Target Chamber Gas Issues in Near Term ICF Facilities

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INTRODUCTION

The next generation of Inertial Confinement Fusion (ICF) facilities will most likely have the tasks of driving targets to ignition, and then, demonstrating that high yield targets can be ignited and burned. The target chamber conditions must be considered before one seriously considers generating thermonuclear explosions with yields in excess of 100 MJ in a laboratory environment. The first ICF facilities to explode high yield targets will experience target chamber conditions far different from what is found in current facilities. A steel or aluminum target chamber will become radioactive enough after a single high yield target shot that hands-on access will be impossible until after a waiting period of perhaps several days.[1] This may lead to target chamber designs that are small enough to allow remote removal.[2] Small target chambers could lead to x-ray or fireball radiation fluences on the first surface high enough to vaporize part of the first wall or to high blast wave pressures on the first wall. We have been studying these effects in small ICF target chambers and will report on our work in this article.

We will begin with a discussion of target chamber gases. The gas must allow diagnosis of the target, which puts a limit on the density of the gas. We will then discuss the physics of vaporization in ICF target chambers and the interaction of the vaporized material with the target chamber gas. We will describe a series of computer calculations that demonstrate how this interaction can affect the target chamber.

TARGET CHAMBER GASES

We have previously considered target chamber gases of argon,[3] nitrogen,[4] and several condensable vapors.[5] In near term facilities we believe that a low atomic number gas may be preferable and have therefore chosen helium as the target chamber gas for this study. Our aim in choosing helium is to avoid degradation of target diagnostics.

Certain target diagnostics involve the detection of x-rays that either the target radiates or that are passed through the target.[6] The spectra of these x-rays may range from below 100 eV up to several keV. Our concern is that the target chamber gases be low enough in density that these x-rays

Table 1. X-Ray Stopping in Helium

	Density of Helium Gas (cm^{-3})		
	3.5×10^{15}	3.5×10^{16}	3.5×10^{17}
Fraction of 95 eV x-rays to propagate 50 cm	.84	.12	0
Fraction of 225 eV x-rays to propagate 50 cm	.98	.81	.09

will not be severely attenuated between the target and the x-ray detectors positioned at or behind the wall of the target chamber. We believe that sensitive and expensive x-ray optics should be protected from the target explosion generated blast wave and therefore, the optics and detectors should be kept some distance from the target. The diagnostics could be placed behind the target chamber wall, where a port would be provided to allow transmission of the x-rays, or one could imagine putting optics a little bit closer to the target if they had sufficient protection.

We have calculated the fraction of x-rays that traverse 50 cm of helium at various densities. The x-ray energies were arbitrarily picked to be 95 eV and 225 eV. The results are shown in Table 1. The calculations leading to these results were done with x-ray stopping cross sections from the Biggs tables.[7] One can see that, if 95 eV x-rays are used in a diagnostic, the target chamber gas should be no denser than 3.5×10^{16} cm^{-3} (1 torr @ 0 ^{o}C). If 225 eV photons are required, then the gas pressure might be allowed to be as high as 10 torr if 9% of the x-rays are sufficient for the diagnostic. The 50 cm propagation distance is somewhat arbitrary, but the results in Table 1 can be scaled with the product of propagation distance and density. The several keV x-rays used in some diagnostics would not be affected by these densities of helium gas.

VAPORIZATION PHYSICS IN ICF TARGET CHAMBERS

Vaporization of first wall material in ICF target chambers greatly complicates the physics of the cavity gas. In the absence of vaporization, the mechanical loading on the first wall is due to shock waves generated by the target explosion. When vaporization occurs, the wall experiences a recoil mechanical impulse equal to the momentum of the vapor as it moves off of the surface, but the vapor can help shield the wall from the target generated shocks. We have previously noted that the total impulse, i.e. the sum of the recoil and shock impulses, is relatively insensitive to the amount of vaporization.[2] This observation is the result of a series of computer simulations that have demonstrated complexity of the target chamber gas dynamics.

Target generated x-rays volumetrically deposit their energy in the target chamber wall and can vaporize part of it. The details of the vaporization process are a subject of active research that we are currently pursuing. The x-rays deposit their energy over a time short compared to the thermal transport time in the wall, so that the wall can reach a condition where a region of the wall has a local energy density greater than that required for vaporization. This region is 1 micron thick for typical ICF parameters and becomes vaporized. A second region has a local energy

Table 2. X-Ray Vaporization of Graphite with Helium Cavity Gas

	Density of Helium Gas (cm^{-3})		
	$3.5x10^{15}$	$3.5x10^{16}$	$3.5x10^{17}$
Total x-rays to reach wall (MJ)	63.4	63.0	60.9
Vaporized mass (g)	230	230	230

density less than that required for vaporization, but more than the sensible energy for the material when it is at its boiling temperature. This region may be several microns thick and it is not clear how much of this is vaporized. Target chamber gases can attenuate the x-rays and reduce the amount of wall vaporization.

