S-AA-M-12

OMEGA
System Operations Manual
Volume I–System Description

Chapter 8: Targets and Target Fabrication

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Chapter 8
Targets and Target Fabrication

8.0 Introduction

The OMEGA system was designed primarily for direct-drive inertial confinement fusion experiments. This involves using all 60 beams to implode spherical targets that are approximately 1 mm in diameter and are placed at the center of the target chamber. Other types of experiments and system preparation and characterization operations involve a variations of spherical targets and other target types. The range of target types used on OMEGA includes:

- Spherical implosion targets consisting of glass or polymer shells filled with a mixture of gases.
- Surrogate targets (equivalent-size solid spheres) used for beam pointing and focusing using the continuous UV alignment laser.
- Gold coated spheres that are shot to provide x-ray images used to verify beam pointing and focusing.
- Planar targets used for hydrodynamic stability and plasma physics research.
- “Hohlraum” targets for indirect drive experiments.

Many of the targets are fabricated at LLE, but components and some complete targets are provided by other organizations as part of the overall National Inertial Confinement Fusion Program. At present, all of the targets are shot at room temperature. A project that will provide OMEGA with the capability of filling, characterizing, positioning and shooting cryogenic targets is underway.

The current LLE Target Fabrication Facilities are used to fabricate, assemble, and characterize a wide assortment of targets for varying experimental campaigns. Physical and analytical methods for their preparation, inspection, and mounting have been developed.

8.1 GLASS AND POLYMER SHELLS

Current spherical implosion targets, such as that shown in Fig. 8.1-1, consist of thin-walled glass or plastic shells filled with a DT or DD gas mixture frequently containing trace amounts of a diagnostic gas. Depending on the type of experiment, these targets are coated with various metals, inorganic (salt), and polymeric materials. Target-quality glass and plastic shells are fabricated by General Atomics, Inc., the DOE-designated target contractor and supplier for the ICF fusion community. The desired gas mixture is permeated into the shell at room temperature if the shell material is plastic or at ~300°C if the material is glass. The required soak times are determined from the measured permeation time constant for each gas and the shell wall properties.

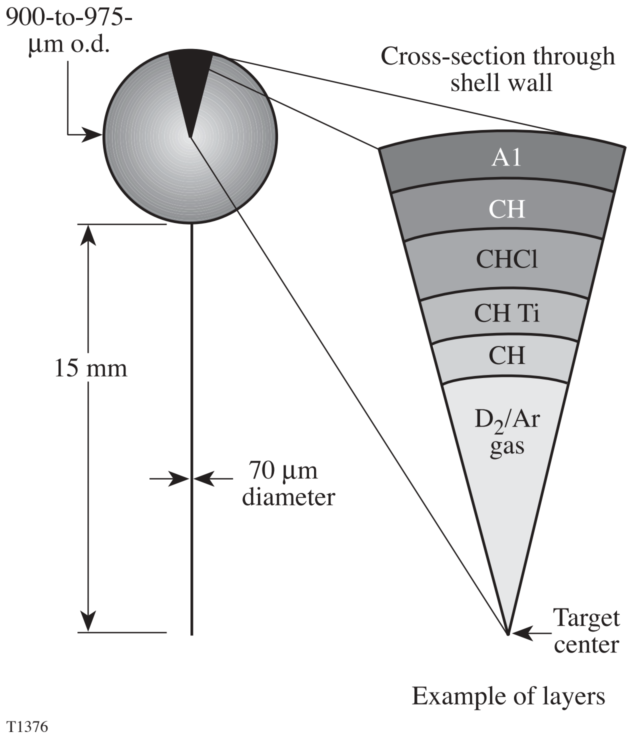


Figure 8.1-1
Spherical implosion target.

<u>Glass shells</u>

Glass shells are available with diameters in the range of 700 μm to 1400 μm and wall thicknesses in the range of 1 μm to 4 μm. The typical surface roughness is <500 nm rms for spherical harmonic modes (ℓ) 2 to 100 and the typical “out-of-roundness” is <2 μm. The glass shells typically contain up to 40 atmospheres of D_2 or DT (depending upon the wall thickness and aspect ratio). DT is permeated into the shells at Los Alamos National Laboratory. D_2 is permeated into the targets at LLE.

