Fusion Science and Technology

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Fusion Science and Engineering

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Fusion Energy Promise

Fusion Energy offers the long term potential to provide safe, environmentally attractive, and economically competitive energy source for future generations with a virtually unlimited fuel supply.

Scientific and Technological Challenge

A grand challenge for science is to develop the advanced technologies and materials for a practical and attractive fusion energy source. This challenge can not be met today with current knowledge and available materials and technologies. Only through advances in science and innovative solutions to develop improved materials and advanced technologies will the fusion promise of an attractive energy source for future generations be realized.

UCLA Fusion Science and Engineering Program

- Contribute to meeting the fusion challenge through making advances in engineering sciences and providing innovative solutions to critical technological issues.
- Train graduate students in multidisciplinary fields

Exciting News

(March 1997)

UCLA has been selected to be the lead US organization for Inertial Fusion Wall Protection Research

We have won a new major research grant from DOE.
(Competition has been very strong from other universities and national labs.)

Scope

- Develop innovative ideas to protect the first wall of an inertial fusion energy system from very high loads of x-rays, target debris and neutrons
- Perform experiments (Scientific feasibility)
- Develop models and prediction capabilities
- Perform evaluation, analysis & design

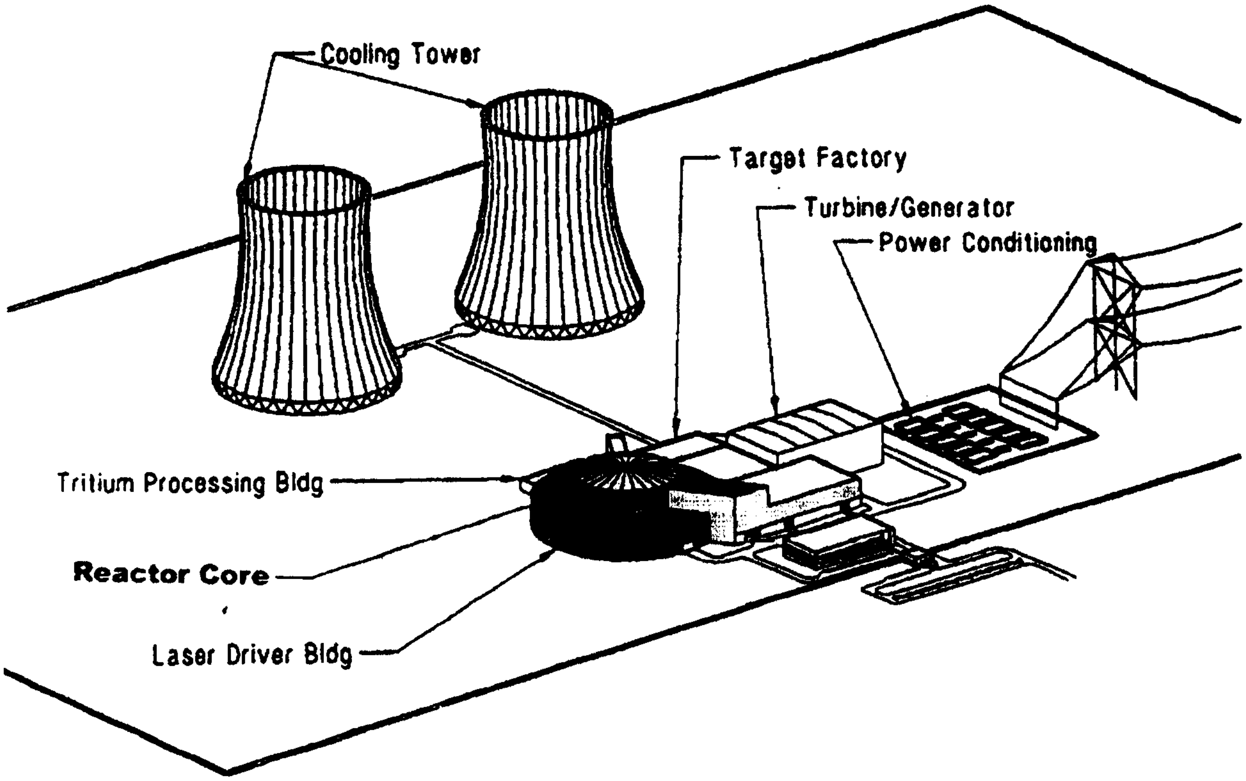


Figure ES-1. Prometheus-L Plant Site Trimetric View

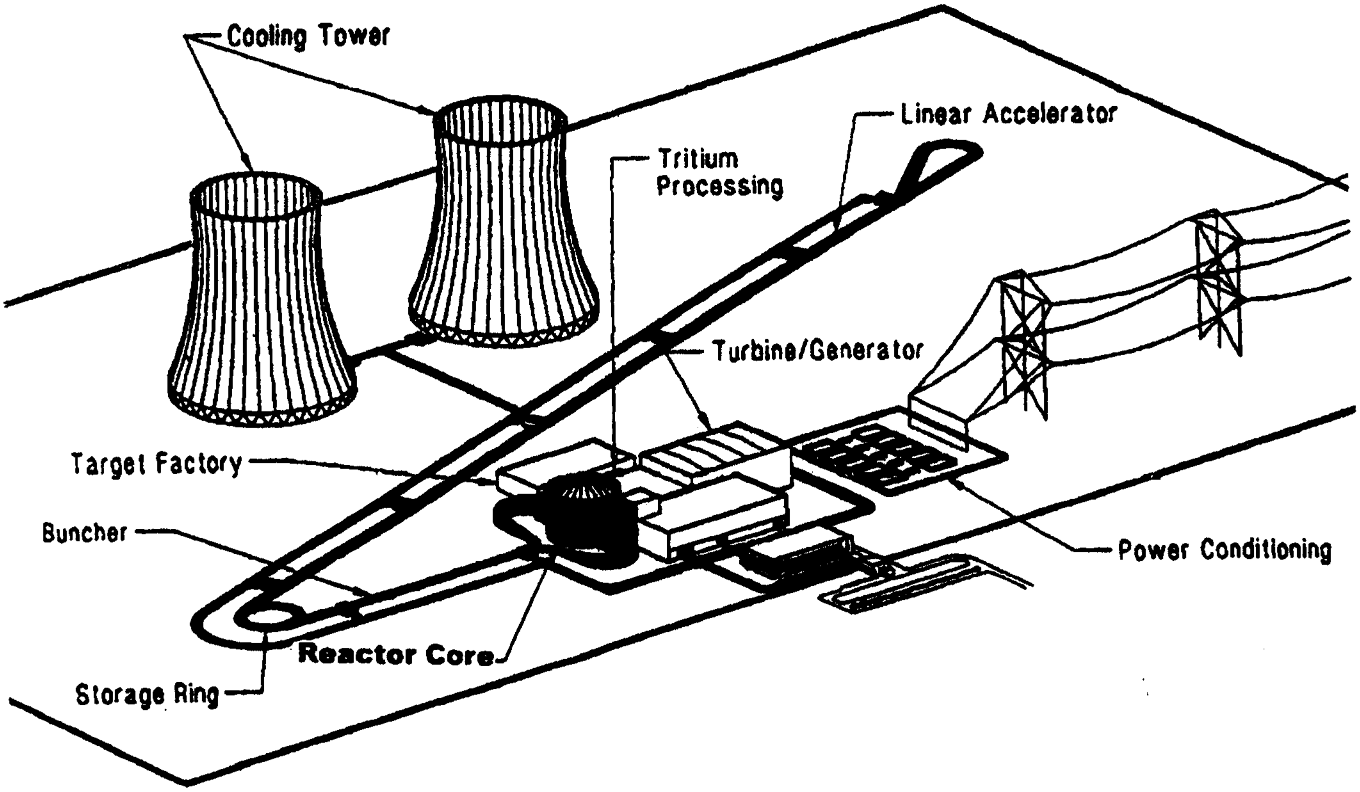
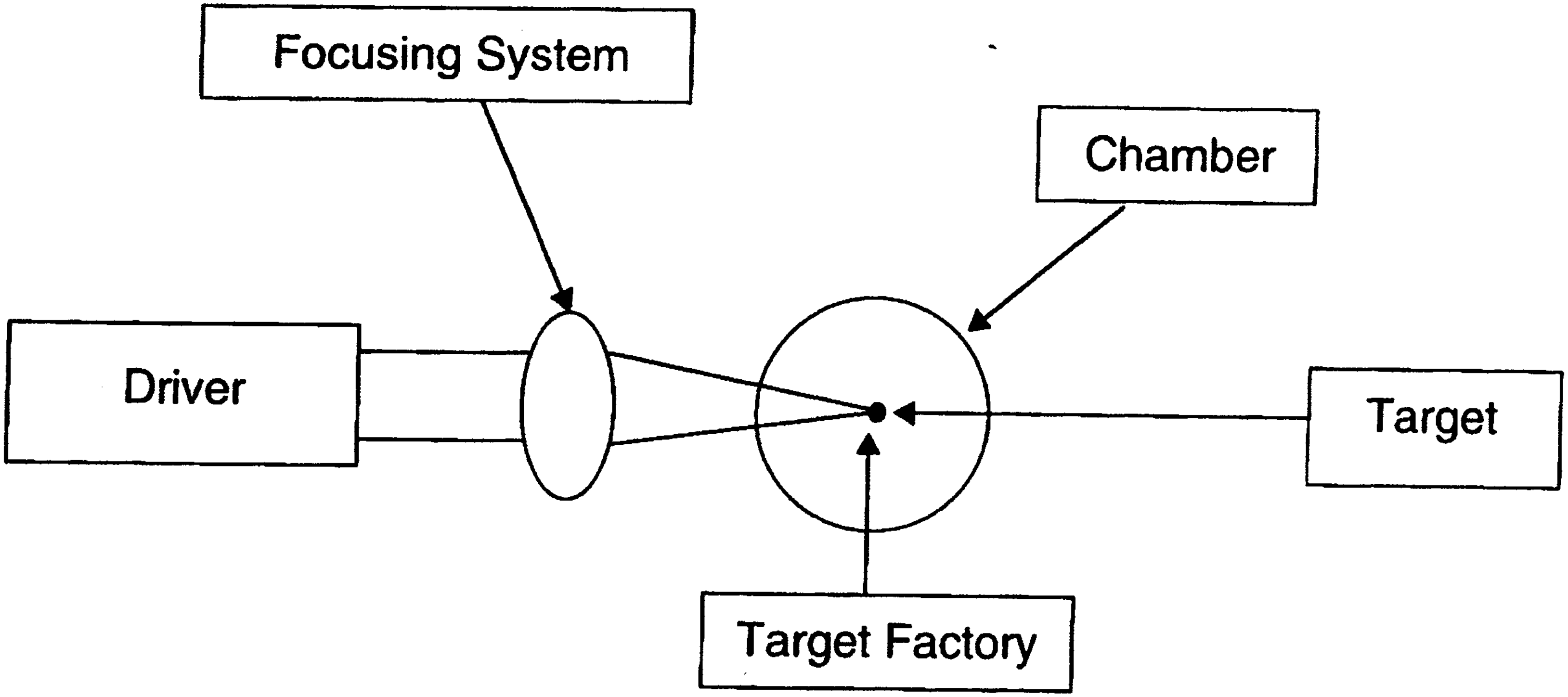


Figure ES-2. Prometheus-H Plant Site Trimetric View

The core of an inertial fusion power plant has five main parts



- All five parts are essential.
- While interrelated, the parts are sufficiently independent to allow great flexibility in plant optimization and design.

