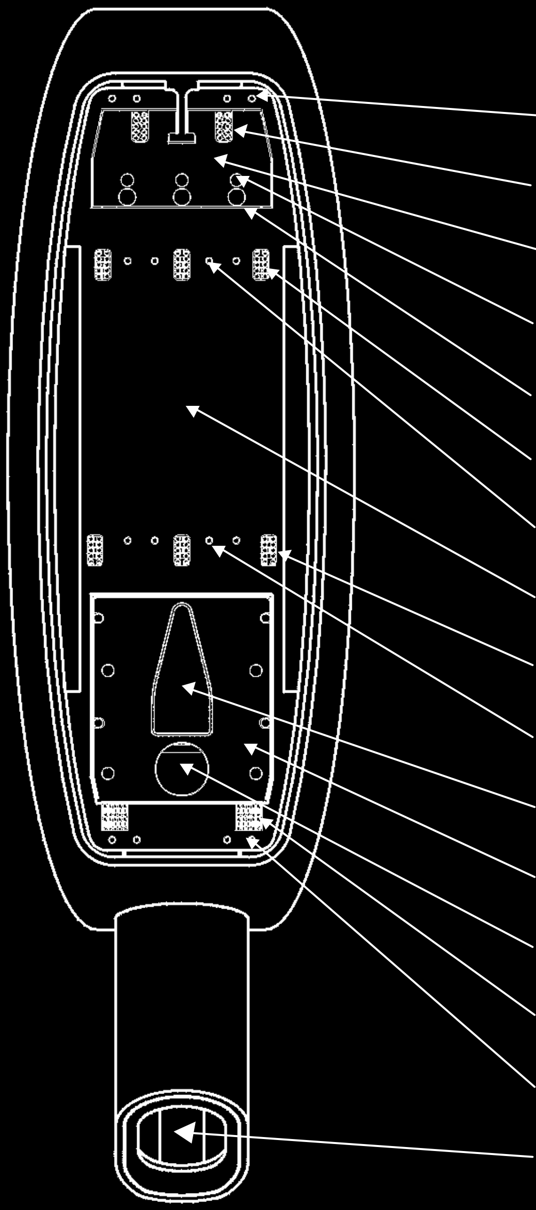
534
500
Fast Flow First Wall Supply
Pump
Film Former
Inboard
Shield
Fast Flow Flibe First Wall
550 Max Surface Temp
Shield
Outboard
Blanket / Shield Supply
500
Heat Exchanger
534
600
Divertor Droplets
600
534
600
534
Fast Flow Return
600
534
Pump
600
Pump
534
Pump
600
Blanket / Shield Return
Flow Schematic

APEX

Piping Arrangement



Pipe summary for CLIFF Flibe case

Circuit type	Power to Circuits per sector	T inlet	T outlet	Flow rate / sector	# Circuits per sector	Pipe size (I.D.)		Velocity
	(MW)	(C)	(C)	(m^3/s)		(cm)	(inches)	(m/s)
First wall fast flow								
IB (inboard)	30.4	500	529	.251	3	15.2	6.0	4.6
OB (outboard)	57.1	500	527	.511	3	20.3	8.0	5.2
Flow under penetration	3.47	500	516	.0524	1	12.7	5.0	4.1
"Bag" blankets								
IB, plasma side	17.6	530	601	.0509	10	5.08	2.0	2.5
IB, coil side	19.4	530	601	.0562	10	4.62	1.8	3.4
OB, plasma side	34.9	530	600	.102	15	4.88	1.9	3.6
OB, coil side	43.3	530	600	.127	15	5.08	2.0	4.2
IB, divertor, plasma side	4.47	530	600	.0132	2	5.08	2.0	3.2
IB divertor, coil side	2.32	530	601	.00673	2	3.81	1.5	3.0
OB divertor, plasma side	12.7	530	601	.0368	2	8.89	3.5	3.0
OB divertor, coil side	14.6	530	601	.042	2	10.2	4.0	2.6
Divertor sled								
IB structure	2.76	530	550	.029	1	10.2	4.0	3.6
OB structure	.0783	530	550	.0008	1	5.08	2.0	0.4
Film former cassette body	10.2	530	550	.105	1	20.3	8.0	3.2
Penetration	16.3	530	600	.0480	1	20.3	8.0	1.5
Main shield								
IB shield	.319	530	540	.0065	1	7.62	3.0	1.4
OB shield	.0977	530	540	.002	1	5.08	2.0	1.0
Vacuum vessel								
IB Vessel	.0861	530	535	.0035	1	7.62	3.0	0.8
OB Vessel	.0166	530	535	.0007	1	5.08	2.0	0.3

