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# THE CRYOGENIC TARGET HANDLING SYSTEM FOR THE OMEGA LASER

## ABSTRACT

The next series of inertial fusion experiments will approach ignition conditions. To achieve sufficient power density to approach ignition conditions with reasonable laser power, these experiments call for cryogenic targets with a uniform condensed fuel layer and a smooth inner surface inside of a thin spherical shell. To field such targets, General Atomics is designing and building the OMEGA Cryogenic Target System (OCTS) for the upgraded OMEGA laser at the University of Rochester's Laboratory for Laser Energetics (LLE).

The OCTS contains sub-systems that operate on targets to fill, freeze, transport, layer, characterize, position to laser confluence, and expose them for laser illumination milliseconds before shot time. The OCTS will fill targets with deuterium-tritium (DT) to densities of up to 0.031 mol/cm$^3$. The pressure cell and rack that contains the filled targets is cooled to cryogenic temperatures in the fill system cryostat. The rack of targets is transferred cold by the cold transfer cryostat to the transfer station cryostat. The transfer station separates individual targets from the rack and inserts them into the moving cryostat. The moving cryostat transports a target out of the LLE tritium lab, layers the target, and inserts the target into the center of the OMEGA target tank. Targets are characterized optically during a pause in the insertion. At shot time, the end of the cryostat is rapidly removed by high acceleration motors mounted in a port on the target tank directly opposite that used to insert the target.

Prototypes of the target filling and cold transfer equipment have been built and operated with deuterium. Mounted targets were successfully filled to densities of 0.026 mol/cm$^3$. Cold transfer of high density targets into and out of the fill system with the cold transfer cryostat was also successfully carried out.

## 1. INTRODUCTION

The next series of inertial fusion experiments will approach ignition conditions. These experiments are planned for the upgraded OMEGA laser at the University of Rochester's Laboratory for Laser Energetics (LLE) [1] and will lead towards ignition experiments in the National Ignition Facility [2] proposed to be built at Lawrence Livermore National Laboratory. To achieve sufficient power density to approach ignition conditions with reasonable laser power, these experiments call for cryogenic targets with a uniform condensed fuel layer and a smooth inner surface, distributed inside a thin spherical shell. To field direct drive high density cryogenic targets, General Atomics is designing and building the OMEGA Cryogenic Target System (OCTS) for the OMEGA laser.

### 1.1. Functions and Requirements

The OCTS accepts mounted but unfilled polymer shell targets and processes them up to the instant of the laser shot. The main processing steps are the permeation filling of the shells, layering the fuel uniformly and smoothly on the inside of the shell, characterizing the fuel layer, insertion of the target into the target chamber, and a rapid and timed exposure of the target to the laser beams at the instant of the laser shot. The OCTS must process targets at the rate of the experimental schedule for cryogenic shots; four targets per day, four days per week.

The targets consist of spherical shells, ranging in diameter between 700 μm and 1100 μm, with wall thicknesses between 5 μm and 10 μm. They are made of polymers comprised mostly of carbon and hydrogen; polystyrene and GDP (glow discharge polymer). Targets are individually mounted in-between three parallel spider webs stretched between the ends of a C-shaped beryllium wire. The target is held in place half-way in-between the arms by a 0.3 μm thick conformal coating of paralyene. A post runs down from the spine of the C-wire. The base of this post is used by the OCTS to manipulate the mounted target.

Targets will be fueled with an equi-molar deuterium tritium (DT) mixture. The solid fuel layer in the targets will be up to 100 μm thick. The fuel must be layered on the inner wall of the shell with a uniformity of at least 2%. The smoothness of the fuel inner surface should be better than 1000 Å. The "beta-layering" technique [3,4] will be used to produce the uniform fuel layer.

The current tritium license at LLE puts stringent requirements on the OCTS design. The quantity of tritium allowable is 1 gram. The location of LLE adjacent to a residential neighborhood restricts the release of tritium to very low concentrations. Based on the tritium lab's stack flow rate, no more than 200 mCi may be released yearly. A single target may hold as much as 600 mCi. This extremely low release limit makes tritium containment a severe design driver.

## 2. OMEGA CRYOGENIC TARGET SYSTEM OVERVIEW

The layout of the OCTS is shown in Fig. 1. Also shown is the target tank where the laser beams will implode the target. The target tank (the sphere inside the 60 hexagonal support structures) is 3.3 m in diameter. The OCTS processes targets as follows:

(a) Empty mounted targets are placed into a rack. The rack is placed into a room temperature cold transfer cryostat (CTC).