Chamber Wall Protection

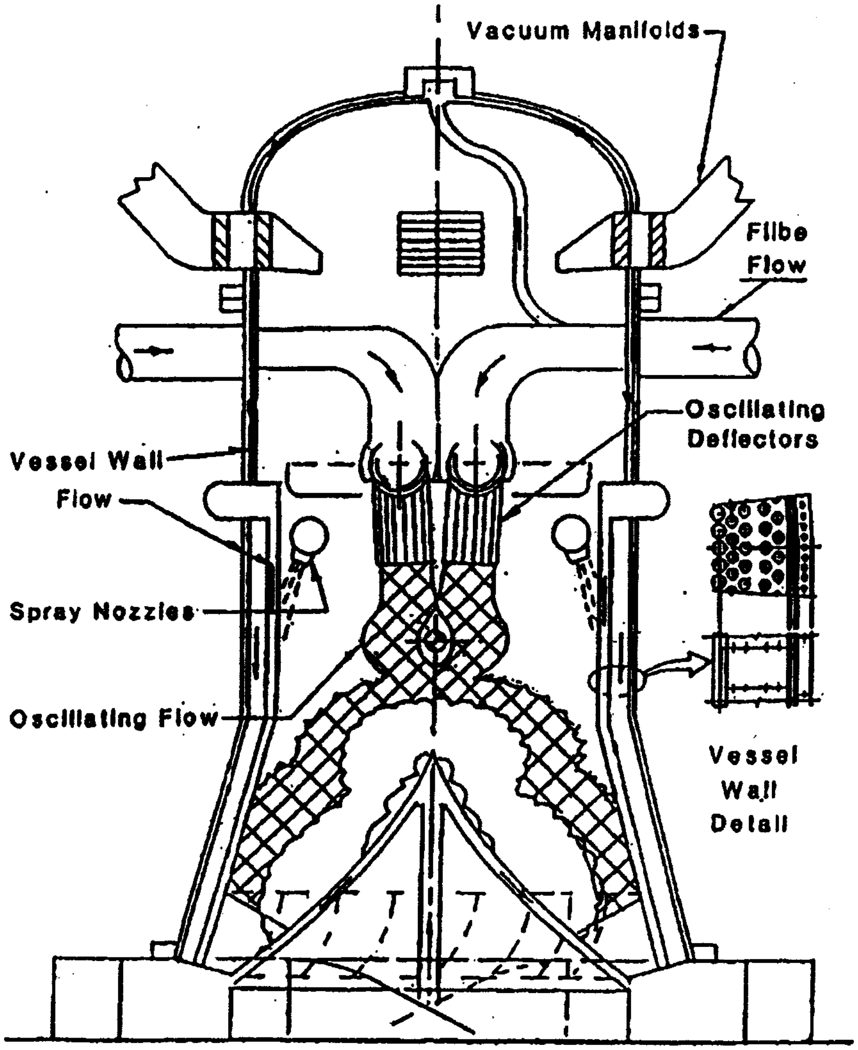
- Next to Ignition, Chamber Wall Protection is likely to be the most serious challenge to IFE.

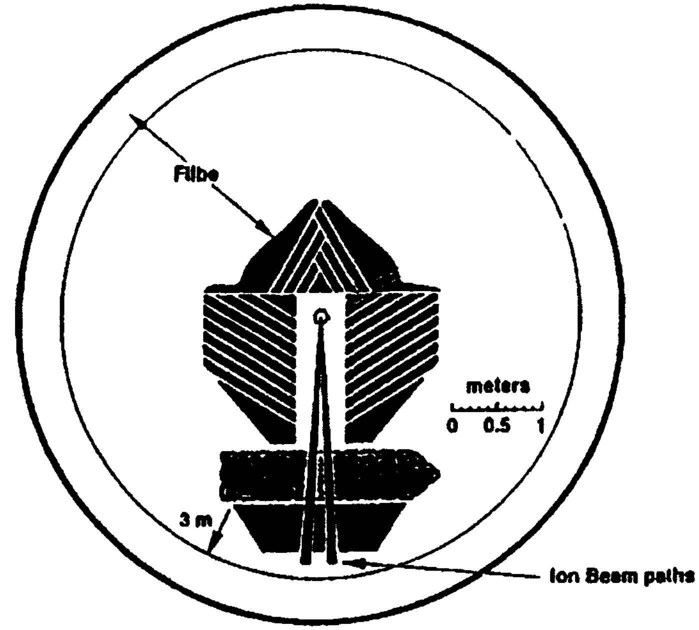
- Very high instantaneous loads of x-rays, target debris and neutrons can lead to serious ablation of surfaces and severe damage of structures surrounding the microexplosion:
  - Fatigue would also be a serious issue
    (> 10^8 cycles per year).

