Light Ion Beam Fusion Target Development Facility Studies - Final Report for the Period January 27, 1984 to September 30, 1984

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FUSION TECHNOLOGY INSTITUTE

UNIVERSITY OF WISCONSIN

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Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

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Fusion Technology Institute
Nuclear Engineering Department
University of Wisconsin-Madison
Madison, Wisconsin 53706

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I. INTRODUCTION

During the period from January to September 1984, several issues critical to the design of a Light Ion Beam Target Development Facility have been addressed by the Fusion Technology Institute of the University of Wisconsin-Madison. The items studied are listed in the statement of work shown in Table I. In Table II, the items in the statement of work are listed with the corresponding reports that describe much of the work performed. As one can see from Table II, the maintenance procedures, the costs, the propagation of fireballs in preformed plasma channels and the overall design of the reaction chamber are not described in the previously issued reports. These topics have been informally described to personnel at Sandia National Laboratory but this report represents the first attempt to document this work. The items that have been previously discussed in reports are not detailed here, but the relevant reports are included in the Appendix.

II. OVERALL DESIGN OF REACTION CHAMBER

A point design for the reaction chamber of the Light Ion Fusion Target Development Facility has been completed. The parameters for this point design are listed in Table III. This design has Al 6061 chamber walls 6 meters in diameter and 6 meters high. The wall has been designed to withstand 50,000 200 MJ target explosions as determined by following the prescriptions in the ASME Boiler and Pressure Vessel Code. The beam ports and end caps in the first wall are also designed according to ASME guidelines. A thermal liner has been included in the chamber design which protects the first wall from the heat pulse emanating from the target microexplosion.

The whole facility is depicted in Fig. 1. The reaction chamber sits under 3 meters of water shield and inside the Target Chamber Access Room

Table I. Statement of Work

1. Design an aluminum alloy reaction chamber for the TDF that:
   a. is a 3 m radius, 6 m high right circular cylinder with end caps, beam ports, etc.
   b. can withstand 50,000 shots of 300 MJ target yield.
   c. conforms with ASME Boiler and Pressure Vessel Code requirements and safety factors.
2. Perform a "scoping study" of other possible aluminum and stainless steel chamber designs of 1.5-5.0 m radius for yields of 50-800 MJ.
3. Evaluate the maintenance, assembly, and disassembly considerations for the target chamber.
4. Provide cost estimates for reactor vessel parts and construction.
5. Design an in-vessel diagnostics package that can survive a specified number of target shots (approximately 50 shots) before refurbishment.
6. Provide target activation calculations for unclassified target designs. Include this information in the determination of residual radioactivity levels in the reactor vessel.
7. Provide a brief study of availability considerations for TDF.
8. Determine the rate of fireball propagation in plasma channels via multigroup calculations which include temperature-dependent opacities.

Table II. Previously Issued Reports

Task #	Description	Report #
1	Overall Design of Reactor Chamber	
2	Parametric Study of Wall Response Versus Chamber Radius and Target Yield	UWFDM-594 UWFDM-595
3	Maintenance	
4	Costs	
5	In-Vessel Diagnostics Package	UWFDM-593
6	Activation of Target Materials	UWFDM-572
7	Availability	UWFDM-531 UWFDM-532
8	Fireball Propagation in Plasma Channels	

Table III. General Target Development Facility Parameters

TARGET	
Nominal Target Yield	200 MJ
# of Nominal Yield Shots per Day	10
Maximum Target Yield	800 MJ
# of High Yield Shots Over Service Lifetime	200
TARGET CHAMBER	
Target Chamber Diameter	6 m
Target Chamber Height	6 m
Wall Material	Al 6061
Wall Thickness	14.8 cm
Liner Material	NEXTEL
Liner Thickness	1 cm
Gas Type	Nitrogen
Gas Density	2.25×10^{-5} g/cm^3
Fatigue Lifetime	15,000 shots
Service Lifetime	5 years
Radiation Dose at Inside Edge of 1st Wall 1 wk after Shutdown	19.4 rems/hr
Shielding	Borated Water
DIAGNOSTICS PACKAGE	
Distance from Target	1 m
Length of Package	1 m
Diameter	30 cm
Thermal Protection Material	NEXTEL
Thermal Protection Thickness	2 cm
Front Plate Thickness	5 cm

