ISSUES OF DRY WALL IFE CHAMBERS

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ARIES Project Meeting

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Subjects Covered

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- **First wall protection schemes for dry wall IFE chambers with examples from several conceptual designs**

- **First wall issues of dry wall IFE chamber**

- **Other issues of dry wall IFE chamber**

- **Suggested scheme for target delivery in dry wall IFE chambers**

There are three ways of protecting the IFE chamber first walls from the X-rays and ion debris emanating from the target.

1) **Distance.** $\frac{1}{R^2}$ **increases the FW area, thus spreading the energy. Applicable to lasers, HIB, LIB. Propagation of ion beams over a long distance can be difficult.**

2) **Gas protection. A low pressure gas in the chamber stops X-rays and ions and radiates the energy to the FW over a longer time scale. Applicable to lasers and some IB.**

3) **Liquid walls. Energy is absorbed by evaporation of a liquid surface on the FW.**

Example of FW Protection with Distance: The Westinghouse IFE Power Plant Study, E.W. Sucov et al., 1980

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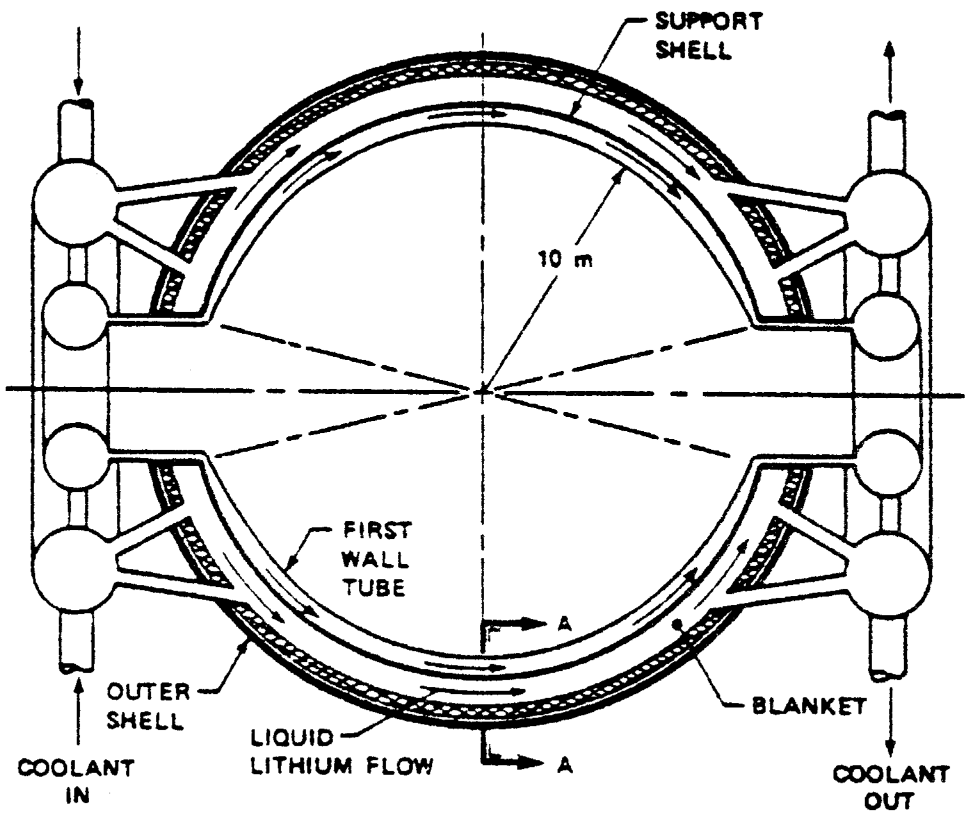
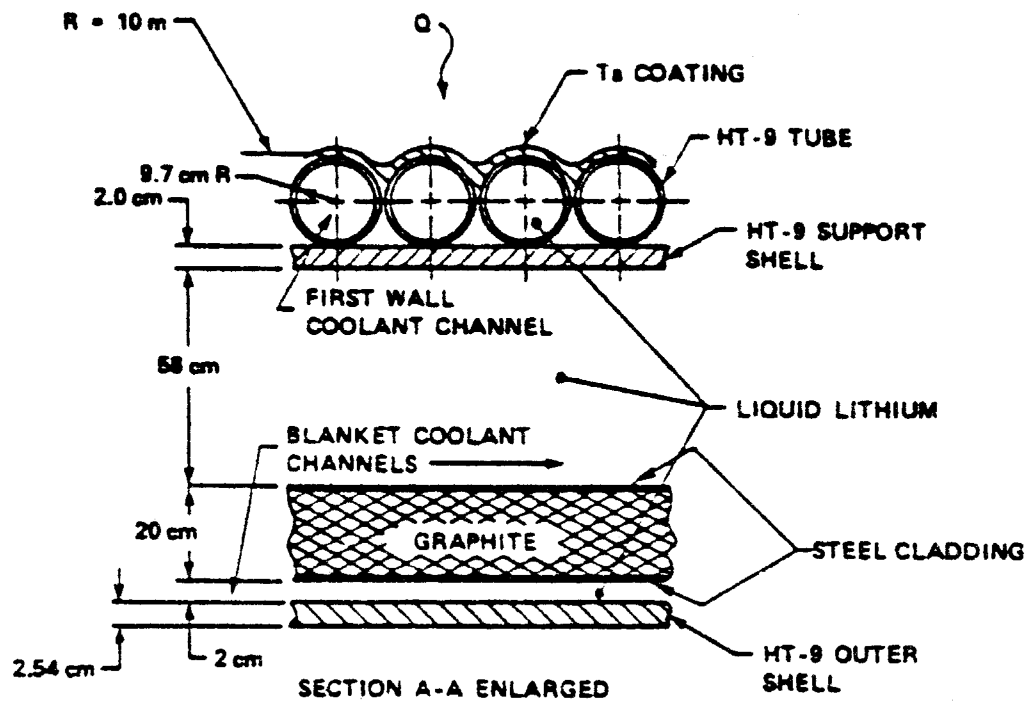