But, this is an excellent example of how a very serious technical <u>Problem</u> that can be turned into a Potential <u>Opportunity</u> through <u>Innovative</u> Design Solutions that Promise to give IFE unique advantages:

- Radically eliminate long-term activation of conventional structural materials.
- Make solid first wall life-of-plant component

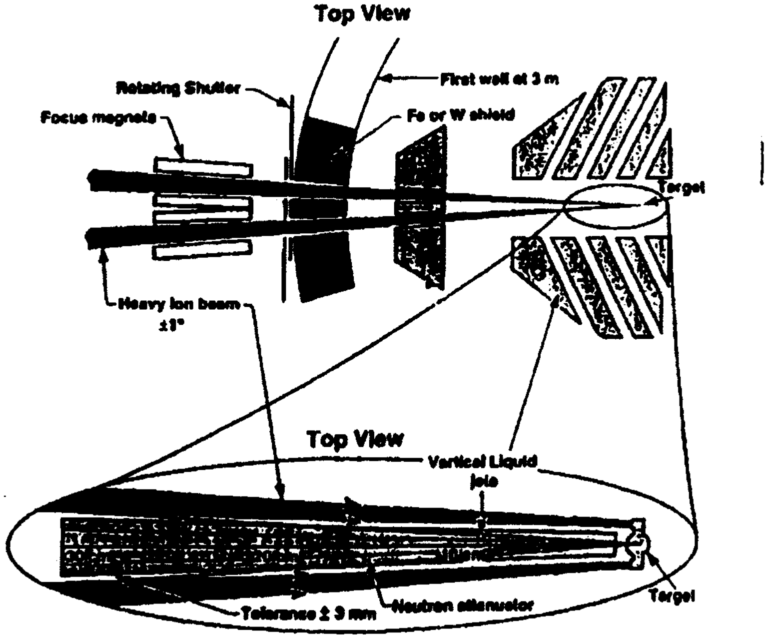
Thick Liquid Protection of Chamber Wall



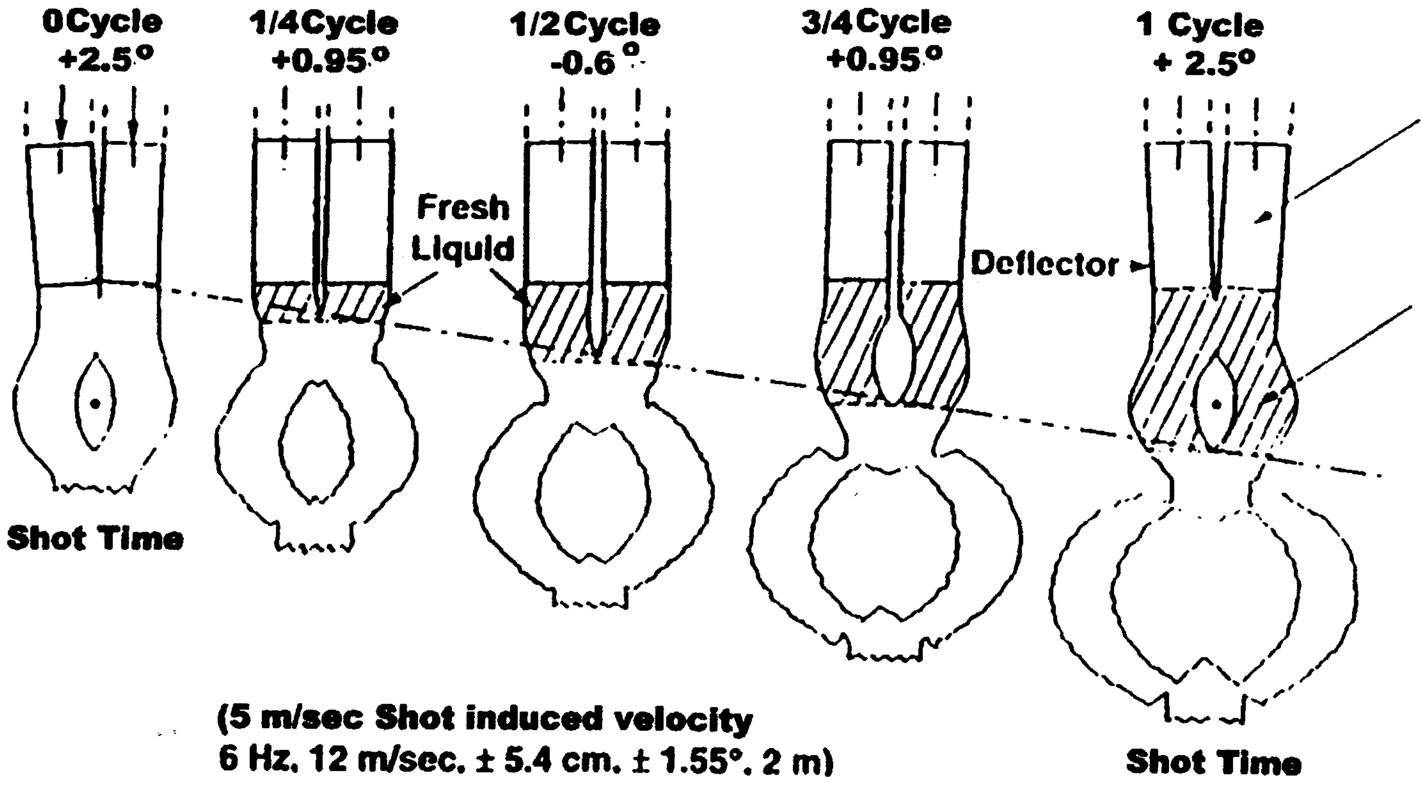


Cross Section through liquid

Top View



The Sequence Shows the Effect of Sweeping the Chamber Clear of Droplets



The 2-m-long deflectors move through + 1.55 or ±54mm

The liquid protects the ends of the deflectors from neutrons at shot time

**(5 m/sec Shot induced velocity
6 Hz, 12 m/sec, ± 5.4 cm, ± 1.55°, 2 m)**

Profound Implications of Thick Liquid Metal Protection for IFE Development

1. Conventional Stainless Steel would become "low activation material" in IFE solid first wall. It would qualify for shallow land burial.
   - (There is presently no other technically credible approach to achieve this goal in any DT fusion concept).
2. The solid first wall and the remainder of the blanket would have much reduced loading conditions. It would become a "simple technology" that could be built with essentially the current data base.
3. Life-of-the-plant structure even with current structural material.
4. It would almost eliminate the cost, time, and the very large uncertainties associated with new material development.

