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# TARGET CHAMBER GAS RESPONSE AND VAPORIZATION IN A LASER AND A HEAVY ION BEAM IFE REACTOR

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## Abstract

Laser fusion and heavy ion fusion have target chamber gas requirements that lead to different optimum target chamber designs. Experimental results indicate that lasers may successfully propagate through gases of high enough density to absorb target x-rays and ions. The density of the gas required for heavy ion propagation is more uncertain than laser propagation and depends greatly on the mode of transport. In this study, auto-neutralized transport is considered and a gas density is used that precludes protection of the first surface of the target chamber from x-rays and ions. The dominant issue in the design of the laser fusion target chamber is the re-radiation of absorbed target energy from the gas to the wall of the target chamber. In the heavy ion fusion target chamber, vaporization of material from the wall is the most important consideration. Both of these issues are analyzed with the CONRAD computer code.

## Introduction

The Fusion Technology Institute of the University of Wisconsin (UW) is involved in a study of the feasibility of inertial confinement fusion energy (IFE) as a source of electrical power [1]. As part of this study, UW is working with Avco, Bechtel, General Atomics, the University of New Mexico, and W.J. Schafer Associates to design IFE power plants using a laser or a heavy ion accelerator to ignite and burn IFE targets. The laser design, named SOMBRERO, uses a KrF laser to directly drive a target. The heavy ion beam design, OSIRIS, uses an indirect drive target. The targets in both cases emit x-rays, neutrons and ions, though the spectra, energy partitioning, and pulse widths will be different. The assumed target parameters are given in Table 1. An important facet of the analysis of these two designs is how the target generated x-rays and energetic target debris affect the target chamber gases and first surfaces.

Table 1. Target Parameters for SOMBRERO and OSIRIS.

| | SOMBRERO | OSIRIS |
|---|---|---|
| Energy on Target (MJ) | 3.6 | 5.0 |
| Target Gain | 118 | 73 |
| Target Yield (MJ) | 425 | 365 |
| Neutron Yield (MJ) | 323 | 256 |
| X-ray Yield (MJ) | 18.5 | 71.9 |
| X-ray Pulse Width (ns) | 0.1 | 1.0 |
| Debris Yield (MJ) | 83.6 | 37.1 |

The target chamber gas requirements differ for the two driver types. In SOMBRERO, we believe that the laser light can propagate through $1.5 \times 10^{16}$ atoms/cm$^3$ of noble gas. We chose xenon because it has a high enough atomic number to absorb most of the x-rays and ions in roughly $10^{17}$ atoms/cm$^2$ of areal density and protect the first wall with a few meters of gas. In OSIRIS, heavy ion beams probably require a lower density, lower atomic number gas, where the target emanations will not be stopped. Therefore, in OSIRIS, the first surface will likely be vaporized. One can compare the responses of the two target chamber designs to the target explosions. The dominant process in the behavior of the target chamber gas in SOMBRERO is deposition of target energy in the gas and re-radiation of that energy to the target chamber walls. In OSIRIS, deposition and vaporization are the most important phenomena. Radiation transport is important in the early phases of recondensation of the vaporized material but is not a dominant phenomenon. We use the CONRAD computer code [2] to study the behavior of the chamber gases and the vaporization of first wall material.