Cross Section of Reaction Chamber



Cross Section of First Wall

Main Conclusion of Westinghouse Study

- **The study has shown that the first structural wall of an IFE reaction chamber can be protected against damage due to X-rays and ion debris induced temperature transients by using a thin coating of tantalum.**

- **By choosing Ta as the coating material and as a heavy tamper in the pellet, problems of incompatibility are avoided.**

Examples of Laser Driven Dry Wall IFE Designs

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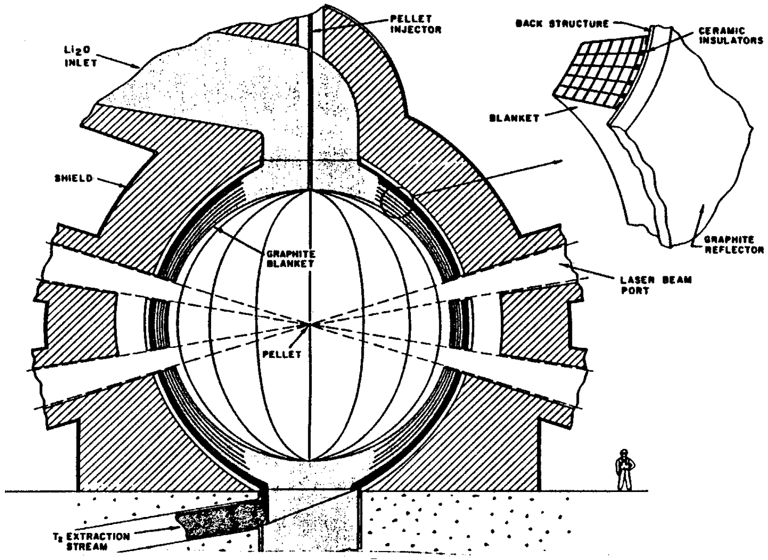
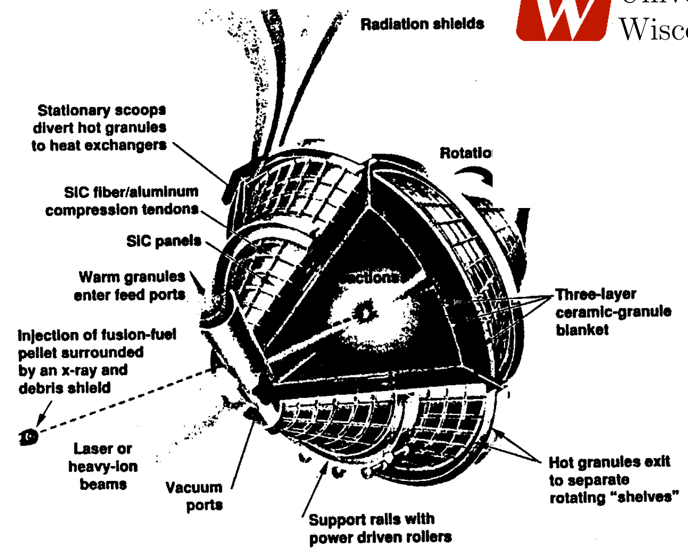
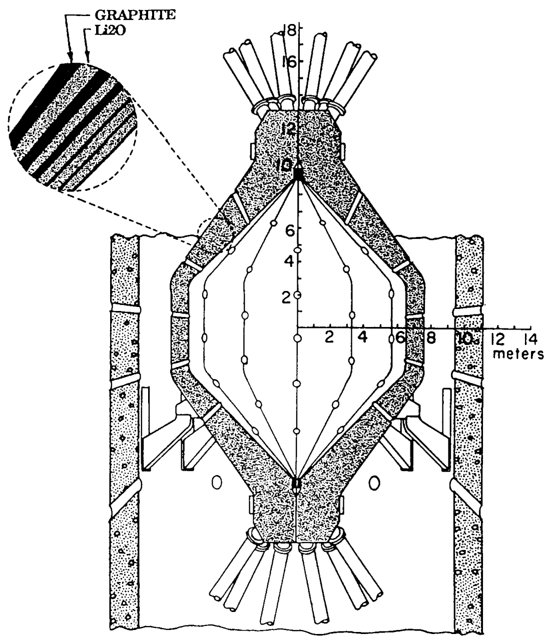


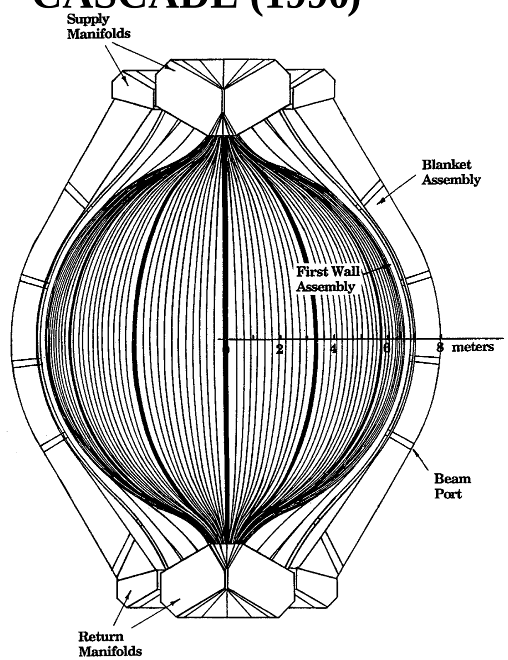
SOLASE (1977)



CASCADE (1990)



SOMBRERO (1992)



SIRIUS-P (1993)