(b) The CTC inserts the target rack into the permeation cell in the fill station's permeation cryostat through a vacuum lock. The CTC detaches from the cell and begins cooling. Once the targets are cold, all subsequent operations on them by the OCTS will maintain them at cryogenic temperatures.

(c) The targets are permeation filled at room temperature to pressures as high as 150 MPa. The targets are then cooled until the gas inside reaches the saturated liquid phase and the pressure inside the target is low enough to prevent shell rupture when the DT external to the targets is removed from the cell. At these high densities, thin wall targets will rupture at 35 K with no external applied pressure.

(d) Once the excess DT in the cell is removed, the cell is further cooled. The CTC, now cold, removes the target rack from the cell and cocoons it in a gas tight cryogenic shroud. The shroud is maintained with a low pressure of helium gas to thermally link the self heating targets to the shroud. The targets' spider web supports have insufficient thermal conductivity for this task.

(e) The CTC retracts the shrouded targets from the fill station. After disengaging from the fill station, the CTC travels to the vacuum lock of the transfer station

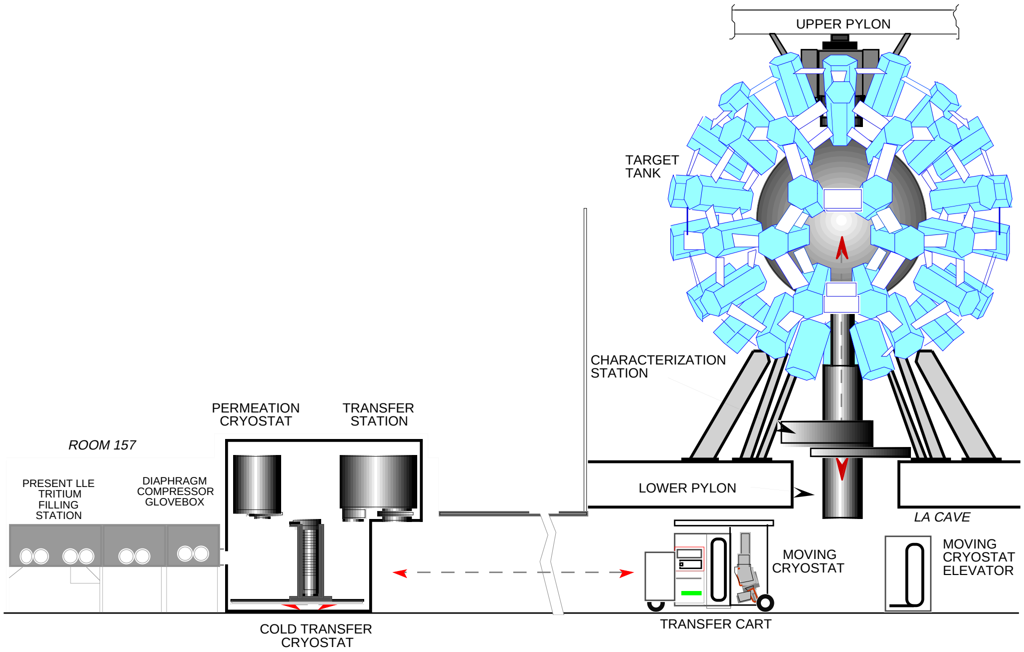

Fig. 1. The major components of the OMEGA Cryogenic Target System and the OMEGA Target Tank.

on a motorized rail system inside the glove box and then inserts the shrouded target rack into the transfer station.

(f) The transfer station disassembles the targets rack. A manipulator in the transfer station places an individual target onto the positioning stalk of the moving cryostat. The moving cryostat enters the transfer station through a vacuum lock that penetrates the glove box and the transfer station.

(g) After the transfer station has replaced the moving cryostat's shroud around the target, the moving cryostat is retracted from the transfer station and wheeled down a hallway into the room below the target tank.

(h) The target is layered in an isothermal environment created in the shroud of the moving cryostat.

(i) The moving cryostat is attached to the lower pylon through a vacuum lock. A rigid chain[1] is inserted from the moving cryostat elevator into the vacuum can of the moving cryostat through a vacuum lock. The rigid chain pushes the moving cryostat up to the characterization station. The characterization will be by an optical interferometric technique provided by LLE.

(j) After the fuel layer of the target is characterized, the moving cryostat is pushed up into the target tank, where it is mechanically locked in place.

(k) A fast shroud retractor descends from the upper pylon and attaches to the moving cryostat shroud.

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[1] Serapid France, Z.I. BP 15 - Route DE Dieppe, 76660 Londiniers, France

(l) Fine positioners in the moving cryostat adjust the target position to the point where the laser beams will converge in the target tank.

