Target Chamber Designs for the Light Ion Fusion Target Development Facility

R.R. Peterson, R.L. Engelstad, E.G. Lovell, G.A. Moses

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Abstract

The light ion fusion Target Development Facility (TDF) would provide a means of testing high gain inertial confinement fusion targets. Construction of the TDF could occur in the mid 1990's. We have designed two target chambers for the TDF, and have analyzed how both target chambers respond to target explosions. One design is optimized for minimum radioactivity induced in the target chamber while the other is of small size and greater simplicity. We show that both designs are credible and discuss the advantages of each.

Introduction

The light ion fusion Target Development Facility (TDF) would provide a means of testing high gain inertial confinement fusion targets at a rate of 10 shots a day[1]. There is a general paper on the TDF in these proceedings. The TDF would be constructed in the 1990's. The target would yield from 50 to 800 MJ of energy per explosion when they are irradiated with a collection of beams of ions containing a total of 10 MJ in a properly designed pulse. The beams would consist of lithium atoms with energies between 25 and 35 MeV and would be propagated from ion diodes to the target through a target chamber gas in plasma channels. The energy released in the target explosion is about 72% in neutrons and 28% in x-rays and debris ions. The target x-rays and ions deposit their energy in the target chamber gas in a manner that generates a blast wave that mechanically and thermally loads the wall of the target chamber. The target chamber must survive these loads.

That the target chamber must survive is clear and is the main subject of this paper, but there are other target chamber issues which we should mention here. Radioactivity induced in target chamber structures limits access to the target chamber and requires shielding around the target chamber. Radioactivity in the TDF is the subject of another paper in these proceedings. Diagnostics of the ion beams and the target are required in TDF so we must insure that the target chamber environment allows the proper operation and the survival of the diagnostics. We plan to study these diagnostics issues in the near future. Target handling and injection or insertion are important issues because the fuel must be kept at cryogenic temperatures. We have not, as yet, addressed these issues. The ion beams must propagate to the target, a requirement that puts some constraints one the target chamber gas that we will discuss in this paper.

We have pursued two target chamber designs, which face these target chamber issues differently. One design, shown in Fig. 1, attempts to minimize the induced radioactivity in the target chamber structure with the use of a graphite moderator. We have found that, under some circumstances, radioactivity due to fusion neutrons can be reduce by softening the neutron spectrum[2] and this design uses this fact. The graphite neutron moderator is roughly 50 cm thick and the target chamber has a radius of 3 meters. The second design is much smaller, 1 meter in radius, and