We have performed calculations of the amount of vaporization from the graphite walls of a 50 cm radius target chamber. The target yield was 320 MJ and it had an x-ray spectrum centered around 1 keV, with a total of 63 MJ in x-rays. Calculations were performed with the CONRAD computer code, which is described below. The vaporization option used assumed that all of the wall material heated to above the vaporization energy density is vaporized and that that fraction of the material above the sensible heat but below the energy density for vaporization that is energetically allowed to do so, is vaporized. The results are shown in Table 2 for a variety of gas densities. One sees that, for these parameters, the vaporized mass is not affected by the gas density because most of the x-ray energy reaches the wall for all three densities. The x-rays that deposit in the gas are the short range soft x-rays that would only heat the surface of the graphite and not contribute to volumetric heating and vaporization in a major way.

The vaporized material moves into the target chamber, where it can mitigate the effects of the target generated blast. The energy deposited in the gas by x-rays and debris ions forms a blast wave that moves towards the wall. This blast will meet the vaporized material and collide with it. If the vapor has the greater momentum, it will continue driving the gas, including the shock, inward. If the shock has the greater momentum, the reverse will occur. If the two have roughly equal momenta, they will reflect. Also, the outward moving shock will drive a shock through the vapor that will reach the wall but will have much less strength than did the original shock. If the gas is not dense enough to absorb much ion energy, then the ions will deposit in the vapor and will drive a shock through the slug of vapor. In the next section, we will describe computer simulations of these effects.

COMPUTER SIMULATIONS

We have used the CONRAD computer code to simulate the behavior of target chamber gases in ICF target chambers.[8] CONRAD is a one-dimensional Lagrangian hydrodynamics program with 20 group radiation transport. The code calculates x-ray transport with up to 100 energy groups and x-ray heating of the target chamber gas and the wall material. It also transports the debris ions from the target throughout the target chamber in a time-dependent manner, where the time-of-flight of the ions is taken into account, and calculates the ion energy deposition in the gas. The code calculates heat transfer, surface and volumetric energy deposition in the walls, and the vaporization of material from the wall. The vaporization is dependent upon the local energy density in the wall and the wall's surface temperature. The code also simulates the condensation of vaporized material back onto the walls.

We have studied the interaction of the vaporized material with the target generated blast waves in the target chamber gas. We have performed calculations for target chamber gas densities of .1 torr and 1 torr. The gas species was helium, the target radius was 50 cm and the target yield was 320 MJ. The target yield was partitioned into 63 MJ of x-rays and 26 MJ of ions. The x-rays vaporized 230 g of graphite from the wall in both cases. This vapor comes off of the wall at a velocity of 2 x 10^5 cm/s. This is shown in Fig. 1, where the positions of Lagrangian zone boundaries in the gas are plotted against time for a gas density of 0.1 torr. One can