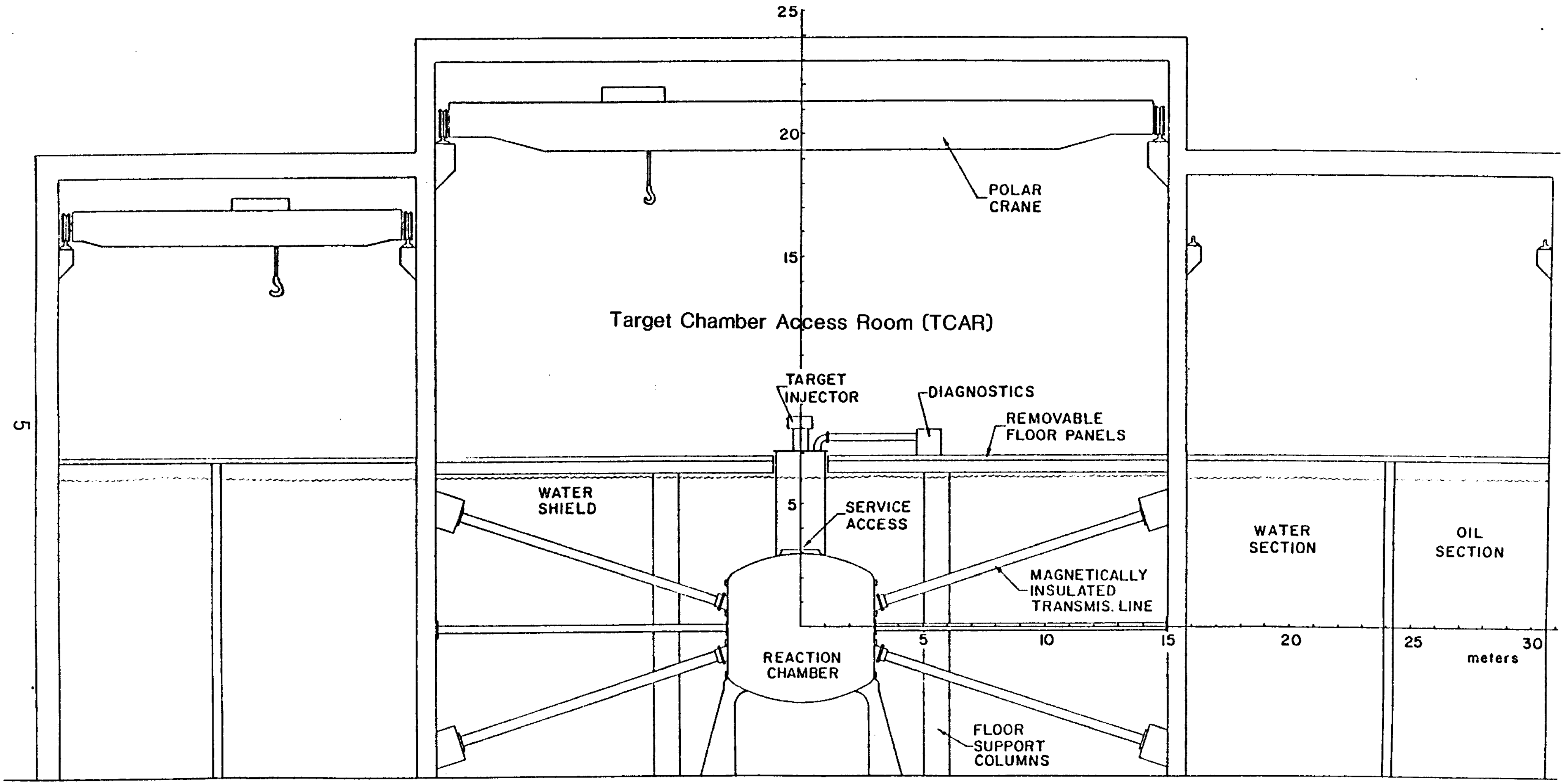

Figure 1. Overall View of Target Development Facility.

