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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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LIGHT ION FUSION TARGET DEVELOPMENT FACILITY PRE-CONCEPTUAL DESIGN

G.A. MOSES, R.R. PETERSON, R.L. ENGELSTAD, E.G. LOVELL, G.L. KULCINSKI, K.J. O'BRIEN, A.M. WHITE, J.J. WATROUS, University of Wisconsin
Nuclear Engineering Department
1500 Johnson Drive
Madison, WI 53706
(608) 263-3368 (G.A. Moses)

D.L. COOK
Division 1251
Sandia National Laboratory
Albuquerque, NM 87185

ABSTRACT

The light ion fusion target development facility will be used to test high yield ICF targets (50-200 MJ) at the rate of 10 shots per day. The 6 meter diameter cylindrical target chamber is designed as a first wall supported by a structural frame and is capable of withstanding 15,000 full yield shots over a 5 year lifetime. It is made from Al 6061, thus greatly reducing induced activity. The chamber is shielded by a water pool to allow easy access.

TARGET DEVELOPMENT FACILITY DEFINITION

The light ion beam fusion target development facility (TDF) is the third in a series of multi-module pulsed power facilities designed to verify the feasibility of light ion driven fusion for commercial and military applications. Its predecessors are PBFA-I and PBFA-II. The PBFA-I facility is currently in operation while the PBFA-II facility is in the construction phase with operation expected in 1986. The TDF will be based upon extensions of the pulsed power technology developed for PBFA-I and PBFA-II. It is expected that the TDF driver will be a multi-module pulsed power machine capable of delivering in excess of 8 MJ of energy to the diodes. This should provide enough energy at the target (~ 4 MJ) to ignite and burn high gain targets. The TDF will be the first engineering step toward the eventual development of ICF to produce electricity on a commercial basis.

The proposed schedule, purpose, and characteristics of the TDF are given in Table I. Although it is a so-called single shot facility, the TDF is the first truly "nuclear" facility in this series of pulsed power machines. The high yield targets that will be tested in the TDF will place severe design limits on the structure and shielding of the target reaction chamber. These issues are the major theme of this paper.

TABLE I. Target Development Facility

Schedule, Purpose and Characteristics

<u>Schedule</u>	
Preconceptual Design	1981-84
Conceptual Design	1984-86
Engineering Design	1986-88
Construction	1988-93
Operation	1993
<u>Purpose</u>	
Test high gain (10-50), high yield (50-200 MJ) ICF targets driven by light ion beams.	
Qualify high gain targets for eventual reactor applications.	
<u>Characteristics</u>	
Lifetime	5 years
Number of Shots	15,000
Shot Rate	10/day
Maximum Yield	200 MJ

TARGET DEVELOPMENT FACILITY DESIGN

The conceptual design of the TDF is shown in Fig. 1. The major parameters for the design are given in Table II. The following is a brief discussion of the various aspects of the TDF conceptual design.

The arrangement of the multi-module pulsed power machine around the target chamber is expected to be the same as in PBFA-I and PBFA-II. However, the linear dimensions of the TDF are about a factor of two larger than PBFA-I. The exact number of modules and their specific design have not been determined at this time. In Fig. 1 the pulsed power machine is shown schematically to be similar to PBFA-I, with an oil section, a water section and magnetically insulated transmission lines feeding individual diodes. The specific design is not critical

