Task III presentations

• Nelson (ORNL)	Sn-CLiFF Configuration and Status (15 min.)
• Nygren (SNL)	Divertor Integration Status (20 min)
• Rognlien (LLNL)	FW and Diveror Temperature Limits for Sn (15 min.)
• Youssef (UCLA)	Power Deposited in Liquid Tin Layer from Surface Heating (5 min)
• Smolentsev (UCLA)	Sn Surface Temperature and Heat Transfer Enhancement (10 min.)
• ALL	Discussion (20 min.)

Task III CLiFF Configuration Studies / Status

B. Nelson, P. Fogarty, APEX E-meeting, March 1, 2001

- Review of Task III A, B plans
- Status of selected items
  - Design parameters and assumptions for Sn-CLIFF
  - Configuration status
  - Field gradients in ARIES-RS
- Preparation for Review

Plans and Status

- **Goal:**

  Estimate the limits on performance and the identify the technical issues associated with a flowing liquid wall in a fusion reactor.

- **Assumptions:**

  The design will be based on Sn as the FW liquid, flowing over a blanket made from SiC and containing Pb-17Li as the breeder/shield/coolant.

- **Approach:**

  A design concept will be developed as a tool to ensure self-consistency of parameters for the study. The design will incorporate at least the following features:

  - Liquid flow inlet nozzle system
  - Liquid flow collection / drain system
  - vacuum pumping duct / system
  - divertor system
  - blanket system
  - inlet and exit piping for all components
  - maintenance scheme
  - flow startup scenario
  - tritium breeding, shielding, and activation assessment
  - safety assessment

Plans and Status

- **Topics to be explored:**
  - FW flow velocity, thickness, temperature
  - Blanket flow velocity, thickness, temperature
  - Divertor flow, flow augmentation (if any), temperature
  - Effect of applied currents in liquid to control / assist FW flow
  - Effect of applied currents in liquid to control divertor flow

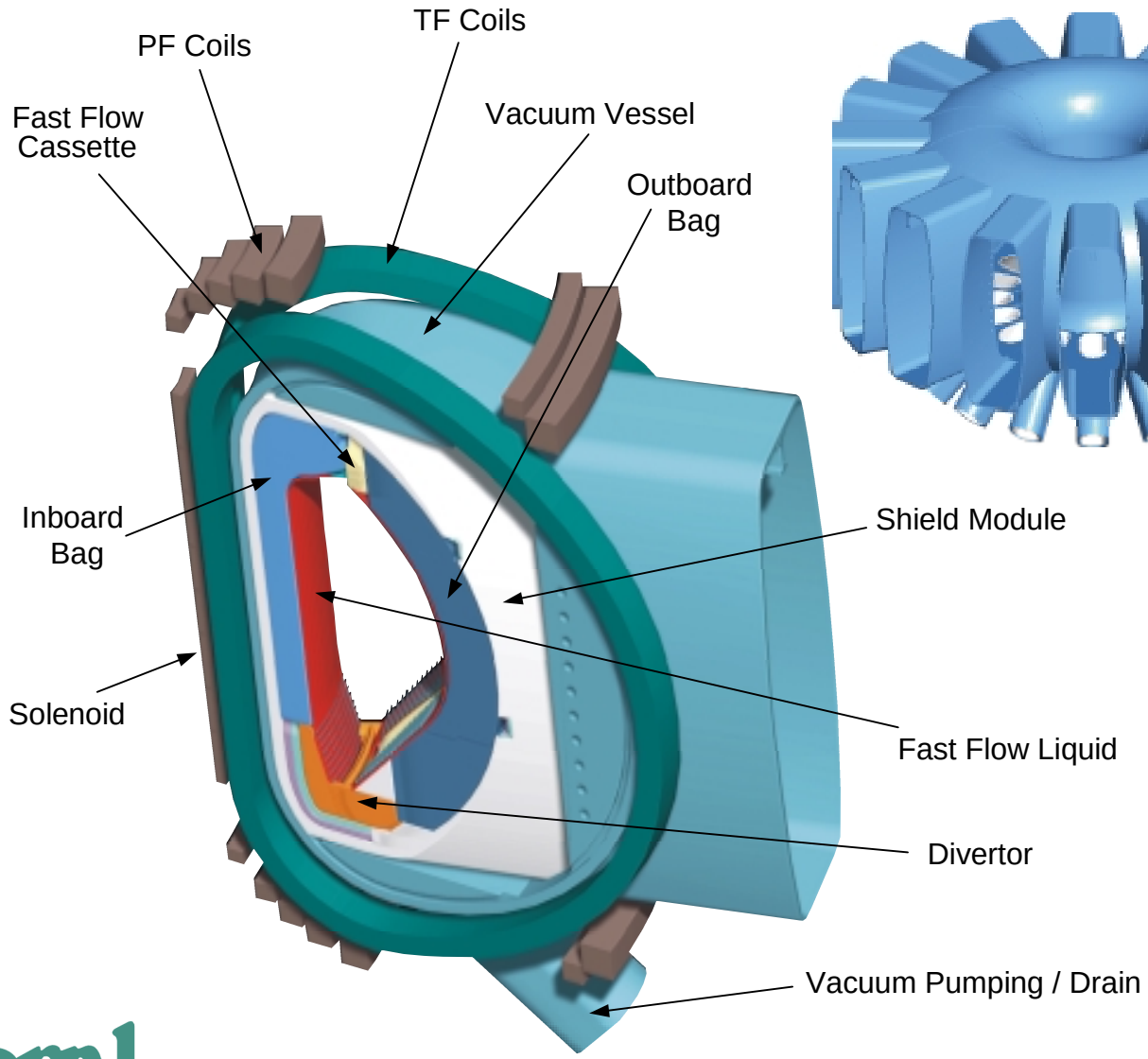
Plans and Status, Task IIIa (Sze)