The Liquid Wall Protection Offers Opportunity for Challenging "Science" Research

The thick liquid metal protection design uses a curtain of oscillating and stationary molten salt (flibe) sheet jets to protect the reactor chamber solid wall and beam ports. The design concept relies on:

- Generating controlled and precise liquid geometries.
- And condensing ablated vapor on spray droplets, which also sweeps away the droplets rapidly to provide a clean path for target injection and beam transmission.

The current literature is inadequate for predicting the stability of such high velocity (high Reynolds and Weber numbers) jets in vacuum, exposed to turbulent fluctuations and large-scale secondary jets (Re = inertia/viscous, We = inertia/surface tension).

Characteristics of Liquid JET Protection (HYLIFE-II)

Quantity	Flibe	Quantity	Flibe
Jet Reynolds number	2.43×10^5	Nozzle oscillation frequency [Hz]	6.0
Jet Weber number	1.03×10^5	Nozzle oscillation amplitude [cm]	9.0
Jet thickness [cm]	7.0	Ambient pressure [atm]	~0
Jet width [cm]	100	Fluid temperature [°C]	660
Jet aspect ratio	14.3	Fluid density [kg/m^3]	1963
Jet fall distance [m]	2.0	Fluid viscosity [$kg/m \cdot s$]	6.78×10^{-3}
Jet velocity [m/s]	12.0	Fluid surface tension [N/m]	0.193
Jet volumetric flow rate [m^3/s]	0.84		
Jet dynamic pressure (pU_j^2) [Pa]	2.83×10^5		

Isochoric Heating and Outward Forces

- The thick liquid wall protection has to also serve as the blanket (partial) with heat removal and tritium breeding.

- The liquid blanket is subjected to forces associated with X-ray ablation, gas pressure (from drag), and shear (skin drag) that impart an outward radial motion toward the vessel wall.

- These contributions may be augmented further by the net effect of break up (fracture of the liquid) following neutron-induced isochoric heating of the blanket [Isochoric, constant-volume heating is the intense, instantaneous, volumetric heating that occurs as the fusion neutrons are absorbed in the liquid, generating internal pressures of hundreds of atmospheres].

- One estimate is that the liquid blanket will receive an average velocity of ~7m/s, which would result in impacting the bottom of the wall with low pressure. But many complex phenomena are involved and can not now be predicted with confidence.

Issues To Resolve For Thick Liquid Metal Protection

1. Hydrodynamic Stability of high Reynolds number jets in vacuum exposed to turbulent fluctuations and large scale secondary flows

2 To show that the condensation of the evaporated liquid is quick enough to permit the required pulse (repetition) rate without interfering with the passage of the beams to the target

3. To show that the incoming liquid clears the <u>splashed</u> liquid from a prior micro-explosion to not interfere with the target injection and ion beam propagation for the next shot

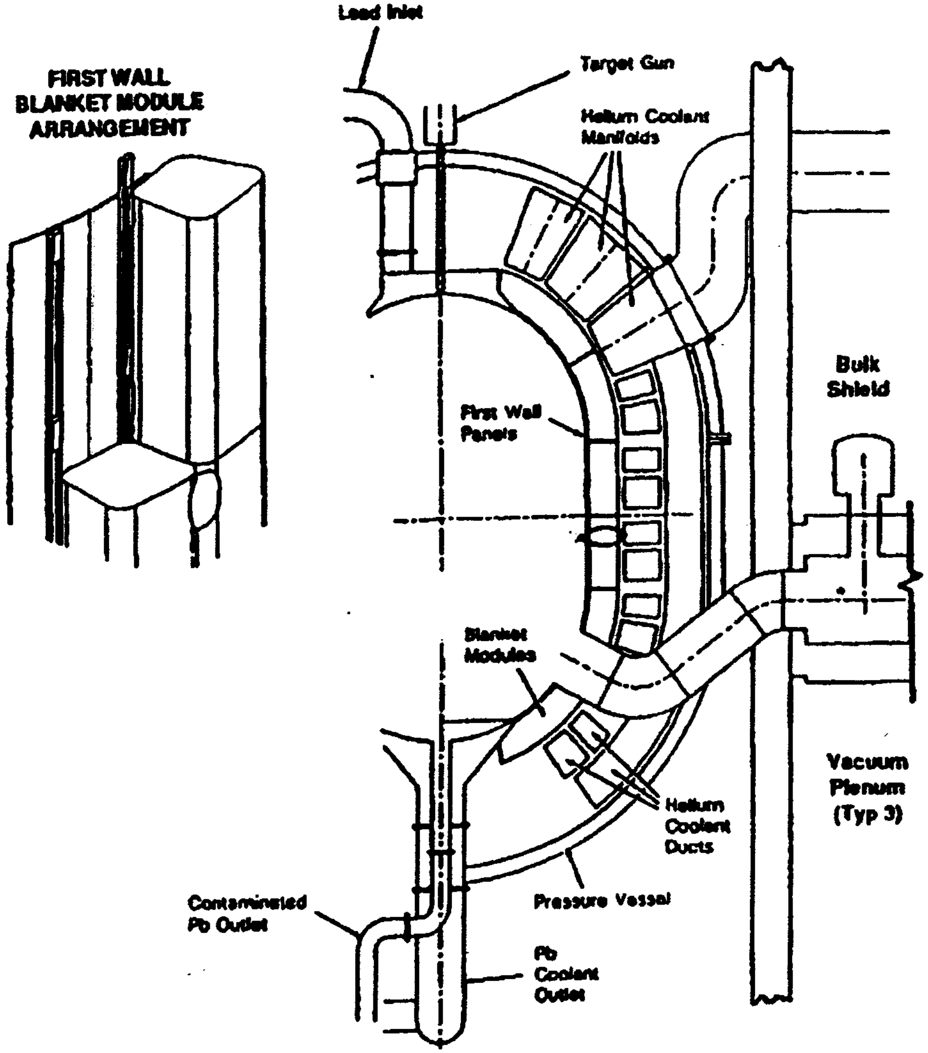
4. Show that the liquid jet configurations can be made to meet the required conditions (including protection of beam ports, particularly focusing magnets)

