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Design and Testing of Cryogenic Target Systems

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Abstract

General Atomics (GA) together with the University of Rochester/Laboratory for Laser Energetics (UR/LLE) and Los Alamos National Laboratory (LANL), has designed the OMEGA Cryogenic Target System. This system fills, cools, and layers DT targets and places them in the center of the OMEGA Target Chamber. All equipment was procured, assembled, and tested at GA and UR/LLE. GA along with Lawrence Livermore National Laboratory and LANL is designing a test unit to evaluate the key process parameters and design issues associated with fielding cryogenic targets on the National Ignition Facility.

1. The OMEGA Cryogenic Target System

1.1. Introduction

The OMEGA Cryogenic Target System (OCTS) was designed to provide direct drive, cryogenic targets for the OMEGA laser at the University of Rochester/Laboratory for Laser Energetics (UR/LLE). Key system requirements were: (1) Filling of 12 targets per week at gas pressures (up to 1500 atm) that result in a 100–140 µm DT ice layer when the target is cooled to cryogenic temperatures; 2) provisions for beta-layering with options to accommodate auxiliary smoothing techniques like IR or micro-wave; 3) delivering the layered cryo-targets to the center of the target chamber (within ≤5µm); and 4) removal of the target protective shroud ≤100 milliseconds before the shot.

The complete OCTS (*figure 1.*) consists of a number of subsystems that are shown below with the organizations that have prime responsibility for each subsystem.

1. The DT High Pressure System (UR/LLE)
2. The Fill/Transfer Station (GA)
3. The Moving Cryostat with Transport Cart (GA)
4. The Lower Pylon (UR/LLE)
5. The Upper Pylon with the Shroud remover (GA)
6. The Control System (UR/LLE)
7. The Glove Boxes (LANL)

Work on the OCTS started in 1992 and was completed in 1999 with the delivery of all equipment to UR/LLE. The following section will describe the design and the results of the testing of the major pieces of the OCTS equipment at GA.

1.2. DT High Pressure System

The function of the DT high pressure system (DTHPS) is to slowly permeation fill four Omega targets in the permeation cell with DT gas to densities as high as 0.157 g/cm^3 using at most 1.67 g of DT. The main sub-units of the system are: the DT input section, the "low pressure" filling section, the high pressure filling section, and the DT recovery section. The system is housed in a glove box to provide for secondary containment of tritium. The key component of the DTHPS is the diaphragm compressor, which is connected to a syringe