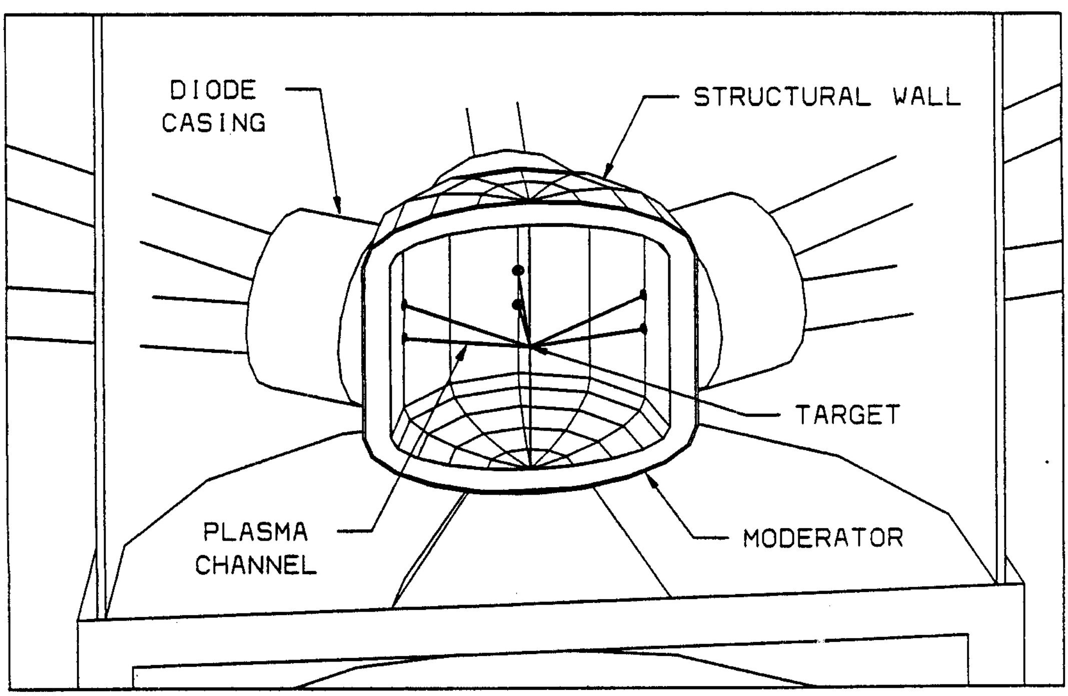

Fig. 1. Target Chamber Design with Graphite Neutron Moderator.
The distance from the target to the moderator is 2.5 meters.

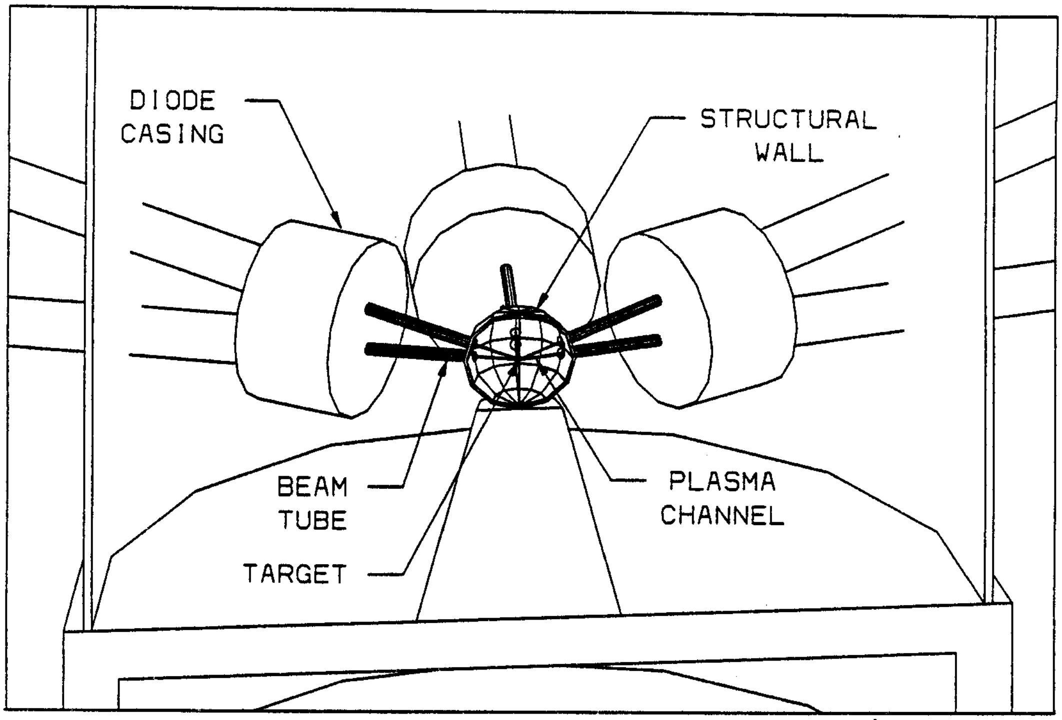

Fig. 2. Target Chamber Design Without Graphite Neutron Moderator. The distance from the target to the first surface is 1 meter.

has only a thin liner of graphite. This is shown in Fig. 2. In this design, ion beams and radiation for diagnostics must propagate through much less target chamber gas than in the first design. We will present results for both designs when the first wall material is an aluminum alloy, though we have also considered steel.

Target Chamber Gas Behavior

The target chamber gas must be able to sustain plasma discharge channels for ion beam propagation, yet must also allow diagnostics of the target performance. We have simulated the formation and behavior of plasma channels in the TDF with the ZPINCH[3] computer code and have studied the limits on the ion power per channel with the WINDOW computer code.[4] The issue of channel behavior and ion beam propagation is far from settled, but at this time, our best estimate is that for nitrogen gas at a number density of 10^{17} cm^{-3} is adequate for plasma channel formation.[5] Some diagnostics require that few hundred eV x-rays propagate sufficiently through the gas to detectors, while others require the collection of target debris. The target chamber gas will interfere with these diagnostics to some degree, but we have still to determine the maximum allowed gas density and distances between the target and the diagnostics. For the work presented in this paper, we only use beam propagation to determine the target chamber gas and have chosen 10^{17} cm^{-3} nitrogen as the target chamber gas.