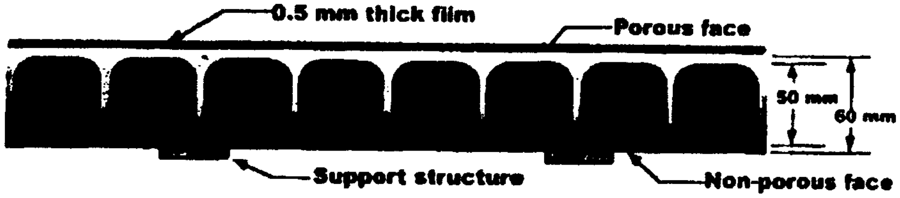
5. Reliability of metal nozzles and mechanical moving parts, including fatigue and vibration

6. Understand Isochoric Heating and Gas Venting to predict net outward momentum

7. Show that tritium self sufficiency can still be satisfied in a system that uses this concept

Thin Liquid Protection of Chamber Wall





First Wall Panel

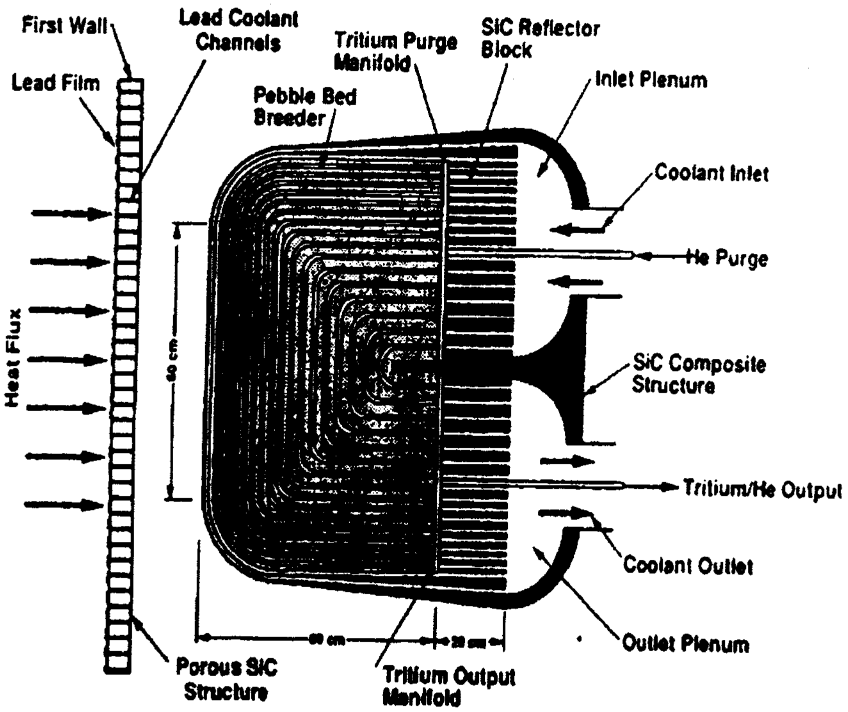


Figure 2.4-9 Schematic of a Blanket Module

Thin Liquid Film Protection Schemes for Inertial Fusion

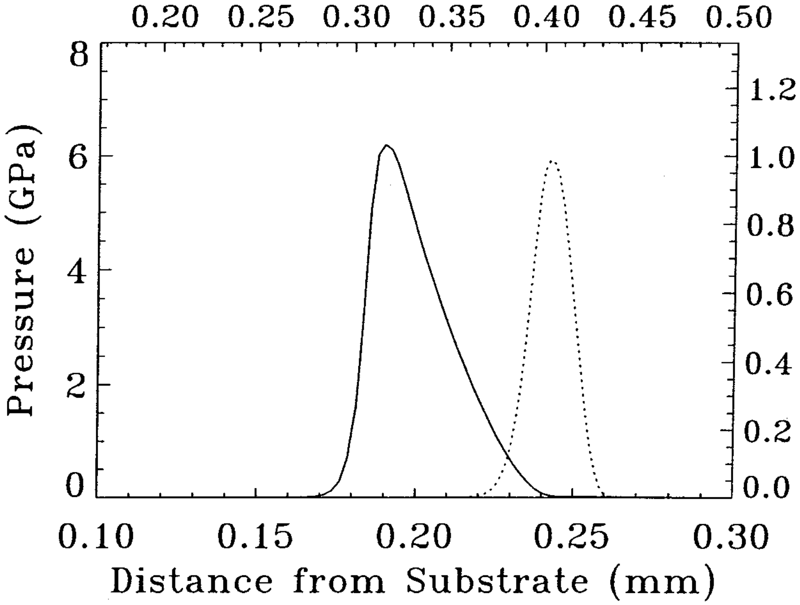
Shock waves in liquid films induced by X-Ray Ablation of the liquid surface

- Figure shows calculated pressure profiles for:

  Solid Line, Main Axes - 0.3 mm thick molten salt (Flibe) film in the Osirus reactor after 25 ns

  Dotted Line, Alternate Axes - 0.5 mm thick Pb film in the Prometheus reactor after 50 ns

- Both result in tensile pulses after reflection from the solid substrate on the order of several hundred MPa, which is probably not sufficient for film spallation