<u>Polymer shells</u>

Spherical polymer capsules with diameters typically ~900 μm and wall thicknesses from 2 to 30 μm, depending upon the goal of the experiment, are also used. Polymer shells are desirable for their low density, mass, and atomic weight. However, they are more expensive and complicated to produce than glass shells. The best surface smoothness that can be presently achieved is ~60 nm rms roughness for $2 \leq \ell \leq 100$, although typical smoothness values are ~40–200 nm.

Plastic targets are available with a discrete layer of plastic doped with a mid- to high-atomic-weight element at a well-defined location in the shell wall. Elements such as silicon, germanium, chlorine and titanium are available at concentrations of 6, 2, 3, and 5□at. %, respectivelyThe actual concentration is known to ±20% of the requested dopant level.

A variation of the partially doped target is the “surrogate” cryogenic target. Here, the hydrogen in the plastic is replaced with either deuterium or a combination of deuterium and tritium. Fully deuterated plastic shells are available; partially tritiated plastic shells are under development. Mid-*Z* “spectroscopic marker” atoms may be present at discrete regions of the capsule wall.

The polymer shells are filled at LLE with D_2 or DT to pressures of 2 to 40 atm. In addition, trace concentrations of inert gases, i.e., Ne, Ar, Kr, and Xe can be added to the D_2 (only) gas.

All shells receive a 1000 Å Al shine-through barrier on the outside of the shell. In addition, polymer shells that must contain gas need a ~100-Å-thick semi-permeable aluminum layer applied prior to permeation to retain the gas during assembly. The impermeable 1000 Å Al shinethrough barrier is added as the last processing step.

8.2 MATERIALS FOR PLANAR TARGETS

Flat-foil or planar targets, such as that shown in Figs. 8.2-1 and 8.2-2, are used to study the growth of the Rayleigh–Taylor instability and laser imprinting. These generally consist of a 20-μm-thick polymer substrate over-coated with an element of higher atomic number, e.g., gold or aluminum (<1000 Å). The polymer substrate may also possess a well-defined roughness embedded in the surface of the plastic, typically a single- or multi-mode sinusoidal perturbation with a wavelength of 20 to 100 μm and an amplitude of 0.1 to 2 μm. These foils, and specifically the perturbation on the surface, are aligned perpendicular to the axis of the laser beam to an accuracy of ±0.5°. This accuracy requires precision-machined fixtures to assemble the targets and high-resolution metrology equipment to measure the accuracy of the assembly. The targets are assembled to specification at LLE. The plastic foils with imposed perturbations are available from Schafer Corporation, a co-contractor with GA on the DOE Target Fabrication Contract. These targets may be overcoated with an acrylate or polystyrene foam (10- and 50-mg/cc densities; 50 to 100 μm thick) to study the propagation of radiation and shock waves through the foam. Opposing the plastic film is a foil of U, Mg, or Al that is used to generate x rays to backlight the ablation of the plastic. Between these foils is a small-mesh Be screen (~6 μm grid size), or an Al or CH foil, used to transmit x rays but shield the polymer target from debris from the exploding backlighter.

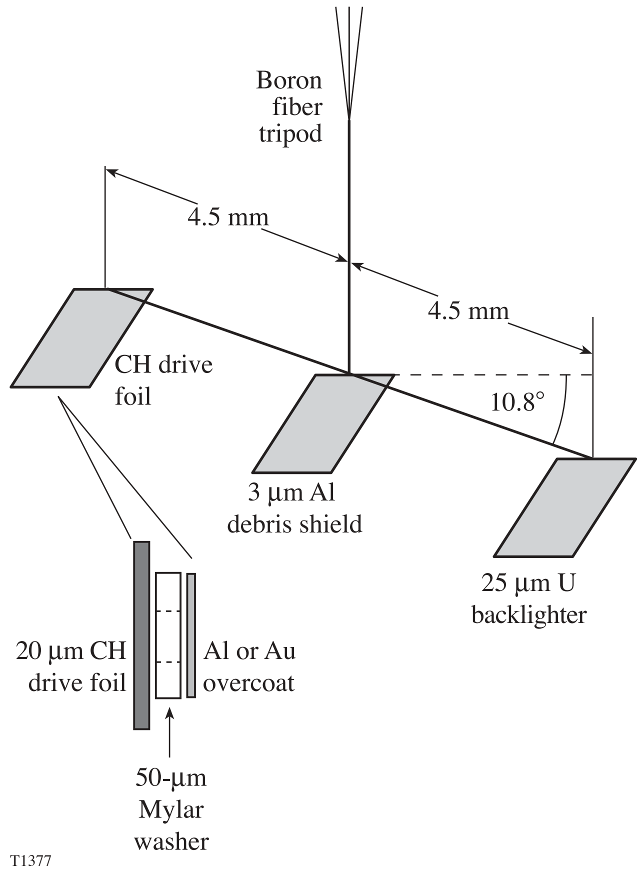


Figure 8.2-1
Typical planar plasma physics target. Each of the three elements is approximately 1 mm × 1 mm with the thickness shown.