task #	Task	Primary deliverable	Deliverable date	Input to Task #	Required Inputs, task #	Subtask lead
III.0	Develop FY01 plan	FY01 resource loaded plan	4-Dec-00			Sze
III-a.1	Assess the maximum allowable temperature for the Sn-CLIFF.	Upper end of temperature window for FW liquid		IIIa-5		Roen-glien
III-a.2	Redo the heat transfer calculation including, a. Poloidal heat flux distribution. b. Nuclear heating. c, Brems radiation energy and fraction. d. Coola	peak and average temperature of FW liquid vs velocity, thickness, location		IIIa-5, IIIb-3		Smolen-tsev
III-a.3	Neutronics calculations a. Impact of Brems radiation energy on the heating deposition in Sn. b. Tritium breeding c. Finalize the thickness	details of heat deposition in FW liquid, tritium breeding assessment, blanket thickness requirements, effect on tritium breeding of conducting shell		IIIa-2, IIIa-7, IIIb-3, IIIb-4		Youssef
III-a.4	Material issues a. Select a structural material for the reactor system. b. Estimate the temperature window for both irradiation and ma	Material choice, temperature window and velocity limits for Sn and Sn-Li		IIIa-5, IIIb-3		Zinkle
III-a.5	CLIFF temperature window assessment	Proposed FW liquid operating temperature		IIIb-3		Sze
III-a.6	Define the blanket and the blanket coolant temperature for optimum power conversion and select the power conversion system.	Proposed blanket operating temperature and power conversion system		IIIb-3		Sze
III-a.7	Resolve the tritium/material interaction and recovery issues	Proposed system for tritium recovery		IIIb-3		Sze
III-a.8	Do the activation calculations	Activation and waste disposal characteristics		IIIb-3	IIIa-4, IIIa-5,	Khater
III-a.9	Do the safety assessment.	Safety assessment			IIIa-4 thru IIIa-8	Merrill

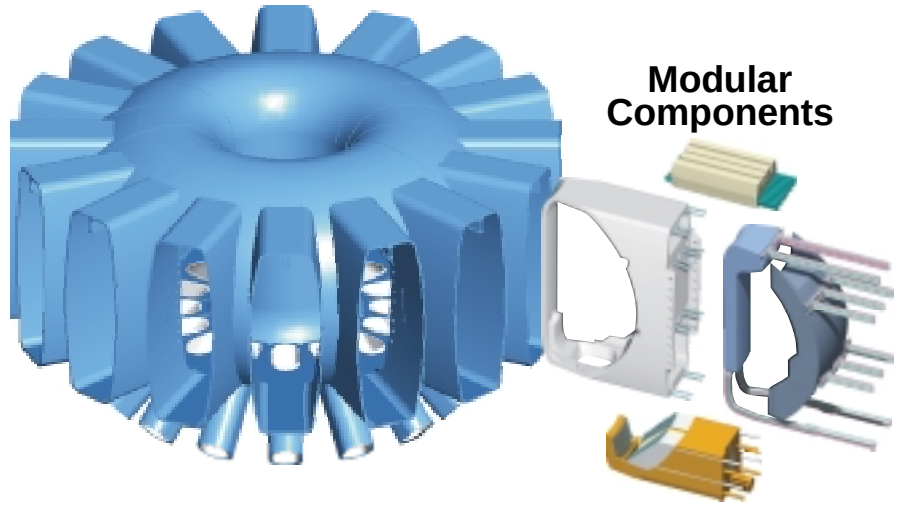
Plans and Status, Task IIIb (Nelson)

task #	Task	Primary deliverable	Deliverable date	Input to Task #	Required Inputs, task #	Subtask lead	Partici-pants
III-b.1	List requirements for APEX configuration study	List of requirements	10-Dec-00			Nelson	Sze, Nygren
III-b.2	Document baseline configuration, including drawings, liquid surface geometry, dimensions of pipes, materials of construction, etc.	Reference document on web	1/10/2000 for first issue			Nelson	Fogarty,
III-b.3	Compile baseline performance data such as flowrates, pressure drops, temperature rise, nuclear heating, shielding, activation, waste disposal ratings, etc. (based on analysis from all sources)	Reference document on web	2/1/2000 for first issue			Nelson	Sze, Nygren, Sawan, Petti, Morley
III-b.4	Develop CAD models of revised configurations for each subsystem	updated CAD models	Quarterly			Nelson	Fogarty,
III-b.5	Develop divertor geometry for FW flow option	CAD geometry	1-Feb-00			Nygren	Fogarty
III-b.6	Construct magnetic model of ARIES-RS and calculate 3-D magnetic fields along piping and plasma facing surfaces	report with field files	1-Mar-00			Nelson	Nelson
III-b.7	Develop divertor geometry for augmented flow option	CAD geometry	30-Aug-00			Nelson	Fogarty
III-b.8	Develop nozzle designs for test at UCLA. Requires close interaction with UCLA for experiment parameters and scaling information	nozzle design and rapid prototype model	30-Jul-00			Morley	Fogarty, Hulin
III-b.9	Develop penetration designs for testing at UCLA Fli-Hy facility	penetration geometry and rapid prototype model	30-Jul-00			Morley	Fogarty, Hulin
III-b.10	Compile vacuum pumping parameters and evaluate vacuum pump options	report	30-Jul-00			Nelson	Fisher, Gouge
III-b.11	Develop list of R&D issues	report	30-Sep-00				
III-b.12	Prepare configuration section of report for FY-01	report input	according to project schedule			Nelson	Fogarty