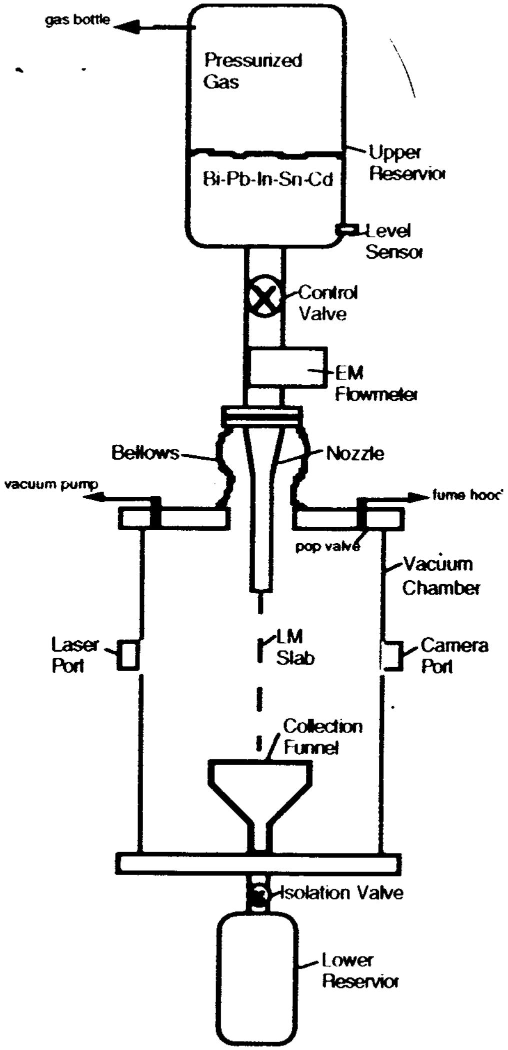
UCLA Turbulent Jet Experiments

Experimental Objectives:

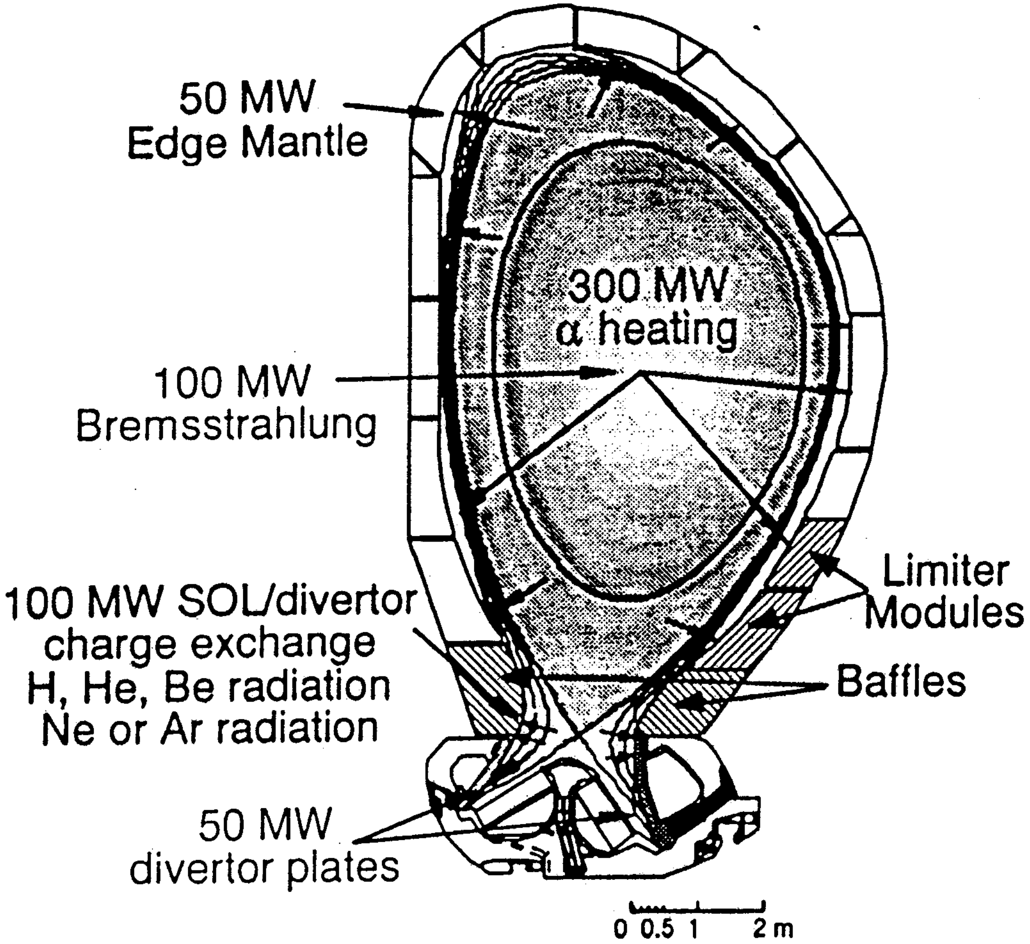
- realization of high Re, We number rectangular jet LM flow
- investigate jet breakup length and surface ripple in working region
- investigate stationary and forced oscillation jets

LM advantages:

- entrance into vacuum possible with no flashing of liquid
- thin elongated jets possible at low flowrates



