

APEX Mechanical Design Considerations

presented by B. Nelson

APEX Meeting
UCLA

May 7, 1998

Presentation Outline

- Status of Activities for mechanical design and availability group
- General Design Requirements and Concept Information
- First thoughts on flowing liquid concept
- Summary

Concepts vs Configuration

- Which concepts are suitable for which configurations?
- Which configurations are preferred for mechanical design work?

Concept	Advanced Tokamak	ST	Stellarator	FRC / Spheromak	RFP (pulsed)
Convective (thin) liquid wall (Neil Morley)	Yes				No?
Thick liquid wall / partial blanket (Alice Ying / Ralph Moir)	Yes				No?
Magnetically restrained thick liquid blanket (Robert Woolley)	Yes				No?
Free falling Li ₂ O Particulates (Dai-kai Sze)	Yes				
Helium cooled solid refractory wall (Wong / Ulrickson)	Yes				Yes?
Liquid metal jet cooled solid refractory wall (Malang)	Yes	Yes	Yes	Yes	Yes?

ARIES RS Parameters

ref <http://aries.ucsd.edu/PUBLIC/ariesrs.html>

Major Radius	5.52
Minor Radius	1.38
Plasma Aspect Ratio	4
Number of Sectors	16
Fusion power (MW)	2170.5
Neutron Power (MW)	1735.5
Alpha power (MW)	433.1
Fusion power density (MW/m ³)	6.38
Average neutron load (MW/m ²)	4.03
peak neutron load (MW/m ²)	5.67
Average FW surface heat flux (radiative), MW/m ²	0.4
Peak FW surface heat flux, MW/m ²	0.47

Liquid Wall Concept

- Thin layer of fast flowing liquid intercepts surface heat flux
- Thick layer of slower flowing liquid intercepts neutron flux

Goals:

Nothing inside vacuum vessel but liquid

Cooler fast stream to keep vapor pressure low

Hotter thick stream for more efficient heat recovery

Sufficient shielding to protect vacuum vessel, allow rewelding

Mechanical Design Challenges for Liquid Wall concept

The following features must be included:

- Film forming device
- Film collecting device
- Concept for starting system
- Concept for providing heating and diagnostic penetrations
- Vacuum pumping concept
- Divertor concept

Mechanical Design Issues for Liquid Wall concept

A few of the issues include:

- How do you move $\sim 10^5$ kg/s of Li or Flibe in and out of the machine?
- How do you separate the thin and thick flow regimes?
- How do you start the two streams?
- How far can the stream flow before narrowing or becoming unstable?
- How do the passive stability currents move the surfaces around?
- How do you accommodate a double null configuration?
- What are the failure modes?