(m) The shroud retractor rapidly removes the shroud to expose the target. The lasers fire at the target shortly after the shroud has cleared the target, ~100 ms.

## 2.1. Fill Station and Transfer Station

A layer thickness of 100 µm requires densities of up to 0.031 mol/cm$^3$ in smaller targets. This corresponds to 150 MPa at 300 K. The polymer targets can be easily crushed during permeation filling. The pressure difference on the weakest targets must kept well below 280 kPa.

The existing LLE tritium fill system will supply moderate pressures (~200 bar) to the high pressure system from a cryogenic condensation tube. This gas will be metered into the cell and diaphragm compressor through a small volume trapped between two valves. Once sealed off, the diaphragm compressor will slowly reduce its volume by 30:1; boosting an initial 124 bar to 1500 bar. Pressure is increased at a rate slow enough to allow DT to permeate into the targets and prevent target crushing.

The permeation cell is sealed with a replaceable, cone and taper seal in a breech lock. Force is applied to the seal by high pressure (130 bar) helium acting on a diaphragm.

The fill station's permeation cryostat contains the permeation cell and the shroud manipulator. The shroud manipulator removes and replaces the CTC's shroud. The permeation cell is thermally isolated from the inner wall of the permeation cryostat. Two independent secondary cooling loops operate using helium to remove heat to two Gifford-McMahon cryocoolers. One loop is used to continually keep the inner wall of the cryostat and the shroud manipulator cold. The other rapidly cycles the cell between room and cryogenic temperatures. In order to facilitate maintenance in the glove box, the permeation cryostat features a wide mouthed Dewar design for access to items in its inner vessel. Only removal of one room temperature elastomer seal is required to gain access to the cell and shroud manipulator. Both the cryostat body and lid are vacuum and super-insulated, and have liquid nitrogen shields.

The transfer station contains a shroud manipulator, manipulators for disassembling the target rack and placing individual targets onto the moving cryostat positioning stalk, and a fast cooler for the moving cryostat's shroud. As with the permeation cryostat, the transfer station is designed with the wide-mouthed configuration and the dual cooling loops to cryocoolers. One loop is dedicated to maintaining cryostat temperature, the other to supply cooling to the fast shroud cooler.

## 2.2 Cold Transfer System

A motorized rail system shuttles two cold transfer cryostats between the fill and transfer stations. The rail line has a spur line to allow the cryostats to pass each other. The CTC attaches to the stations through a vacuum lock formed with gate valves. The CTC inserts a cryogenic shroud into the stations by collapsing the long welded metal bellows that forms its outer vacuum boundary. A cryocooler removes heat from the shroud through conduction. Shroud manipulators in the stations remove (replace) the CTC's shroud to expose (enclose) the target rack. A manipulator at the tip of the CTC is used to actively grasp the target rack and cell plug assembly. The manipulator floats on a spring loaded plate to provide compliance during mating with the cell. Removing the cell plug with the target rack after each fill cycle allows the cell seal to be replaced

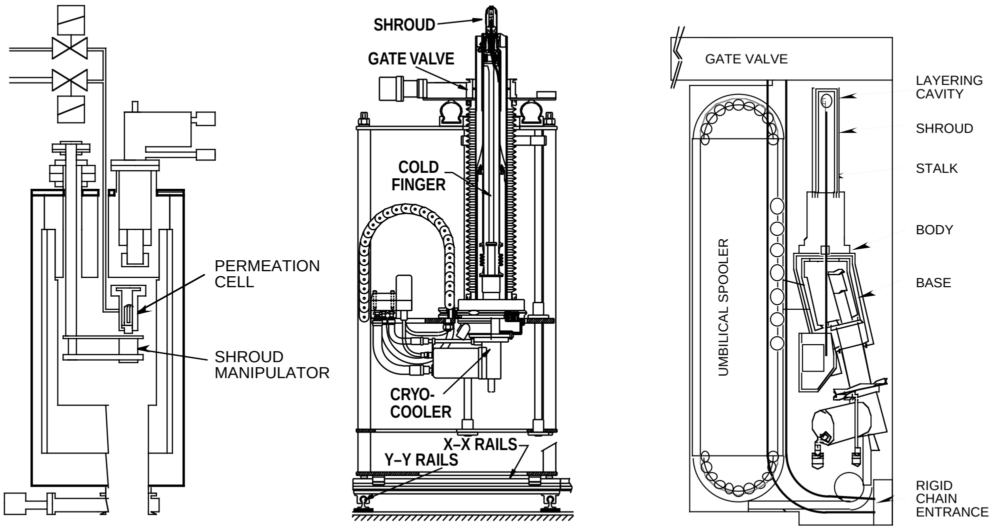

Fig. 2. The fill station's permeation cryostat, the cold transfer cryostat, and the moving cryostat.

each time. The breech-locked shroud is sealed vacuum tight at cryogenic temperatures with an indium coated copper gasket [5]. This seal is actuated by a mechanical linkage to an air cylinder located in the room temperature base of the CTC.

