Pressure Loadings on the Walls of a Light Ion Laboratory Microfusion Facility Target Chamber

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MICROFUSION FACILITY TARGET CHAMBER

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ABSTRACT

The design of target chambers for the Inertial Confinement Fusion (ICF) Laboratory Microfusion Facility (LMF) requires a good understanding of the pressure loadings experienced by the chamber walls. Beam transport, diagnostics, and LMF applications place severe constraints on the chamber fill gas; in current light ion beam concepts only 1.5 torr-meters of helium are between the target and the closest target chamber structures. Simulations of the unavoidable vaporization of the first wall have been performed with the CONRAD computer code for a light ion beam LMF concept. Results show that the peak pressure on the wall is a function of the target x-ray power density on the wall, while the impulse on the wall is a function of x-ray fluence.

INTRODUCTION

The LMF would explode ICF targets of yields up to roughly 1000 MJ at a rate up to two per day.[1] Currently, both light ion beams[2] and short wavelength lasers are under consideration as possible drivers for the LMF. Heavy ion beams could also be used, though this author knows of no heavy ion beam LMF conceptual designs. The LMF would be used to develop high yield targets and to explode these targets for use in weapons physics, weapons effects simulation, and ICF technology experiments.

An important part of the design of an LMF is the target chamber in which the target explosion is contained and where these experiments occur. The target chamber design must meet certain constraints imposed by beam transport, diagnostics, and the experiments. The chamber must also be designed to survive for a prescribed lifetime. Concern for these issues must lead to an integrated target chamber design.

A crucial component to the design of the chamber is a good knowledge of the pressure loading on the target chamber structural walls. The loading generally consists of three components: a fill gas pulse from a shock wave in the fill gas striking the wall, a vaporization pulse from the rapid vaporization of wall material by the target x-rays, and a quasi-static residual pressure from the target energy remaining in the fill gas long after the explosion. The relative importance of these components is very much a function of the target, fill gas, and target chamber design.

In this paper I will describe computer simulations of the response to target explosions of the target chamber gas and first wall in a light ion beam LMF. I will begin by describing a conceptual design for the target chamber of a light ion beam LMF. I will then describe the target emanations of x-rays and debris ions that drive the target chamber response. The computer methods used in these simulations will be presented. The results consist of parametric studies that show how different components of the pressure loading vary with target yield, target chamber radius, and x-ray pulse width.

LIGHT ION BEAM LMF TARGET CHAMBER DESIGN

The target chamber must be designed within the constraints of beam propagation, target diagnostics, and experimental conditions. These determine the fill gas species and density and the distance between the target and other structures in the target chamber. In current light ion beam LMF concepts, the ions are propagated in a ballistic mode. In this scheme, focusing magnets must be positioned 150 cm from the target for most of the ions to hit a 1 cm radius target. A fill gas of helium at a room temperature pressure of 1 torr will avoid beam loss due to scattering while providing adequate current neutralization.[3]

Two target chamber designs for a light ion beam LMF are under consideration that have these fill gas conditions. The first design places the focusing lenses behind the target chamber wall, so the wall radius can be no more than 150 cm. The wall is taken to be a 150 cm radius cylinder, 450 cm high, with conical ends, each extending to 500 cm from the target and which are 333 cm in radius at their bases. Therefore, the total height is 1000 cm. The second design places the lenses inside the walls of beam tubes that penetrate into the target chamber through the 300 cm radius cylindrical chamber walls. The lenses

In both designs, the walls are lined with 1 cm of woven graphite composite. The x-rays from the target will vaporize some amount of graphite on every shot. Computer simulations show that vaporization cannot be avoided until the target yield falls below a very low value. This will apply vaporization and residual pressure loadings on the target chamber walls. A fill gas pulse is not present because the vaporized material protects the wall from the relatively weak shock in the fill gas. The nature of these loadings is the topic I have studied with computer simulation.

TARGET PARAMETERS

I have assumed that the target used in the LMF is the target used in the LIBRA light ion beam power plant study.[4] This target, shown in Figure 1, was originally designed by Bangerter[5] and is a thick lead shell, surrounding a low density seeded foam, surrounding a D-T fuel capsule. When this target implodes, it burns and releases its energy 20% in x-rays, 6% in ions, and 74% in neutrons.[6] The neutrons are absorbed in a larger volume of material and do not play an important role in the pressure loading. The ions are mostly lead at an energy of 550 keV. I have assumed that the ions are emitted in a pulse 10 ns long. The time-integrated x-ray spectrum is shown in Figure 2 and the time-dependence of the x-ray power is shown in Figure 3. The x-rays leave the target in three distinct pulses that are due to various phenomena occurring during the target burn.