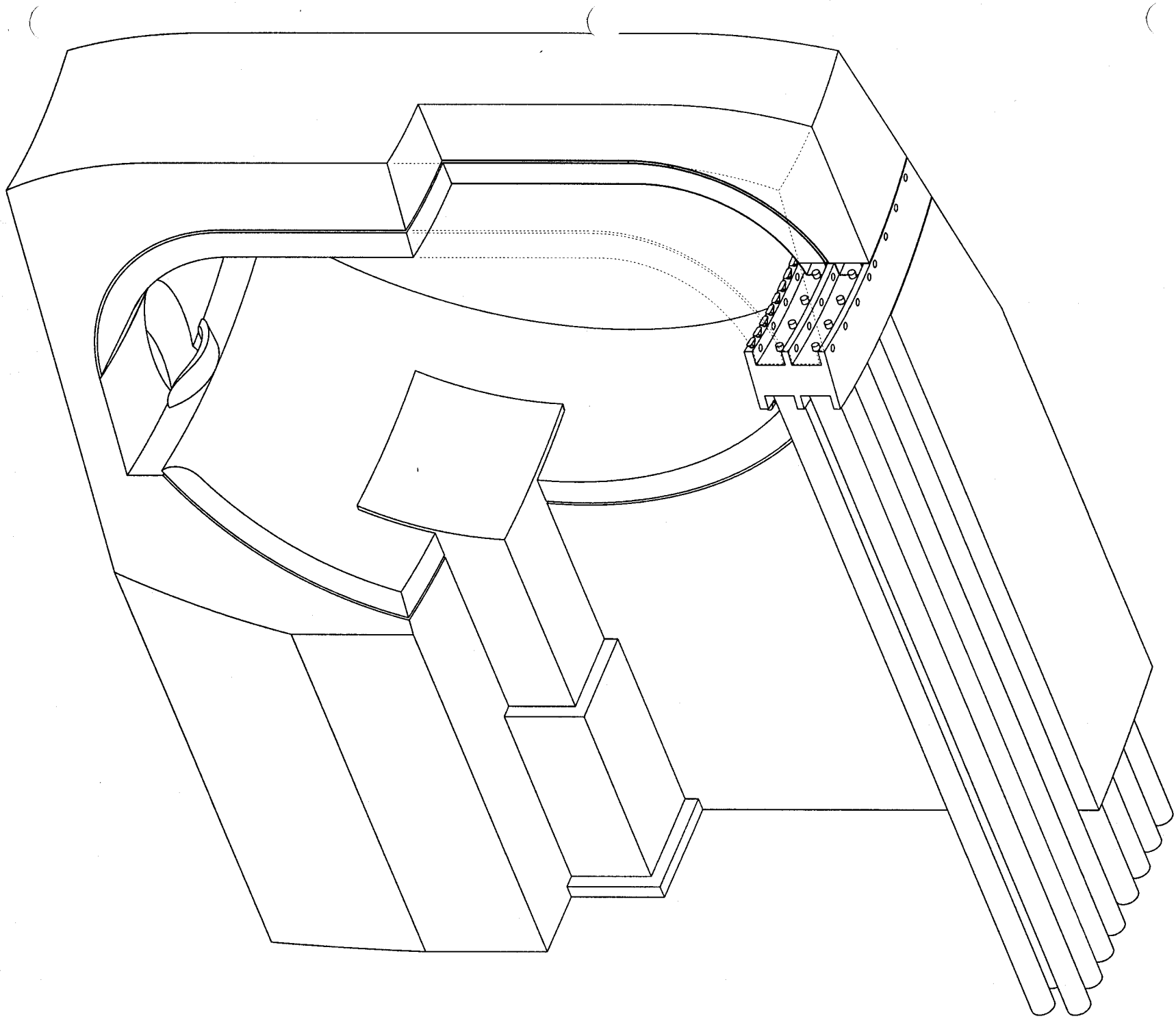
Mechanical Design Approach for Liquid Wall concept