Total power per sector 270 MW
Total power all sectors 4320 MW

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General Design Requirements

Function	Requirement	Value/Goal
Power Extraction	Neutron Wall Load Surface Heat Flux	7 MW/m ^ 2 avg* 10 MW/m ^ 2 peak* 2 MW/m ^ 2*
Tritium Breeding	Self Sufficient	TBR > 1
Shielding	Radiation exposure of coils (insulation) Nuclear heating of coils (sc cable) Re-weldable confinement boundary	< $1x10^9$ Rad < $1kW/m^3$ < 1 appm He
Vacuum	Compatible with plasma - Base partial pressure, non-fuel - Base pressure, fuel (H,D,T)	< $1x10^{-9}$ Torr < $1x10^{-7}$ Torr
Plasma Exhaust	Divertor required	to remove helium

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Design Requirements (cont'd)

Penetrations	Plasma Heating Power Density - NBI - ICH Diagnostics	 ~4 MW/m^2 ~6 MW/ m^2 viewing through Labyrinth / mirrors
Operating Parameters	Pulse Length Number of pulses Disruptions	Steady State < 3,000 TBD
Availability	Maximize total availability	A_{plant} > .75 $A_{blanket/FW}$ > .98
Safety	Confinement Boundaries	At least 2

*** Values are minimum goals for steady state operation**

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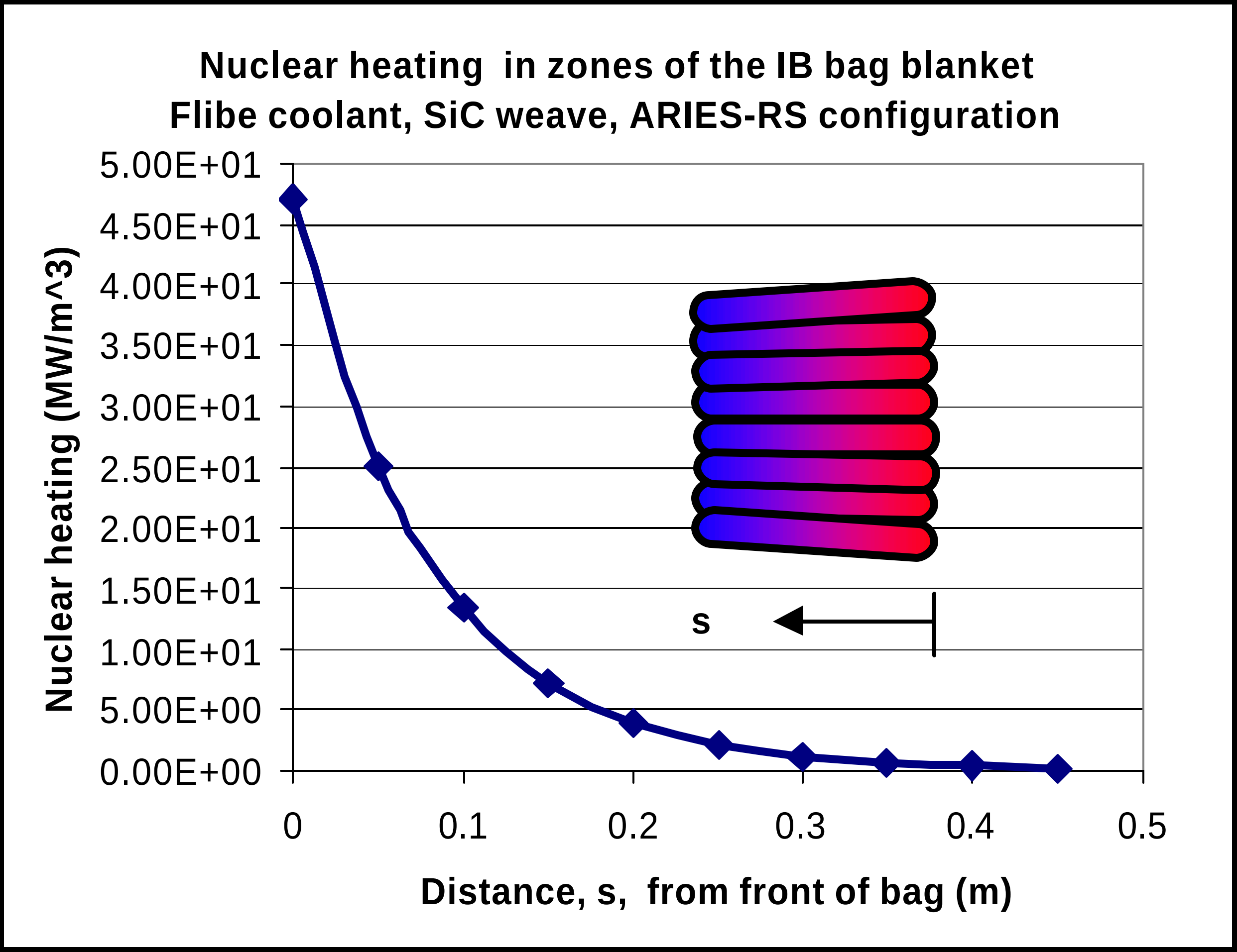
Estimated IB Blanket Heating

