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PRECONCEPTUAL DESIGN OF THE LIGHT ION BEAM FUSION TARGET DEVELOPMENT FACILITY

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Abstract

The light ion fusion target development facility (TDF) will be built in the 1990's, following the successful operation of PBFA-II. While PBFA-II is a pulsed power driver system that is expected to drive ICF targets to breakeven conditions, the target development facility driver is large enough to ignite high yield targets. The TDF is the first light ion facility that must be designed to withstand the environment created by high yield targets. A target chamber with a fatigue lifetime of 15,000 shots at 200 MJ and 200 additional shots at 800 MJ using conservative ASME guidelines has been designed. Alternative design features to reduce the induced radioactivity in the chamber will be discussed.

Introduction

The light ion fusion target development facility (TDF) is the experiment that will follow the successful operation of PBFA-II. It will be used to test high yield targets driven by light ion beams and is expected to be built during the 1990's. This time frame requires that the TDF be designed using currently existing engineering technology if possible. The facility is expected to test 15,000 high yield shots (200 MJ) over a five year period at the average rate of 10 shots per day. Additional very high yield shots (800 MJ) should be allowed in limited numbers. The TDF combines the problem of high levels of radiation with the need for frequent maintenance and is the first such light ion facility to face this problem.

The TDF is in the preconceptual design phase at this time with attention directed toward critical issues that affect the feasibility of the construction and operation of a facility with these characteristics. These issues currently include: (1) structural design of the target chamber to meet fatigue lifetime criteria, (2) design of the first surface to withstand thermal loading of the target generated microfireball, (3) neutron activation of the target chamber and the implications this has on maintenance, (4) creation of plasma channels to efficiently transport the ion beams from the diodes to the target, and (5) design of a high power pulse power driver and reusable diodes.

TDF Design Approach

The TDF has been in the critical issues stage of investigation since 1981. Over this time it has evolved as more conservatism has been built into the design and as more has been learned about the critical issues. During the period 1981 to 1983, the effort was directed toward numerical modeling of the microfireball created by the target microexplosion and the overpressure and thermal effects of the microfireball on the first wall [1-6]. This work was important to the eventual design of the target chamber. Design of a target chamber consisting of metal panels supported by a rigid structural frame was investigated [7]. Detailed thermal response of a bare first wall was estimated. A materials evaluation based upon mechanical and thermal criteria as well as radiological criteria was made [8]. These studies showed that a small chamber (6 meter diameter) could be designed to withstand

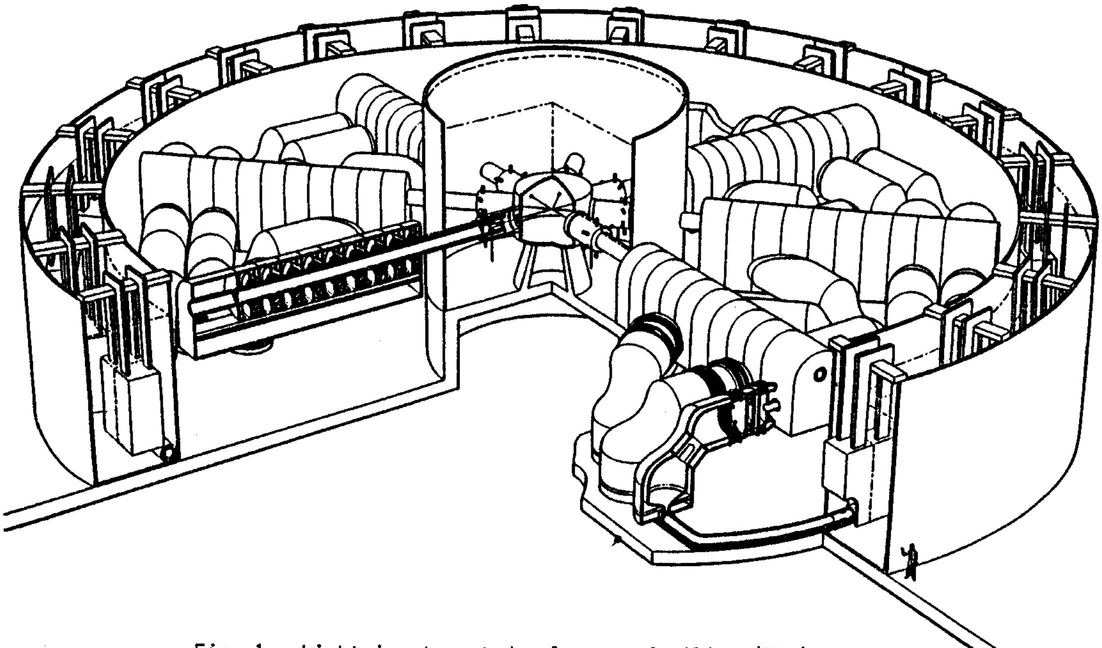

Fig. 1. Light ion target development facility (TDF) concept.

the environment created by 100-200 MJ target explosions [6].