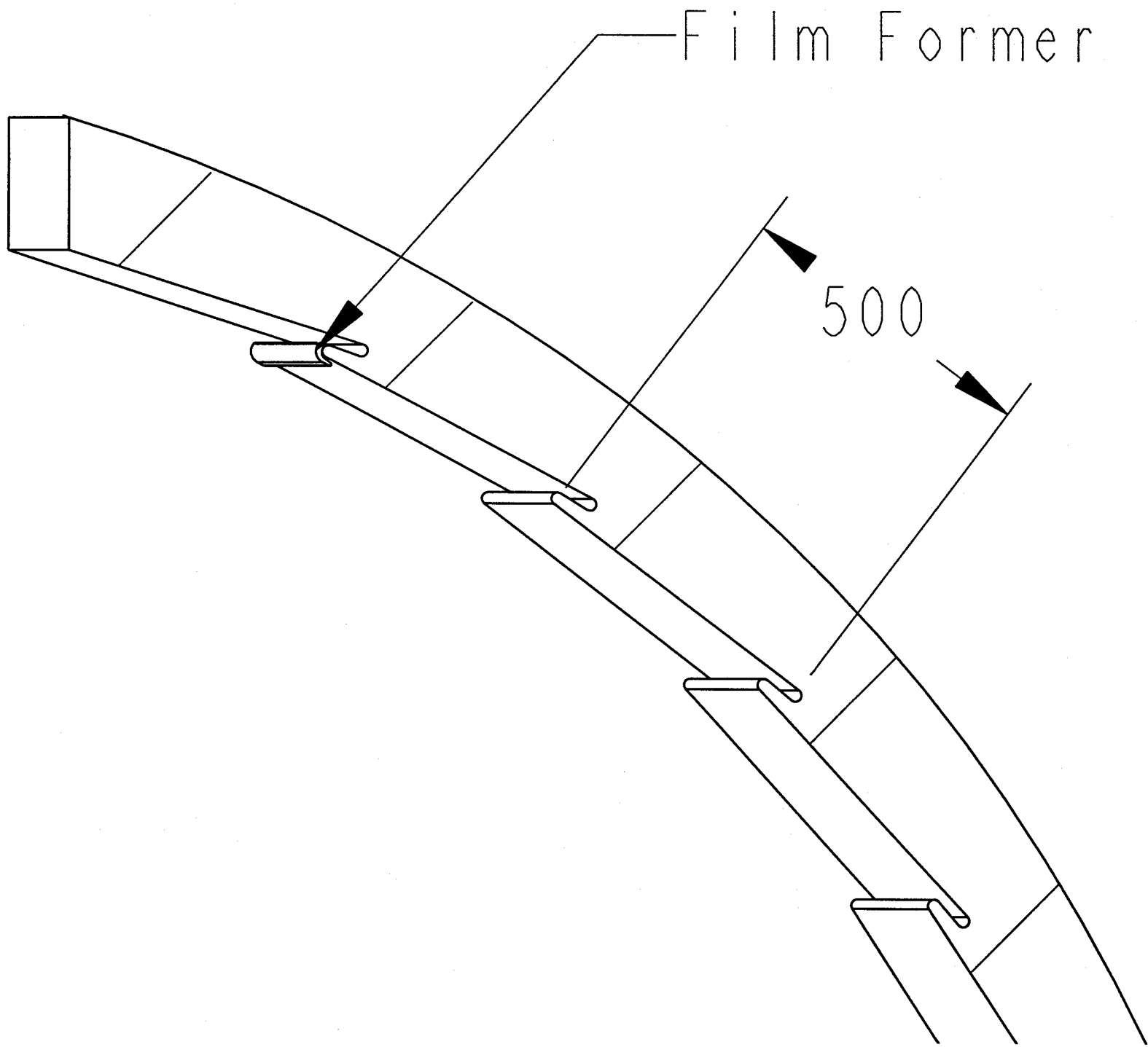
- Start with ARIES-RS as basic configuration
- Try to incorporate features for thinner, fast moving FW stream
- Leave slower, thicker stream within a solid boundary (ie, look at thin fast stream first)
- Iterate design with concept advocates

Liquid Wall Features

Film Forming Device

- Located at top of blanket/maintenance module
- Performs several functions
 - Splits stream into inboard and outboard paths
 - Distributes stream uniformly in toroidal direction
 - Imparts sufficient velocity (20-30 m/s?) in poloidal direction
 - Provides adequate shielding
- Is protected from plasma by additional jets?





Liquid Wall Features, (cont'd)

Film Collecting Device

- Located at bottom of machine under blanket module
- Toroidally continuous slot with ducts btween TF coils leading to collection tank