Most heat is deposited in first 10 cm



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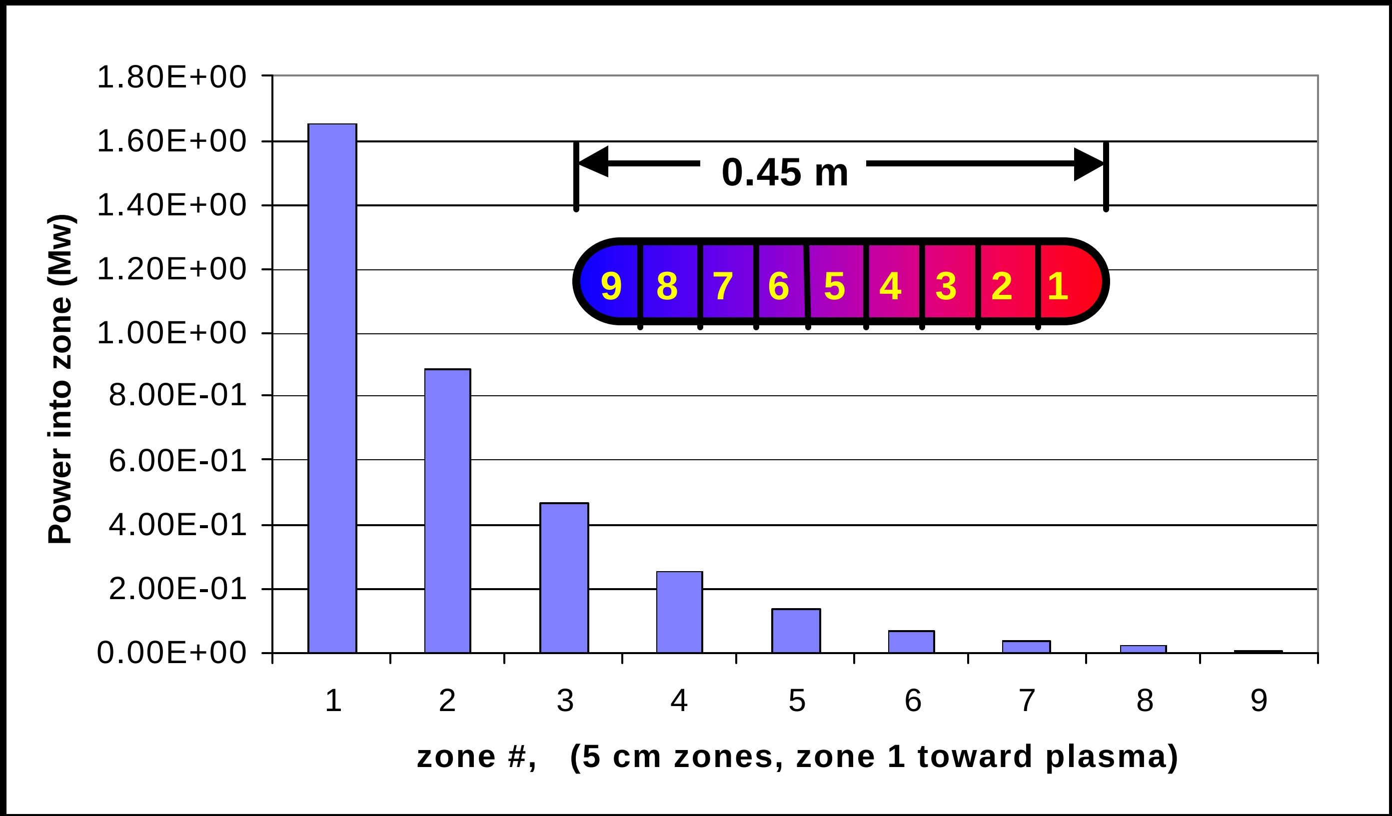
Integrated Power (MW) in Zones of the IB Blanket Flibe Coolant, SiC Weave, ARIES-RS Configuration