### 2.3 Moving Cryostat

The moving cryostat resides in a vacuum can located on the transfer cart. Once a target is picked up from the transfer station, the moving cryostat layers it in a spherical cavity in a copper block located in the tip of the moving cryostat's shroud. Smooth, uniform layers are formed using beta-layering [6] by maintaining a uniform temperature (42 µK/mm or better across shell) around the target; just below the fuel triple point. The low thermal conductivity of DT and its internal heat generation cause thick portions of the layer to be hotter. The vapor pressure above the hotter portions condenses on the cooler thinner portions until the inner boundary of the fuel is isothermal and of equal thickness. Once the layer is formed, until the target is shot, the temperature must remain within ±0.3 K, otherwise thermal strain is expected to deform the layer.

The moving cryostat is divided into three main parts: the base, the body, and the shroud. The wheeled base holds the cryocooler. The captured wheels roll in the same channel as the rigid chain that is used to push the cryostat up the lower pylon to the target tank center. There are gaps in the channel that are crossed at vacuum lock gate valves. The cryostat body holds the target positioning stalk piezo-motor drives. The cryostat's cryogenic shroud rides on top of the body and is connected to a special thermal joint. The joint can be opened to a low friction state just before the shroud's fast retraction by the upper pylon at shot time. The mating part of the joint in the body connects to the cryocooler with copper wire cable. When positioning the target, the body is clamped to the target tank and the base is slightly lowered by the chain. This imposes the building floor between the cryocooler and the target stalk, leaving only flexible cable as a path for cryocooler vibrations to the target stalk. The shroud contains windows to the target for characterization and positioning.

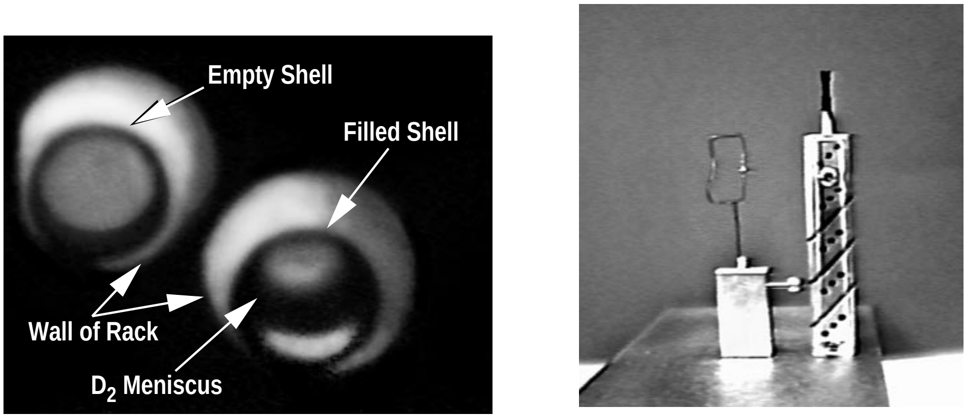

Fig. 3. (left) An unmounted polymer shell shown before and after a 110 MPa fill and cryocondensation . (right) A C-mount target and a rack for filling unmounted shells.

## 3. TECHNOLOGY DEVELOPMENT

Prototypes of a deuterium fill station and cold transfer cryostat were built and operated. C-mounted polymer targets were filled to a density of 0.026 mol/cm$^3$ (110 MPa at 300 K), cooled to 20 K, and removed from and returned to the fill station with the cold transfer cryostat without damage. A prototype diaphragm-actuated permeation cell was successfully built and operated.

## 4. SCHEDULE

Design of the OCTS is underway. We are in the detailed design phase for the fill station and cold transport system. A number of equipment sub-units are currently undergoing DT testing at Los Alamos National Laboratory (LANL). The transfer station and moving cryostat are in the late preliminary design stage.

After fabrication, the OCTS will be tested in a component-wise and then integrated fashion at General Atomics using deuterium. It will then be shipped to LANL for component and integrated testing with DT. After successful completion of integrated system testing, the OCTS will be shipped to LLE and put into operation after acceptance testing. The system is expected to be delivered to LLE and operational by August 1999.

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