(TCAR). Each of these serve as biological shields to the radioactivity induced in the reaction chamber and as tritium barriers. The TCAR has a polar crane which is separate from the crane system for the rest of the facility. This has the advantage of avoiding cranes with extremely long spans. Objects would be moved into and out from the TCAR through an air tight door that is not shown.

The reaction chamber with the thermal shield and the in-vessel diagnostics package are shown in Fig. 2. It was determined that ASME Code design rules require the Al 6061 wall to be 14.8 cm thick. Heat transfer calculations for the liner have determined that a NEXTEL[1] fabric will be adequate for the point design parameters. The design of the beam ports is shown in Fig. 3. The holes are reinforced with the same amount of material that would have been in the hole. Calculations of the dose at the outside edge of the wall due to the radioactivity induced in the wall and in the target debris have shown that after one full power year of operation (3120 shots) and one week of shutdown the dose is 18 rem/hr. The water shield reduces the dose at the operation floor to a very low value.

III. MAINTENANCE

Maintenance problems pertaining to the reaction chamber have been examined. Remote removal and replacement of the thermal liner is a crucial item. The liner may have trapped large amounts of radioactive target debris in its fabric during the operation of the facility, making hands-on maintenance improbable or impossible. In Fig. 4 an umbrella type device is shown that could be used to insert the liner and press it up against the wall. The liner could be held on the wall with a metal "velcro" that could be fastened with pressure and removed with pulling by the umbrella. The liner would be