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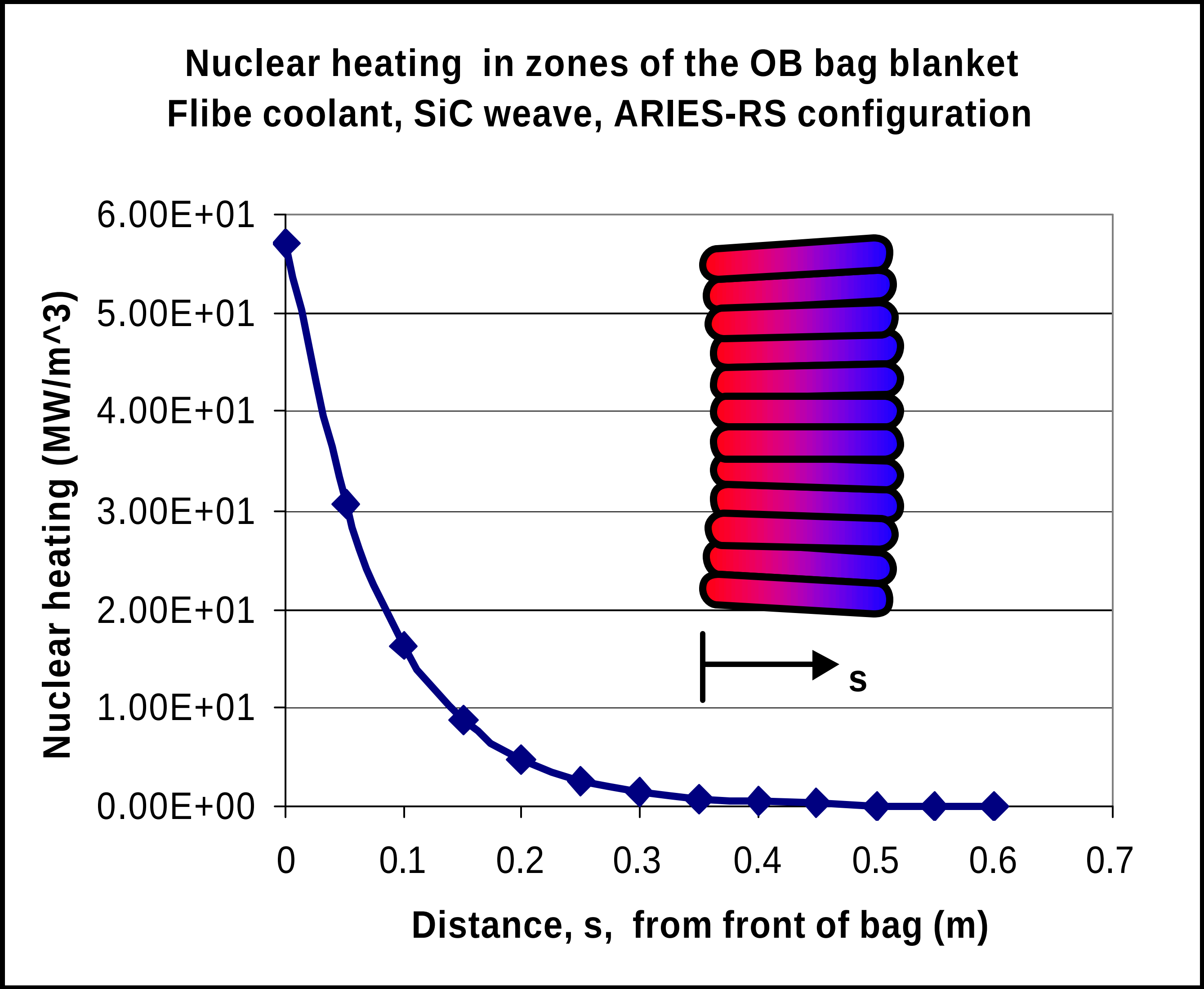
Estimated OB Blanket Heating



