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GENERAL ATOMICS/SAN DIEGO STATE UNIVERSITY TEAM INVESTIGATES IFE TARGET HEATING DURING INJECTION

by
PROJECT STAFF

JULY 2000

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General Atomics is currently designing an experimental IFE target injection and tracking system. As part of this effort Nathan Siegel, a graduate student from the Department of Mechanical Engineering at San Diego State University, has been working with GA for the past 18 months investigating direct and indirect drive target heating during injection (Fig. 1). The work has formed the basis of Nathan's Master's Thesis. His results confirm that current indirect drive targets are far more resistant to damage caused by heating than are direct drive targets. This is due primarily to the protection provided by the low-density (and low thermal conductivity) materials that make up the indirect drive hohlraum. In addition, the thermal environment inside direct drive reactors is much more severe as the wall temperatures are generally higher and a low-density fill gas is often present (Table 1). For these reasons, the majority of the target heating analyses focus on direct drive systems.

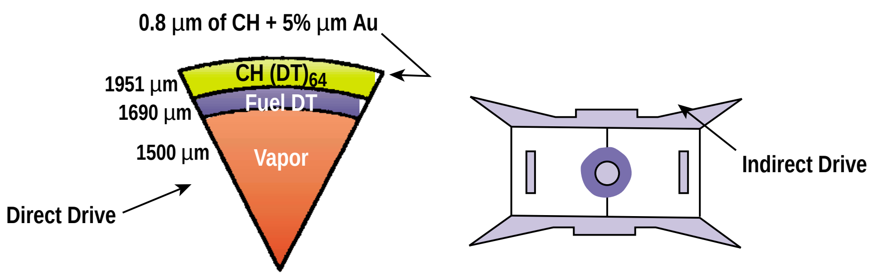

Fig. 1. IFE target concepts.

	Direct Drive (SOMBRERO)	**Indirect Drive (OSIRIS)**
Temperature, °C	1485	923
Gas species	Xenon	Flibe
Gas density, cm^{-3}	3.55 x 10^{16}	3.55 x 10^{12}
Chamber radius, m	7	3.5

A key direct drive target heating issue involves the temperature rise allowed in the DT/CH foam ablator (shown in yellow, Fig. 1) during injection. For an initial target temperature of 18 K, a temperature rise of about 0.8 K is calculated to produce thermal stresses in the target that will exceed the estimated yield strength of DT and may damage the target. As the temperature continues to rise, melting and/or vaporization of the DT will occur at the triple point (19.79 K). This will lead to hydrodynamic instabilities during target implosion. Three injection regions can then be defined: Successful Injection (18 K<T<18.8 K), At-Risk (18.8 K<T<19.79 K), and Excessive Heating (T>19.79 K).

In the SOMBRERO IFE power plant, which is representative of a class of dry-wall, gas filled chamber designs, the first wall temperature during operation is estimated to be 1485°C. At this temperature, there is a significant amount of thermal radiation, emitted by the first wall, incident on the target. Applying a reflective coating to the surface of the target can reduce the magnitude of the absorbed thermal radiation flux. Vapor deposited gold coatings with thicknesses of about 2000Å have shown reflectivities of ~98% and are essentially opaque over the thermal emission spectrum of IFE reactors with wall temperatures of 700–1485°C. A xenon fill gas is also present in the chamber [pressure of 0.5 torr (67 Pa) at 300 K] to shield the first wall from x-rays and debris ions. This gas, at a temperature of 1485°C, will transfer heat to the target as it passes through. Under these chamber conditions, and assuming 98% surface reflectivity, the total heat flux on the target is about 14 W/cm^2 for injection at 400 m/s. The resulting DT temperature rise is excessive (for successful injection at 400 m/s, the total heat flux on the target must be less than about 0.6 W/cm^2). Of the 14 W/cm^2, about 90% is due to convection heat transfer from the chamber fill gas to the target. The remaining heat flux comes from thermal radiation.

During injection, the heat flux from thermal radiation is distributed symmetrically around the surface of the target. The component from convection was modeled with ANSYS FLOTRAN, a computational fluid dynamics code, and was found to be distributed asymmetrically around the surface of the target (Fig. 2). This asymmetry causes increased heating at the leading edge (stagnation region) of the target and produces nonuniformities in the density of the solid DT fuel, which will lead to hydrodynamic instabilities during target implosion.