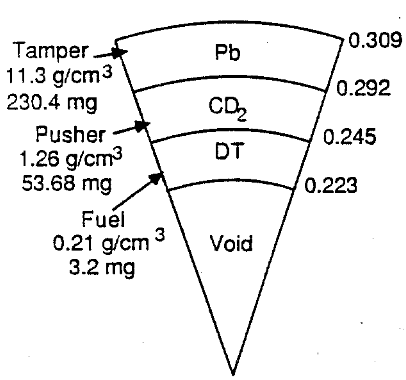

Figure 1. LIBRA target design.

3 is represented by a Gaussian width of 1 ns. This history and spectrum of x-rays is assumed to be independent of target yield. The target yield is varied by scaling the spectrum in Figure 2. The width of the x-ray pulse is dependent on the exact nature of the target. Since the target might not be exactly like LIBRA target, I have varied the x-ray pulse width in the simulations. I have also varied the target yield downward from 1000 MJ.

COMPUTER SIMULATION METHODS

I have used the CONRAD computer code[7] to simulate the pressure loadings on the LMF target chamber walls. The equation-of-state and opacity tables are from the IONMIX computer code[8] and from the SESAME equation-of-state library.[9] Radiation transport has been calculated with a 20 energy group diffusion model. In all calculations, the fill gas is 1 torr of helium and the wall material is carbon. The calculations assume spherical symmetry.

Three sets of simulations are presented. First, the non-neutronic fraction of the yield is varied between 12.4 and 278.6 MJ for an x-ray pulse width of 1 ns and a wall radius of 300 cm. Second, the same is done for a wall radius of 150 cm. Finally, calculations are done for the non-neutronic yield fixed at 249.4 MJ and the radius at 300 cm for a pulse width between 1 and 5 ns.

RESULTS

The results of these computer simulations are shown in Figures 4 through 9. In Figure 4, I show the pressure at the interface between the vaporized and unvaporized graphite as a function of time for 278.6 MJ of non-neutronic yield, a wall radius of 300 cm, and an x-ray pulse width of 1 ns. Time is measured from the start of the x-ray pulse on the surface of the graphite. Other calculations in this parametric study give qualitatively similar results. The peak value of 84.6 GPa (0.846 Mbar) occurs at 1.3 ns and the width of the pressure pulse is about 2 ns. This is what I have referred to as the vaporization pressure. Several microns of material are vaporized by the x-rays over the x-ray pulse width. The vaporization pressure pulse is due to a shock that passes through the vaporized graphite. This shock is generated by the initial temperature and pressure profile that the x-rays cause in the vaporized graphite. The passage of this shock through the vapor delays, reduces, and spreads the vaporization pressure pulse. This process is very important to understanding the nature of the vaporization pressure. Because the shock propagation through this thin vapor layer is the dominant process, most features should be a function of non-neutronic energy fluence and power density on the wall. This is demonstrated in Figures 4 through 6, where I have plotted vaporized thickness, peak vaporization pressure and impulsive pressure on the wall versus non-neutronic energy fluence. The x-ray pulse