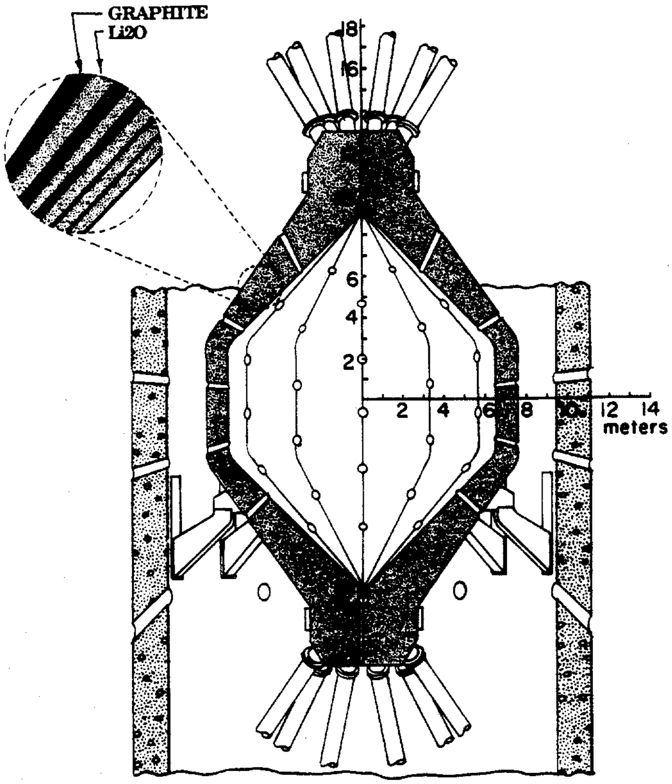

Figure 1. SOMBRERO target chamber.

## Target Chamber Designs

We have chosen a separate target chamber design for each of the two reactor concepts. Since target chamber requirements and conditions are different for laser and heavy ion IFE, a single target chamber design would not be the optimum for either concept but would require compromises. By choosing to have a generic target chamber design, we may be excluding an advantage that one reactor concept would have over another. Since one purpose of the current study is to compare the technologies, a generic target chamber would not be helpful to the overall study.

### Sombrero - KrF Laser Fusion

The SOMBRERO target chamber is shown in Fig. 1. The chamber is filled with $1.78 \times 10^{16}$ atoms/cm$^2$ of xenon. The target x-rays and ions are stopped in the xenon. The energy in the gas is then re-radiated to the walls over a period of several hundred $\mu$s. The surface of the target chamber is constructed of woven graphite that is hardened with a graphite matrix. The graphite surface is cooled from the back by $Li_2O$ particles that are falling by gravity in channels. Two atmospheres of helium is also

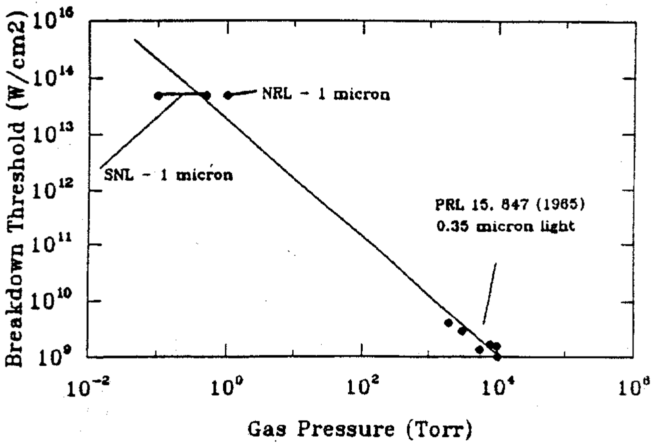

Figure 2. Experimentally measured breakdown thresholds in xenon.

present in the channels to move the particle bed. To prevent leakage of helium into the xenon gas, the surfaces of the graphite are sealed with a thin layer of SiC. A more detailed discussion of the moving bed is included in another paper in these proceedings [3].

Primary to the SOMBRERO design is the choice of xenon gas density that fills the target chamber. We believe that breakdown of the gas by the laser places an upper limit on the density of the gas. We have examined past experimental studies into laser induced breakdown and have found that the wavelength and density dependence is well documented [4]. In these experiments, the breakdown threshold of xenon was measured above 1000 torr of gas pressure, three orders of magnitude higher than in SOMBRERO. Other experiments have measured the breakdown threshold near the SOMBRERO density for 1 $\mu$m laser light [5, 6]. The results of all these experiments are shown in Fig. 2, where the quoted laser intensity thresholds for break down are plotted against gas density. One aspect of breakdown for which we have found no experimental studies is the effect of laser coherence. The target illumination parameters are shown in Table 2. If laser light must be coherent to breakdown gas, then light overlapped from multiple beams will have no more ability to break down the light than a single beam. From Table 2 and Fig. 2, one sees that break down can be avoided with SOMBRERO parameters if we assume that the laser light must be coherent to breakdown.