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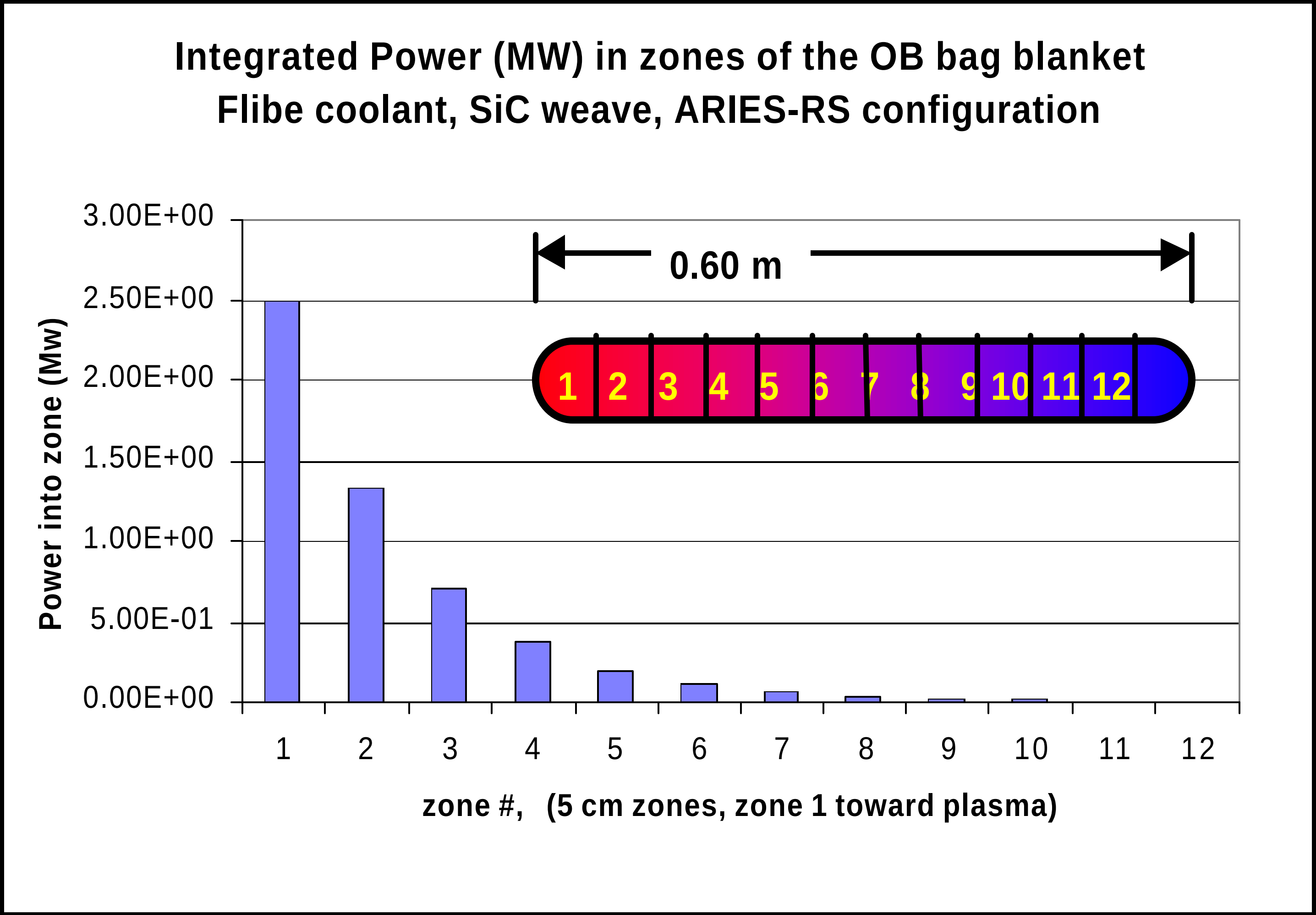