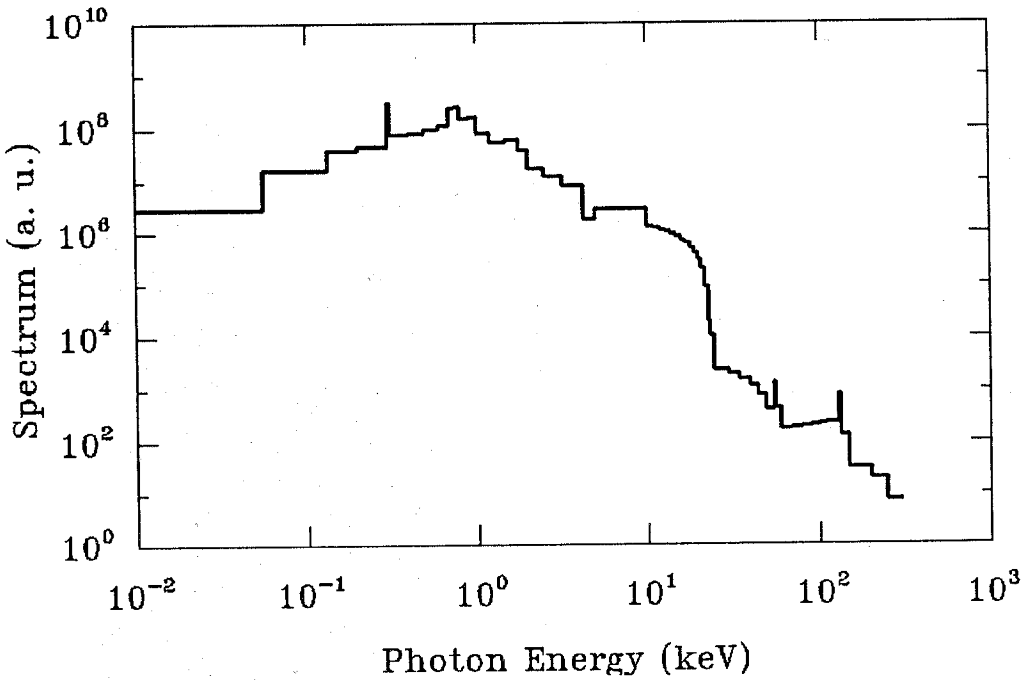

Figure 2. Time integrated x-ray spectrum emitted by LIBRA target.

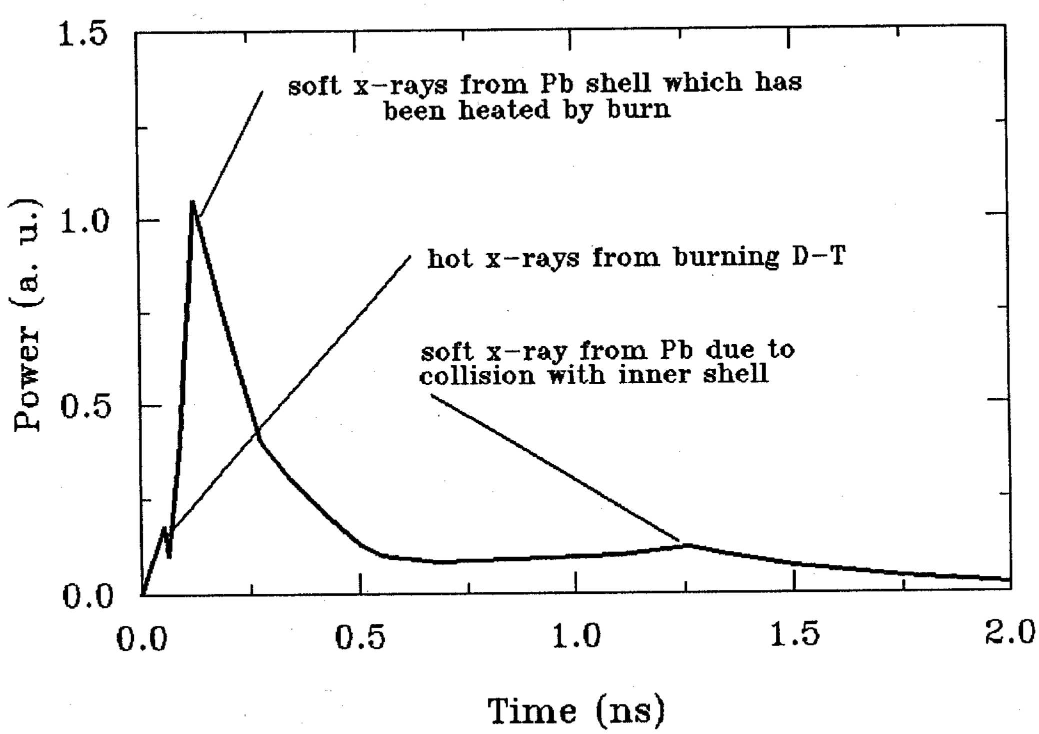

Figure 3. X-ray power emitted by LIBRA target versus time.

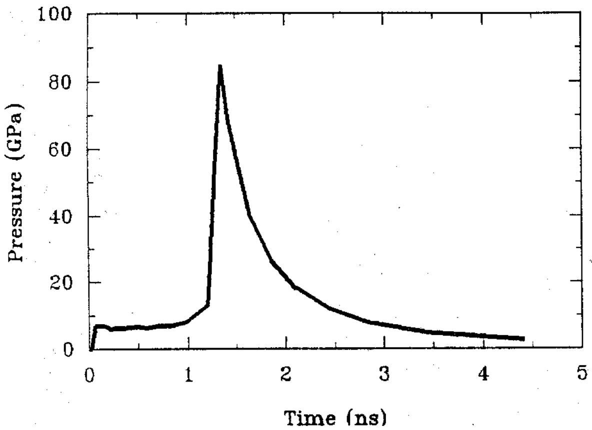

Figure 4. Peak pressure at the vapor/solid boundary in the graphite liner of the LMF. Non-neutronic yield is 278.6 MJ, wall radius is 300 cm, and x-ray pulse width is 1 ns.