Modular Components



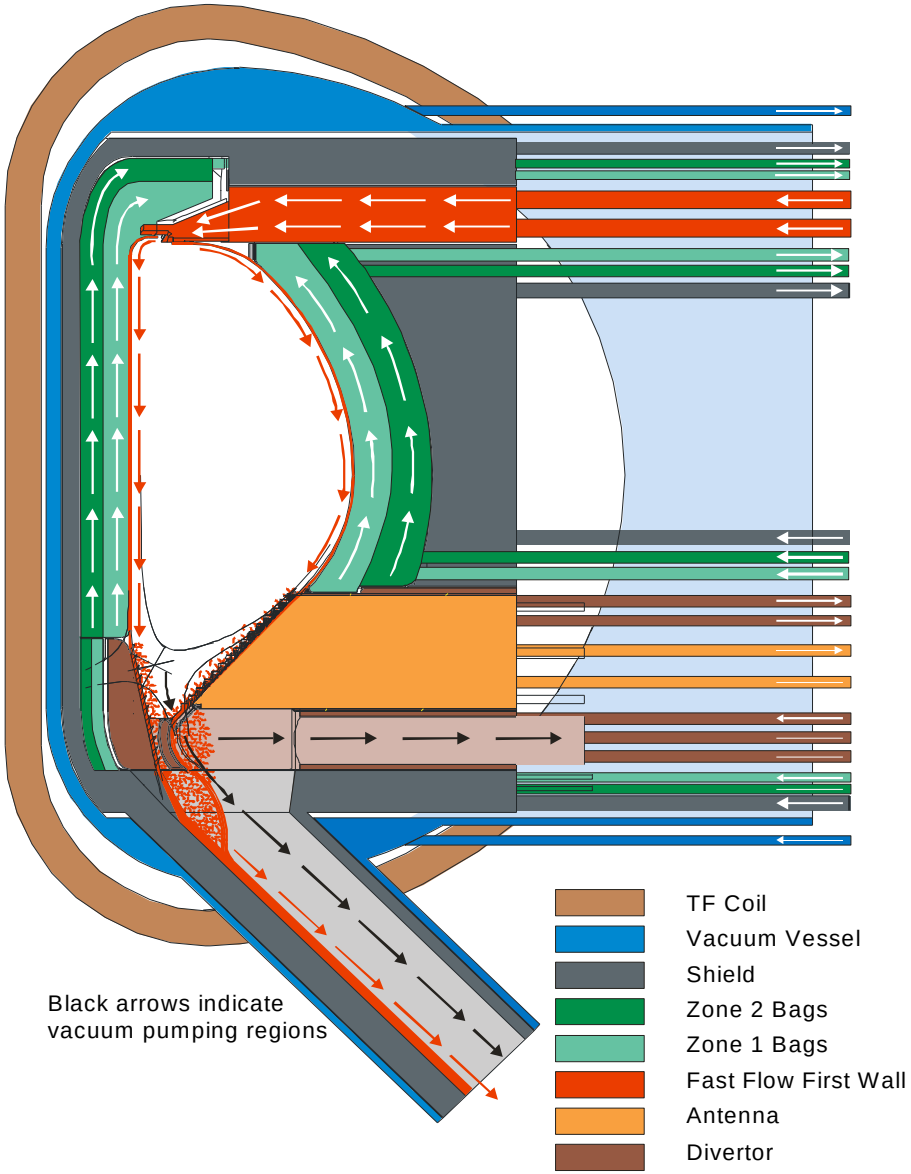
360º Vacuum Vessel Assembly



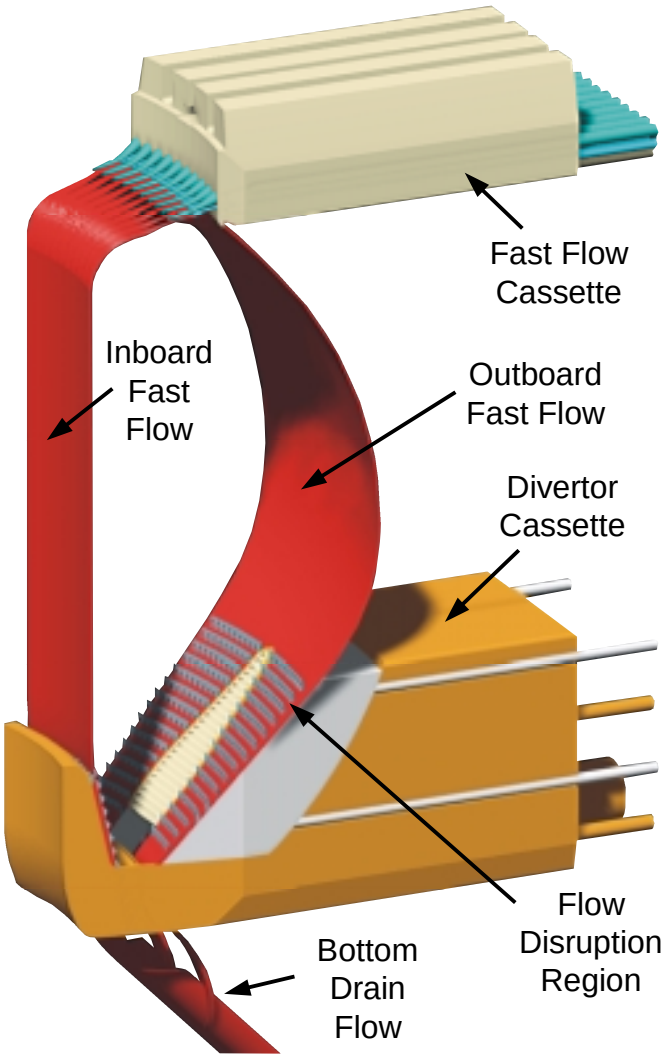
Component Properties

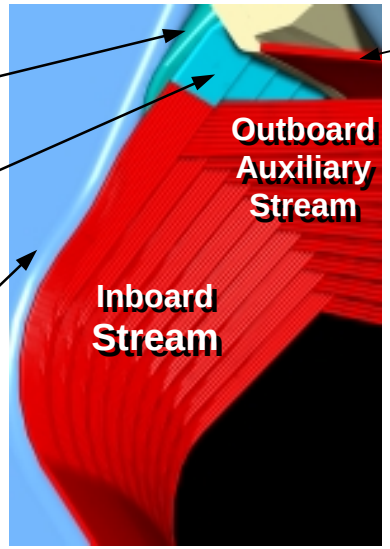
Component Description	Volume (m^3)	Surface Area (m^2)	Density (kg/m^3)	Component Material	Sector Wt (kg)	Total Wt x 16 (kg)
Vacuum Vessel	30. 2	361	8,400	SST	2.54E+05	4.06E+06
Duct Sleeve	5.41	46.9	8,400	SST	4.54E+04	7.27E+05
Shield Module	34.6	210	8,400	SST	2.91E+05	4.65E+06
I.B. Bag (x 10)	0.83	13.1	8,700	Sic / Li-Pb	7.22E+03 (7.22+04)	1.16E+06
O.B. Bag (Ends x 2)	1.04	14.3	8,700	Sic / Li-Pb	9.05E+03 (1.81E+04)	1.34E+05
O.B. Bag (Middle x 13)	.96	12.6	8,700	Sic / Li-Pb	8.35E+03 (1.09E+05)	1.74+06
Bag Piping I.B. – Upper I.B. – Lower O.B. – Upper O.B. - Lower	 .083 .23 .07 .07	 35.3 99.5 26.9 26.9	 8,400 8,400 8,400 8,400	 SST SST SST SST	 6.97E+02 1.93E+03 5.88E+02 5.88E+02	 1.12E+04 3.09E+04 9.41E+03 9.41E+03
Film-Former	9.25	16.3	8,400	SST	7.77E+04	1.24E+06
Divertor	19	208	8,400	SST	1.60E+05	2.55E+06
I.B. & O.B. Fast Flows	1.63	87.89	6,800	Sn	1.11E+04	1.77E+05
TOTALS					(1.04E+06) 1140 Tons	1.67E+07 18,340 Tons

