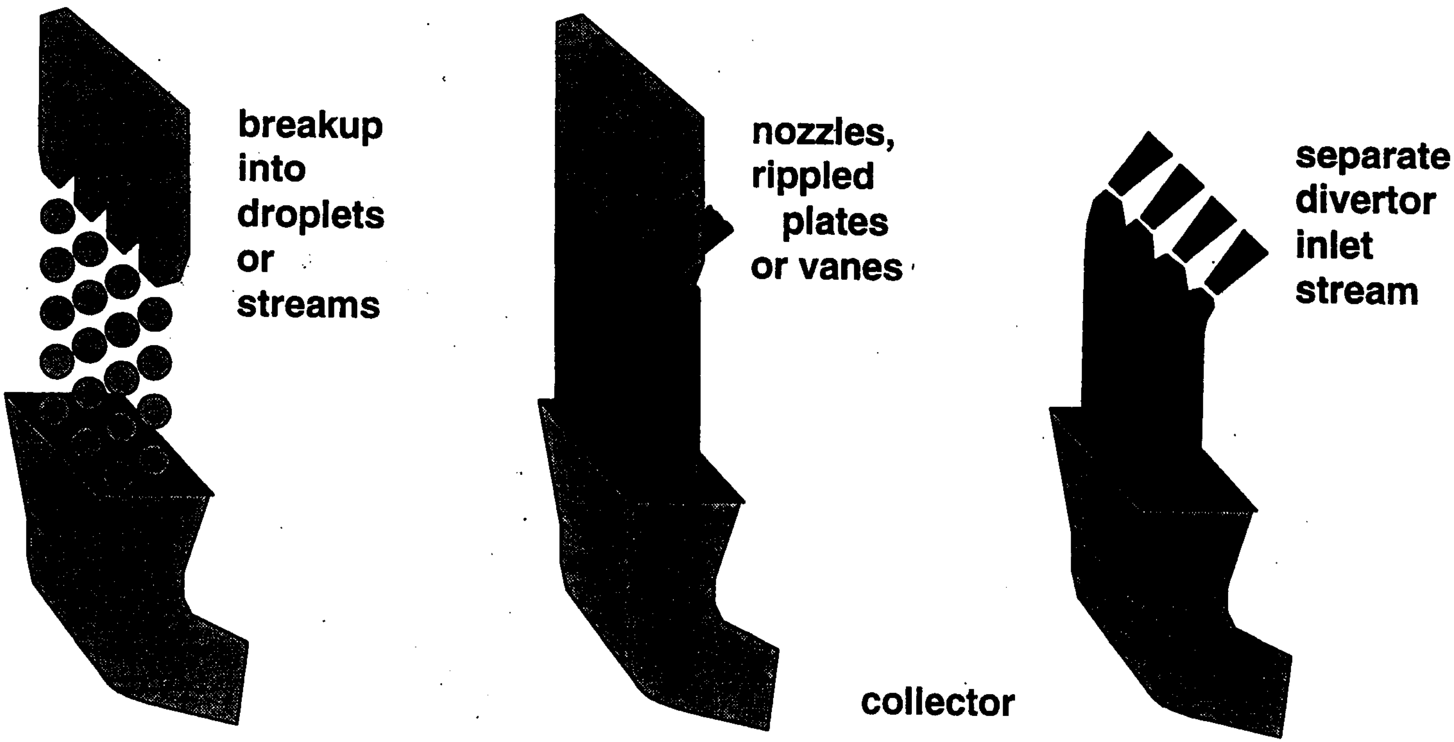
APEX Task III.2 Divertor Integration

Richard Nygren *Sandia National Laboratories*



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University of California, Los Angeles, Westwood, California

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Task III.2 Divertor Integration (Richard Nygren)

Fluid collection - collector and (liquid) pump for the divertor.
[some overlap with FW]

Among the concerns are:

(1) envelope for a low-head fluid collector and exhaust ducts,
(2) splashing (analysis and mitigation), and
(3) drainage and liquid pumping.

Divertor stream - develop preliminary options (6 mo), then pick one (or maybe two) among several possible approaches.

Helium pumping - either show that He entrainment is effective or design an adequate He pumping system.

Consider more aggressive task with thick wall designs.