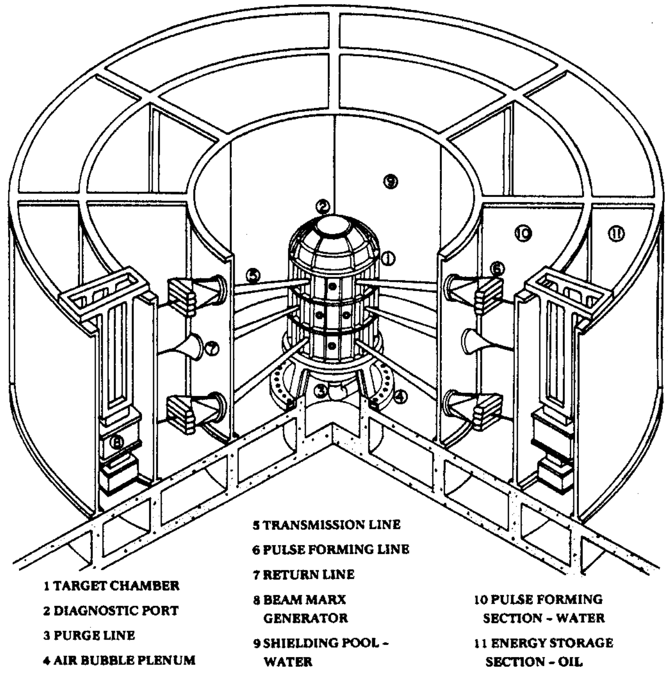

Fig. 1. Light Ion Beam Target Development Facility.

because the emphasis of this paper will be upon the design of the reaction chamber in the center.

It is presumed that the ions are focused into preformed z-pinch plasma channels that extend from the diodes to the target in the center of the vessel. These plasma channels are formed in a two step process. First, a low power laser fired coaxially down each beam line, through the center of each diode, pre-ionizes or pre-excites a pathway in the cavity gas between the target and the diodes. Second, a capacitor bank is discharged along these preformed paths and back through similar return current paths creating a z-pinch channel with an azimuthal magnetic field to confine the ions on their way to the target. A cryogenic target is injected into the chamber to a position where all of the plasma channels meet in the center of the reaction chamber.

The reaction vessel itself consists of metal panels supported by a metal frame as shown in Fig. 1 and in more detail in Fig. 2. The vessel is 6 m in diameter with a cylindrical portion that is 6 m high and endcaps that have a depth of 1 m each. The wall panels and structural frame are conservatively designed to withstand the stress of 15,000 full yield shots, and hence should last for the lifetime of the facility. The circumferential wall panels are 6 m in height but may be designed to span a number of the supporting stringers. This can be determined by the largest practical size for the panels. The panels are welded in a semi-permanent fashion to the supporting frame. With this design, the analysis of the wall response to the microfireball blast is reduced to the study of a single panel area bounded by two ribs and two stringers. A modal analysis has been done to determine the displacement, frequency, and stress history in a panel undergoing flexural action as a result of a time varying uniform pressure pulse.[1]

This pressure pulse results from a blast wave created in the chamber gas by the target explosion. Radiation hydrodynamics calculations have been done for the 20 torr of nitrogen gas that is expected to be used in the TDF.[2] The

TABLE II. Target Development Facility

Operating Parameters

Target	
Energy Requirement	< 4 MJ
Yield	50-200 MJ
Radius	0.5 cm
Driver	
Energy in Store	15 MJ
Energy at Diodes	8 MJ
Diode Voltage	4-30 MV
Power at Diodes	200 TW
Pulse Width at Diodes	40 ns
Plasma Channels	
Length	4. m
Current	85 kA
Number	60
Radius at Firing Time	0.5 cm
Cavity Gas	
Type	20 torr N_2
Cavity	
Shape	cylindrical
Height	6 m
Diameter	1.7 MPa
Max. Overpressure at Wall	1.7 MPa
Max. Energy Fluence	53 J/cm^2
Shot Rate	10/day
First Wall	
Material	Al 6061
Thickness	3 cm
Design	Solid plate panels supported by frame
Number of Panels	60
Panel Width	0.47 cm
Panel Height	2 m
Fatigue Life	1.5×10^4
Shield	
Type	Borated water with air bubbles to suppress acoustic waves

shock wave from a 200 MJ target is shown in Fig. 3 and the overpressure at the wall is given in Fig. 4. A maximum overpressure of 1.38 MPa is expected. The nitrogen gas radiates very little energy to the first wall (~ 2.3 MJ in 1.5 msec) during the blast. Hence, transient thermal stresses at the wall surface are small for