Divertor

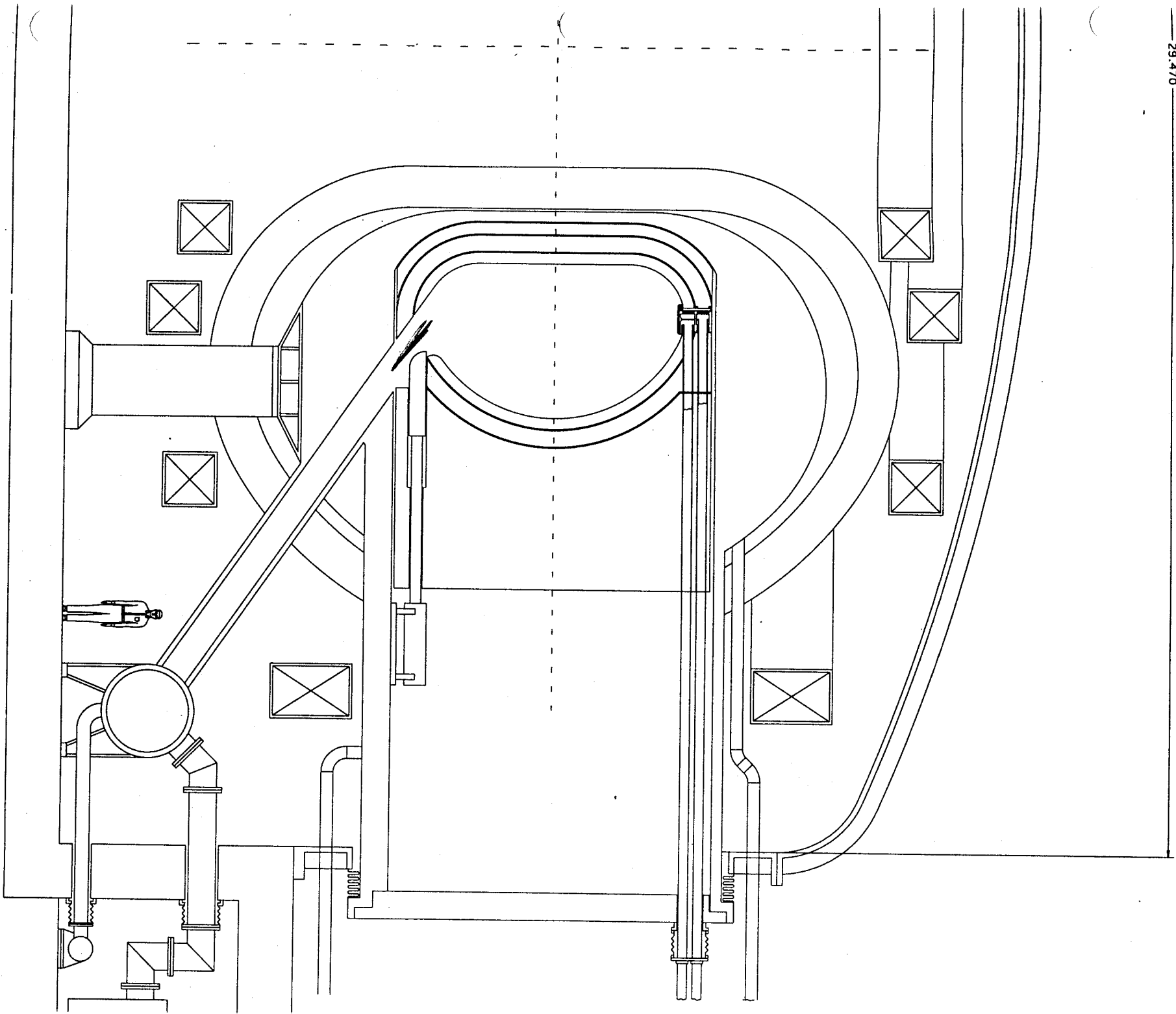
- Located at bottom of blanket only, single null configuration
- Film in collecting stream should be adequate for divertor, since 85% of power has already been accounted for at first wall
- Additional jets could be provided if necessary

Vacuum Pumping

- Uses same duct as collection system, (“deflector” needed to create opening in stream?)

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Mechanical Design Priorities

- What should be done first?