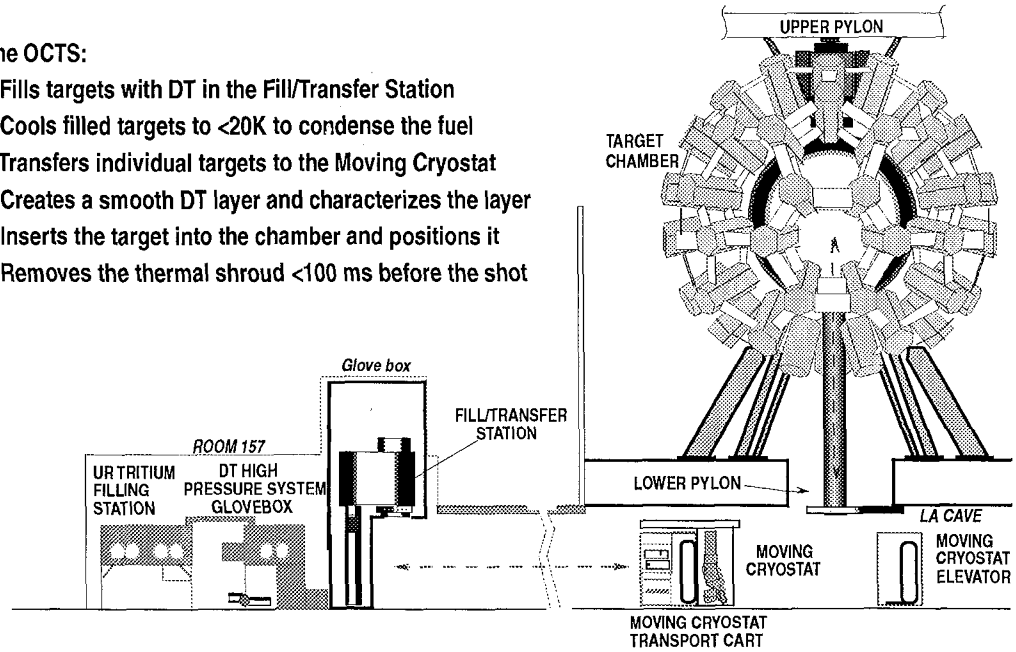

Fig. 1. The OMEGA Cryogenic Target System.

pump. It raises the DT pressure on the targets in the cell to as much as 1500 atm in very small, controllable increments. This is accomplished when the syringe pump's piston is driven forward at a slow rate, causing the hydraulic oil to act upon the diaphragms of the compressor and thus reducing the volume in the compressor from 30 cm^3 to as little as 1 cm^3. When the permeation cell is cold, the excess DT that condensed in the cell outside of the targets is removed by pumping.

1.3. Fill/Transfer Station

The function of the fill/transfer station (FTS) is to fill four targets in the permeation cell with DT delivered by the DTHPS, cool the targets to cryogenic temperatures (≤18 K), remove individual cryogenic targets from the cell and place them on the moving cryostat (MC) for transport to the target chamber. The main components of the system are: the FTS cryostat that houses the cryogenic equipment of the FTS; the inserter which delivers the target rack with four unfilled targets to the high pressure cell; the permeation cell that allows diffusion fill of the targets, the target manipulator that removes individual targets from the permeation cell and places them on the MC stalk; and the cooling module which provides the cooling for the FTS and all its components.

The FTS cryostat was shipped directly to UR/LLE and the final assembly and testing was carried out there. We had provided a surrogate cryostat base plate for warm testing of the moving components of the FTS at GA. Individual component testing was carried out successfully at GA. A prototypical permeation cell was pressurized to 150 mPa (1500 atm) with D_2 and cooled to <20 K. After removal of the D_2, opening of the cell was also demonstrated at cryogenic temperatures. Operation of the cooling module was demonstrated. The cooling module is located outside FTS cryostat for easy maintenance.

Testing at UR/LLE has demonstrated filling, cooling, and transferring of a cold target.

1.4. Moving Cryostat and Transport Cart

The MC is housed inside the moving cryostat transfer cart (MCTC). Its function is to remove individual cryogenic targets from the FTS, layer the targets, and position them in the center of the target chamber while maintaining the targets at cryogenic temperature. The function of the MCTC is to provide cooling capability for the MC during its transport from the target filling area to the target chamber area and to house the electric and gas supply lines that are required when the MC is pushed to the center of the target chamber (~26 ft/~8 m). Pictures of the MC with the shroud and the MCTC are shown in *figures 2 and 3*.

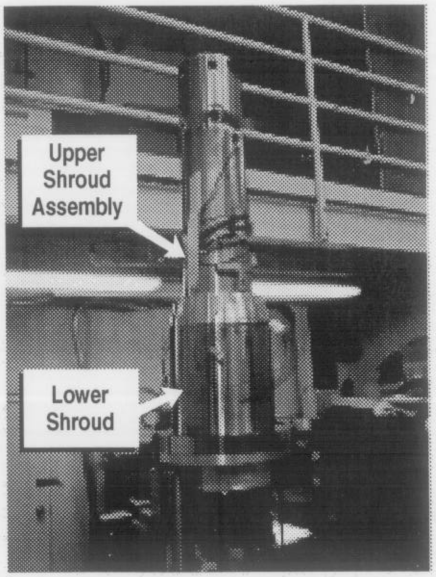

Fig. 2. OMEGA moving cryostat with thermal shroud assembly.

Fig. 3. Moving cryostat transfer cart.