Table 2. SOMBRERO Target Illumination Parameters.

| | |
|---|---:|
| Laser Pulse Width | 10 ns |
| Peak Total Intensity on Target | 494 TW/cm$^2$ |
| Peak Intensity on Target per Beam | 33 TW/cm$^2$ |
| Target Radius | 0.311 cm |
| Number of Beams | 60 |
| F Number for Final Laser Optics | 50 |
| Overlap Radius | 1.20 cm |
| Fill Gas Species | Xenon |
| Fill Gas Density | $1.8\times10^{16}$ cm$^{-3}$<br>(0.5 torr) |

## OSIRIS - Heavy Ion Beam Fusion

The OSIRIS target chamber is shown in Fig. 3. Because the target chamber fill gas density must be low (we have assumed $3.55\times10^{12}$ cm$^{-3}$) for proper heavy ion beam propagation, and because of limits on the transport length of the beams, the x-ray intensity is rather high on the target chamber walls. Therefore, vaporization of the surface of the wall is unavoidable. We address this problem by continuously coating the surface of the wall with the liquid molten salt, FLIBE (2LiF + BeF$_2$). The FLIBE is vaporized from the near walls of the target chamber, the vapor being directed downward by the shape of the walls into the condensing mist and pool at the bottom of the chamber. The liquid FLIBE is replenished to the surface of the walls by bleeding of liquid FLIBE through the woven graphite that supports the film. The critical issue addressed for OSIRIS in this paper is the vaporization process at the nearest point to the target explosion on the wall.

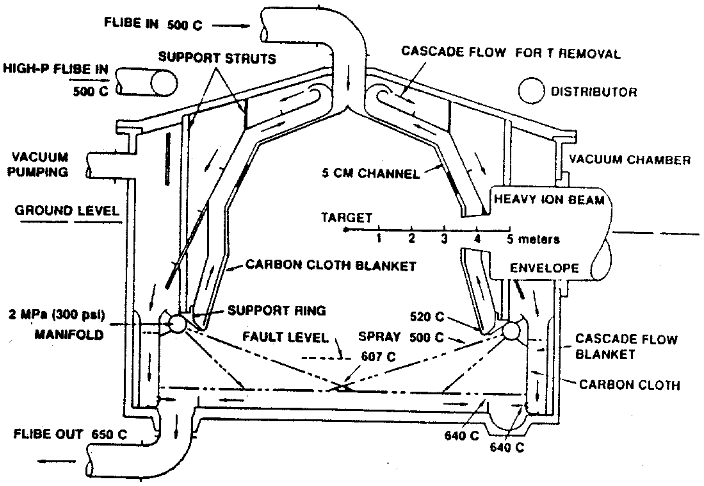

Figure 3. OSIRIS target chamber.

## Computer Methods

We have used the CONRAD computer code [2] to analyze the target chamber designs for SOMBRERO and OSIRIS. CONRAD is a one-dimensional Lagrangian finite difference computer code that calculates hydrodynamic motion, radiation transport, and vaporization and condensation in a slab, cylindrical, or spherical geometry. Radiation transport is calculated with flux limited multigroup diffusion. Time-dependent target x-ray and ion deposition are calculated in the fill gas and walls. Heat transfer calculations are performed by CONRAD to get wall surface temperatures and temperature profiles in the wall at all times. Vaporization and condensation calculations can then be done.

Equation-of-state and opacity data is read by CONRAD from tables. The properties of the materials are, therefore, assumed to be quasi-static. The data tables are created with equation-of-state results from the IONMIX [7] computer code or from the SESAME [8] library. IONMIX is better suited to materials much less dense than solids or liquids, while SESAME is preferred at higher density. Opacity tables are constructed with results from IONMIX. 20 energy group opacities are used in the OSIRIS calculations and 180 group opacities are used in SOMBRERO calculations.