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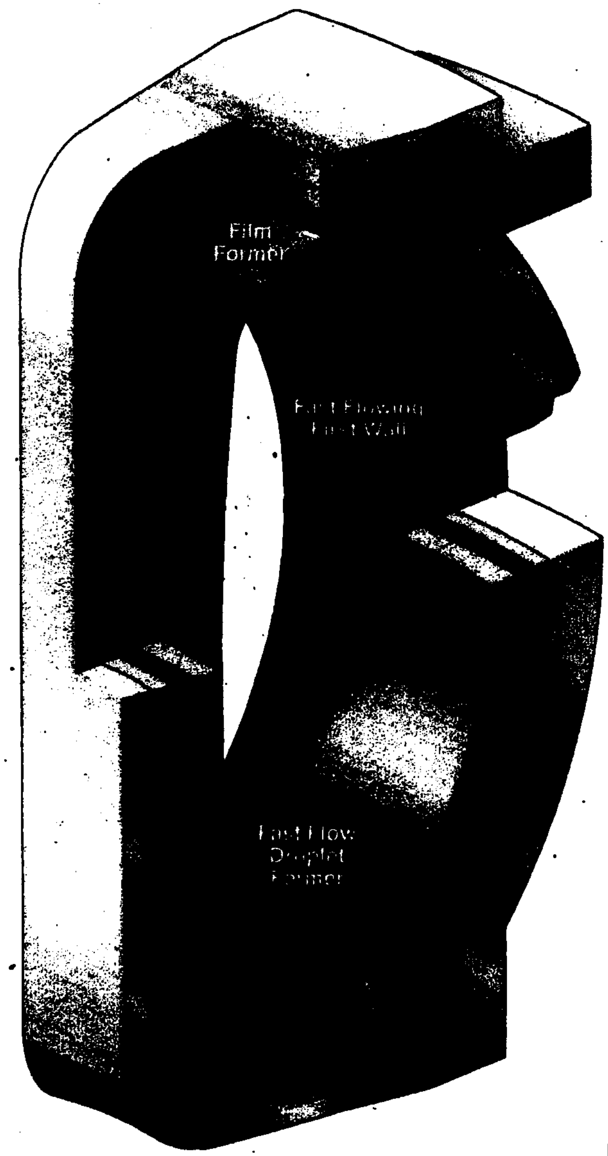
Convective Liquid Flow Firstwall (CLIFF) Concepts

- First Structural Wall protected by a fast moving layer of liquid, typically 1 to 2 cm thick at 10 m/s.
- Flibe, Lithium, and Sn-Li considered
- The liquid layer:
  - is injected at (or near) the top of the reactor chamber with an independently removable nozzle assembly
  - adheres to curved structural wall by means of centrifugal force
  - serves as an integrated divertor, either film or droplet type
  - is collected and drained at the bottom of the reactor through combination vacuum/drain port
- Liquid recirculated to breeder blanket based on ARIES-RS located behind the CLiFF-wall

CLIFF Configuration

1/16 Sector - 3D Cutaway



UCLA

Divertor Stream Approaches

1. "Natural divertor" - <u>First wall flow</u> is manipulated so fresh fluid (T_{bulk}) is brought to surface and makes a workable divertor.
   a) natural breakup with sufficient momentum transfer to rotate the fluid so that we get a stream and/or droplets;
   b) structure (vanes, rippled back plate, whatever) introduces sufficient flow redirection or turbulence near the surface to move fresh fluid from the bulk to the surface; or
   c) electrodes introduce sufficient current that MHD forces move fresh fluid from the bulk to the surface. (This may be more appropriate for liquid metals).

Divertor Stream Approaches - *continued*

2. **Augmented Flow - Injected secondary stream is added to the FW flow. Secondary stream has two functions:**

   (a) adds cooler liquid, and

   (b) redirects flow - surface FW flow is mixed with cooler fluid.

   These designs will likely be based on injection of fluid at or near the free surface of the FW stream.

3. **Separate Divertor - divertor flow is separate from FW flow.**

   Flibe is a poor choice for heat removal, but we must see how far we can go here. We may introduce Flibe at a lower temperature and higher velocity than for the FW. We then must see the effect on overall efficiency and also find space for the divertor and the blanket collector and exhaust. This option may work better for liquid metal options.

III.2.A - Divertor Features and Layout

Functional Requirements:

1. Assess trade-offs in power and particle handling shared between the FW and divertor.

For all divertor schemes, we must look at the trade-off between heat loads to the FW and divertor and how the proximity of the FW to the plasma influences pumping, impurities, etc. at the FW.

2. Assess helium pumping - a) He entrainment, b) He exhaust

There may be some evidence for the potential for He entrainment as useful pumping mechanism, but there is also conventional wisdom from PSI researchers against this. Without adequate pumping by entrainment, a conventional pumping duct of adequate size must be located in a region of appropriate pressure to provide adequate He exaust.

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III.2.A - Design Features and Layout - *continued*

Features/Requirements - Establish the functional features of the divertor schemes and identify the main requirements. Three activities will proceed in parallel.