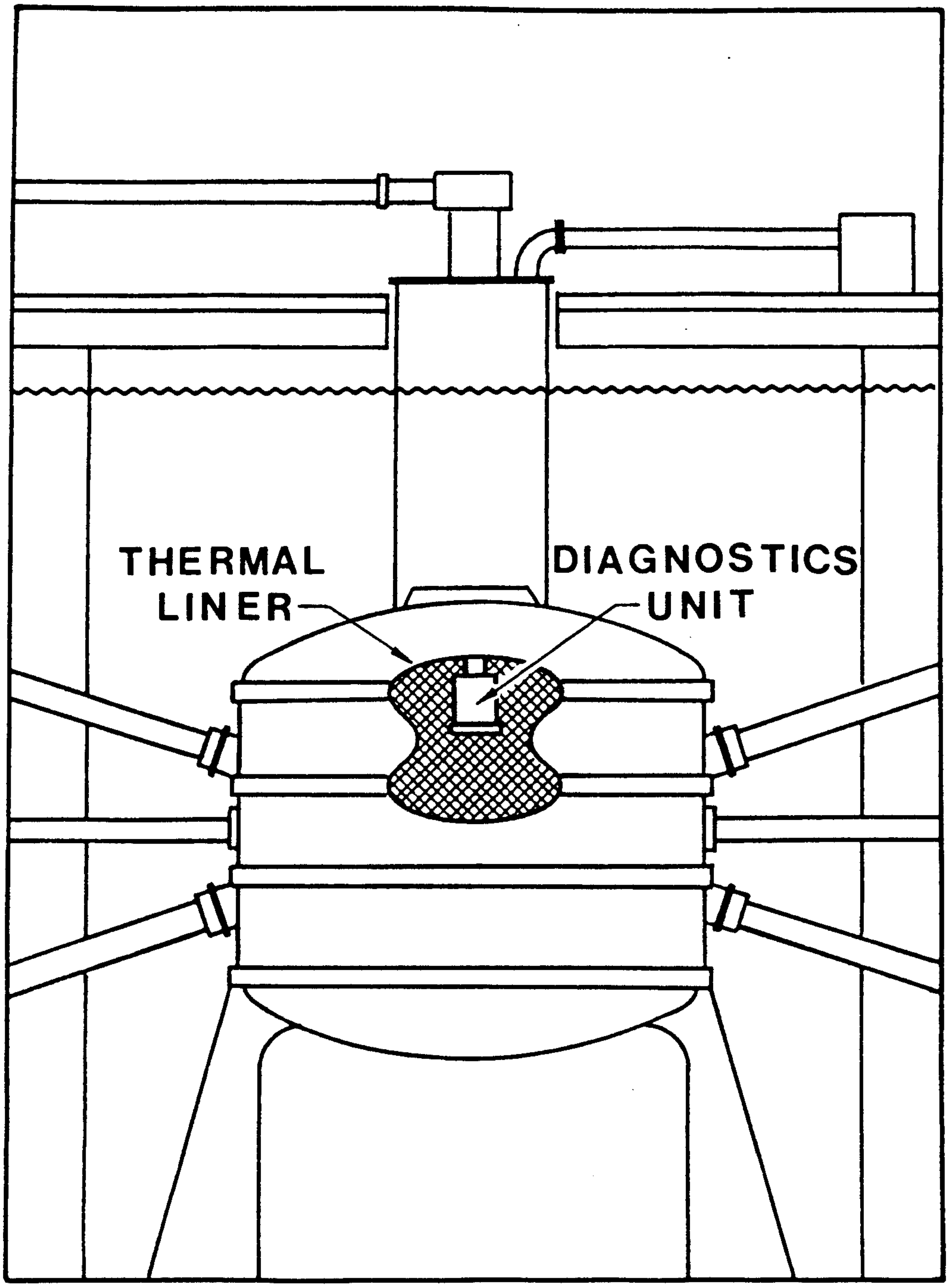

Figure 2. Reaction Chamber with Thermal Liner and Diagnostics Package.