Flow / Vacuum Pumping Schematic



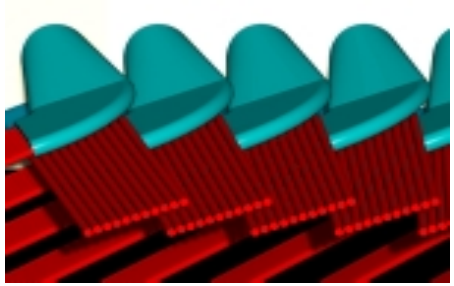
Fast Flow System

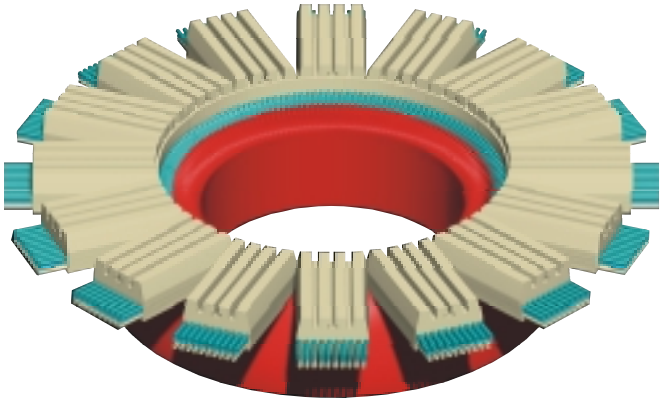




Nozzle Design

Front View of Nozzles





360º Top View of Fast Flow Cassette Assembly Cut at Mid-plane

Flowrates and Piping for Sn first wall

- **Assume following temperature limits**

	Tin	Tout
• Bulk	500 C	550 C
– Surface	500 C	< 750 C
– Divertor	750 C	<1300 C

- **Total Sn flow rate:** 14.0 m^3/s
- **Velocity in pipes:** 1.4 to 1.8 m/s

Circuit type	Power to circuits in one sector	Tinlet	Toutlet	Flow rate per sector	Flow rate per sector	No of circuits per sector
	(MW)	(C)	(C)	(m^3/s)	(l/s)	
First wall fast flow						
IB (inboard)	26.9	500	548	2.58E-01	258	10
OB (outboard) main flow	33.3	500	547	3.27E-01	327	10
OB (outboard) auxiliary flow	25.0	500	548	2.42E-01	242	10
Flow under OB penetration	3.0	500	548	2.93E-02	29	21

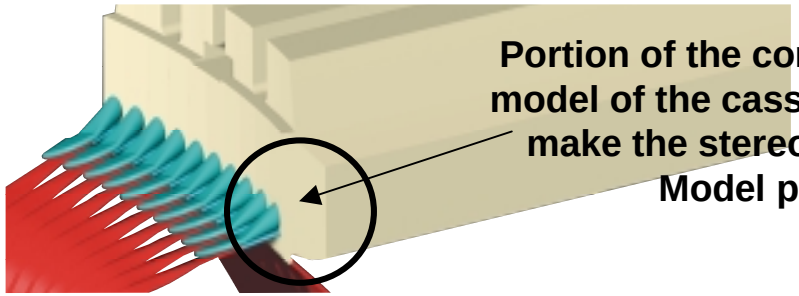
Nozzle Configuration

We want to reduce velocity and temperature at liquid-nozzle interface

- **Nozzle erosion proportional to square of velocity (or worse)**
- **Reaction of liquid metal with coatings, structural materials decreases with temperature**

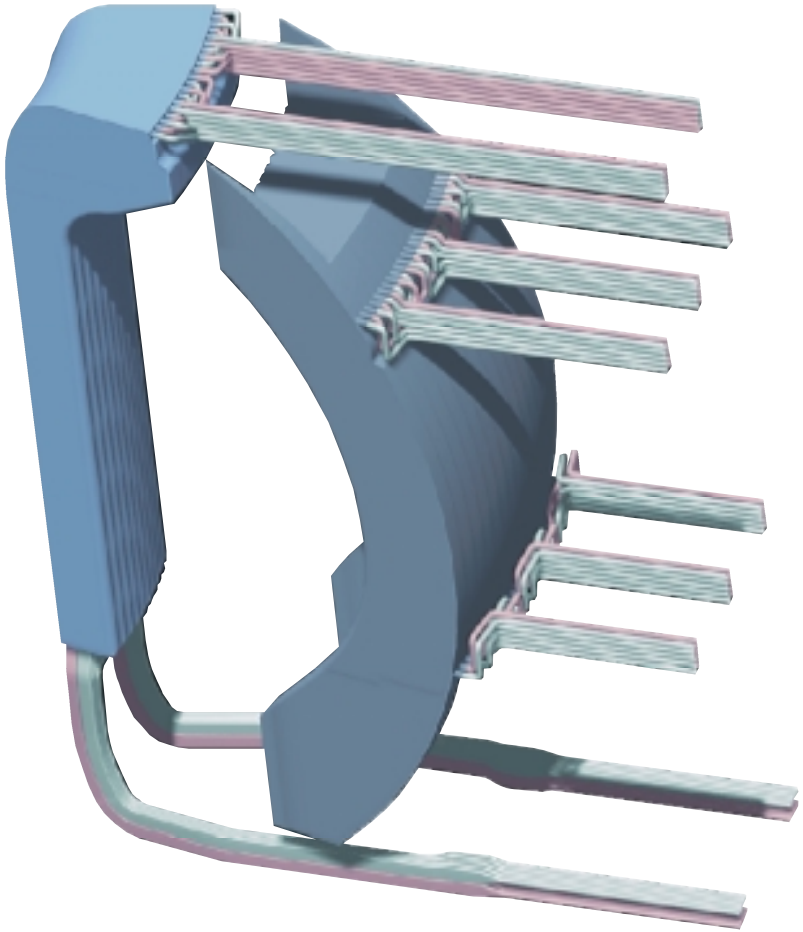
Nozzles can be arranged for mutual protection

Nozzle design can be prototyped in plastic for flow tests

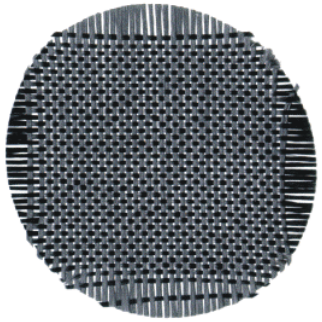


Portion of the computer CAD model of the cassette used to make the stereolithography Model pictured here

