LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-JRNL-404974

Design of the NIF Cryogenic Target System

C. Gibson, J. Baltz, T. Malsbury, D. Atkinson, V. Brugmann, F. Coffield, O. Edwards, B. Haid, S. Locke, S. Shiromizu, K. Skulina

June 27, 2008

Fusion Science and Technology

DESIGN OF THE NIF CRYOGENIC TARGET SYSTEM

CHUCK GIBSON*, JAMES BALTZ
General Atomics, P.O. Box 85608, San Diego, California 92186-5608

TERRY MALSBURY, DENNIS ATKINSON, VAUGHN BRUGMANN, FRED COFFIELD, OLIVER EDWARDS, BEN HAID, STAN LOCKE, STEVE SHIROMIZU, KEN SKULINA
Lawrence Livermore National Laboratory, 7000 East Ave, Livermore CA USA 94551

*E-mail: gibson31@llnl.gov

The United States Department of Energy has embarked on a campaign to conduct credible fusion ignition experiments on the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory in 2010. The target assembly specified for this campaign requires the formation of a deuterium/tritium (DT) fuel ice layer in a 2 mm diameter capsule at the center of a 9 mm long by 5 mm diameter cylinder, called a hohlraum. The ice layer must be formed and maintained at temperatures below 20 K. At laser shot time, the target is positioned at the center of the NIF target chamber, aligned to the laser beams and held stable to less than 7 µm rms. We have completed the final design of the Cryogenic Target System and are integrating the devices necessary to create, characterize and position the cryogenic target for ignition experiments. These designs, with supporting analysis and prototype test results, will be presented.

KEYWORDS: NIF, cryogenic target system, ignition, cryocooler

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and by General Atomics under Contract DE-AC03-95SF20732.

I. INTRODUCTION

The NIF ignition target design[1] is shown in Figure 1. The mission of the NIF Cryogenic Target System (CTS), shown in Figure 2, begins when the target assembly is delivered to the NIF with its target base reservoir filled with DT fuel. The target assembly is first mounted to the end of a target positioner which sits just outside the NIF target chamber. After mounting the target, the positioner vessel is pumped to high vacuum and the cryogenic system begins to cool the target.

During cool down, temperature differentials are used to drive the DT fuel from the reservoir into the capsule. Once the capsule is filled, further cooling begins to form the fuel ice layer. The processes of fuel transfer and ice layer formation are monitored with 3 axes of x-ray and/or optical imaging that is built into the vessel. During these steps, the target remains just outside the NIF target chamber on the 7-meter long boom of the CTS.

After the DT ice meets the smoothness specification, the CTS uses the boom to extend the target to target chamber center. Near target chamber center, the NIF Target Alignment System (TAS) provides feedback for positioning of the target. The TAS can also image the NIF alignment laser beams and is used to align all beams to the upper and lower hohlraum windows. After the shot, the boom is retracted, the spent target is removed, and the system is readied for the next shot cycle.

II. CRYOGENIC TARGET SYSTEM DESIGN

The NIF Cryogenic Target System can be divided up into three subsystems: 1) the Target Positioning System, 2) the Target Imaging System, and 3) the Cryogenic System.

II.A. Target Positioning System

The CTS positioner design is based on the existing and proven NIF room temperature target positioner. The CTS positioner provides 5 degrees of freedom including three translations and two rotations of the nose cone (roll and nod). The positioner uses a 7-meter long low coefficient of thermal expansion carbon composite boom to place the target at the center of the 10-meter diameter NIF target chamber.

The error budget for laser-on-target positioning has allocated 7 µm rms to positioning of the target. The existing room temperature target positioner has demonstrated the ability to meet this requirement. The primary source of positioning error is vibration, which has been measured using accelerometers to be < 1.5 µm rms.

Target positioning with CTS will more fully utilize the 7 µm rms budget. The cryogenic system is designed to eliminate cryocooler vibration so that the CTS positioner vibration component should be nearly identical to that of the room temperature target positioner. The remainder of the positioning error budget, approximately 5 µm, is allocated to longer term drift primarily caused by imperfect control of positioner temperature. Both environmental and internal sources contribute to this error component.