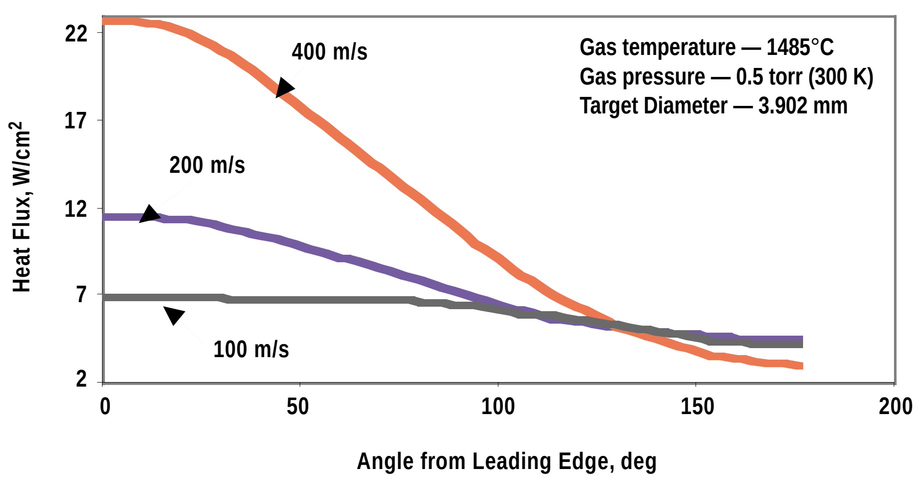

Fig. 2. Convection heat flux is distributed asymmetrically over the target surface.

Ideally, the total heat load during injection would be applied symmetrically over the entire surface of the target. This may be accomplished by spinning the target in a manner that limits the amount of time that any portion of the target surface spends in the stagnation region. In this case, energy deposited on the surface conducts through the capsule (~0.8-µm thick), which offers negligible resistance to heat flow and begins heating the DT/CH foam adjacent to the capsule, termed the outer ablator. Calculations done with ANSYS, a finite element code, indicate that the temperature rise in the outer ablator is a function of several parameters including fill gas density, reactor wall temperature, surface reflectivity, and injection velocity (Fig. 3). For the SOMBRERO design conditions, the outer ablator temperature following injection is calculated to be about 70 K. This result represents an extrapolation (with regard to DT material properties) as the target will certainly be destroyed long before the DT temperature approaches 70 K. Also shown in Fig. 3 are the chamber conditions of the OSIRIS power plant design, representing liquid-wall or wetted-wall concepts. The relatively low wall temperature and gas pressure facilitates target injection as the amount of heat transfer is substantially reduced.

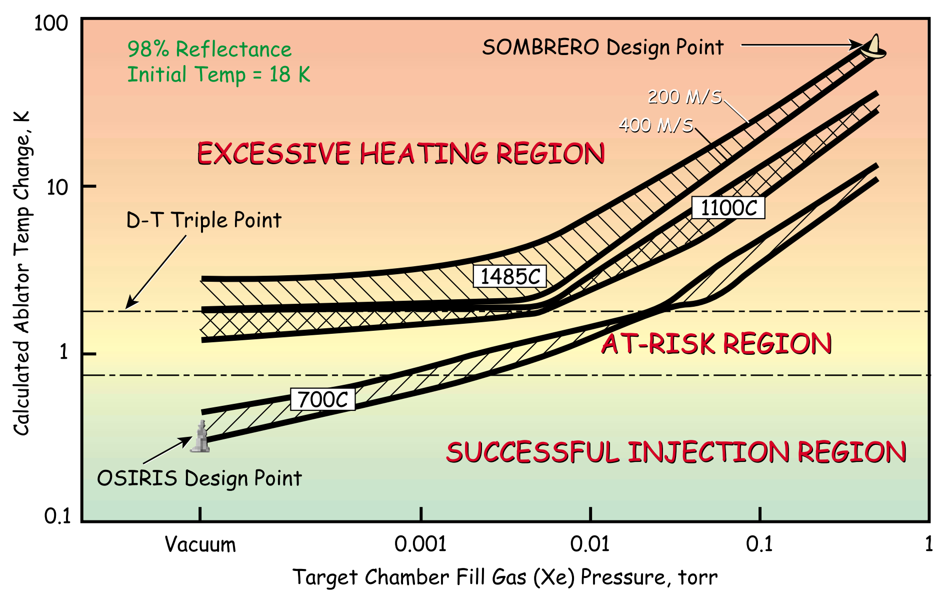

Fig. 3. Calculations of target heating during injection show reductions in gas pressure and/or temperature are required.