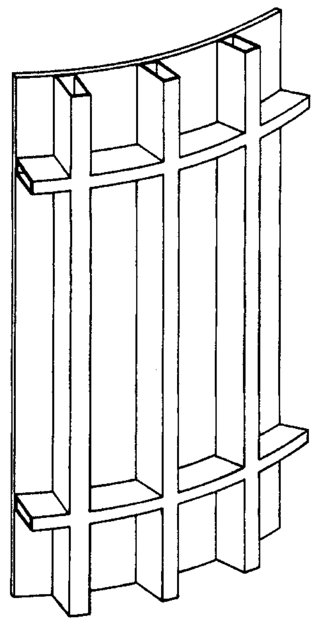

Fig. 2. First wall panel and structural frame.

nitrogen gas and are not a design issue. Earlier analysis of Ar gas showed these thermal stresses to be an important design consideration.

Several alternative materials were investigated for the first wall and frame. These included 6061 and 5086 aluminum, HT-9 ferritic steel, 304 stainless steel, Ti-6Al-4V titanium alloy, and two Cu-Be alloys.[3] Physical properties and fatigue data (cycles to failure vs. maximum stress) for each of these materials were collected. Using these data, along with a calculation of maximum stress vs. panel thickness, the wall panel thickness required to withstand 15,000 full yield (200 MJ) shots was determined for each material. As input for these calculations a maximum overpressure of 1.7 MPa, which is near to the strong shock theory limit, was used. This is most certainly an overestimate of the shock overpressure incident on the first wall panels, hence the design is quite conservative. The stress-time-history of a 6061 aluminum panel subjected to this overpressure is shown in Fig. 5. A determination of maximum allowable flexural stress vs. panel thickness for different lifetime (cycles to failure) constraints is shown in Fig. 6 for the

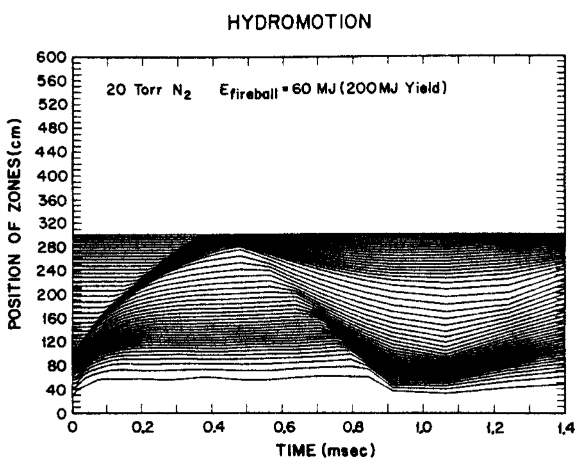

Fig. 3. Hydrodynamic-motion of Lagrangian zone boundaries plotted against time. Target yield is 200 MJ in 20 torr (@ 0°C) of N_2.

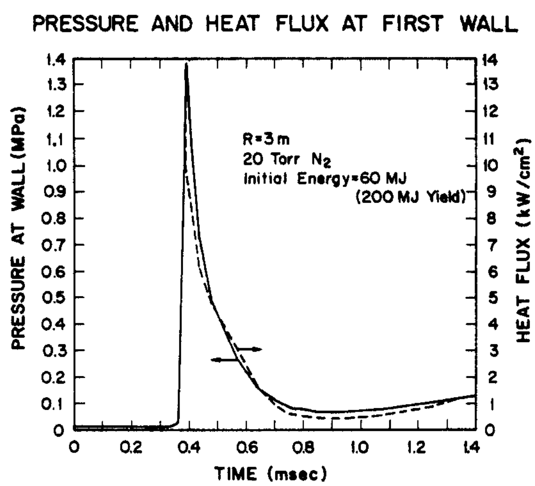

Fig. 4. Heat flux and overpressure at a 3 meter radius first wall of a cavity filled with 20 torr (@ 0°C) of N_2. Target yield is 200 MJ.

same aluminum material. A 3 cm thick aluminum panel meets the lifetime requirements.