The main components of the MC are a cryocooler, the shroud, and the target fine positioner. The cryocooler provides the cooling power for the MC during operation. The shroud consists of a lower shroud and an upper shroud which contains the layering sphere. The layering sphere establishes a uniform temperature environment for the target during the layering process. The design of the shroud includes a parting-joint with gas-activated bellows, which establishes the heat transfer path when the bellows are inflated but allows for the upper portion of the shroud to be removed very rapidly without creating vibrations in the target when the bellows is deflated. The target fine positioner controls the final location of the target in the center of the target chamber.

The MC assembly was completed and installed in the MCTC. Testing was carried out to establish the thermal performance of the shroud. It took about 4 h and 20 min to reach 63 K on the layering sphere, then the sphere temperature plunged to ~12.7 K in 30 min. The ultimate layering sphere temperature attained was 11.8 (*figure 4*).

The total heat load from all sources during normal operation is about 3 W. When 6 W was applied to the layering sphere, its steady state temperature was 18 K, indicating a good

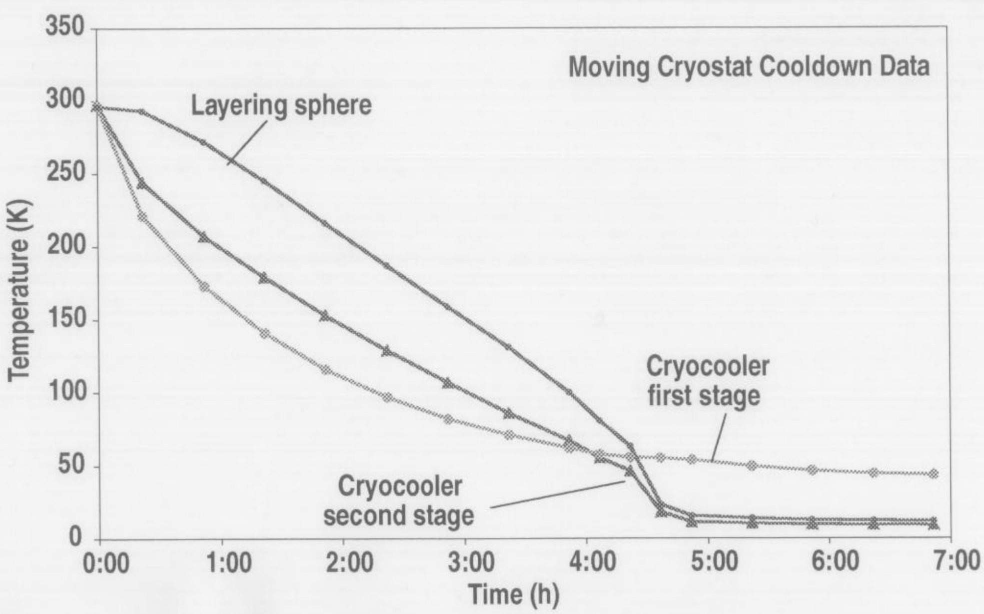

Fig. 4. The layering sphere reached <12.7 K in about 5 h.

margin in the thermal performance. The results obtained so far indicate that the MC easily satisfies all temperature operating requirements, both for baseline and augmented beta-layering conditions.

1.5. The Lower Pylon

The lower pylon provides the pathway for the MC to traverse from La Cave below the target chamber to the target chamber center. At its lower end, it provides a flanged connection to the MCTC and an air-lock valve. At its upper end, it provides the primary positioning reference of the MC relative to the target chamber center.

1.6. Upper Pylon with Shroud Remover

The upper shroud, which protects the target during transport and positioning, must be removed within 100 ms of the laser shot time to prevent the DT layer in the target from deteriorating. The function of the upper pylon is to house the motor that pulls the upper shroud off the MC.

The equipment that will perform the shroud handling processes for OMEGA was installed and tested at GA from March through May 1999. The test apparatus closely represents the OMEGA installation. LLE provided much of the equipment that was used, including a 3-m long surrogate target tank that simulated the OMEGA Target Chamber. This unit was equipped with a target viewing system and a high-speed camera capable of capturing 500 frames per second. Other equipment provided by LLE included a cryostat elevator system, transport cart, and the lower pylon which locates the cryostat inside the target tank. Various LLE personnel participated in the installation, checkout, and testing of the equipment. *Figure 5* shows the upper portion of the test installation, including the shroud pulling system and the top segment of the surrogate target tank, which extends through the floor from below. *Figure 6* shows the remainder of the surrogate target tank, the transport cart, cryostat elevator, and a work platform. The entire installation was about 9-m tall.