SiC Bag Concept



Sector Blanket Assembly



Standard Weave in Hi Nicalon Material

Satin Weave in Tyranno Material

Material has flexibility for shaping bags

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

Pb-Li flowrates and Piping

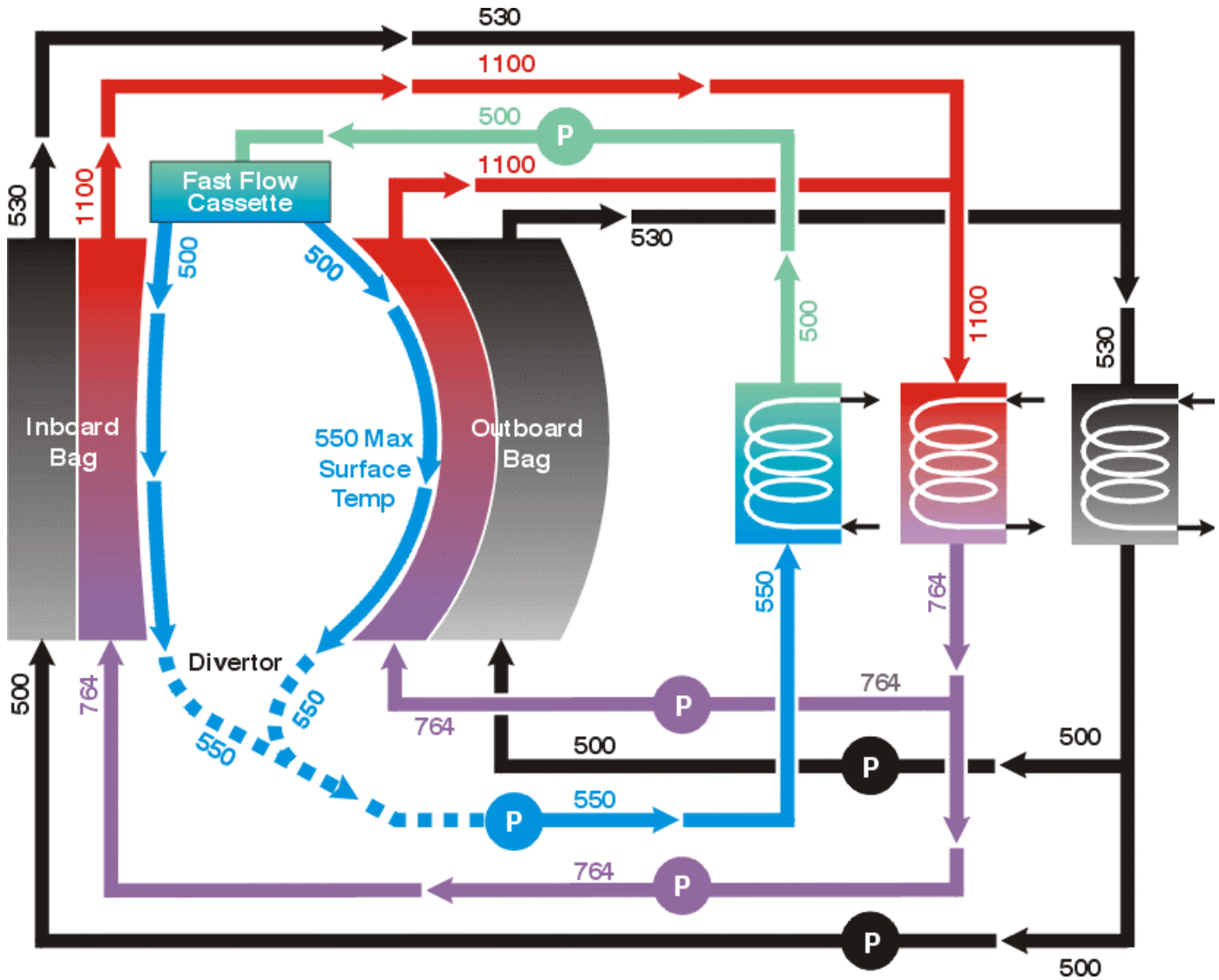
- **Assume SiC / Pb-Li blanket (similar to ARIES-AT)**