High Heat Flux Components in Tokamak



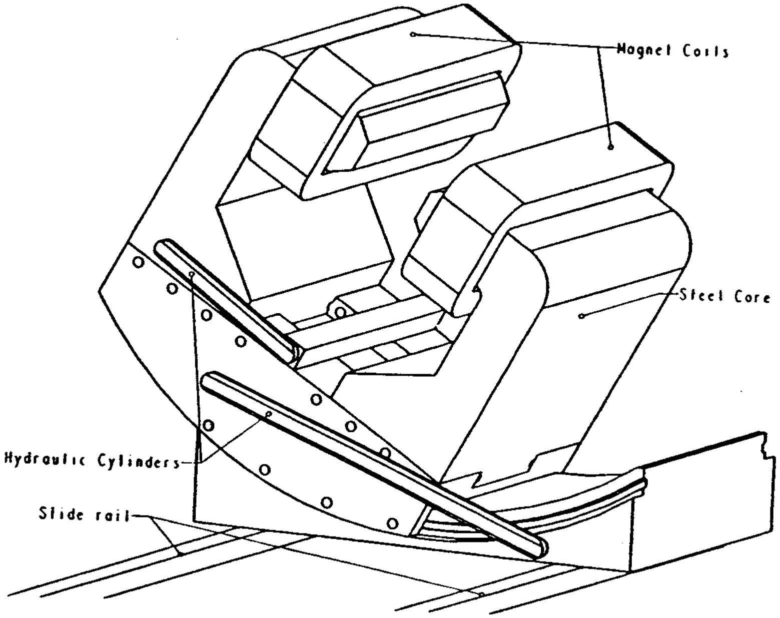
MeGA-Loop Magnet Upgrade

Features:

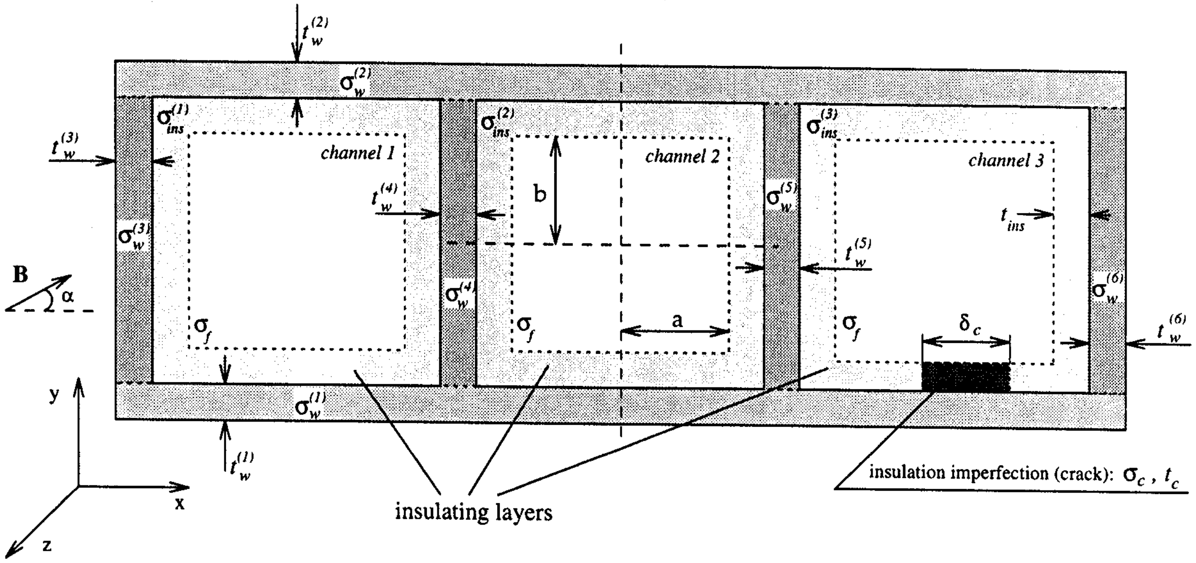
- Adjustable gap, 10–36 cm
- Max Field, 1.5 T
- Transverse inclination, 0–30°
- Axial inclination, 0–5°
- Axial translation, ±2 m
- Easy test article access

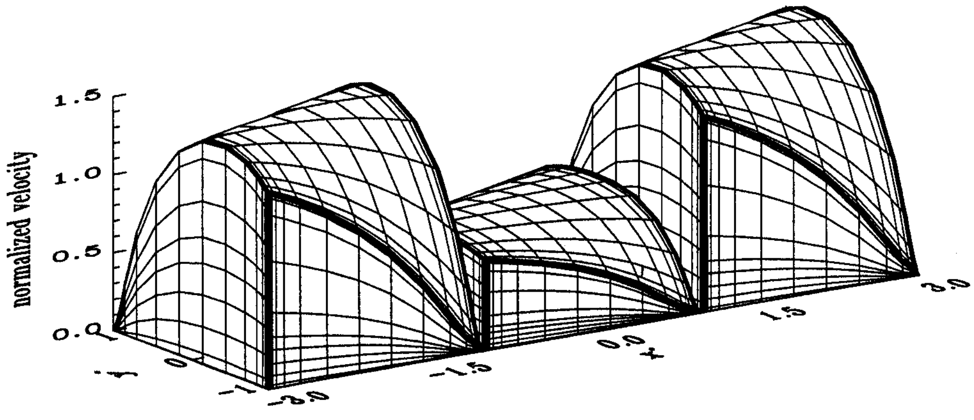
Components:

- Oil-Cooled Electromagnets
- Magnetic steel core
- Hydraulic rotation cylinders



Fully developed flow of liquid metals in a system of three straight rectangular ducts which are electrically coupled by common conducting walls covered with an imperfect insulating layer





Velocity profiles in three adjacent channels.
Ratio of the flowrate in channel #2 to the total flowrate $Q_2/Q^{\Sigma}=0.18$.

Hartmann number $M=10^4$, wall conductance ratio c=0.1, angle of the oblique magnetic field $\alpha=20°$. Perfect insulating layers in channels #1 and #3. Nondimensional resistance of the insulating layer $\theta=\frac{\rho_{ins}t_{ins}}{2bM/\sigma_f}=0.5$ in channel #2.