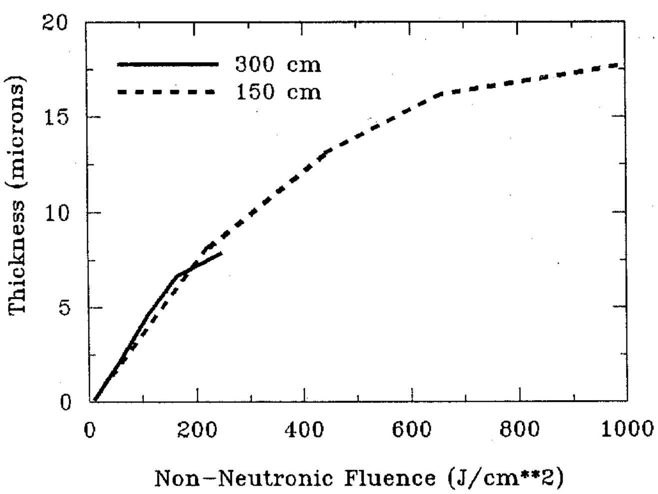

Figure 5. Initial thickness of vaporized material in the graphite liner of the LMF. X-ray pulse width is 1 ns.

width is 1 ns. The results of simulations at 150 cm and 300 cm and several non-neutronic yields have gone into these plots. The impulsive pressure is defined as the time integral of the pressure on the wall. Because these results scale as the energy fluence, one can use these as design curves for yields and radii that have not been directly considered.

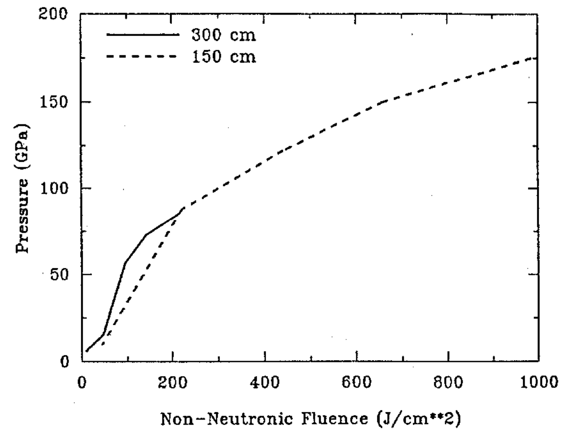

Figure 6. Peak pressure at the vapor/solid boundary in the graphite liner of the LMF. X-ray pulse width is 1 ns.

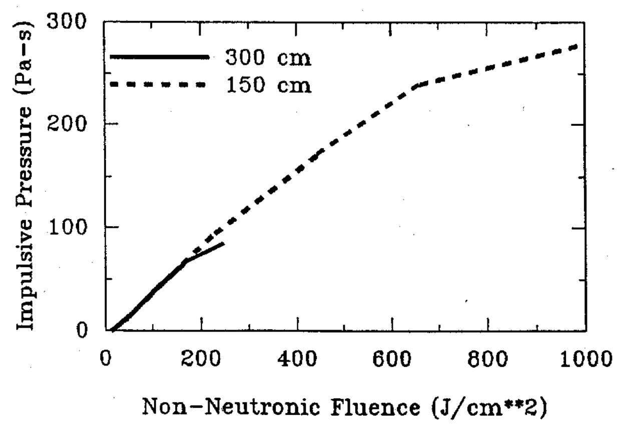

Figure 7. Impulsive pressure at the vapor/solid boundary in the graphite liner of the LMF. X-ray pulse width is 1 ns.