## Results

We have performed CONRAD simulations for both SOMBRERO and OSIRIS. These computer simulations address what we believe are the dominant issues in the two target chamber designs. For SOMBRERO, the simulation predicts the re-radiation time for the energy absorbed in the 0.5 torr xenon gas and the resulting temperature on the graphite surface of the

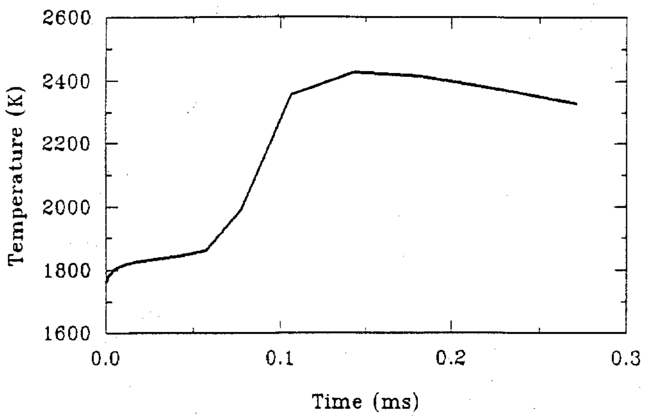

Figure 4. SOMBRERO first wall surface temperatures for a 400 MJ yield, 0.5 torr xenon fill gas, and a 650 cm radius chamber.

target chamber. For OSIRIS, the issues of x-ray vaporization are addressed by the simulations. All simulations are done in spherical geometry.

SOMBRERO

The essential parameters for the SOMBRERO simulations are shown in Table 3. The wall is taken to be 6.5 m in the simulation as this is the closest point in a non-spherical chamber. A steady state heat transfer calculation of the surface heat through the graphite leads to a steady state surface temperature of 1485 C. The CONRAD simulation predicts a peak surface temperature at the closest point on the wall of 2155 C, well below the sublimation temperature for graphite of 4100 C. CONRAD predicts that no graphite is vaporized. The xenon gas is very effective in slowing the transfer of energy from the target to the wall, which is why there is no vaporization. The surface temperature of the graphite is shown as a function of time in Fig. 4. The broad temperature pulse, which reaches a maximum at 0.134 ms, should be compared to the almost instantaneous target x-ray pulse and the target ion pulse width of 5 ns. Based on this simulation, we believe that a 6.5 m radius graphite lined chamber filled with 0.5 torr of xenon will survive a 425 MJ target explosion.

Table 3. SOMBRERO Gas and First Wall Parameters.

| | |
|---|---|
| Gas Species | Xenon |
| Gas Density | $1.8\times10^{16}$ cm$^{-3}$<br>(0.5 torr) |
| Distance to Wall | 6.5 m |
| Wall Material | Woven Rigidized Graphite |
| Steady State Wall Temp. | 1485 C |
| Peak Wall Temp. | 2155 C |
| Time of Peak Wall Temp. | 0.134 ms |

OSIRIS

We have performed a CONRAD simulation for OSIRIS, the essential parameters of which are given in Table 4. The closest point of the FLIBE coated wall is 3.5 m from the target, so the x-ray fluence on the liquid FLIBE is 46.7 J/cm$^2$. The x-ray intensity is 46.7 GW/cm$^2$. The x-rays vaporize 2.35 mg/cm$^2$ or 11.9 $\mu$m of FLIBE from the wall. The x-rays create a high pressure gradient in the vapor that drives a shock into the vapor.