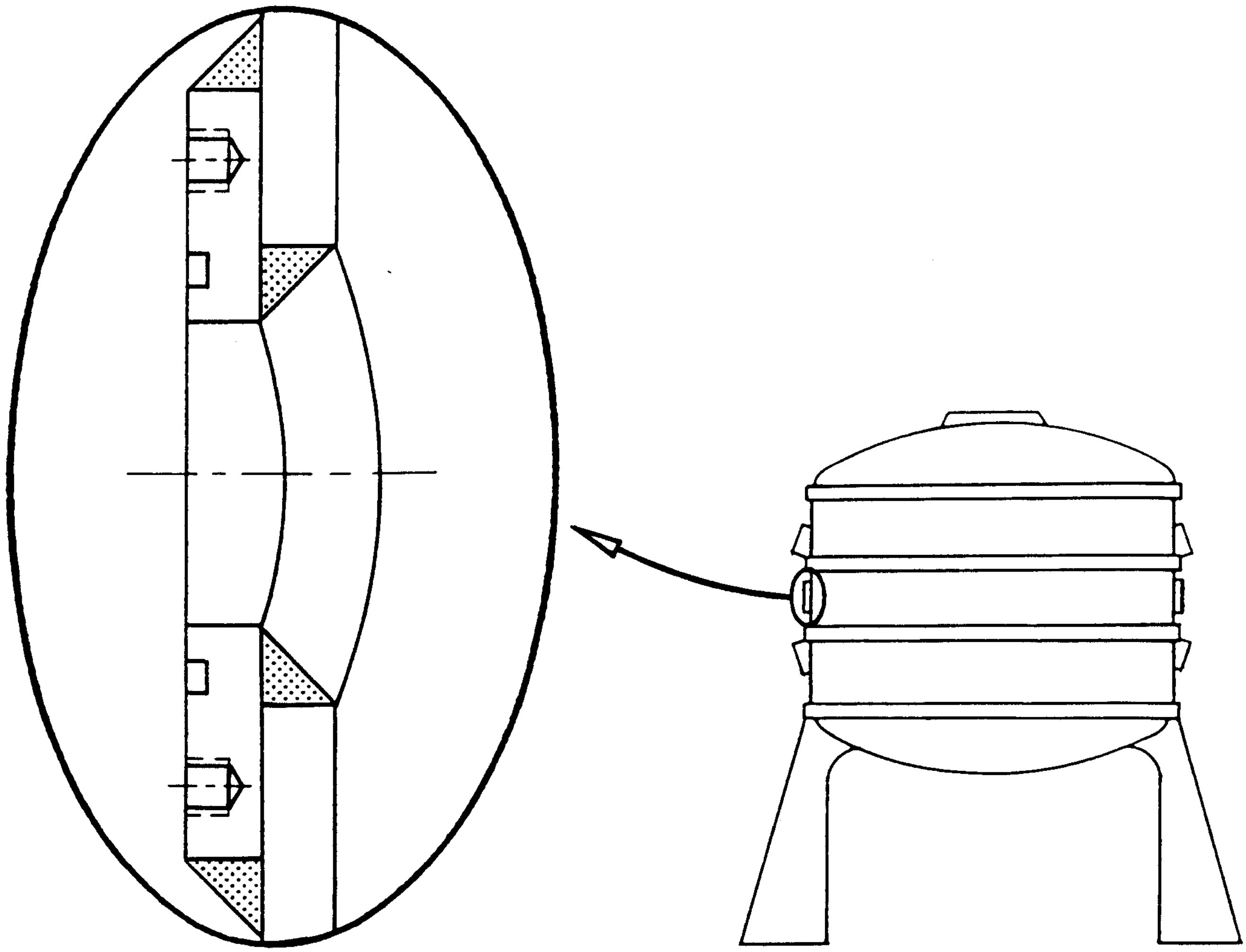

Figure 3. Detailed View of Beam Port Reinforcement.