Between 1983 and 1985 the design activity turned toward a more conservative approach. More energy on target (6-10 MJ) was assumed to be required for high gain and therefore the yield increased to a nominal value of 200 MJ. In addition, a limited number of 800 MJ shots were included in the chamber lifetime analysis. The target chamber materials choices were narrowed to ferritic steel and aluminum since these were common structural materials. The target chamber design was simplified to reduce the number of welds, and thus reduce the possibility of weld failure. The chamber wall was designed using the conservative ASME Boiler and Pressure code guidelines that determined the allowable thickness using the maximum overpressure on the wall, dynamic load factors to account for the pulsed nature of the overpressure, and stress based fatigue criteria [9]. The surface of the wall was protected from the thermal effects of the microfireball by a ceramic cloth or curtain. This allowed the wall design to be independent of thermal stresses and temperature dependent properties. Uncertainties in the overpressure were taken into account by using a safety factor of two in the maximum overpressure. With all of this conservatism, the target chamber design was acceptable from a structural point of view [10]. A conceptual picture of the TDF and the target chamber are given in Figs. 1 and 2. Table 1 gives parameters for this design. Reference 10 gives a more detailed description of the design.

Table 1. Target Development Facility Parameters

Target	
Nominal Target Yield	200 MJ
No. of Nominal Yield Shots/Day	10
Maximum Target Yield	800 MJ
No. of High Yield Shots Over Service Lifetime	200
Target Chamber	
Target Chamber Diameter	6 m
Target Chamber Height	6 m
Wall Material	Al 6061 2-1/4 Cr-1 Mo steel
Wall Thickness	14.8 cm (Al)* 4.7 cm (steel)
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 Outside Edge of 1st Wall 1 wk After Shutdown	1.5 rems/hr (Al) 35.4 rems/hr (steel)
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
TDF Driver Parameters	
Marx Voltage	10 MV
Energy per Marx	2.4 MJ
Number of Marxes	24
Number of PFL's	48
PFL Output	360 kJ/module
Energy to Diodes	14 MJ
Diode Efficiency	80%
Pulse Compression in Channels	2
Channel Efficiency	80%
Final Pulse Width	15 ns
Energy on Target	7-8 MJ

*No extra 800 MJ shots allowed for Al

New Design Features

With the confidence that a conservatively designed target chamber could be constructed, an investigation of the problems posed by radioactivity in the structure was undertaken. It was found that the radiation dose received by a worker standing at the outside surface of the TDF chamber was unacceptably high for hands-on maintenance even one month after shutdown [11]. This was contrary to earlier estimates that were in error [6]. With this realization, an investigation of the sources of the induced activation showed that high energy neutron reactions in the chamber structure play a significant role in the creation of this activation [12]. This is shown in Table 2. In principle, the thermal neutron induced activity can be eliminated with appropriate absorbers and the activated target debris can be removed from the interior of the chamber. However, this does not substantially change the level of dose received by the worker. This can only be done by softening the neutron spectrum so that a large fraction of neutrons are at energies below the thresholds for the high energy neutron reactions given in Table 3. To accomplish this a graphite moderator region was introduced interior to the chamber, as shown in Fig. 3. This softened the neutron spectrum and reduced the dose to the levels shown in Table 4. At these levels hands-on maintenance that limits the dose to acceptable values can be scheduled. This is shown in Fig. 4. A worker can perform hands-on maintenance for 8 hours per day for two days of scheduled maintenance. This two days is preceded by 6.5 days of cooldown after oper-

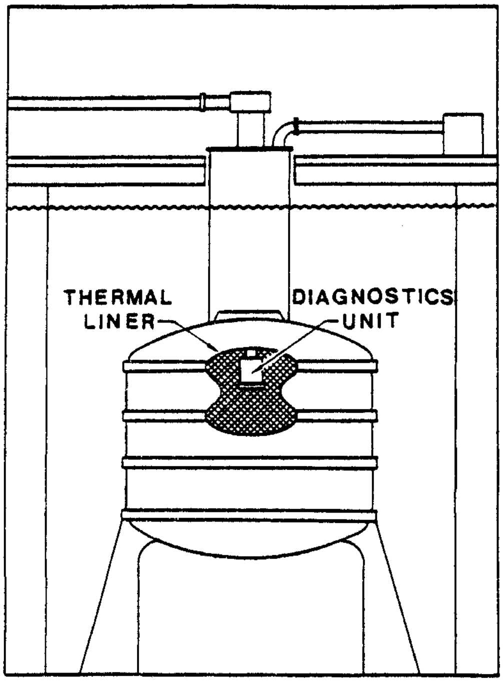

Fig. 2. Reaction chamber with thermal liner and diagnostics package.