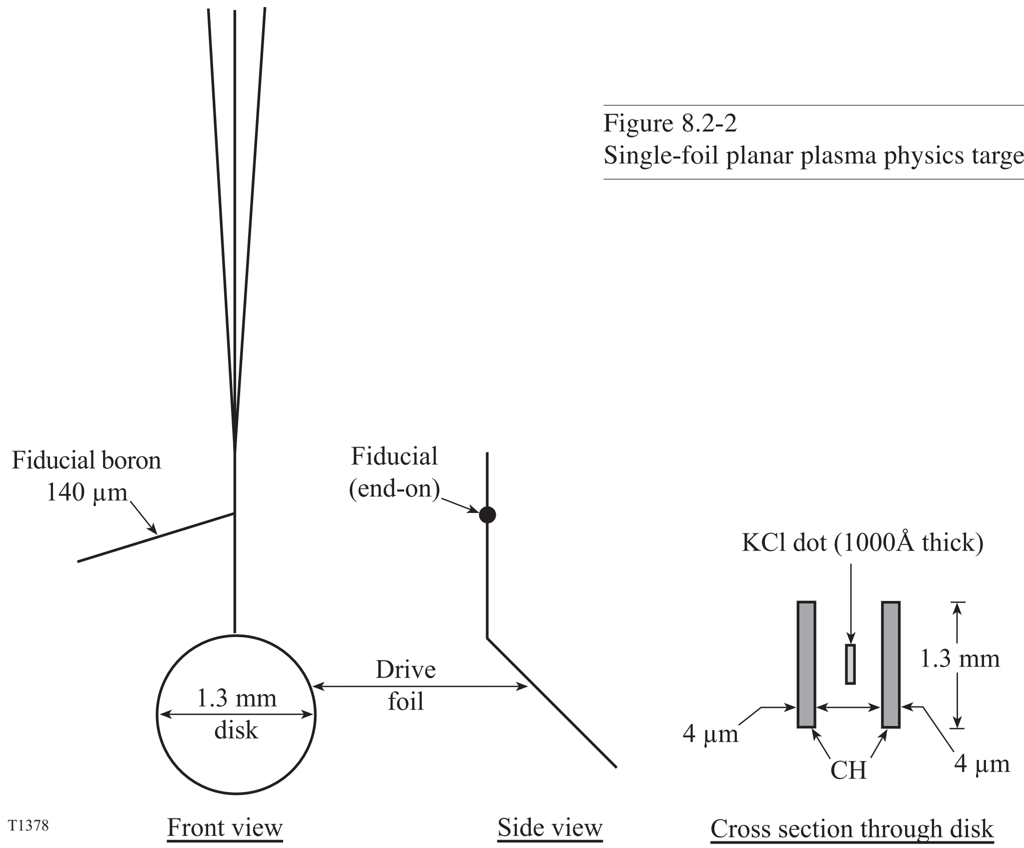


Figure 8.2-2
Single-foil planar plasma physics target.

The plastic films required for these experiments need to have a uniform thickness and a smooth surface. They are produced by casting a solution of the polymer material onto a mold and then heating the material very slowly to polymerize the solution (the time required is typically 1 day). The film has a surface smoothness better than 10 nm, a thickness of 5 μm or greater (as specified), and a curvature less than 1-μm vertical rise per 1-mm chord length. Polystyrene films are routinely available. Silicon-doped polystyrene and plasma polymer flat foils are being provided on a developmental basis.

Typical foils that will be needed during the next five years have the following specifications: The wavelength of the single-mode sine-wave perturbation will be a permutation of the following wavelengths: 10, 20, 30, and 60 μm with amplitudes of 1.0, 0.5, 0.2, 0.1, or 0.05 μm. Some experiments will require two or more of these single-mode perturbations to be superimposed on the same surface (either perpendicular or parallel to each other). Future experiments will require the plastic foils to be doped with silicon, chlorine, or germanium to study the stabilization of the ablation interface and flat-foil “burn-through.” These dopants must be constrained to a 1- to 2-μm layer buried a predetermined distance from the front surface. Other experiments will require the entire plastic to be uniformly doped to control the adiabat.