Integrated Power (MW) in zones of the OB bag blanket
Flibe coolant, SiC weave, ARIES-RS configuration
0.60 m
1 2 3 4 5 6 7 8 9 10 11 12
Power into zone (Mw)
3.00E+00
2.50E+00
2.00E+00
1.50E+00
1.00E+00
5.00E-01
0.00E+00
1 2 3 4 5 6 7 8 9 10 11 12
zone #, (5 cm zones, zone 1 toward plasma)

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Issues	Plans
Integration of Be in front region of blanket	Work with Mahmoud, Mohamed Sawan on Be form, quantity
Integration of Passive stabilizer structure with blanket	Work with ARIES-RS team on requirements
Damage limit for SiC	Work with Steve Zinkle & Mtls Grp
Divertor and vacuum pumping integration	Work with Richard Nygren
Divertor flow modifier structure	Work with Richard Nygren
Fast Flow nozzle design and placement	Work with Karani and Sergey on nozzle models
Split between blanket / shield / vv	Work with Mahmoud, Mohamed Sawan
Flow temperature / flow details	Work with Dai Kai

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Tasks for May 8th Meeting

- Strawman set of CliFF design parameters tabulated
- Divertor integrated with pumping duct and liquid flow
- CliFF CAD model completed for strawman design
- Model of Film forming nozzles completed, including first stereolithography model

APEX

Summary

First Wall

- Thin layer of fast moving Flibe ~ 2 cm thick @10 m/s, 465 C **minimal vapor pressure**

Blanket

- Thick zone of slow moving Flibe ~ 47 cm thick @ 5 m/s, 600 C, with **multiple** radial zones for **better flow / temperature control**
- **Flexible** "Bags" woven from SiC fibers with passive stabilizers and extra 10 cm zone of Be at front of bag **improves breeding**
- Hot liquid **leaking** from bags is cooled by fast flow layer
- Bags expand to **close** any sector to sector **gaps**
- **No** halo currents, **minimal** load asymmetry, **low** thermal stress

Maintenance

- **Removable**, high-maintenance **divertor** and **film former** cassettes - while all **other components** are maintained **outside** of the device when the sector module (1 of 16) is completely removed