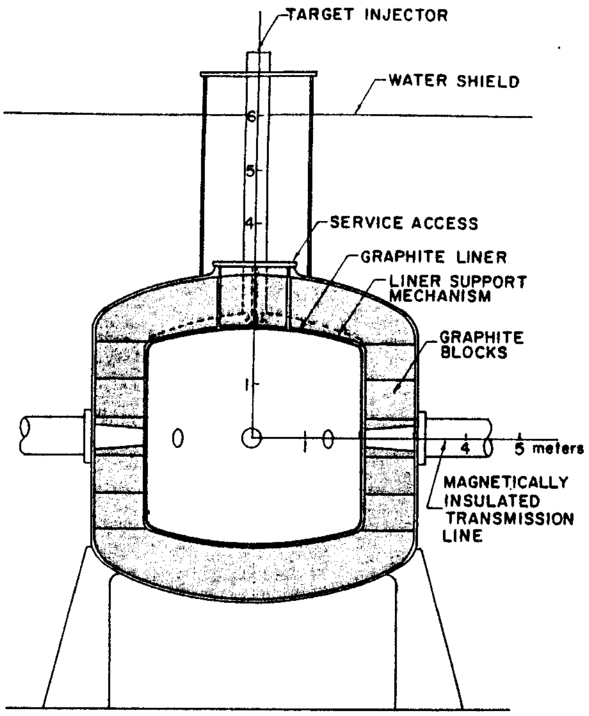

Fig. 3. Target chamber with internal graphite neutron moderator.

Table 2. Relative Contributions to the Dose Rate from Target Debris, Thermal Neutron Reactions, and Primary Fusion Neutron Reactions

	Target Debris	Thermal Neutrons	Fast Neutrons
Steel	1%	53%	46%
Aluminum	16%	16%	68%

Table 3. Fast Neutron Reactions in Aluminum

$^{24}Mg(n,p)^{24}Na$	4.9
$^{27}Al(n,p)^{27}Mg$	1.9
$^{27}Al(n,\alpha)^{24}Na$	3.3
$^{28}Si(n,p)^{28}Al$	4.0
$^{52}Cr(n,2n)^{51}Cr$	12.3
$^{56}Fe(n,t)^{54}Mn$	12.1

Table 4. Dose Rate Comparison Between Bare Aluminum Chamber and Al Chamber With Graphite Moderator*

(mrem/hr)

Time After Shutdown	Bare Chamber	With Graphite
0	3.8×10^4	2.75×10^6
1 day	$4. \times 10^3$	8.6×10^5
1 week	13.1	1.3×10^3
1 month	6.67	718.

*1 meter thick, 40% porosity

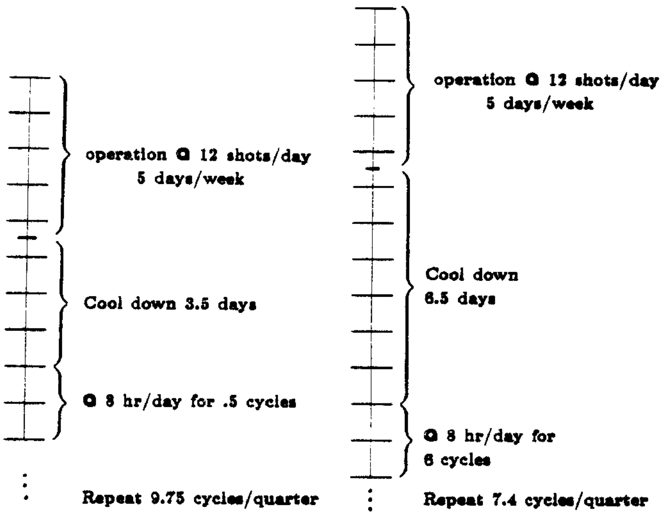

Fig. 4. Quarterly maintenance schedule for TDF meeting limits on radiation exposure.

ating for 5 days at 12 shots per day. This 5 days of operation, 6.5 days of cooldown, and 2 days of maintenance can be repeated 7.4 times per quarter and the person can work for 6 of these 7.4 cycles to receive his maximum allowable exposure. This schedule is consistent with TDF operating characteristics.

An open question that continues to be investigated is the efficiency of ion propagation to the target through preformed z-pinch plasma channels [13]. The efficiency of this transport may be the limiting factor in the target chamber dimensions now that the target generated microfireball has been shown to be manageable. In anticipation of more stringent requirements strain based fatigue analysis of the chamber has been done with the impulse on the wall as the driving function rather than the maximum overpressure [14]. This more physically realistic modeling of the blast phenomena significantly reduces the wall thickness requirements or equivalently, opens the possibility of smaller chambers with the same wall thickness.

Conclusions

The preconceptual design of the light ion fusion target development facility continues to evolve as the critical issues for the feasibility of its design and operation are investigated. Target chambers designed using ASME code guidelines are feasible for both steel and aluminum structural materials. Strain based fatigue calculations show that the ASME code overestimates the required wall thickness for the specified TDF operating conditions. This opens the possibility for thinner walls, smaller chambers, or larger target yields without compromising the feasibility of the design concept.

Activation of the target chamber is a great impediment to hands-on maintenance. The inclusion of a graphite moderator inside the target chamber greatly reduces the dose rate due to activation product decay. Further work must be done to investigate the response of this graphite to the target generated microfireball.

Acknowledgement

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