Because the x-ray pulse width is not well defined, I have studied the dependence of these same parameters on the pulse width. I have found that the impulsive pressure and vaporized thicknesses are not functions of the pulse width, as conservation of momentum and energy would lead one to believe. However, I have long believed that the

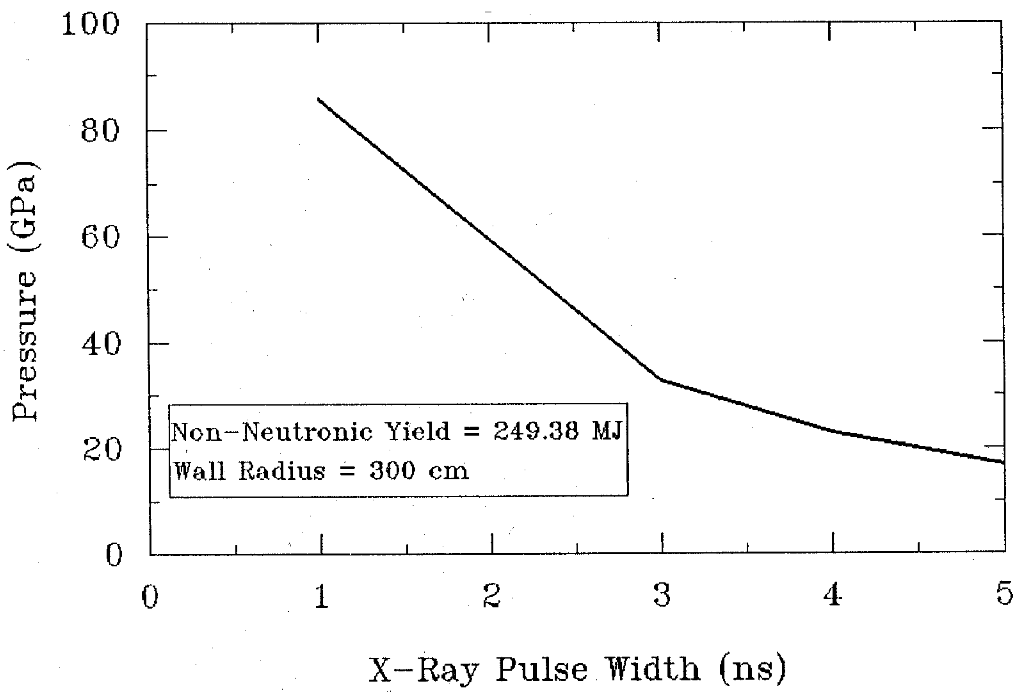

Figure 8. Peak pressure at the vapor/solid boundary in the graphite liner of the LMF versus x-ray pulse width.

peak pressure should be a function of power density.[10] In Figure 8, I plot the peak vaporization pressure at the vapor/solid interface versus x-ray pulse width for a fixed non-neutronic energy fluence. One can see that the peak pressure is inversely proportional to pulse width, or proportional to power density.

One important parameter that is not a function of the intrinsic variables is the residual pressure. This is proportional to the energy per unit volume in the chamber, so it is dependent on the target chamber design. I have calculated the residual pressure as $(\gamma\text{-}1)\ E/V$, where γ is the ratio of specific heats, E is the energy in the gas and V is the volume of the target chamber. I have taken γ to be 1.5, a value I have found by comparing this formula with CONRAD simulations. E is taken from the simulations and V comes from the target chamber designs. The residual pressures versus non-neutronic yield are shown in Figure 9 for 150 and 300 cm wall radii. One can increase the effective chamber volume, therefore lower the residual pressure, by venting the chamber. This is a topic currently under consideration.

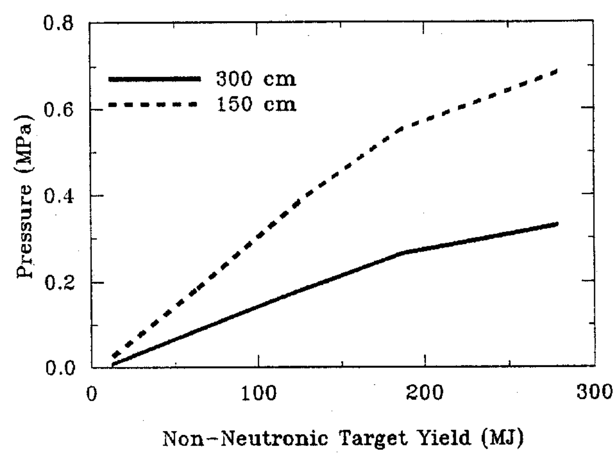

Figure 9. Residual pressure for the LMF. X-ray pulse width is 1 ns.

SUMMARY

Using the CONRAD computer code, I have completed a parametric study of the wall pressure loading in a light ion LMF. I have found the impulsive pressure and vaporized thickness are a function of non-neutronic energy fluence and that peak pressure is a function of non-neutronic power density. I have provided plots that can serve as design curves for the target chamber structural response. I have also calculated the residual pressure. I have found that the fill gas pressure loading is not important.

ACKNOWLEDGEMENT

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