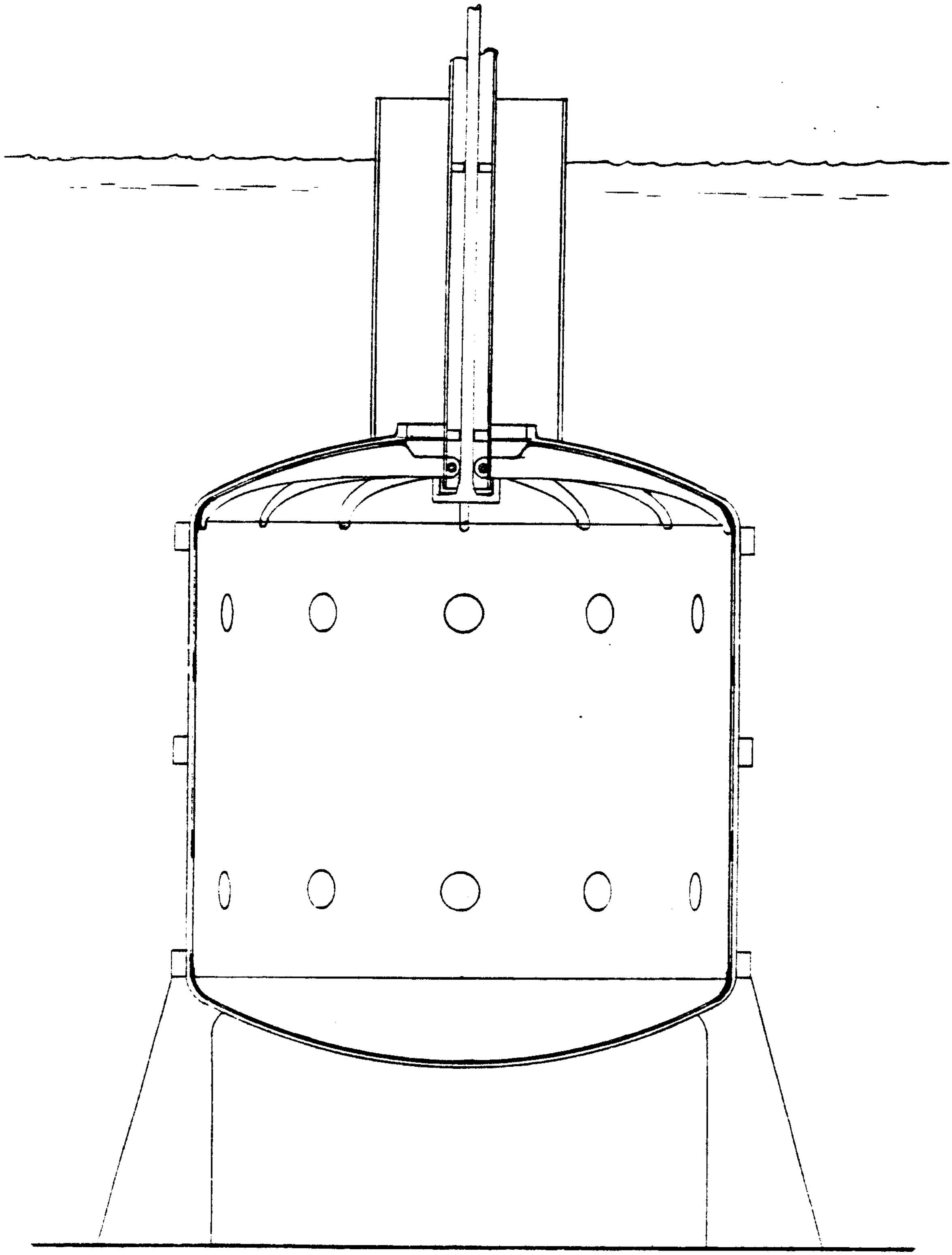

Figure 4. Removal and Replacement of Thermal Liner.

put into and removed from the chamber via the service access. Once the used liner has been removed from the service access, it will be held in the TCAR. The TCAR is shielded and provides an additional tritium barrier and is shown in Fig. 1. While the used liner is in the TCAR it will be compacted and put into a shielded capsule in which it can be transported to a suitable disposal facility.

One maintenance issue that has not been addressed is removal or repair to the diodes themselves. The diodes may require frequent attention, they are under water and they and their surroundings may be radioactive. These things make the maintenance to the diodes a critical issue for the future.

IV. COSTS

The cost of the first wall has been estimated for the point design for both steel and aluminum. The Al 6061 first wall is somewhat more expensive than the 2-1/4 Cr-1 Mo steel at 6.1 M$ compared to 3.3 M$. These costs are broken down in Table IV. One can see that the fabrication costs make aluminum more costly even though the material costs are higher for steel. For either case, the costs are small compared to that of the whole facility.

V. FIREBALL PROPAGATION IN PREFORMED PLASMA CHANNELS

The response of preformed plasma channels to the target explosion generated fireball is important to the design of the reaction chamber because the channel may focus the target explosion energy onto particular places on the wall. Two Lagrangian hydrodynamics computer codes have been used to simulate the axial(2) and radial(3) behavior of the channel-fireball system. It has been found that the radial heat transfer out of the channel is an important energy loss for the axial propagation of the fireball but that radial expansion is too slow to affect the axial heat transfer.(4) Much of the energy in

Table IV. First Wall Costs

	Al 6061	2-1/4 Cr-1 Mo
Wall Thickness (cm)	14.8	3.5
Volume (cm^3)*	4.33×10^7	9.99×10^6
Density (g/cm^{-3})	2.7	7.75
Mass of Wall (kg)	1.17×10^5	7.74×10^4
Unit Bulk Cost ($/kg)	1.8	18
Cost of Materials in First Wall ($)	2.1×10^5	1.4×10^6
Unit Fabrication Cost ($/kg)	50	25
Fabrication Cost for First Wall ($)	5.9×10^6	1.9×10^6
Total First Wall Cost ($)	6.1×10^6	3.3×10^6

*Hemispherical caps and support structure included.

the channel after the explosion is due to ion beam heating of the channel during propagation of the ion beam from the diode to the target.

VI. CONCLUSIONS

A point design for the Target Development Facility's reaction chamber has been completed and several critical issues have been examined. The major unsolved problem seems to be the high dose rates at the outside of the first wall which may severely impact maintenance to the diodes. In fact, these dose rates do not include the effects of radioactivity induced in the diodes themselves. Work underway intends to reduce the dose rates at the outside of the first walls through additional shielding or through novel wall designs.

ACKNOWLEDGEMENT

This work was performed under contract to Sandia National Laboratory.

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