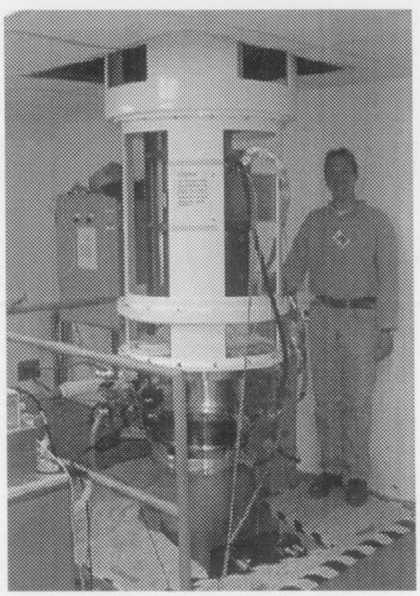

Fig. 5. Shroud puller system.

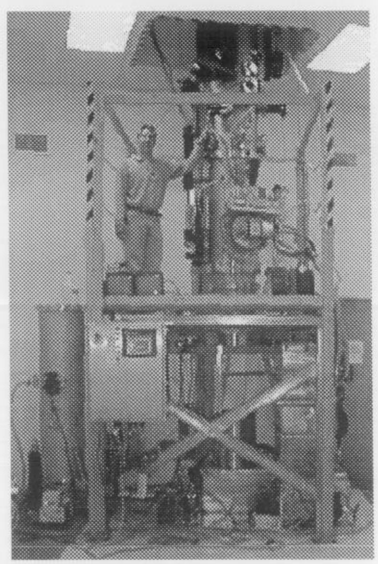

Fig. 6. Surrogate target tank, transport cart, and cryostat elevator.

During the testing period, all system operational functions were repeatedly performed successfully. The transport cart was docked under the surrogate target tank, and the MC was elevated into it and locked in place. The cryostat's fine positioner was used to position the target. The target was observed using the viewing system. Video recordings of the target's motion during shroud removal and replacement events were made. The shroud pulling system was used to remove the MC's upper cooling shroud at full speed and replace it. Twenty shroud retraction cycles were performed with a target in place. Numerous shroud retractions were also performed without a target. The target was never dislodged during the trials, and the cooling shrouds did not incur significant signs of wear. The surrogate target tank, transport cart, and cryostat elevator vacuum chamber were operated at 2×10^{-5} torr during the testing activity. All tests were performed with the MC at ambient temperature.

2. The D_2 TEST SYSTEM

2.1. Introduction

The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) will shoot cryogenic ignition targets consisting of a capsule inside a hohlraum, for indirect drive, and a bare capsule for direct drive targets. The capsule is filled with DT to pressures of 400 to 1000 atm to provide the required thickness of DT ice when the target is cooled to cryogenic temperatures. A cryogenic target supply system, similar to the OMEGA system, must be developed. The main subunits of the NIF Cryogenic Target System (NCTS) are:

1. The DT pressurization system (DTPS) that fills individual targets with DT.
2. The target insertion cryostat (TIC) that transports the filled cryogenic targets from the DTPS to the insertion system at the NIF.

No test system currently exists that can address (a) the critical technical issues associated with the filling of capsules in a hohlraum, (b) layering of the DT ice in the nonsymmetrical environment of the hohlraum, and (c) the critical engineering issues (*e.g.*, providing cooling to the hohlraum and transporting targets over some distance using full-size target assemblies). GA, in cooperation with LLNL and LANL, is designing a test unit to evaluate these key process parameters and design issues associated with fielding cryogenic targets on the NIF.