The amount of heat that reaches the DT ablator and fuel is strongly dependent on target geometry. In the original SOMBRERO design, targets consisting of thick-walled capsules (~50 µm) were used. These targets were substantially more resistant to DT heating, when compared to current targets with thin-walled capsules (~1 µm), because the increased thickness provided additional resistance to heat conduction. For the successful injection, 18 K<T<18.8 K, of current (thin wall) target designs, both the fill gas pressure and wall temperature must be reduced from the SOMBRERO design point. Whether or not the fill gas pressure can be reduced and still provide adequate first wall protection, is a crucial point. This issue is to be resolved as part of an integrated systems study scheduled to begin this summer under the direction of the University of California San Diego ARIES team. One aspect of the study will focus on xenon x-ray opacity and debris ion energies, both of which factor into determining the necessary amount of fill gas in the reactor chamber.

A finite element heating analysis was also performed on a close-coupled indirect drive target to determine if the central DT fuel heats during injection (Figs. 1 and 4). A uniform heat flux was applied to the outer surface of the hohlraum for a time period corresponding to injection at 100 m/s. The magnitude of the heat flux was determined by the reactor wall temperature of 700°C and the assumed value for surface reflectivity, 90%. It was found that the low-density materials used in the construction of the hohlraum offered substantial resistance to the conduction of heat from the target outer surface to the DT fuel. Figure 4 shows that any temperature rise during injection is confined to a depth of about 1 mm from the outer hohlraum surface. The central DT capsule, which is located ~3.5 mm from the outer surface, experiences a negligible amount of heating. This analysis did not take heat generated by tritium decay into account, which causes a temperature rise of 0.029 K/s for this particular target design.

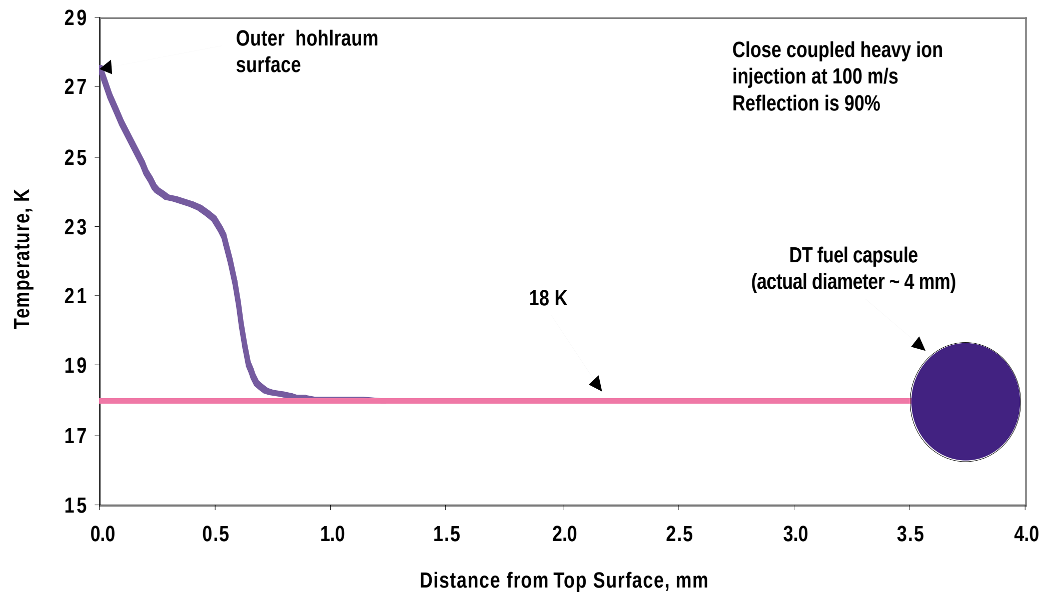

Figure 4. The DT fuel in the center of an indirect drive hohlraum does not heat appreciably during injection.

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