Concept	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5
Convective (thin) liquid wall (Neil Morley)					
Thick liquid wall / partial blanket (Alice Ying / Ralph Moir)					
Magnetically restrained thick liquid blanket (Robert Woolley)					
Free falling Li ₂ O Particulates (Dai-kai Sze)					
Helium cooled solid refractory wall (Wong / Ulrickson)					
Liquid metal jet cooled solid refractory wall (Malang)					

Summary

- **Some Guidelines are proposed for Design Concept Evolution**
 - Basic Requirements for all concepts
 - Specific Concept Parameters must be defined (size, coolant, flow, etc)
 - Availability (must be included from onset of design, cannot be sprinkled on later)
- **ARIES RS, ARIES ST, FRC(?) are proposed as configurations to use for concept development**
- **First mechanical design activities started for thin liquid wall design in ARIES –RS**
- **Design activities will accelerate, propose one week workshop June 15-19 at UCLA**

Mechanical Design and Availability Group

Charter:

This group will be responsible for assisting all design conceptualization groups in developing mechanical design and integration. The group has responsibility for:

1. Vacuum boundary concept
(separate vacuum vessel, resistive shield, or other approaches)
2. Mechanical configuration
3. Maintenance approach (innovative ideas to enhance maintainability)
4. Reliability (suggestions for reducing failure rates and for fault-tolerant designs)
5. Minimum wall thickness
6. Fabrication techniques

Members:

Chair: Brad Nelson, ORNL

Others from ORNL, including Paul Goranson, Paul Fogarty, John Haines, Dave Lousteau (ITER JCT)

Mark Tillack, UCSD

Siegfried Malang, FZK

M. Dagher, Alice Ying; UCLA

Don Clemens, Rocketdyne

Igor Sviatoslovsky (UW)

Status of Activities

Progress:

- Reviewed ARIES RS design and obtained CAD files
- Took first pass at incorporating thin liquid wall in ARIES RS configuration

Plan:

- Begin to assist design advocates with specific designs (incl workshop / meeting at UCLA June 15-18)
- Review vacuum topology again
- Identify availability issues and possible improvements for specific designs

Goal and Scope

General Goal:

Develop attractive Fusion Power Technology system

Fusion Power Technology, FTP, is defined to include*:

- Vacuum environment
- Plasma exhaust
- Power extraction from plasma particles and radiation
- Power extraction from neutrons and secondary gammas
- Tritium breeding
- Tritium extraction and processing
- Radiation protection (shielding + confinement)

APEX is focused on power extraction, but other items must be considered

* ref. M. Abdou, APEX kick-off meeting, Oct. 15, 1997

General Mechanical Design Approach

- Develop Requirements

- Identify Generic configurations
 - ARIES - RS
 - ARIES - ST?
 - FRC?

- Produce strawman design for each concept
 - Identify main features of concept
 - Provide 3-D layouts with space blocked out for piping, special components, etc.
 - Identify changes to generic configuration, if any
 - Determine if any requirements must be relaxed

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) Reweldable 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
Safety	confinement boundaries	2?

* Values are minimum goals for steady state operation

Other Design Assumptions

Function	Requirement	Value/Goal
Plasma Exhaust	Divertor required	to remove helium
Penetrations	Plasma Heating Power Density - NBI - ICH	~4 MW/m ² ~6 MW/ m ²
	Diagnostics	TBD
Operating Parameters	Pulse Length Number of pulses Disruptions	Steady State TBD TBD
Availability	Maximize total availability	$A_{\text{plant}} > .75$ $A_{\text{blanket/FW}} > .98$

Concept Information needed by Mech Des. Group

- **Device type**
 - Point design device (conventional tokamak, ST, stellarator, RFP, etc.)
 - Limitations (will only work for _____)
- **Configuration**
 - General - 1 m² chunk of the FW/blanket, including materials
 - Integrated - schematic of system for point design device (eg, tokamak)
- **Size/total power:**
 - Point design – Assume equivalent to 1 GW electric power? for developed concept
- **Shielding:**
 - thickness required for breeding
 - thickness required to limit coil heating/insulator damage
- **Coolant parameters:**
 - cooling media (lithium, flibe, helium, solid, combination)
 - flow rate per unit FW area or unit power
 - inlet and outlet temperatures
 - inlet and outlet pressure and pumping method