Radiation-Driven Targets for Heavy-Ion Fusion

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1. CAPSULE DIMENSION AND IMPLOSION CALCULATION

The capsule structure is shown in Fig. 1. The ablator is made of beryllium and its outer radius is 0.234 cm. The ablator encloses the fuel layer of solid DT, which has an outer radius of 0.212 cm. The fuel layer encloses low-density DT gas, which serves for spark-plug formation. Figure 2 shows the radiation temperature profile required for implosion, which is peaked at 260 eV.

The capsule implosion is calculated with the radiation hydrodynamic code HYADES.¹ Figure 3 shows the implosion trajectory. The peak velocity of the fuel layer is about 3×10^7 cm/s. Estimates show that the fuel layer should be able to survive Rayleigh-Taylor instability that arises during the acceleration and stagnation phase. The capsule reaches the assembled configuration at 38 ns; the energy absorbed by the capsule at this time is 1 MJ, and the yield is 430 MJ.

2. HOHLRAUM CONFIGURATION AND ILLUMINATION SYMMETRY

The hohlraum for the capsule described is shown in Fig. 4. The converters have radius r_c , and the radius r_0 of the converter opening is 0.15 cm. The shine shields in front of the converters block the direct-line-of-sight illumination from the converters. By adjusting the positions of the shine shields, A_2 (where A_n represents for the coefficient of the Legendre polynomial P_n) for the flux asymmetry can be minimized. The A_4 coefficient can be reduced by using the rings located at about 45° . The initial capsule-to-hohlraum surface area ratio is about 0.075. The hohlraum case is made of lead.

To calculate the illumination symmetry of the capsule, it is necessary to consider the fact that the capsule radius decreases with time (as shown in Fig. 3) and that the inward expansion of the hohlraum wall from exposure to radiation with temperature history in Fig. 2. The wall motion is characterized by the motion of the location at which the Rosseland mean optical depth τ equals unity. The location of this surface as a function of time, calculated using HYADES, is plotted on Fig. 5 for a thin spherical shield with 0.7-cm initial radius, and with the outer radius fixed in time. This figure shows that the surface moves considerably, so that the decrease in area of this surface caused by the spherical convergence is noticeable. The effective albedo of this spherical shell is higher than that for the planar case as shown in Fig. 6. The effective wall albedo is defined as

$$\alpha_{\text{eff}} = 1 - \frac{\dot{E}}{A_0 \sigma T^4}$$

where $\dot{E}$ is the rate of energy absorbed by the shell, A_0 is the initial area of the spherical shell, σ is the Stefan-Boltzmann constant, and T is the radiation temperature. The expansion of the $\tau = 1$ surface can be slowed down somewhat if the hohlraum is filled with a few milligrams of helium.

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ABSTRACT

The baseline hohlraum configuration for heavy-ion fusion has the radiation converters placed at opposite ends. For a capsule that absorbs about 1 MJ and has an initial radius of 0.234 cm, the minimum initial capsule to hohlraum surface area ratio that can provide an adequate time-dependent symmetry requirement for a capsule implosion is about 0.075, based on calculations using the view factor code GERTIE. The capsule implosion is calculated using the hydrodynamic code HYADES. The energy coupling efficiency between the hohlraum and the capsule is 21%, the peak hohlraum temperature is 260 eV, and the gain of this target system can be as high as 80. By placing the converters outside the hohlraum, the radii of the converters can be varied according to the beam focusing requirements while the hohlraum dimensions remain unchanged. By bending the radiation converters by 90°, one can obtain a hohlraum configuration that requires the ion beams to come in from only one direction.

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Based on the above information on the trajectory of the capsule radius, hohlraum wall motion, and the wall albedo, the time-dependent illumination asymmetry seen by the capsule (expressed in terms of A_2/A_0 and A_4/A_0) calculated using GERTIE² at various times between 0 and 38 ns, is plotted in Fig. 7. The asymmetry shown in this figure is tolerable from the capsule implosion point of view. Note that the geometry of the rings can be assumed to be roughly constant in time since they can be made of low-density lead foam with a plastic liner (to minimize the expansion of the foam).

To calculate the energy coupling efficiency η_e between the capsule and the hohlraum, we use the respective α_{eff} for the capsule and the hohlraum (the dashed curve in Fig. 6) and let the capsule radius and the hohlraum wall be fixed at their initial locations. The value for η_e obtained from GERTIE is about 21%.

3. RADIATION CONVERTER SYSTEMATICS

The radiating and beam-stopping material, contained inside the lead converter casing, is composed of beryllium mixed with a small amount of lead.³ The converter radius r_c is determined by the focal spot size of the ion beams.⁴ Since the converters are placed outside the hohlraum, the hohlraum dimensions can remain invariant even if r_c changes (but r_0 remains constant). The LASNEX⁵ result for the radiation conversion efficiency η_c is plotted against r_c for various beam ion energies in Fig. 8. (The energy absorbed by the casing is already taken into account.) Knowing η_c and η_e , the gain of the target system can be obtained; the result is plotted in Fig. 8.

4. NOVEL TARGET CONFIGURATION

The hohlraum described above requires bending high-current beams using quadrupole magnets, which can be difficult. The hohlraum with the converters bent by 90°, as shown in Fig. 9, requires the beams to come in from only one direction and hence avoids the requirement of beam bending.

5. CONCLUSION

Time-dependent calculations show that the hohlraum can satisfy the illumination symmetry requirements for implosion while the target system can still have high gain. Detailed 2-D LASNEX calculations are in progress.

6. ACKNOWLEDGMENT

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7. FIGURE CAPTIONS

Fig. 1. Capsule structure.

Fig. 2. Radiation temperature profile.

Fig. 3. Capsule implosion trajectory.

Fig. 4. Hohlraum configuration.

Fig. 5. Location for the $\tau = 1$ surface for the thin spherical lead shell with initial radius of 0.7 cm.

Fig. 6. Albedo of lead for the spherical shell (dashed curve) and for the planar case (solid curve).

Fig. 7. Time dependent illumination asymmetry seen by the capsule expressed in terms of the coefficients of the Legendre polynomial.

Fig. 8. Conversion efficiency η_c (solid curves) and gain (dashed curves) versus converter radius r_c for ion beams with ion kinetic energy of 5, 7.5, and 10 GeV.

Fig. 9. Hohlraum configuration that requires the ion beams to come in from only one direction.

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16DMH/wh

Figure 1

50-01-0894-3164pb01

16DMH/lwh

Figure 2

50-01-0894-3163pb01

16DMH/wh

Figure 3

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18DMH/wh

Figure 4

50-01-0894-3168pb01

16DMH/twh

Figure 5

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16DMH/lwh

Figure 6

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19DMH/twh

Figure 7

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18DMH/lwh

Figure 8

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18DMH/wh

Figure 9