The TDF reaction chamber supporting frame is constructed from the same material as the

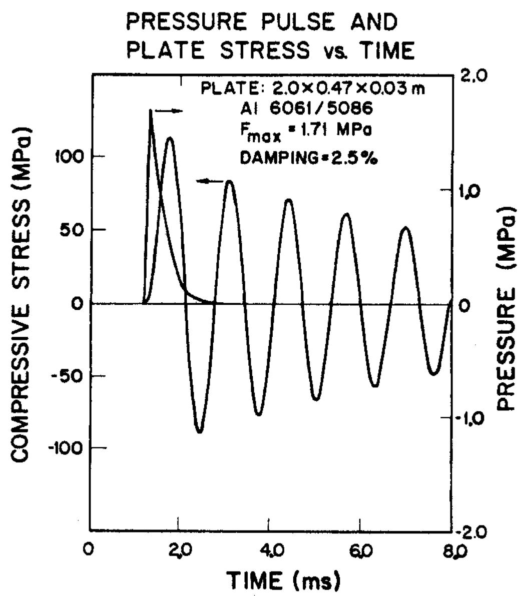

Fig. 5. Plate stress as a function of time.

panels, hence the frame analysis has been carried out for each of these materials as well. The frame is modeled as a system of beams in which the curvature and hoop force capacity of the ribs are not included. In addition, as far as the frame is concerned the plates are assumed to transmit the full strength of the over-pressure, without resistance from circumferential tensile stresses. The analysis of the frame design consisted of determining the beam cross-sectional area that was necessary to produce acceptable stresses and deflections in the rib and stringer elements. The beams are tubular in design to increase the strength/weight ratio. For the worst case of a 1.7 MPa overpressure and aluminum 6061 first wall and frame, the mechanical stress vs. time for one of the tubular ribs is shown in Fig. 7.

The components surrounding the reaction vessel are protected from neutrons by a water shield with 200 ppm boric acid that fills the space between the water dielectric section and the reaction vessel (see Fig. 1). This very effectively shields the neutrons and gammas from a target shot. The water shield can be easily drained to allow convenient access to the chamber and diodes. Access to the interior of the chamber is gained by removing the top end-cap, after draining the water of course. This

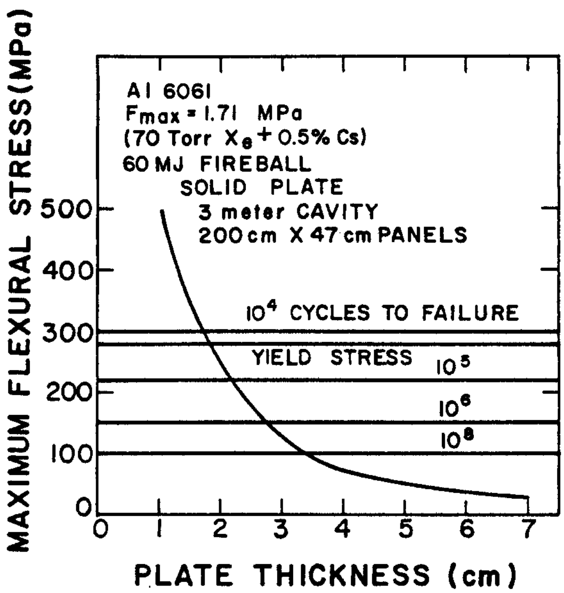

Fig. 6. Maximum flexural stresses in a plate of Al 6061 versus plate thickness for the pressure pulse.

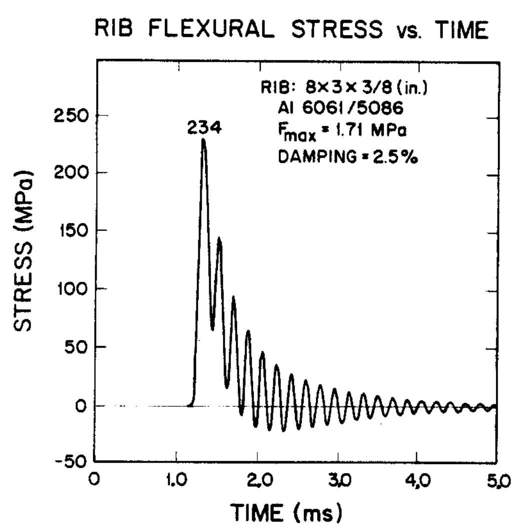

Fig. 7. Structural frame rib stress as a function of time.