Flat-foil target types to be used more extensively in the future are: (1) a two-layered target consisting of a CH ablator doped with a higher-*Z* element and containing a perturbation on the drive surface and overcoated by a lower density CH material; and (2) a cylindrical target composed of CH ~20 μm thick with a pure ℓ-mode or a cosine mode imposed on the surface. Both target types have been fabricated and fielded in recent experiments: the former target was made by Schafer Corporation and the latter type by LANL.

8.3 COATINGS

The application of coatings to targets is a necessary step in the fabrication of many of the multilayered shells required by different experiments. Several processing systems are available: Deposition methods such as thermal evaporation and sputtering (physical vapor deposition) are used to provide metallic coatings. Plastic coatings (e.g., CH) are applied by the vapor phase deposition of oligomers that polymerize on the surface. A parylene generator is available for plastic deposition. Salt coatings, such as KBr, KCl, NaF, and NaCl are deposited using evaporation techniques.

Uncoated glass shells are essentially impermeable to hydrogen at room temperature. Bare plastic shells, on the other hand, are highly permeable and must be coated with a thin layer of aluminum prior to filling. The aluminum layer extends the permeation time constant from about 2 min to 6 to 10 h. This allows the desired gas mixture to be established and maintained through subsequent processing. After the initial coating step, the gas mixture is permeated into the shell over a 24- to 48-h period. When permeation is complete, an additional 900-Å layer of aluminum is applied. This final layer seals the target and also acts as a shinethrough barrier. This technique has been used to fill polymer shells with D_2, DT, and mixtures of up to three gases: Ne, Ar, Kr, Xe, each of which has a different permeation rate.

8.4 TARGET CHARACTERIZATION

Each target provided by GA to LLE can be fully characterized: viz. physical dimensions, weight, and surface roughness on request. LLE has the equipment necessary to confirm most of these measurements.

Surface finish

The smoothness of the outer and inner capsule surfaces is important. The shells must be spherical (to within <0.5% of the radius) and concentric. The rms surface roughness, calculated from the power spectrum of the modes, must be less than 300 nm for modes $\ell = 2$–100. The roughness of the outer surface is presently measured at GA using a modified atomic force microscope (AFM) to profile discrete great circles around a target. (The target is mounted on an air bearing and rotated beneath the AFM sensing head. The circularity and alignment of the target are sufficient to ensure that the target surface remains within the dynamic range of the AFM.)