The details of the target explosion dictate where the target yield energy deposits, and this directs the target chamber gas behavior. The main mission of the TDF is to test high yield targets so that target designs can be optimized. For this reason, the details of the target explosions will change over the lifetime of the TDF. For the purposes of this work we have chosen what we feel is a target design typical of what will be used in the TDF[6]. This target, which has a lead shell outside a shell of a lead-lithium mixture, and a hollow cryogenic deuterium-tritium fuel capsule, releases 20% of its yield in x-rays and 8% in debris ions. The typical target explosion will contain a total of 200 MJ, though the yield may range between 50 and 800 MJ. The x-ray spectrum consists mainly of a roughly 1 keV "blackbody" spectrum, with a much smaller component at 100 keV. Debris ions have a normalized energy of 0.85 keV/amu and include deuterium, tritium, helium, lithium and lead.

We have calculated how the target x-rays and ions deposit their energy in the target chamber gas and the resulting mechanical loadings imposed on the target chamber walls. We have completed these calculations with the CONRAD computer code.[7] CONRAD is a one-dimensional Lagrangian hydrodynamics code with multigroup radiation transport. This code simulates the formation and propagation of a blast wave in the target chamber gas and predicts the gas pressure on the wall surface. We show the pressures on 1 meter and 3 meter radius walls in Fig. 3. One sees here that for a 3 meter radius, the pressure falls to insignificant values from a 1 MPa maximum in about 0.3 ms. On the other hand, the 1 meter radius chamber pressure remains high for a much longer time. This occurs because the energy deposited per unit mass in the gas is much higher in the smaller chamber. We believe that we have been conservative in these calculations because we have purposely underestimated the energy lost by blast waves due to radiation. Since both target chamber designs have first walls lined with graphite, radiant energy to the first walls does not pose a threat to the survival of the target chamber, and this would be true even if all of the blast wave energy were released as radiation.

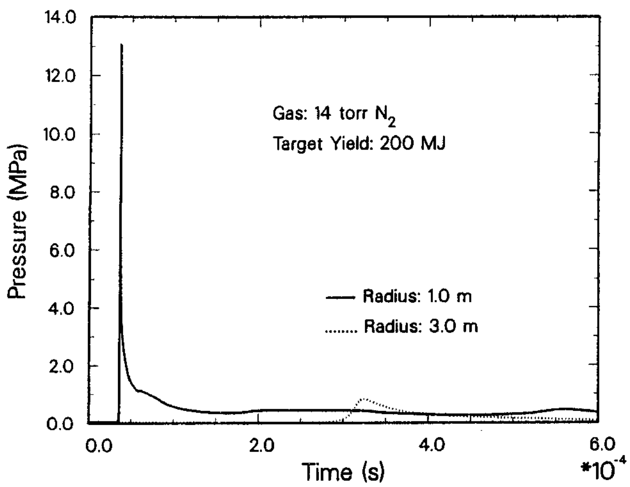

Fig. 3. Calculated Blast Overpressures on First Surface of TDF versus Time. Wall radii are 1 meter and 3 meters.

Target Chamber with Graphite Moderator

In the target chamber with a graphite moderator, the 50 cm of graphite is considered to be a nonstructural assembly. We assume that the moderator has no circumferential strength to oppose the radial pressure, so that it just transfers the load to the structural first wall. Thus, the pressure pulse loading the 3 meter structural wall is taken as the value calculated at the inside edge of the moderator, which is an impulse of about 100 Pa-s. We have assumed that the thermal loading does not damage the graphite.