Cross Section of SOMBRERO Chamber

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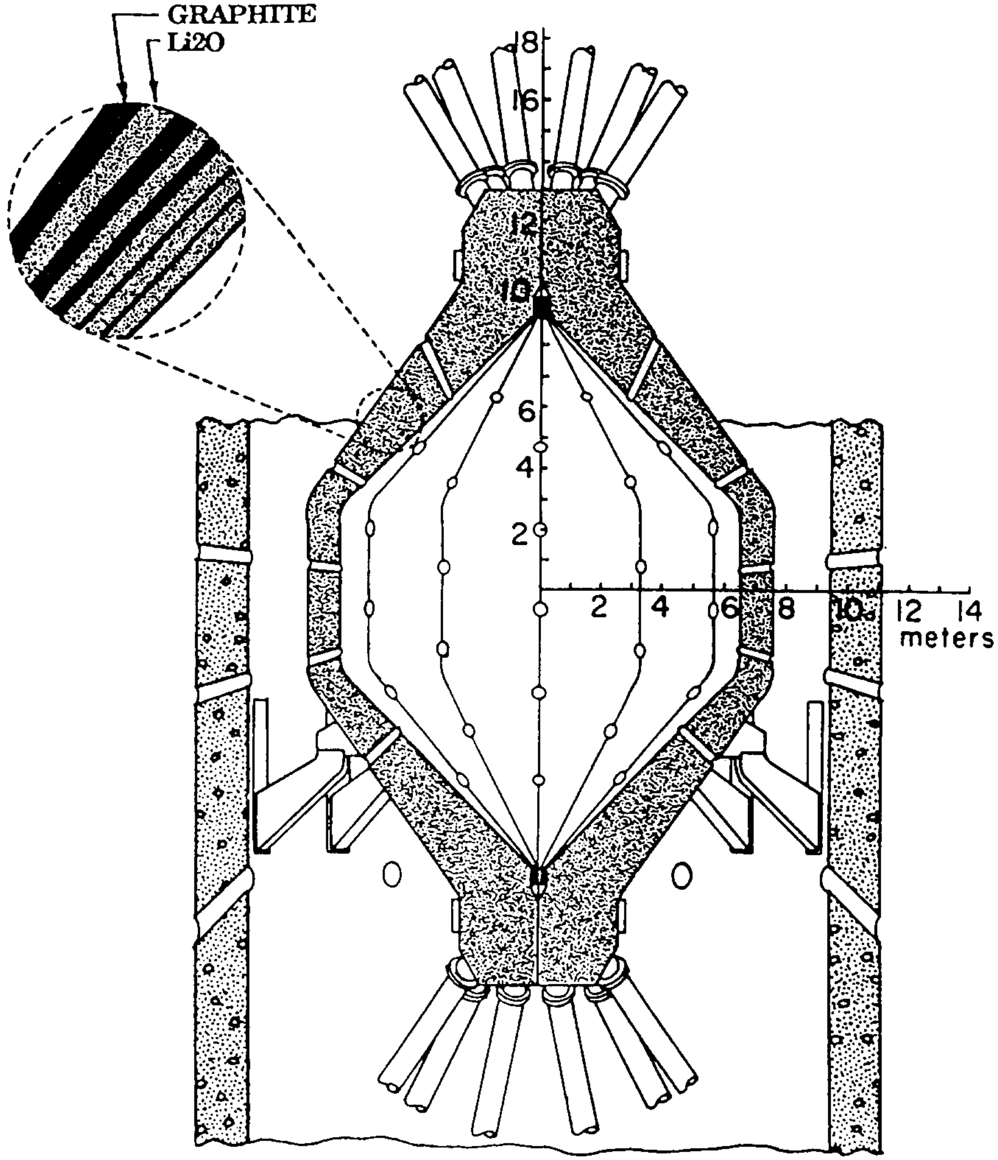