2.2. D_2 Test System Design

The deuterium test system (D_2TS) (*figure 7*) is designed to fill NIF full-sized, cryogenic ignition target assemblies to full fuel density (up to 136 mg/cm^3, DT equivalent), to allow fuel layering experiments (by the IR method and temperature shimming of hohlraum), and to permit the transport of filled targets between laboratories. This will be the first experimental apparatus that will allow fuel-layering experiments on full-sized ignition target assemblies without fill-tubes. The D_2TS will prototype many aspects of the NCTS, including the interface between the target fill system and the TIC, and the transport of cryogenic targets in the TIC. Filling will be done by permeation at room temperature into the target's capsule. The target fill system contains a permeation cell designed to hold 116 mPa of deuterium gas. After cooling to cryogenic temperature (~20 K), the cell will be opened. The D_2TS's main

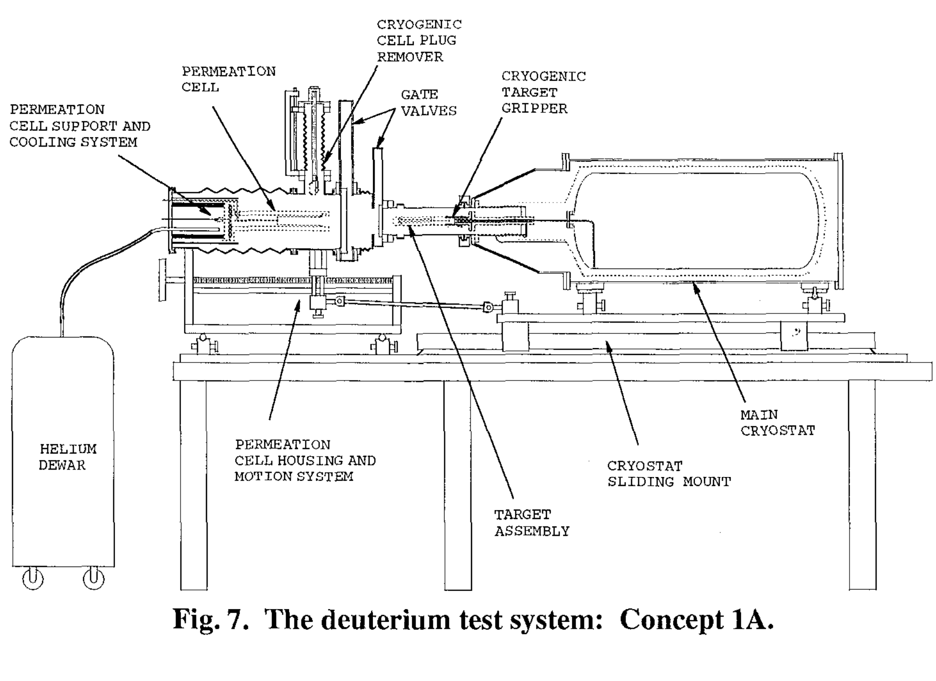

Fig. 7. The deuterium test system: Concept 1A.

cryostat will use a cryogenic target gripper to remove the target assembly from the cell. The cryogenic target gripper makes mechanical, thermal, and electrical connections and makes a gas seal to the base of the target assembly. The gas seal will allow the pressure in the target assembly's hohlraum to be varied. The gripper is designed to grab and hold onto a target at cryogenic temperature. The experimental data on a prototype gripper's thermal, electrical, and sealing performance will be provided. The target can be transported cryogenically in the D_2TS's main cryostat once it is detached from the target fill system. The main cryostat is cooled with liquid cryogens. The cryostat is designed to allow the target assembly base to be cooled to as low as 8 K.

The design and procurement of the system is progressing well. Specification control drawings for the main cryostat and the gate valves were produced and submitted for vendor bids. The permeation cell design was completed and is in safety review at LLNL. The concept of the cryogenic target gripper was developed and early feasibility testing of the system is under way. A supplier for the important multiple electrical feed-through was identified and cryogenic performance testing has started. The preliminary design for the permeation cell support, the cooling system, and the cryostat sliding mount was completed. A preliminary specification for the permeation cell housing and motion system was written. Delivery of the complete system to LLNL is expected by mid-2000.

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