We have calculated stresses for chambers of welded 6061-T6 aluminum. The calculated stresses would be nearly the same for 2.25 Cr - 1 Mo steel, though the strains in aluminum are about three times as high as in steel. The stresses are calculated with an analysis that assumes that the pressure loading occurs in an instantaneous impulse, an assumption valid when the mechanical response time is long compared with the width of the pressure pulse. The analysis calculates the motion of the wall by summing over the linear vibrational modes in the wall. The stress history for this design for a 5 cm thick wall is shown in Fig. 4. The peak stress of 15 MPa corresponds to a doubled strain of 7.8×10^{-4} in aluminum, which is less than the endurance limit of 8.3×10^{-4}. Therefore, the wall will survive more than the required 15,000 shots.

Target Chamber without Graphite Moderator

In the the smaller target chamber that has only a thin graphite liner, we assume that the mechanical loading is also transferred directly to the structural first wall. Therefore, we use the pressure loading calculated at the inside surface of the graphite liner, which is positioned 1 meter from the target. We have assumed that the thermal loading does not damage the graphite.

One consequence of the small chamber radius is a change in the shape of the pressure pulse at the

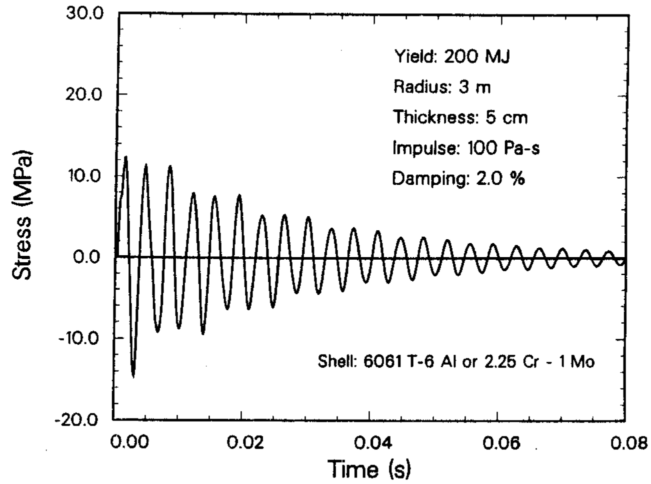

Fig. 4. Mechanical Stresses in Structural Wall of Target Chamber Design with Graphite Moderator.

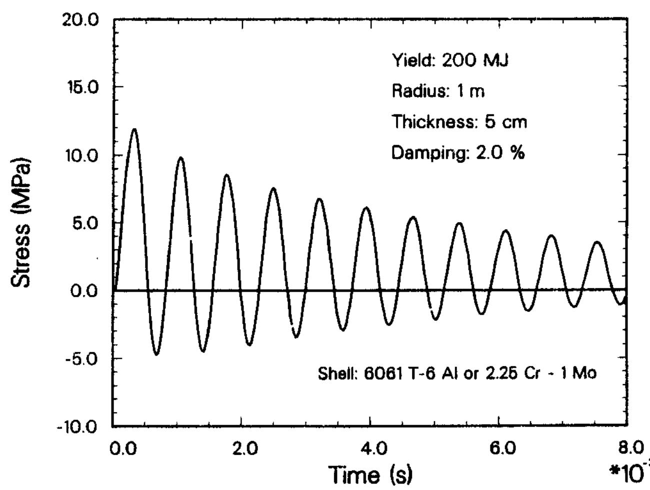

Fig. 5. Mechanical Stresses in Structural Wall of TDF Target Chamber Design Without Graphite Moderator.

wall. The wall pressure remains significant for a much longer time than for larger chambers. Therefore, we can no longer assume that the pressure pulse duration is short compared to the vibrational period of the wall and can no longer use modal analysis to calculate the stress histories. Instead, we have numerically solved for the wall motion and stresses, with the full time-dependent nature of the pressure loading taken into account. The pressure history for a 5 cm thick welded aluminum 6061-T6 wall is shown in Fig. 5. The maximum stress and doubled strain range are 12 MPa and 3.2×10^{-4}, respectively, for aluminum. The strain range is below the endurance limit, so the chamber should be able to survive for 15,000 shots.

Conclusions

The TDF needs a target chamber that meets several criteria. In this paper, we have presented results indicating that two target chamber designs will survive the proposed lifetime of TDF. We have also discussed some of the other criteria. Our best calculations to date indicate that either of these designs are compatible with ion beam propagation. Compatibility with diagnostics is an issue that we have not yet studied in detail but hope to address in the near future.

Acknowledgment

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