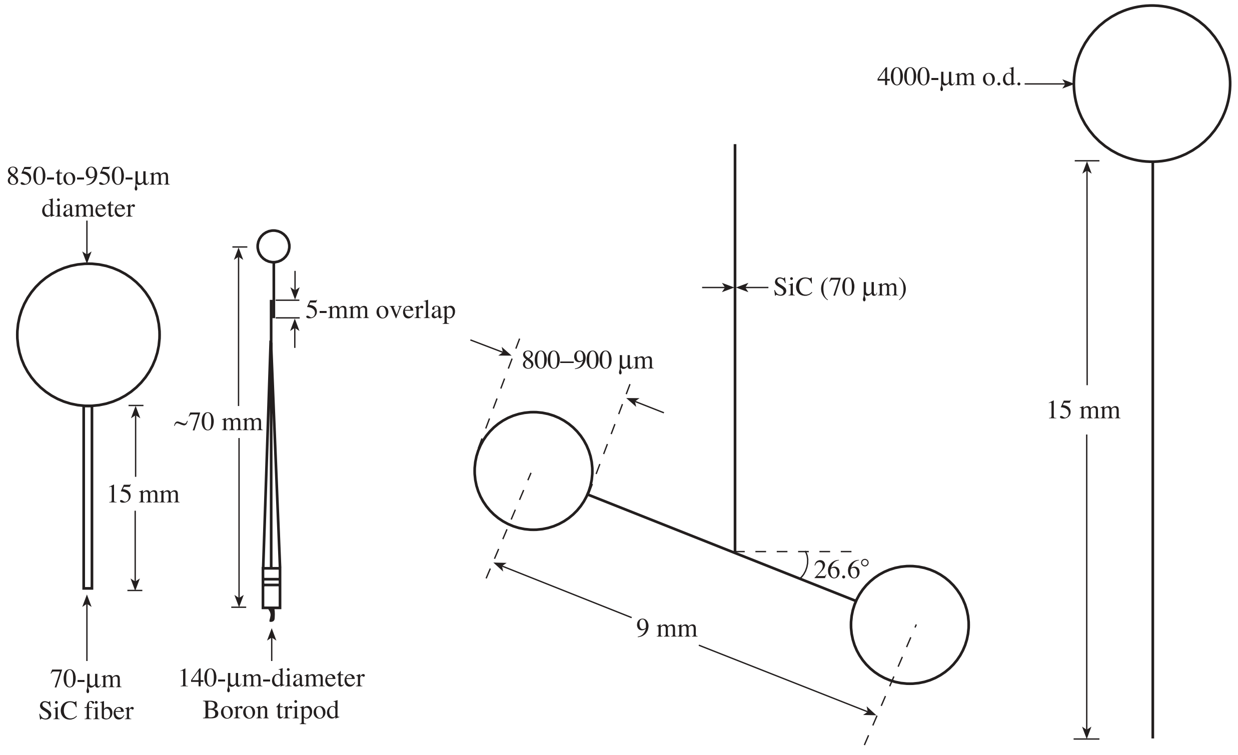
Composition

The elemental composition of the shell is presently determined at General Atomics, Inc., using an x-ray fluorescence (XRF) system that has been calibrated with combustion analysis. Because XRF lacks depth resolution, another surface-science technique, Rutherford backscattering spectroscopy (RBS), is being used to study the target composition. Using a focused helium (or proton) beam, RBS provides 2-μm spatial resolution and probes up to 20 μm into the plastic while providing 50- to 100-Å depth resolution. These data support projects to develop polymer capsules with discrete doped layers and is used to calibrate the XRF data, which is more cost effective than RBS and will remain the primary analytical diagnostic for the production process.

8.5 LOW-MASS TARGET MOUNTS

The technique used to support the target is important for the following reasons: (1) the mass in contact with the target must be kept to a minimum to avoid perturbing the physics of the experiment; (2) the total amount of material in the mount must be minimized to limit damage to optics and diagnostics inside the target chamber due to material ablated from the mount; (3) the mount must not occlude any of the 60 beams; (4) target vibration must be kept below the level required by the experiment. In addition, the mounts for future cryogenic targets must be stable and durable at cryogenic temperatures (168 K).

The design of current target mounts is shown in Fig. 8.5.-1(a). For routine target-mounting requirements, a 1-mm-long, 10-μm-diameter section of parylene-coated spider silk is attached to the target. This, in turn, is attached to a 3-mm-long, 12-μm-diameter section of carbon fiber. Finally, the carbon fiber is supported by a boron-fiber tripod. This mount assembly has caused no ablation damage and possesses a resonant frequency >200 Hz, which is high enough for this application. (The resonant frequency is routinely measured prior to delivering targets.) The "C-mount" design shown in Fig. 8.5-2 is being developed to support cryogenic targets. Here the target is suspended by spider's silk between the open ends of a "C"-shaped mount fabricated from beryllium. For thermal and alignment reasons, the target must be positioned within 50 μm of a centroid position defined by the "C" mount and the cryogenic equipment.



(a)
Surrogate glass target
for laser beam alignment

(b)
Dumb-bell surrogate target
with SiO_2 mandrel

(c)
X-ray pointing
target

Figure 8.5-1
(a) Surrogate target; (b) Dumbbell surrogate target (represents planar target, or hohlraum, for laser alignment); and (c) X-ray pointing target.


G3970a

Figure 8.5-2
The "C"-mount target configuration provides a low-mass support structure and will be used to all cryogenic targets.

8.6 TRITIUM-FILLING STATION

LLE and Ontario Hydro have collaborated since FY86 to construct a facility at LLE to fill polymer shells with DT. The Tritium Filling Station (TFS) was delivered during FY91 and reconfigured to fill stalk-mounted OMEGA targets during FY95.

Tritium is stored reversibly as uranium hydride. The maximum permissible inventory at LLE is 1 gram of tritium. A maximum of 18 targets, divided into three batches of six, can be filled with DT in one cycle. Each batch can be filled to a different pressure, up to a maximum of 150 atm. The length of the cycle is determined by the required fill pressure, the thickness of the target wall, and the permeation time constant of the Al barrier layer. Typically, 1-mm-diameter targets with 10-μm walls are filled to 10 atm in one day. Thicker-walled targets are filled to higher pressures in two days.