Collector and Pump Design

Divertor Stream Options

Helium Exhaust System

thick wall and thin wall options?

- Start with cartoons/drawings to illustrate the main features, then move to basic CAD type drawings.
- Request CAD work sooner for the collector design and He exhaust to assess physical constraints.

Work overlaps with the work for the FW and blanket; part of this mechanical design work seems to be included in Task III.1.

III.2.B - Thermal and Hydraulic Analyses

Heat Removal - We need to evaluate the potential of various concepts to handle the (assumed) heat loads. This initial evaluation does not require very sophisticated treatment.

Detailed 3-D hydraulic analysis and work on nozzle designs will be needed as the divertor schemes develop.

For analyses of 3-D flow, assistance from UCLA, probably Sergei Smolentsev, would be useful. There again seems to be overlap with the liquid wall Tasks III.3, specifically, the injector nozzle analysis to be done by ORNL for the upper injectors for the FW and blanket. Also, the analysis in ALPS of a nozzle for liquid metal divertors will be helpful.

III.2.C - Particle Pumping & He Exhaust

Particle load - source term from plasma edge (Task III.3)

Particle trapping (implanted/entrained He/T/D - PSI model, e.g., residence time for He/D/T based upon the Flibe temperature and the implantation energies.

He pumping - He pressure near exhaust (Task A)

Particle removal - separation system (He/ D/T), Task III.4).

Assumption A: He entrainment - estimate total He removal in FW and divertor

Assumption B: He exhaust - design exhaust duct given He pressure at divertor location

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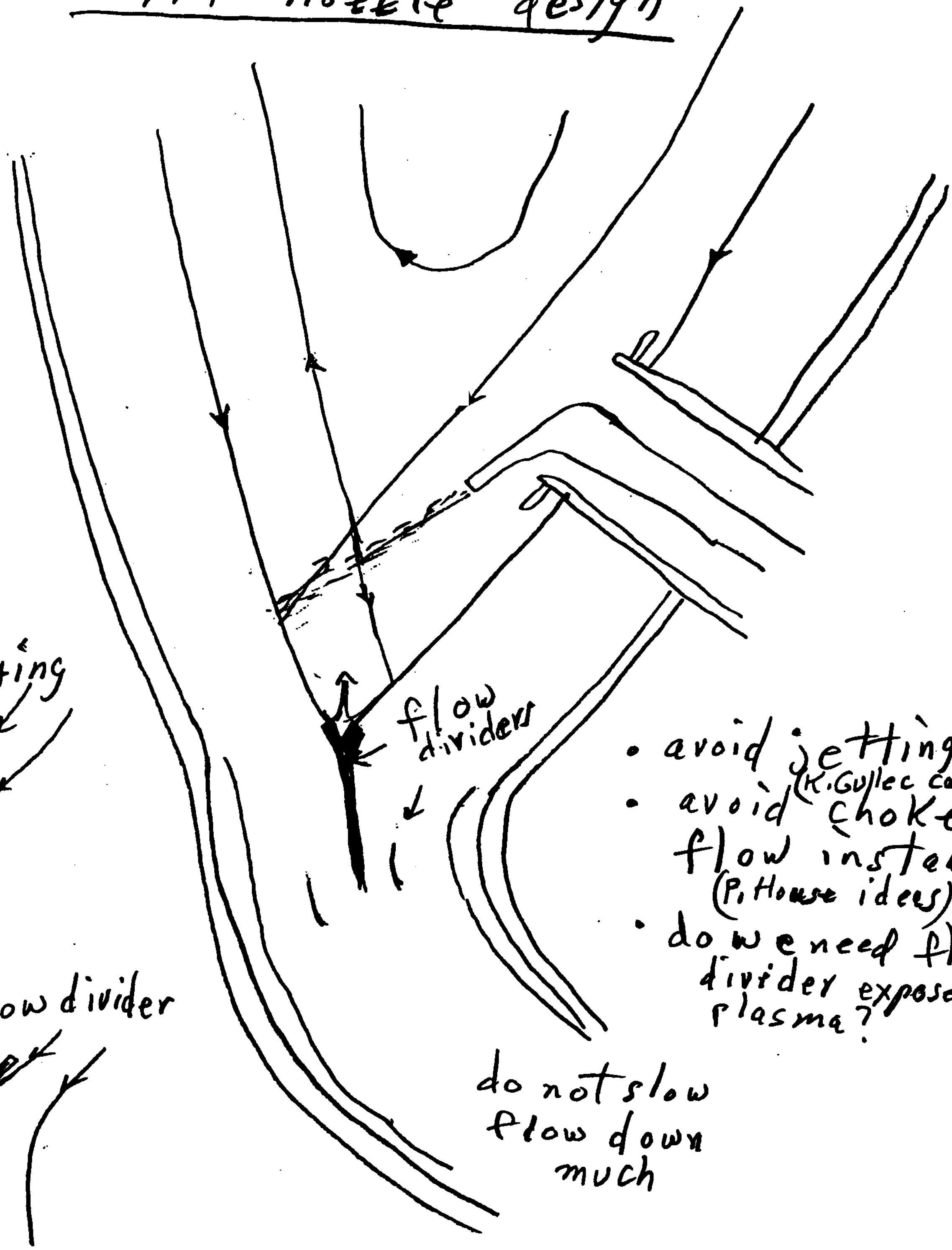
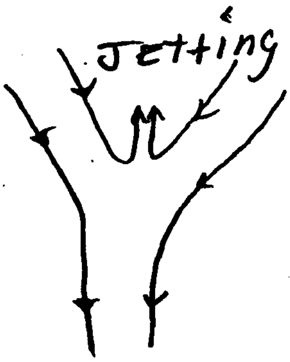
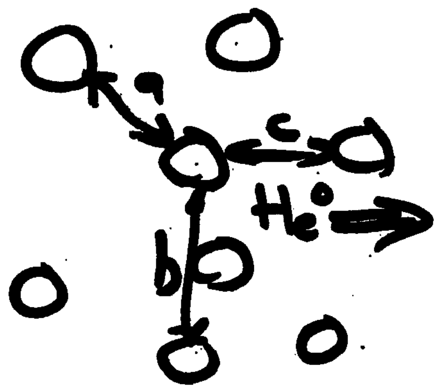
Exit "nozzle" design