	Tinlet	Toutlet
– Blanket	764 C	1100 C
– Shield/structure	500 C	< 650 C

- **Total Pb-Li flow rate**
  - Bags 4.0 m^3/s
  - Structure 3.4 m^3/s

- **Velocity**
  - In bags 0.02 to 0.39 m/s
  - In pipes 0.3 to 3.2 m/s

Flow / Temperature Diagram – Sn + Li-Pb

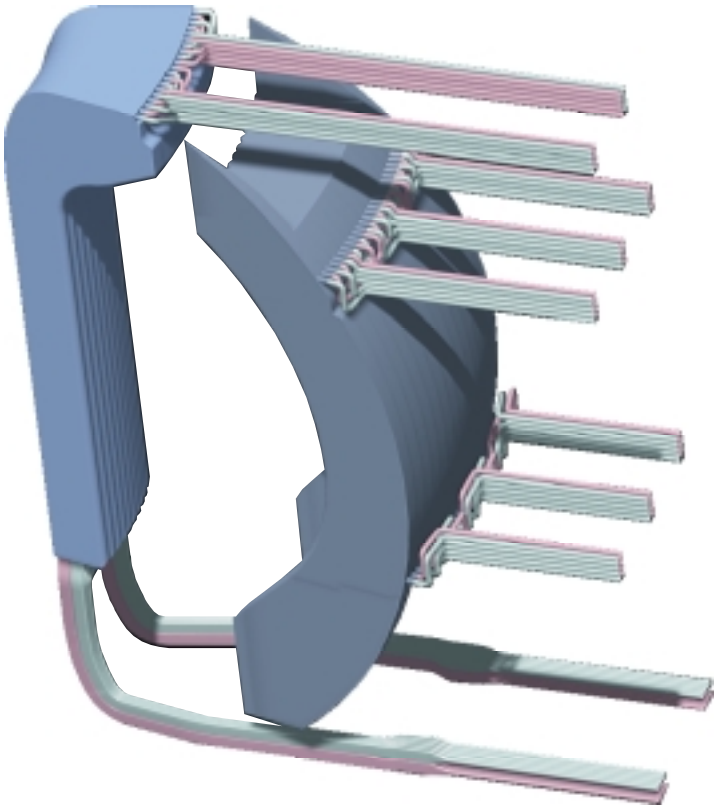


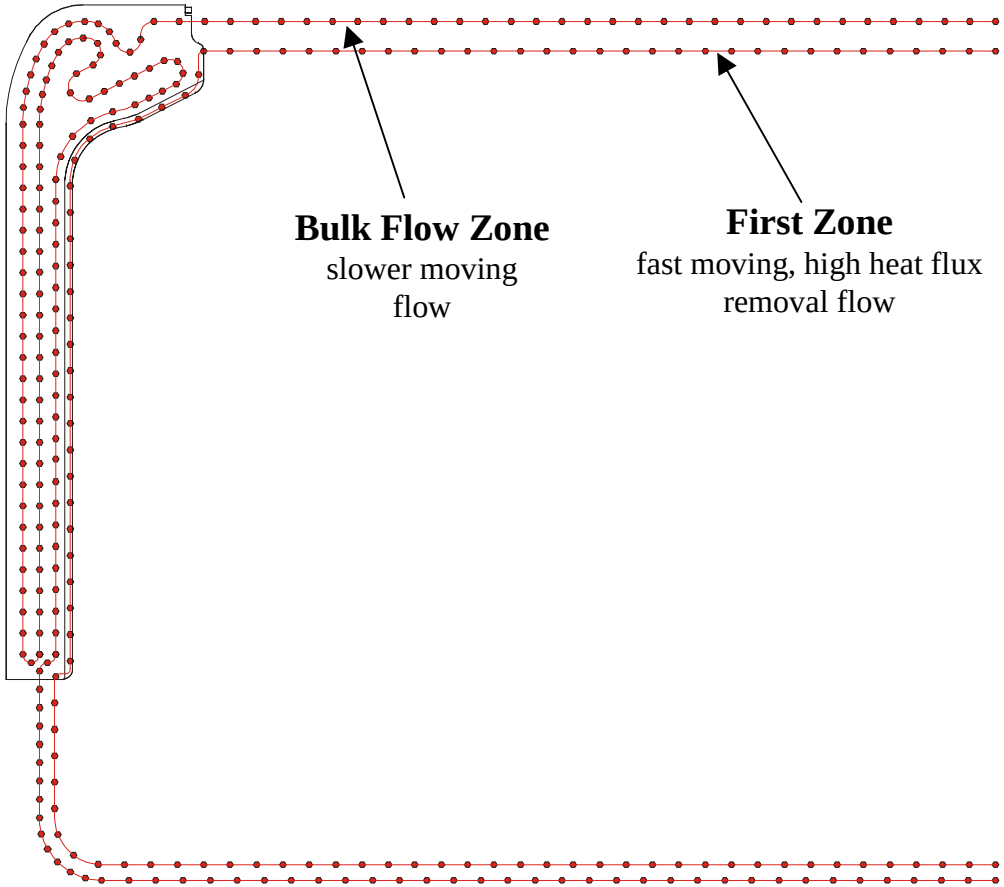
Flowrates and Piping for Li-Pb

Circuit type	Power to circuits in one sector	Tinlet	Toutlet	Flow rate per sector	Flow rate per sector	No of circuits per sector
	(MW)	(C)	(C)	(m^3/s)	(l/s)	
"Bag" blankets						
IB, plasma side	13.6	764	1100	2.50E-02	25	10
IB, coil side	20.1	764	1100	3.72E-02	37	10
OB, plasma side	26.9	764	1100	4.95E-02	50	15
OB, coil side	45.4	764	1101	8.35E-02	83	15
IB, divertor, plasma side	3.4	764	1100	6.34E-03	6	2
IB divertor, coil side	1.8	764	1101	3.29E-03	3	2
OB divertor, plasma side	9.7	764	1100	1.80E-02	18	2
OB divertor, coil side	15.3	764	1100	2.82E-02	28	2
Divertor sled						
IB structure	2.8	500	557	2.80E-02	28	1
OB structure	0.1	500	557	8.00E-04	1	1
Film former cassette body	10.2	500	556	1.05E-01	105	1
Penetration	16.3	500	641	6.72E-02	67	1
Main shield						
IB shield	0.3	500	529	6.50E-03	7	1
OB shield	0.1	500	528	2.00E-03	2	1
Vacuum vessel						
IB Vessel	0.1	500	514	3.50E-03	4	1
OB Vessel	0.0	500	514	6.80E-04	1	1

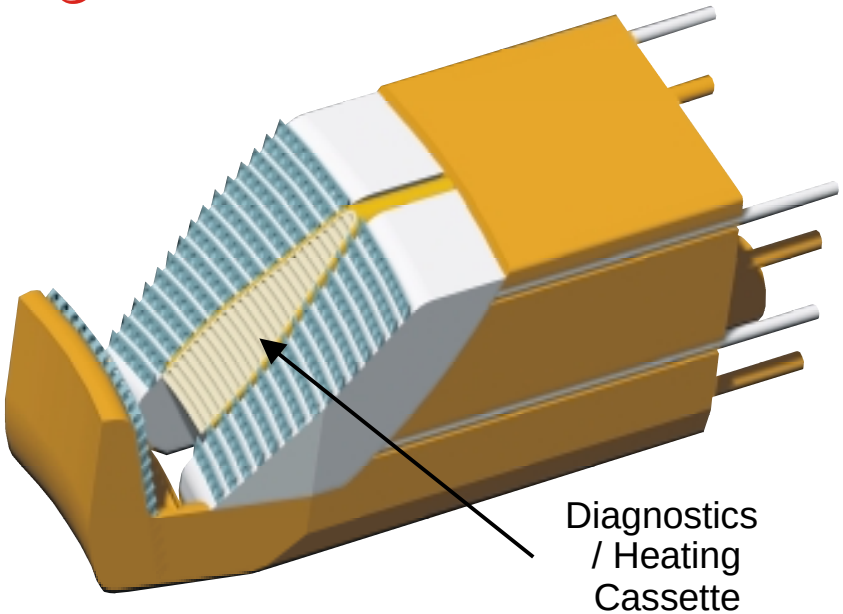
Magnetic field calculations

- **Calculation of MHD effects require detailed magnetic field map**
- **Calculations of field along fluid trajectory has begun**