is an important design feature for an experimental facility such as the TDF. With a water shield in contact with the wall of the reaction vessel, an acoustic wave (not a shock wave) will be transmitted by the flexing wall into the water after each microexplosion. To attenuate this acoustic wave before it reaches the next structural wall between the shield and the water dielectric section, an annular region of bubbles is created in the shield by a manifold on the floor of the tank (see Fig. 1). This bubble screen has been carefully analyzed and designed to attenuate the acoustic waves without reflecting a significant portion of their amplitude back toward the vessel.[4]

A target shot rate of 10/day and a yield of 200 MJ/shot gives an average fusion power output of 23 kW. If 70% of this is in the form of neutrons then the neutron power is 16 kW. At this power level the structural material in the reaction chamber will activate to significant levels. This is not so much of a problem in terms of waste disposal but it does pose problems with operations and maintenance where personnel will be exposed to the decay radiation. The target chamber is shielded by a water shield during normal operation. For each of the candidate materials, one-dimensional neutron transport calculations and radioactivity calculations were done to determine the activation of the materials with the water shield in place.[4] The dose that would be received by a worker at the first wall and 8 m from the target chamber, on the operating platform, were also determined with the water drained from the shield region. It was assumed that the TDF was operated at 23 kW of fusion power for two cases: (1) one week and (2) one year. This difference in operating time would point out any saturation effects for short-lived isotopes. Table III shows the dose received by a worker inside of the vessel at the first wall, and on the operating platform for all of the candidate materials including the effects of trace alloying elements and impurities found in commercial grade alloys. We see that at shutdown, the aluminum structure delivers more dose than any of the others. However, after waiting one week, the dose for the aluminum structure is less than any of the others. These results indicate that hands-on maintenance of an aluminum target chamber would be possible only one week after shutdown. This leads to a very strong incentive to use aluminum as the structural material for the TDF.

A note of caution must be added to this analysis. The low dose levels at one week after shutdown do not take into account any of the

TABLE III. Dose Calculations for One Year Operating Time at 23 kW

Dose at First Wall (mr/hr)

Material	Time After Shutdown 0	1 day	1 week
Al 6061	2,100	260	1.65
HT-9	489	114	101
304 SS	481	109	105
Ti-6Al-4V	515	177	66
Cu-Be	1,060	204	7

Dose at Operating Floor (mr/hr)

Material	Time After Shutdown 0	1 day	1 week
Al 6061	230	28	0.18
HT-9	55	13	11
304 SS	54	12	12
Ti-6Al-4V	59	20	7.5
Cu-Be	118	22	0.82

activated target material that might have condensed on the chamber walls. This additional activity is likely to dominate the dose received at the first wall. These calculations have not yet been done.

CONCLUSIONS

The conceptual design of the light ion fusion target development facility is a continuing project. At this time the design consists of a PBFA-like pulse power machine feeding diodes located at the first wall of a 3 m radius reaction chamber. Ions propagate from these diodes to the target through preformed z-pinch plasma channels. Design features that have been analyzed in some detail are:

1. target explosions in the N_2 gas filling the reaction chamber and the resultant overpressure and heat flux incident on the first wall;

2. neutron activation calculations of the first wall and structure for 5 different candidate structural metal alloys;

3. analysis of the first wall and structural frame system to determine stress levels and fatigue lifetime for 5 candidate metals for 15,000 shots; and

4. analysis of a water shield with an entrained "bubble region" to attenuate acoustic waves in the water created by the flexing target chamber walls.

The choice of nitrogen as the chamber gas and aluminum 6061 as the structural material makes this conceptual design very attractive for the relatively near term target development facility.

ACKNOWLEDGMENT

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