Details of the SOMBRERO Chamber Modules

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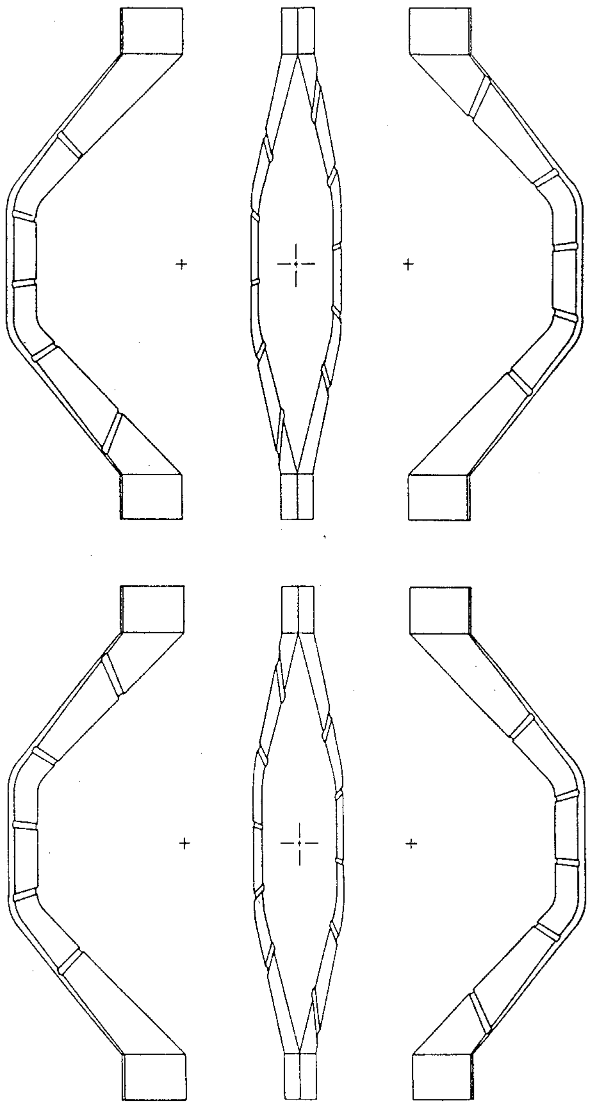
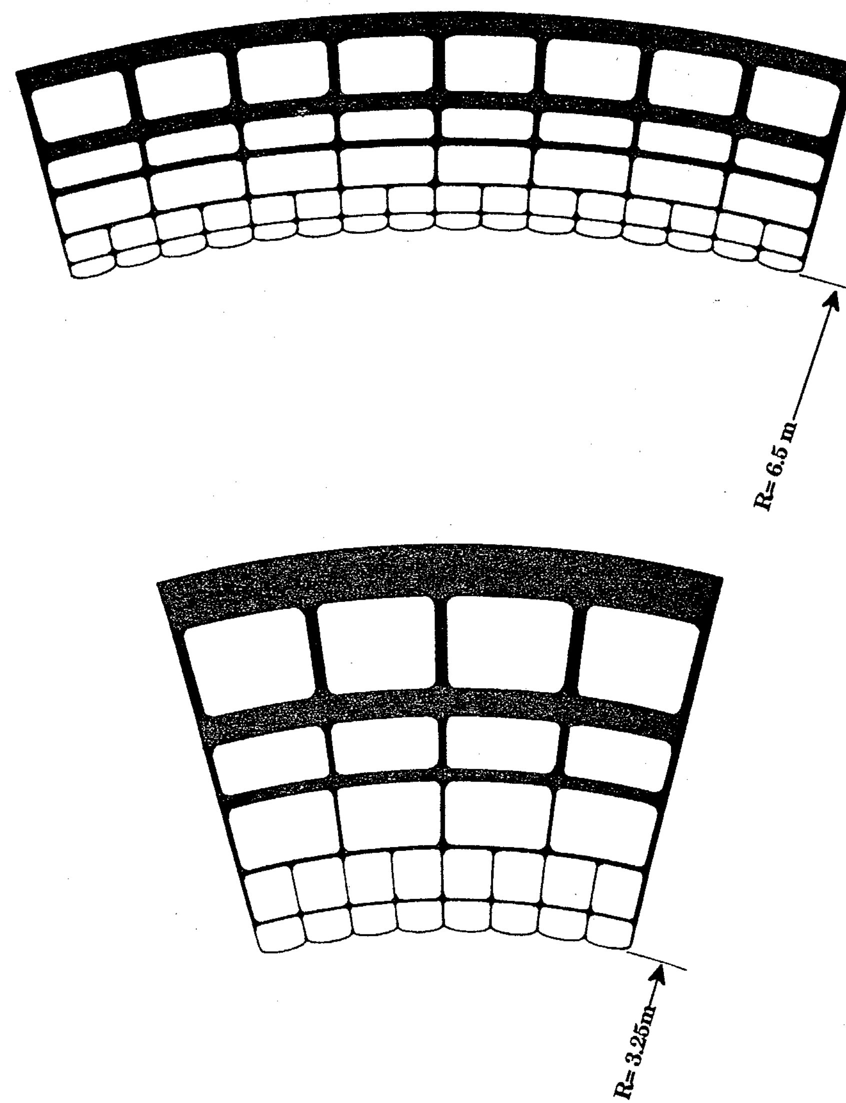


Several views of the two types of modules



Cross section through a module at mid-plane and at Z=5.8 m

SOMBRERO Gas and First Wall Parameters

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	Assumed	Base Case
Gas Species	Xenon	
Gas Density (cm^{-3})	1.8×10^{16} (0.5 Torr)	
Distance to Wall (m)	6.5	
Wall Material	Woven Rigidized Graphite	
Steady State Wall Temperature (°C)	1485	
Peak Heat Flux on Wall (MW/cm^2)	0.138	0.130
Time of Peak Heat Flux (μs)	86.8	86.8
Peak Wall Temperature (°C)	2155	2116
Time of Peak Wall Temperature (ms)	0.134	0.134
Impulse on Wall (Pa-s)	2.21	2.08
Peak Pressure on Wall (MPa)	0.0127	0.0120
Time of Peak Pressure on Wall (μs)	88.7	88.7

Physical Parameters of the SOMBRERO Chamber

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Material of Construction	4D Weave C/C Composite
Chamber Radius at Midplane (m)	6.5
Overall Internal Chamber Height (m)	18
Number of Modules in Chamber	12
Number of Beam Ports in Chamber	60
Structural Mass Per Module (Tonnes)	37.8
First Wall Thickness (cm)	1.0
Radius of Curvature of FW Between Ribs (m)	0.2
Thickness of FW Ribs (cm)	1.0
Number of Ribs per Module at Midplane	17
Maximum Stress in FW (MPa)	42.9

Thermal Hydraulic Parameters of the SOMBRERO Chamber

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Fusion Power (MW)	2677
Thermal Power (MW)	2891
Surface Power (MW)	801
Maximum Surface Heat Load (W/cm^2)	150.4
Maximum Nuclear Heat in FW (W/cm^3)	10.5
Inlet Li_2O Temperature (°C)	550
Outlet Temperature at FW (°C)	700
Outlet Temperature in Rear (°C)	800
Equilibrated Outlet Temperature (°C)	743
Li_2O Mass Flow Rate in 1st Channel (kg/s)	3129
Total Mass Flow Rate in Reactor (kg/s)	5491
Heat Transfer Coefficient at Midplane (W/m^2k)	2758
Inside FW Surface Temperature at Midplane (°C)	1149
Outside FW Surface Temperature at Midplane (°C)	1334
Heat Transfer Coefficient at Z = -4.6 (W/m^2k)	2573
Peak Inside FW Surface Temperature at Z = -4.6 m (°C)	1225
Peak Outside FW Surface Temperature at Z = -4.6 m (°C)	1438

SOMBRERO Gas Dynamics- Vacuum System Parameters

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Chamber Volume (l)	1.37×10^6
Reactor Building Volume (l)	9×10^8
Pressure of Xe in Chamber (Torr)	0.5
Estimated Pumping Speed (l/s)	1.4×10^6
Estimated Time to Evacuate Building (h)	1.6
Capacity of Roots Pumps (l/s)	3×10^4
Number of Primary Pumps	46
Number of Secondary Pumps	10
Power Consumption (MW)	15