After the fill cycle is complete, the targets have a 1000-Å Al barrier layer applied to them. This process is performed in a DT-compatible sputter coater located in a glovebox adjacent to the fill station.

The tritium-handling equipment is housed entirely in a helium glove box that has an integral tritium-decontamination unit and a backup tritium scrubber. The system is computer controlled throughout the multiple-day filling sequence. All the safety devices are passive fail-safe components. To date, the average tritium concentration released to the environment is below the 1×10^{-8} Ci/m^3 limit established by the NYS Department of Environmental Conservation.

8.7 HOHLRAUMS

The hohlraum targets that are used in indirect-drive experiments are provided by other laboratories (typically LLNL). As Fig. 8.7-1 illustrates, this type consists of a hollow cylinder with the implosion target suspended inside. The laser beams are aimed to pass through the open ends of the cylinder and strike its inside surface. X rays resulting from the interaction of the laser energy with the cylinder converge on the implosion target to compress it. Figure 8.7-2 shows one of the specialized hohlraums that have been shot on OMEGA.

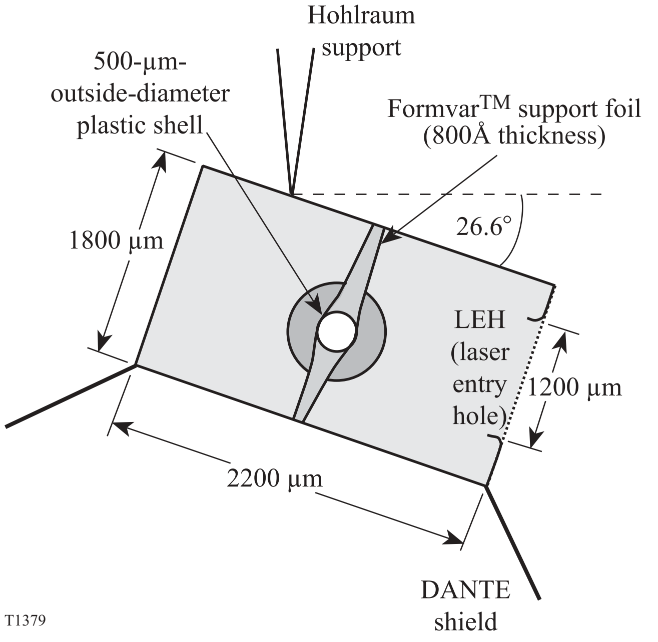


Figure 8.7-1
Schematic of a typical hohlraum target for indirect-drive experiments.

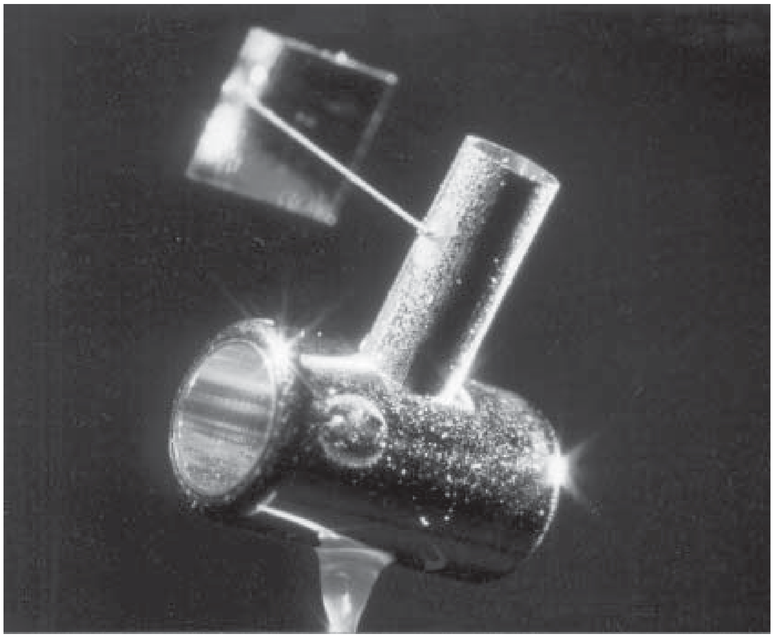


Figure 8.7-2
Photograph of a hohlraum target with shock tube and backlighter target.