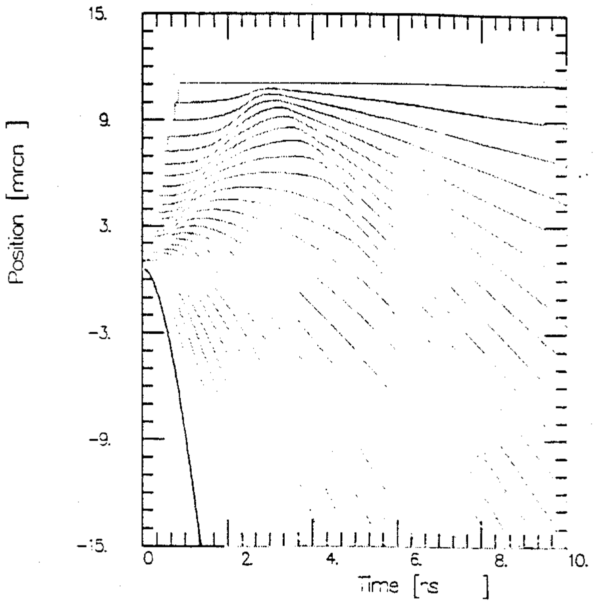

Figure 5. Positions of Lagrangian zone boundaries versus time for vaporization from the OSIRIS first wall. Position equals 0 is the original position of the liquid surface of the FLIBE. All other positions are in $\mu$m.

This shock can be seen in Fig. 5, where Lagrangian zone boundaries that are fixed in the material are plotted against time. The shock propagates through the vapor, which is at or slightly about the liquid density of fluid but in a vaporized state, and eventually reaches the vapor/liquid interface in the FLIBE. The pressure at the interface is recorded as a function of time in Fig. 6. The peak pressure at the interface is 31.2 GPa, which is certainly enough to launch a shock into the liquid FLIBE. The impulse at the interface is 75.6 Pa-s, so the effective pulse width is 2.4 ns. This impulse is not excessive in that several IFE reactor designs have been designed with higher impulses. The issues of where the vapor flows and the propagation of shocks into the liquid FLIBE have yet to be analyzed.

Table 4. Parameters on the Closest Wall of the OSIRIS Target Chamber.

| | |
|---|---|
| Distance from Target | 3.5 m |
| Wall Material | FLIBE |
| X-ray Fluence on Wall | 46.7 J/cm$^2$ |
| X-ray Intensity on Wall | 46.7 GW/cm$^2$ |
| Vaporized Mass | 2.35 mg/cm$^2$ |
| Vaporized Thickness | 11.9 $\mu$m |
| Impulse on Wall | 75.6 Pa-s |
| Peak Pressure | 31.2 GPa |

## Conclusions

We have investigated the target chamber designs for two IFE reactors. The CONRAD computer code has been used to analyze certain critical aspects of these designs. The critical issues differ between the two designs because driver beam transport differences lead to dissimilar designs. In both designs some issues are resolved while others are not.

In SOMBRERO, 0.5 torr of xenon gas should allow beam transport and will protect the graphite wall vaporization by target energy. The issue of thermal stresses in the graphite has not yet been analyzed. Experiments and further analysis are needed to verify the laser propagation in xenon.

In OSIRIS, we have found that the FLIBE is vaporized and that a high peak pressure but moderate impulse shock reaches the vapor/liquid interface in the FLIBE. The effect of the shock and the flow of vapor into the target chamber need further analysis. The condensation of vapor in the mist and pool at the bottom of the reactor needs to be analyzed.

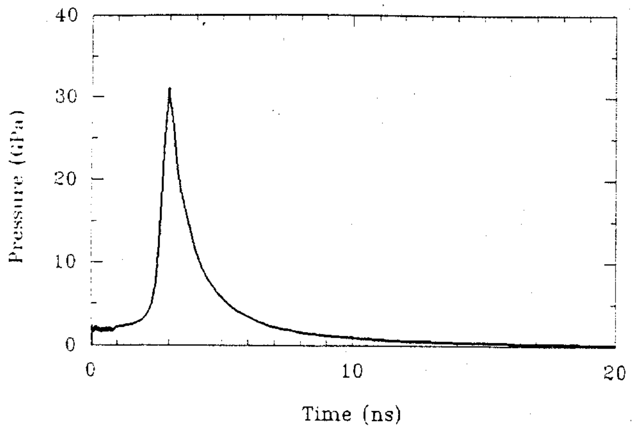

Figure 6. Pressure at the vapor/liquid interface on the closest FLIBE coated wall of the OSIRIS target chamber.

## Acknowledgement

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