SIRIUS-P First Wall Design

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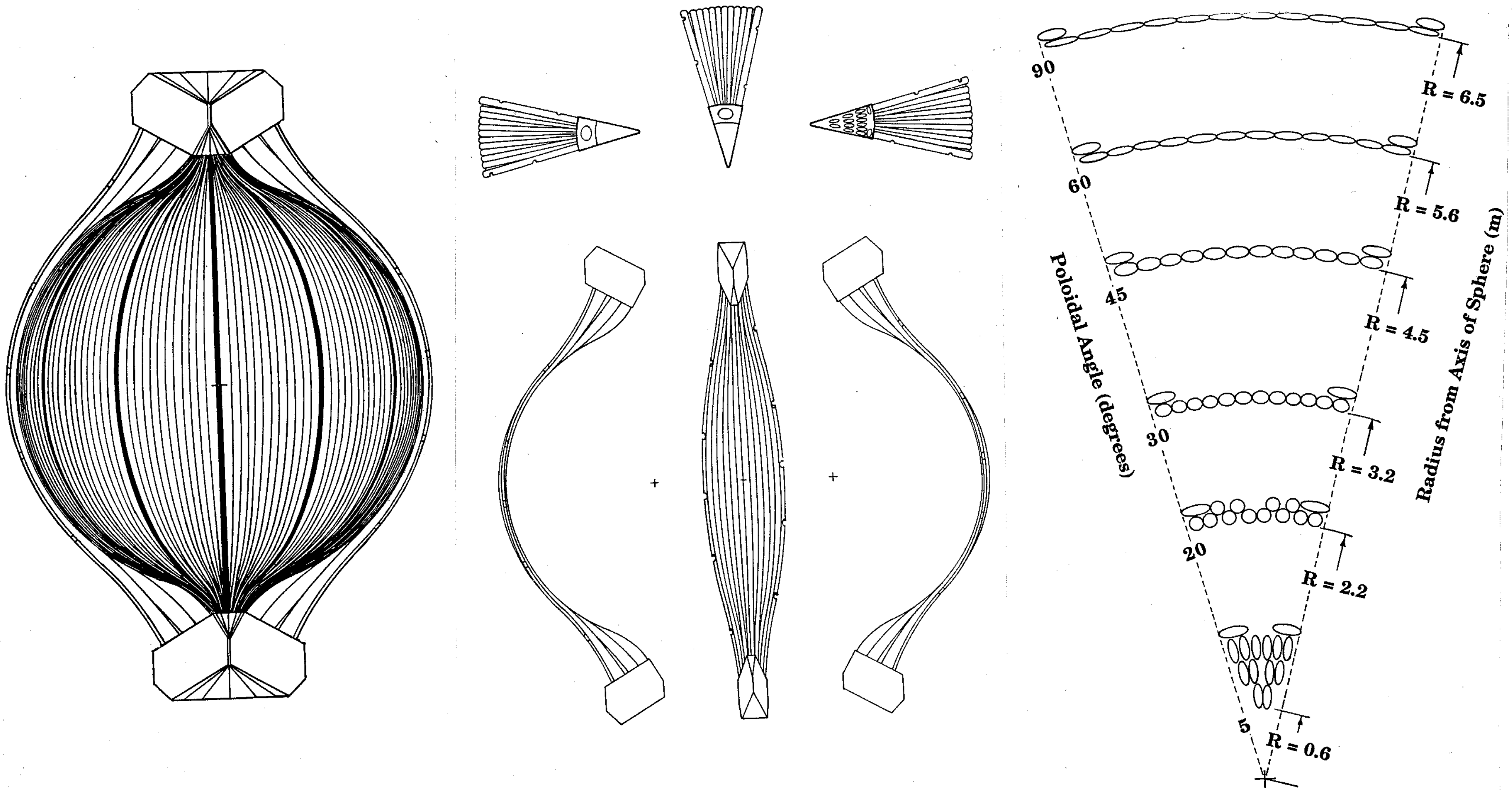

SIRIUS-P Chamber Assembly

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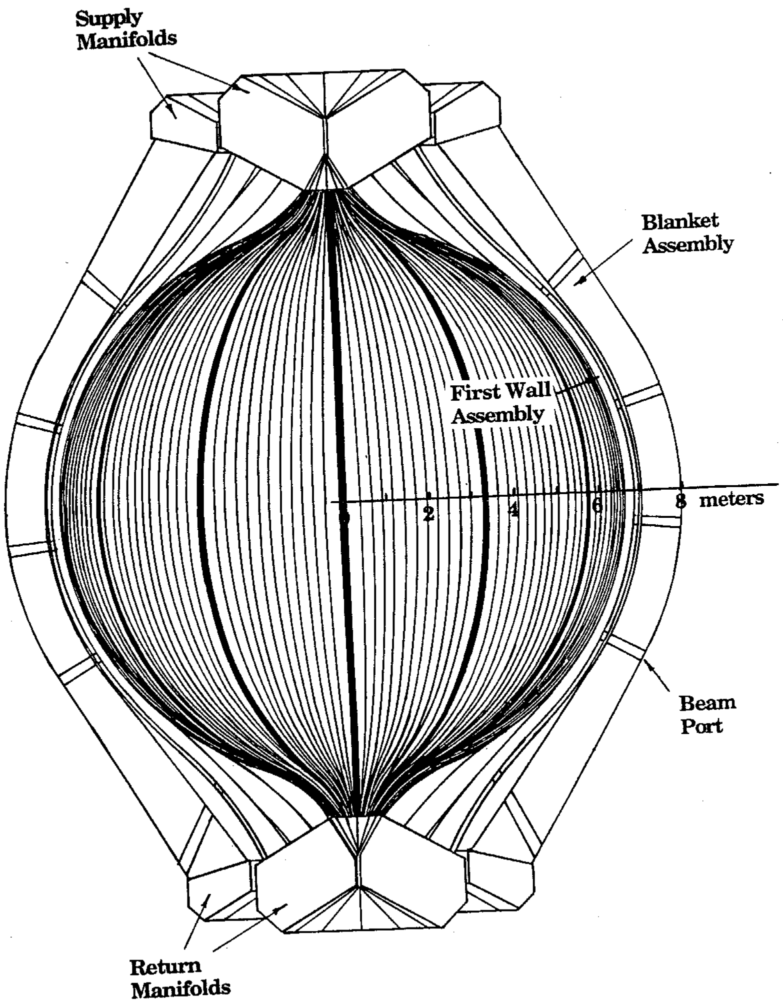