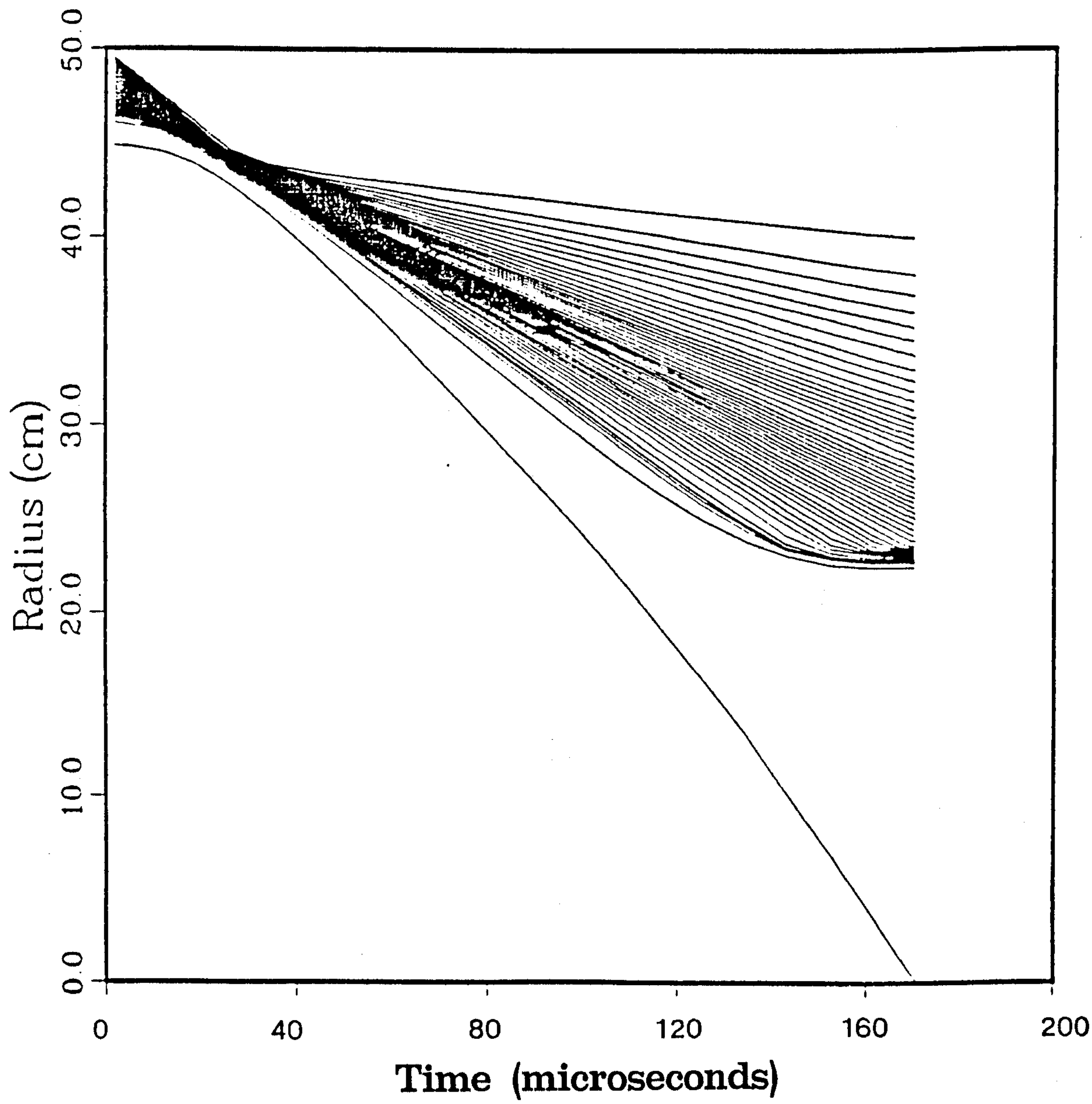

Fig. 1. Positions of Lagrangian Zone Boundaries in Gas versus Time. The gas was 0.1 torr of helium.

see that at a time of 40 microseconds the ions are depositing their energy in the vapor. In this case the vapor was too thin to stop the ions. One sees in this plot that the ion generated shock quickly blows some of the vapor off of the back of the main mass of vapor, which keeps moving towards the center of the cavity until it begins to stagnate at 160 microseconds. A similar plot could be shown for 1 torr of helium, but the result is very much the same. For both calculations, the wall does not experience a hydrodynamic load until after the inward moving vapor has stagnated and moved out to the wall again. Our one-dimensional calculations of the pressure pulse on the wall are not valid for this situation, but one would not expect a well-defined shock to reach the wall.

CONCLUSIONS

The target chambers in which high yield target experiments are conducted may have to be small for radioactivity and diagnostics reasons. These small target chambers would have high x-ray and ion fluences on their first walls, which could lead to vaporization of the first wall. We have shown in this paper that, though the vaporization leads to a recoil impulse, this vapor can shield the first wall from the target generated ions and the blast generated by the x-rays and ions.

ACKNOWLEDGEMENTS

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REFERENCES

1. D.L. Henderson, G.A. Moses, and R.R. Peterson, "Activation Studies of the Light Ion Beam Target Development Facility," J. Nucl. Mat. 141-143 (1986) 49-54.

2. G.A. Moses, et al., "Design Studies of the APEX Light Ion Fusion Experiment," University of Wisconsin Fusion Technology Institute Report UWFDM-735 (October 1987).

3. R.R. Peterson, G.W. Cooper, and G.A. Moses, "Cavity Gas Analysis for Light Ion Beam Fusion Reactors," Nucl. Tech./Fusion 1 (2), (1981) 377-389.

4. R.R. Peterson and G.A. Moses, "Target Explosion Generated Fireballs in the Nitrogen Filled Target Chamber of the Light Ion Fusion Target Development Facility," Nucl. Tech./Fusion 4 (1983) 860.

5. R.R. Peterson, "Analysis of Cavity Conditions in Heavy Ion Beam Fusion Reactors," University of Wisconsin Fusion Technology Institute Report UWFDM-719 (February 1987).

6. S.G. Glendinning, R.E. Turner, and S.M. Lane, "X-ray Imaging of Direct-Drive Targets at Nova," these proceedings.

7. F. Biggs and R. Lighthill, "Analytical Approximations for Total and Energy Absorption Cross Sections for Photon-Atom Scattering," SC-PR-72-0685, Sandia National Laboratory, Albuquerque, NM, December 1972.

8. R.R. Peterson, "CONRAD - A Combined Hydrodynamics-Condensation/Vaporization Computer Code," University of Wisconsin Fusion Technology Institute Report UWFDM-670 (April 1986).