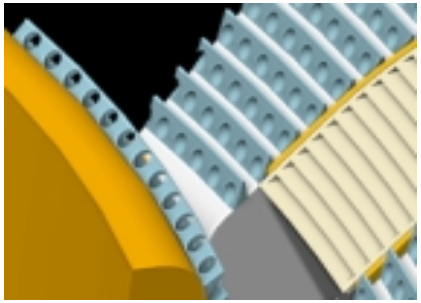




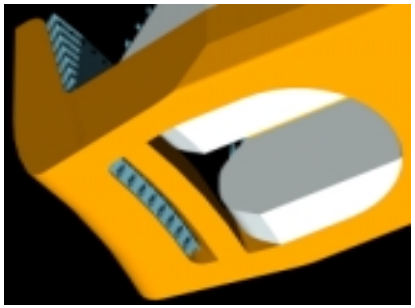
Divertor and penetrations

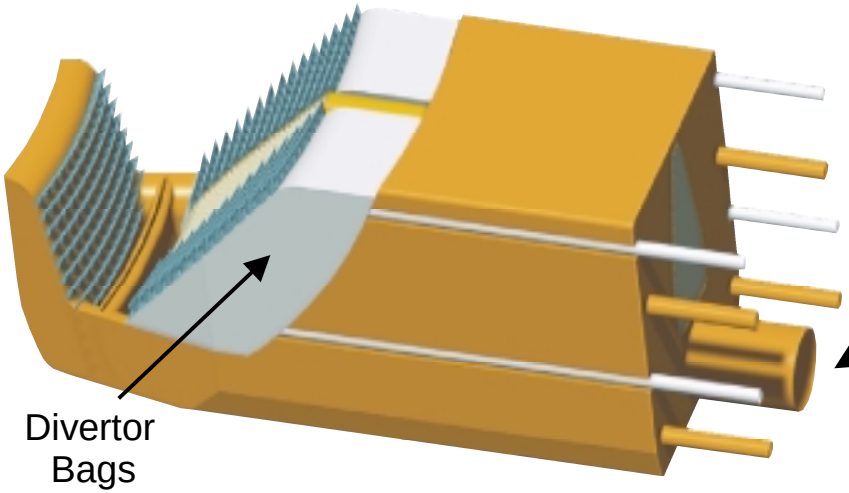


Close-up of flow disruption baffles



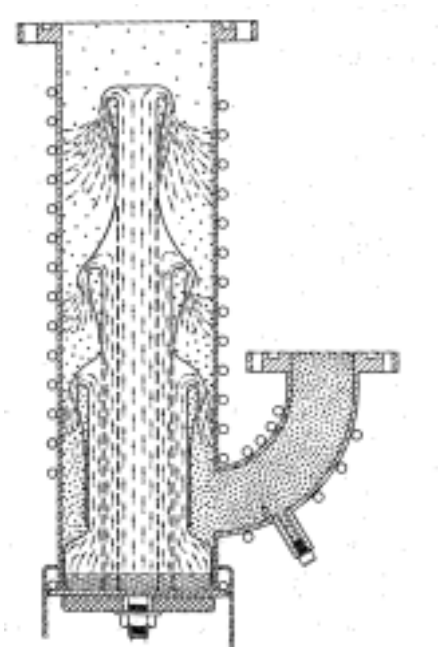
Underneath view showing fast flow drain passages

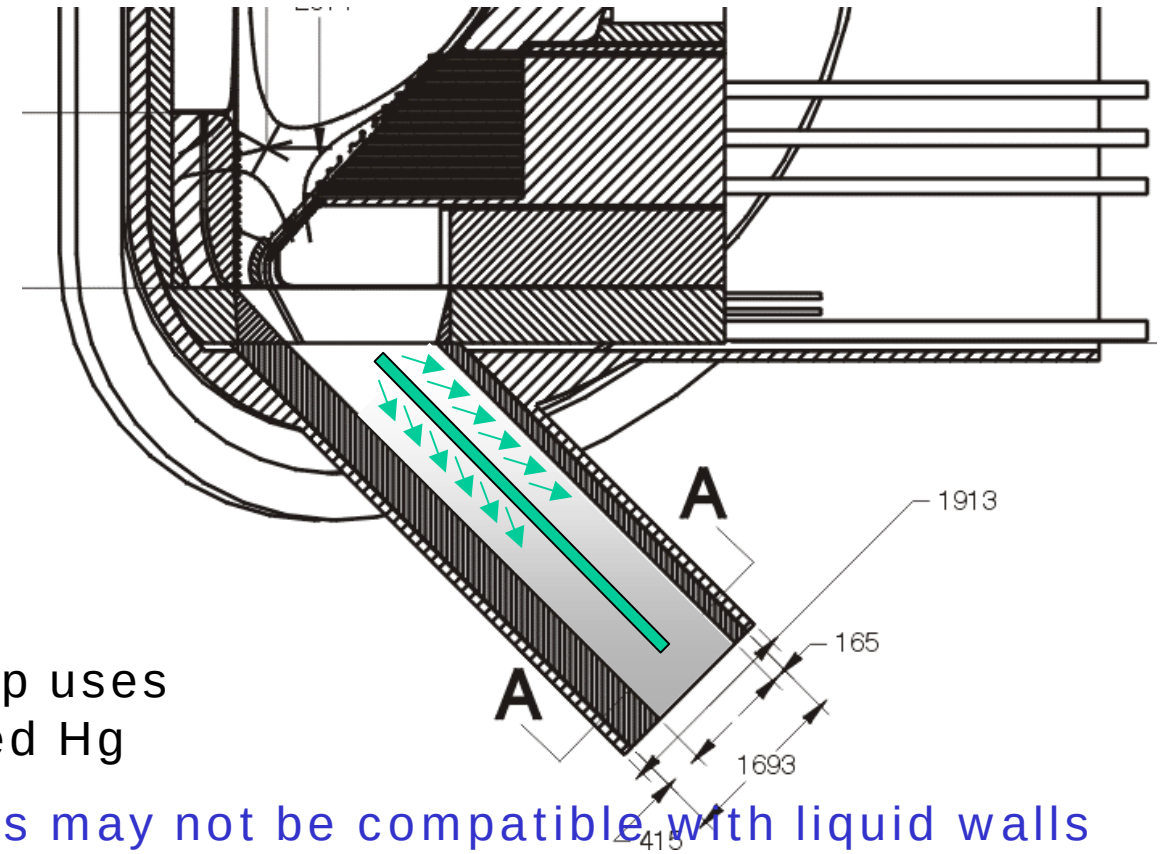




Vacuum Pumping Duct

Can liquid be used as diffusion pump?