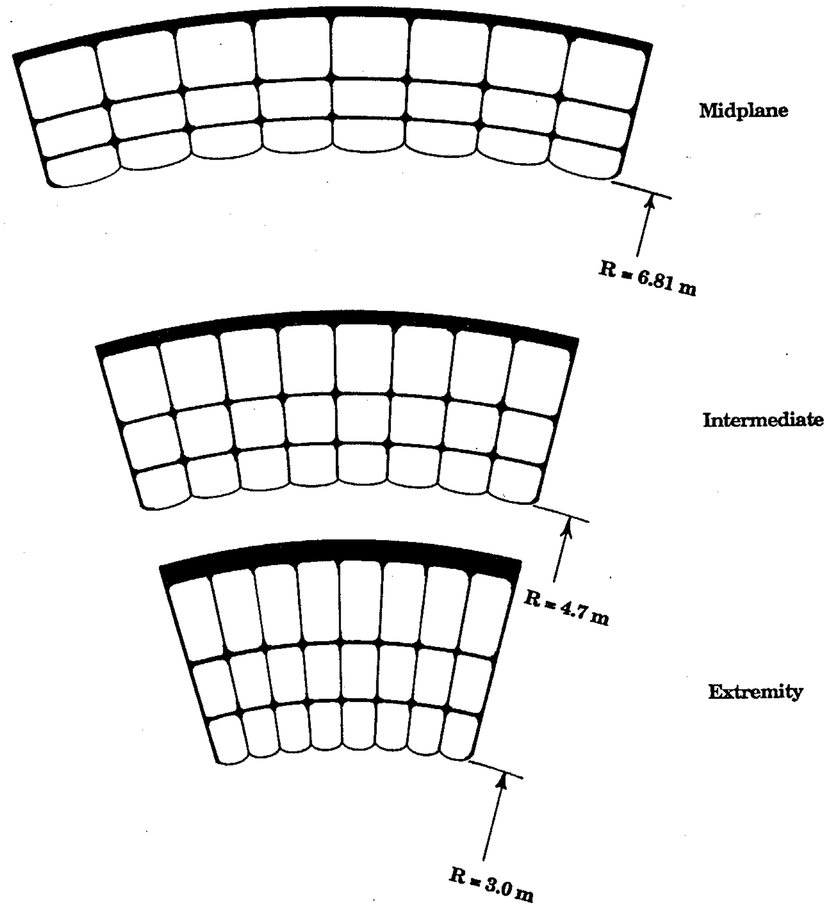

Cross-section of Chamber Assembly

Blanket Sections at Various Levels

Cross-Section of SIRIUS-P Reaction Chamber Building

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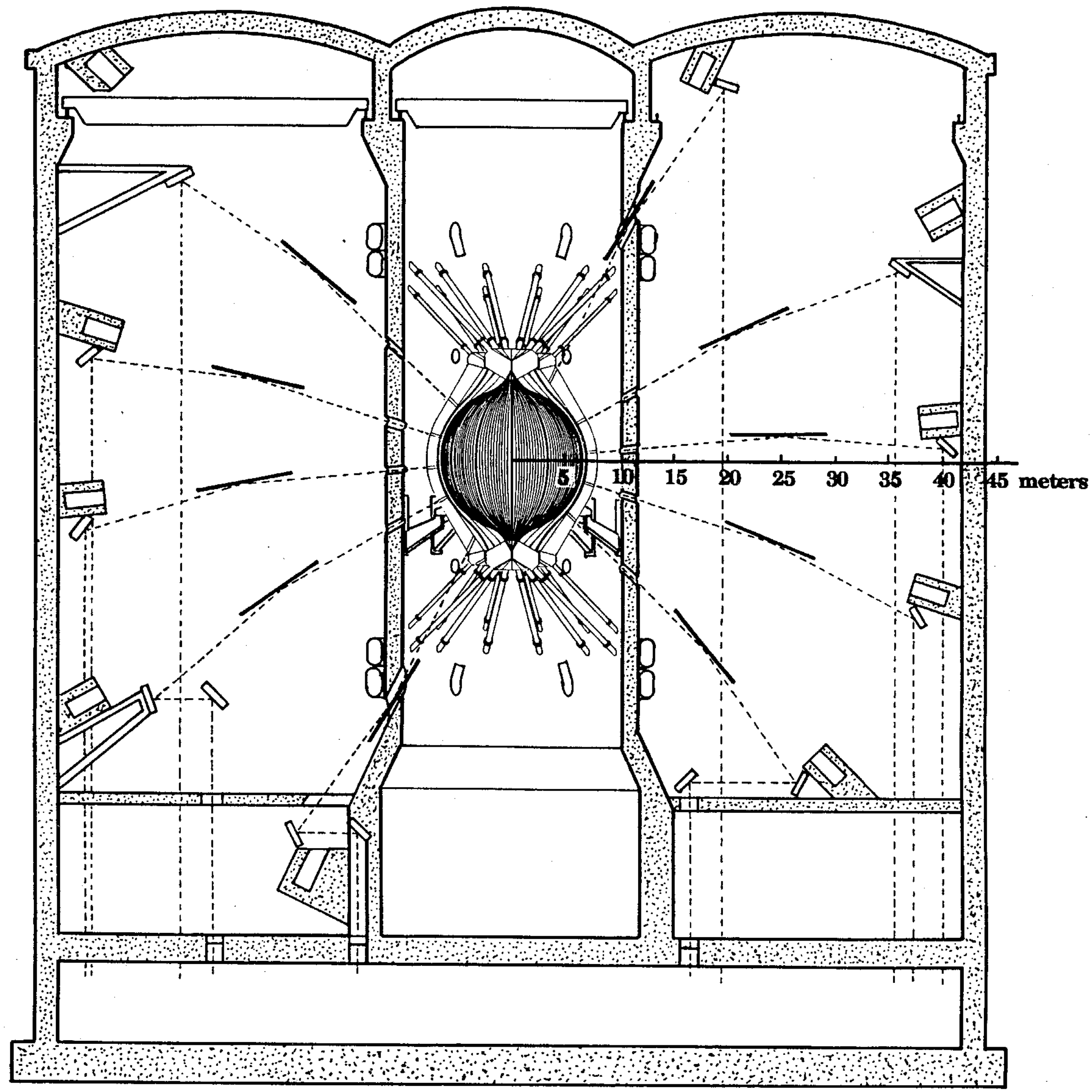