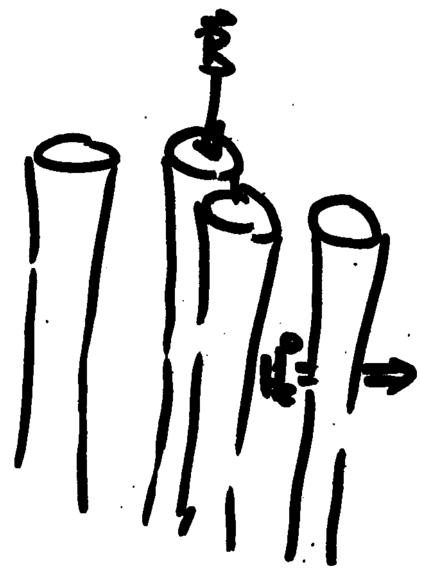


- avoid jetting (K. Gullec calculations)
- avoid choke flow instability (P. House ideas)
- do we need flow divider exposed to plasma?



Divertor "Stream" Issues





PSI • He reflection, thermal emission

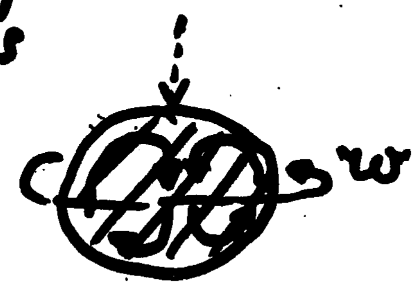
edge • He/D/T particle flux (extended SOL?)
" " + He pressure

PSI • source sink term for evap.