Typical diffusion pump uses oil, older pumps used Hg

- Conventional pumps may not be compatible with liquid walls
- Need compression ratio ~ 10^2 - 10^3
- In principle this should work, although earlier investigations of Na, Li, and Ga as working fluids were not successful

Preparation for Peer Review

- Initial list of presentation slides prepared by Dai Kai
- Dry run scheduled for March conference call
- Must specifically address evaluation criteria

1. Mission statement	Sze
2. Goals for the task	Sze
3. Achievements during the past few years	Team
4. Description of the reference design	Sze
5. System parameters	Sze
6-7 System configuration	Nelson
8-9 First wall/divertor temperature ;limits	Rognlien
10 Heat flux and neutron wall loading	Sawan
11 Brem Radiation effect	Youssef
12-13 First wall heat transfer	Smolentsev
14. First wall temperature window	Sze
15. Heat transfer enhancement	Smolentsev or Morley
16. Penetration cooling	Smolentsev or Morley
17. Nozzle design	Nelson
18-21 Divertor integration	Nygren
22 Power conversion	Sze
23 Tritium breeding	Youssef
24. Activation	Khater
25 Safety assessment	Merrill
26 Key Issues	Team
27 Conclusion	Team

Poster for liquid wall technology

- At November meeting, Sam Berk suggested we produce a poster summarizing the stages of deployment for liquid surface science and technology

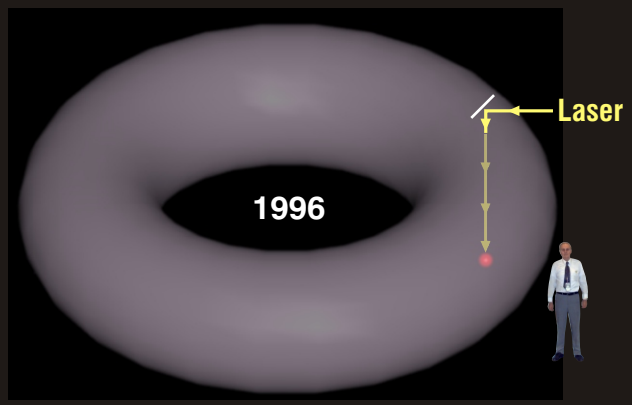
- Paul Fogarty prepared the poster and it has been iterated a few times with Sam

- We are now soliciting comments from the APEX team

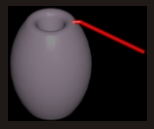
Stages of Deploying Liquid Surface Science & Technology

Plasma Experiments

- Particle Control
- High Heat Flux Handling
- Impurity Control
- MHD Control



TFTR - Dollop



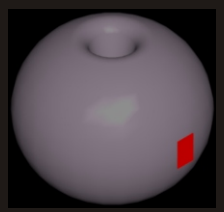
2000

CDX
Limiter Module

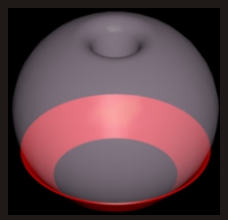
2001

CDX
Belt Limiter

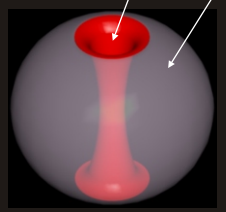
2004-2005



NSTX
Limiter Module



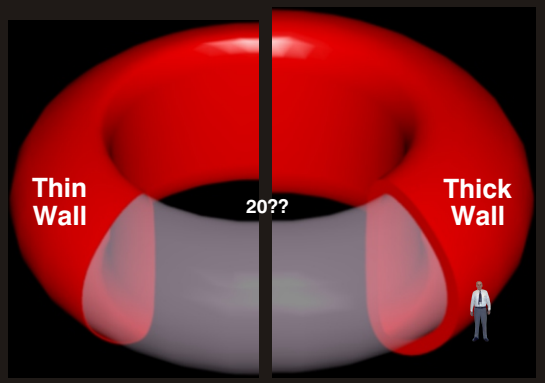
NSTX
Divertor



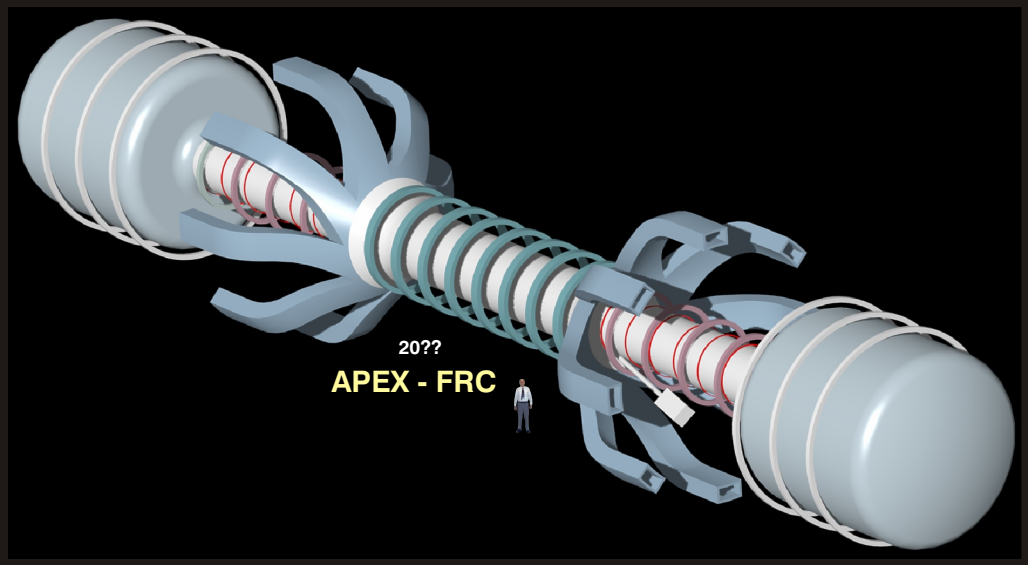
NSTX
Inner Wall

Fusion Devices

- High Power Density
- High Thermal Efficiency
- Long Lifetimes for First Wall and Divertor
- Potential for Improved Plasma Performance



APEX Liquid Wall



Summary

- **The CliFF liquid wall concept is being integrated into the ARIES-RS reactor design assuming:**
  - **Sn for the FW flow (500 –550 C bulk and 750 up to 1300 C surface Temp)**
  - **Pb-Li for the blanket / shield coolant (764 C in and 1100 out for blanket)**

- **The configuration will continue to use the woven SiC "bag" structures in place of conventional blankets and shielding**

- **Changes to the the configuration are being assessed to account for :**
  - MHD effects
  - Material compatibility
  - Vacuum pumping / divertor configuration

- **Preparations are starting for peer review**