Target Propagation Through the Protective Gas

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- *The cryogenic target has to traverse 6-7 m through the protective gas to the center of the chamber where it is imploded.*
- *On the way, it receives radiant energy from the FW that ranges in temperature from 1500 K - 1700 K steady state.*
- *In its flight, it also experiences hydrodynamic effects that heat it up.*
- *Xe gas that freezes at 160 K will condense and freeze on the target.*

The cumulative result of these effects will raise the temperature of the target and will degrade the cryogenic surfaces rendering it inoperative.

Issues Related to Gas Protection in the Chamber

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- ***Target propagation through the gas is one of the most critical issues. An idea will be presented to address this issue.***

- ***Protection of the FW from x-rays and ion debris depends strongly on the opacity and density of the gas in question.***

- ***Time constants and peak heat fluxes on the FW define the required heat transfer. Shock waves also determine impulses on the FW and how to deal with them.***

- ***Gas dynamics between the chamber and its surroundings related to supply and recirculation must be well understood.***

One Possible Way to Mitigate the Problems of Target Injection

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- ***Have a target injection tube extend into the chamber to come within 2m from the center of the chamber.***
- ***Make the tube from C and cool the inside barrel with Xe gas at*** $T_{inlet} \approx 180K$ ***The Xe gas is released in the chamber as the resupply of protective gas.***
- ***The target will not be subjected to radiant energy from the FW for two-thirds of its flight in the chamber.***
- ***Differential pumping of the tube will reduce hydrodynamic effects on the target and condensation of Xe gas on the target.***
- ***As the front face of the tube is ablated away, the tube is moved into the chamber to maintain the correct distance to the chamber center.***
- ***The cumulative effects of heating the target may be reduced to a point where the target will survive its flight.***
- ***This idea will be thoroughly investigated at the UW in this fiscal year.***

Target Injection Tube Shown in SOMBRERO Chamber

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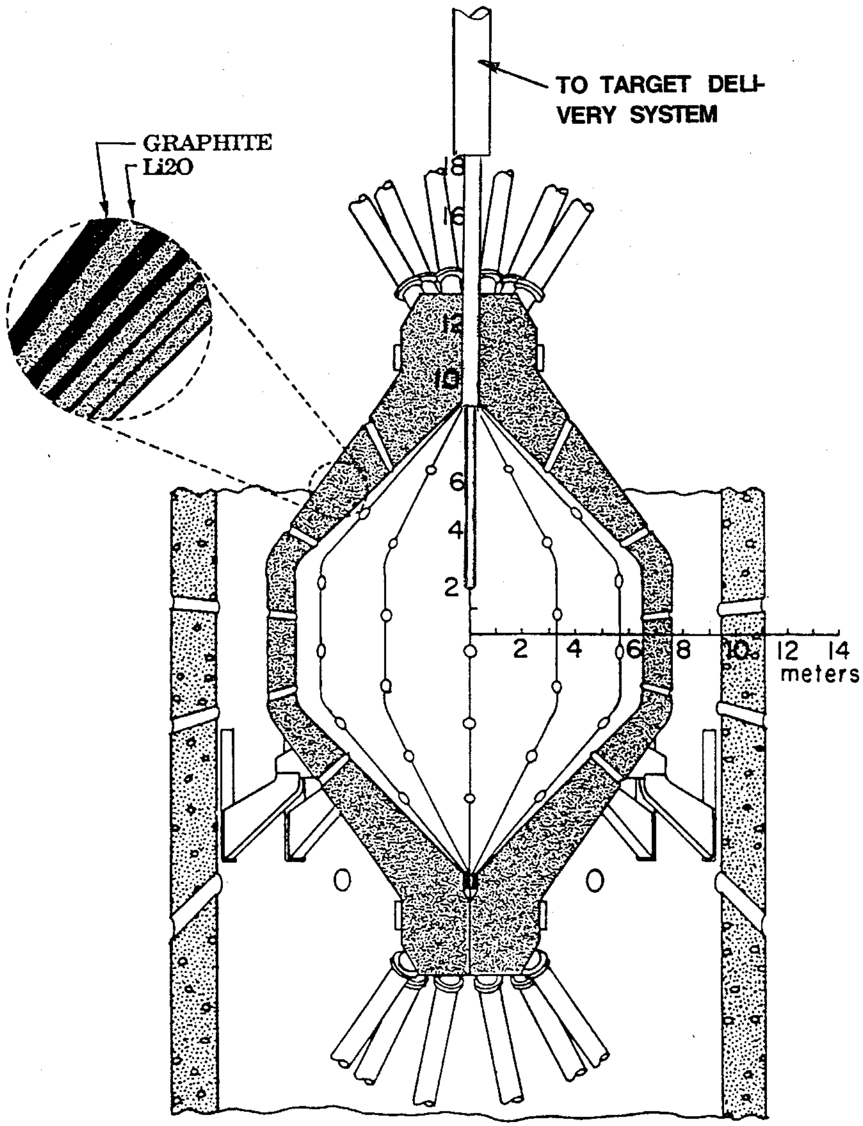

Thermal Hydraulic Effects on the Solid First Wall

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- ***The protective gas in the chamber performs an important task:***
  - → ***It absorbs the x-ray and ion debris energy and re-radiates it to the FW over a longer period.***

- ***Using SOMBRERO as an example, we have:***

→ ***Peak heat flux on the FW (MW/m²)***	***1300***
→ ***Time of peak heat flux (μs)***	***~ 90***
→ ***Peak FW Temperature (C)***	***~ 2100***
→ ***Time peak temperature lasts (ms)***	***~ 0.13***
→ ***Steady-state FW temperature (C)***	***1485***

Thermal Hydraulic Effects (cont.)