TH • effect of curtain density & SOL on heat/particle loads

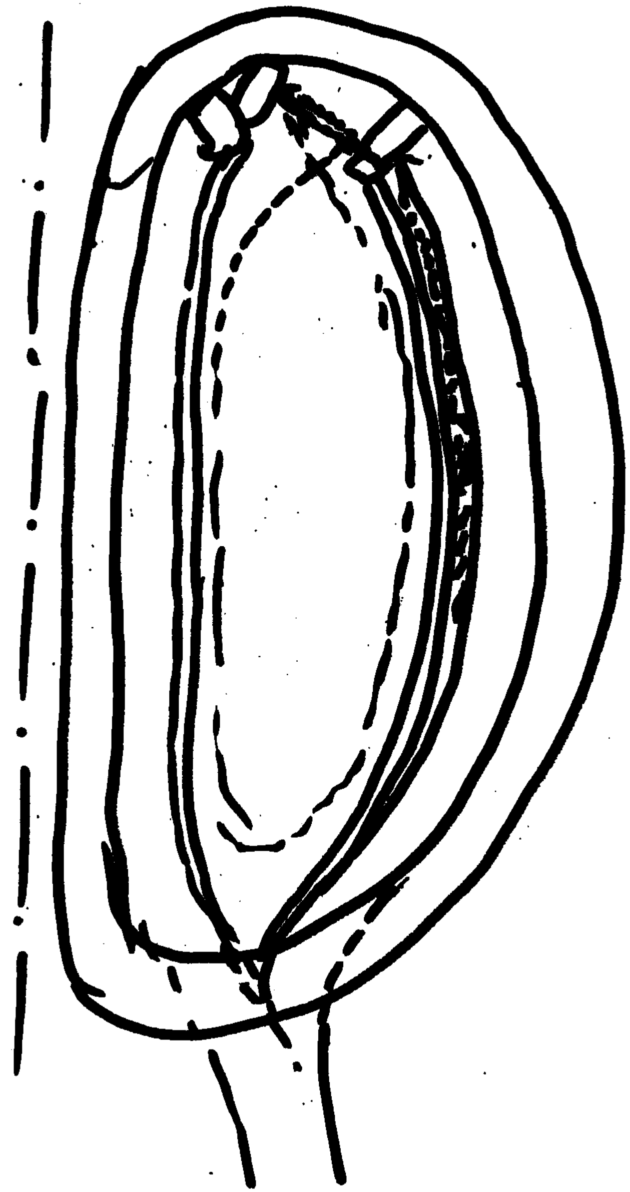
SNL

TH • effects on heat transfer of turbulence rotation



Ulrickson "Invertor"

Put divertor on top
Let stream merge with blanket (rather than FW)
Eliminate separate collector for div.
Let bottom of chamber be for fluid collection.



Beneficial Cooperation

The divertor integration subtask will involve cooperation from several areas within APEX and will also benefit from cooperation with ALPS and ARIES.

Within APEX, divertor integration will involve cooperation with the plasma edge and plasma-materials interactions work (Task A) and with the liquid wall work (Task II).

The APEX divertor integration task will also utilize cooperation with ALPS and ARIES as the ARIES divertor design develops and as ALPS goes forward with nozzle and collector designs.

APEX Task III.2 Div. Integ. Subtasks	+coop+	SNL	UCLA	ORNL	ANL
a) Design for Divertor Functions		70k	10k	in III.1	
Establish functional requirements for:					
heat load and particle pumping	Task A	X			
collector space, flow and pumps	III-1.b,3.b	X		X	
Develop divertor stream options					
Natural divertor	III-1.b,3.b	X			
Augmented flow divertor	III-1.b,3.b	X			
nozzle/jet flow modifications	II-1.c	X	X	X	
EM driven flow modifications	II-1.c	X	X		
Separate flow divertor	III-1.b,3.b	X		X	
CAD drawings, divertor and collector	III-1.b			X	
b) Hydrodynamics & Heat Transfer		20k	30k	in III.1	
preliminary heat removal evaluation	II-2.a	X			
3-D hydraulic analyses	II-2.a		X		
effect of vaporization					X
c) Particle Pumping and He Exhaust		20k		in III.1	
He entrainment calculations	Task A				
He exhaust system	Task A	X		X	

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APEX-Task I. NSTX

Subtask I.2b Divertor Integration	+coop+	SNL	ORNL
• Options for Divertor Integration		15k	in I.2a
Establish functional requirements for:			
heat load and particle pumping	Task A,C	X	
collector space, flow and pumps	III-1.b,3.b	X	X
Assess "natural" divertor option	III-1.b,3.b	X	
CAD drawings, divertor and collector			X
• Particle Pumping			
H entrainment calculations	Task A,C		
• Hydrodynamics & Heat Transfer			
preliminary heat removal evaluation	I.2.c	X	
Subtasks I.4 LM facility I.&5 R&D Plan		10k	in I.2a
• input, possible experiments & R&D plan			

During FY2000, SNL work in this area will be primarily an extension of Task III.2 and not additional independent work.

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APEX-Task III.2 Revised	+coop+	SNL	UCLA	ORNL
a) Design for Divertor Functions		30k	10k	in III.1
Establish functional requirements for:				
heat load and particle pumping	Task A	X		
collector space, flow and pumps	III-1.b,3.b	X		X
b) Develop natural divertor for Cliff		10k		in III.1
preliminary heat removal evaluation	II-2.a	X		
CAD drawings, divertor and collector	III-1.b			X
c) Develop divertor options for thick wall		20k	30k	in III.1
preliminary heat removal evaluation	II-2.a	X		
3-D hydraulic analyses	II-2.a		X	
c) Particle Pumping and He Exhaust		20k		in III.1
He entrainment calculations	Task A			
He exhaust system	Task A	X		X

"Payoff" is really for thick wall designs if they are indeed feasible.

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