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- ***At 6.7 Hz or 150 ms between pulses, the following takes place:***
  - $\rightarrow$ ***The FW coolant travels 17 cm.***
  - $\rightarrow$ ***The FW cools from 2100ºC to 1485ºC < 10 ms.***

- ***The FW temperature depends on the thermal conductivity of the FW material and the heat transfer coefficient of the coolant removing heat from the back of the FW.***

- ***The peak FW temperature facing the target determines the ablation rate of the FW material.***

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There are several material issues related to dry wall designs that imploy C or Sic:

- *Material ablation rates*
- *Effect of neutron damage on thermal conductivity*
- *Swelling due to neutron damage*
- *T_2 inventory in the FW and chamber structures*

Material issues unique to solid granular material cooling:

- *Erosion due to flow against structures*
- *Attrition of the granular particles*

Other Issues Generic to Laser-Driven Systems

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- **Design, protection and maintenance of grazing incidence metallic mirrors and other optics.**
- **Laser beam transmission to 60 ports in the chamber is very complicated and interferes with maintenance.**

SIRIUS-P Building Showing Chamber Maintenance Scheme

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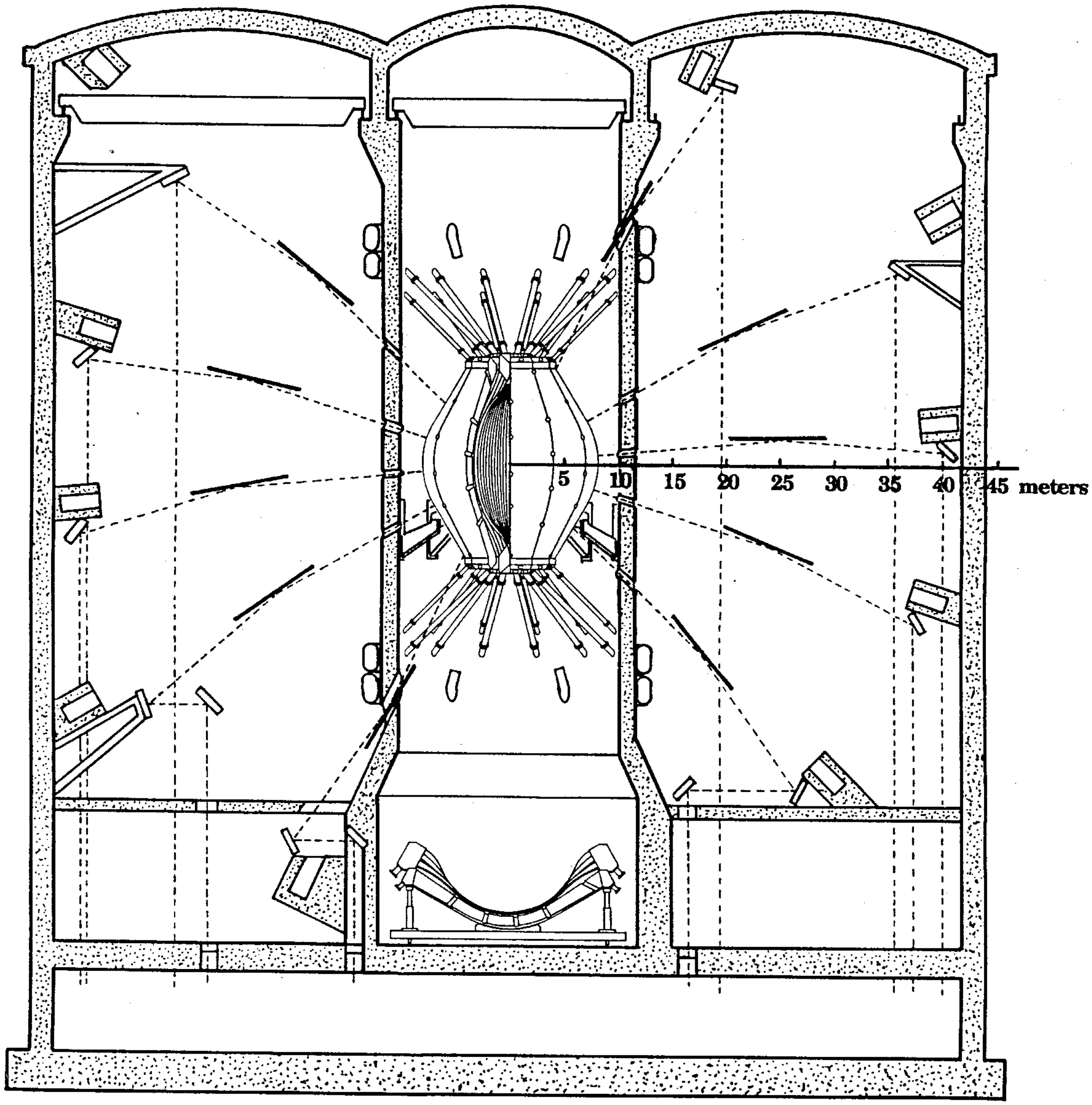

Conclusions

- ***The most critical issue of laser-driven dry wall IFE chambers is the survival of the target during injection.***

  → ***A proposed solution is to use a target injection tube.***

- ***Once the opacity of the protective gas is well known, the effects on the FW will be determined accurately.***

- ***Material issues that need to be experimentally determined are:***

  → ***Radiation damage effects***

  → ***T_2 absorption***

- ***Experiments are needed to test the effectiveness of grazing incidence metallic mirrors.***