The CTS positioner also holds the target during DT fuel ice layer formation. The stability required is dictated by ice layer characterization requirements and the x-ray imaging system. The stability requirement is ± 1 μm during the 6 second x-ray image frame integration time. Measurements made on the existing warm target positioner with the boom retracted, as it will be during ice layer characterization, are just above this requirement. To insure the CTS design can meet this requirement, the positioner design was augmented with stabilizers that can be used with the boom in the retracted position.

II.B. DT Ice Layer Imaging System

The CTS design incorporates a system called the Load, Layer and Characterization System (LLCS). As its name implies, this system is used to load the target into the CTS, to provide the environment for the DT ice to form a smooth layer, and to characterize the quality of the layer.

The LLCS vessel is designed to operate as a glovebox during target loading and as a vacuum vessel during cryogenic operation and characterization of the target. The vessel can also operate as a fume hood during major maintenance operations.

The LLCS characterization equipment can be switched out depending on the type of target that is being fielded. For a target with a beryllium capsule, the characterization equipment consists of three axes of phase-contrast x-ray imaging. Two axes are horizontal through slits in the hohlraum wall and one axis is vertical through the laser entrance holes. For a target with a plastic capsule, the equipment has only one horizontal x-ray axis, but the vertical axis includes both an x-ray and an optical characterization system.

II.C. Cryogenic System

The CTS design incorporates a cryogenic system called the Ignition Target Inserter Cryostat (ITIC), shown in Figure 3, to cool the target. The ITIC is mounted at the end of the 7-meter long boom. The ITIC uses a Gifford-McHahon cryocooler to cool the target base to 7 K and heaters to raise and control the target hohlraum temperature as specified (~18 K) with 1 mK precision.

The ITIC provides cryogenic temperature control of the target while ensuring that all structure influencing target position is maintained at room temperature. In Figure 3, the image to the left shows a prototype of the cryogenic system. It consists of the cryocooler (right edge), connected to the cryogenic thermal capacitance device, followed by a long cold rod system reaching to the target base (left). The inner most conductive path, called the cold rod, is connected to the 2nd stage of the cryocooler and operates near 7 K. Surrounding the cold rod is a 60 K thermal shield which limits heat transfer to the cold rod and is connected to the 1st stage of the cryocooler. Surrounding the 60 K cold shield is a warm shield that is controlled to 293 K using heaters. The cryogenic system, shown in Figure 3 (left), is packaged into the ITIC structure (right). Ignition targets containing DT are installed on the gripper of the ITIC by operators working through the glove box integrated into the LLCS vessel.

A common challenge when using mechanical coolers in precision applications is the significant vibration disturbance caused by the pulsed nature of a Gifford-McHahon design cryocooler. The NIF cryogenic target positioner has overcome this problem by utilizing a thermal capacitance device[2] that permits the cryocooler to be turned off during periods requiring positioning stability. X-ray imaging of the ice presents the most difficult challenge. An x-ray image is constructed from a series of 20 frames, each requiring 6 seconds of CCD integration time.

The cryogenic system must maintain target temperature within ±1 mK with the cryocooler off for the duration of the x-ray imaging time. This is a difficult challenge since most engineering materials lose almost all of their heat capacity at temperatures below 100 K. Our cryogenic system uses the thermal capacitance of high pressure helium at cryogenic temperatures. The helium is confined in a copper structure that minimizes the heat transfer time constant by assuring that all helium is within a few millimeters of a copper conduction path. Figure 4 provides laboratory test results using the cryogenic system in Figure 3 that demonstrate better than ±1 mK hohlraum temperature control with the cryocooler off for periods of 4 minutes. The stability is demonstrated over a 45 hour period with a 4 minutes off and 6 minutes on duty cycle.

III. CONCLUSION

We have described the designs necessary to cool the cryogenic ignition target, to hold the target stable during ice layer characterization and to position the target for a NIF shot. The integrated system is called the CTS. A room temperature positioner is operational and has demonstrated the viability of the design architecture. The cryogenic system has been prototyped and has demonstrated the necessary precision of cryogenic target temperature control. The first Ignition Target Inserter Cryostat (ITIC) has been assembled and will be fielded on the existing

NIF positioner to demonstrate integrated performance of the system. Assembly of the first complete CTS will begin later this year with installation in NIF by 2010.

REFERENCES

[1] Atherton, L.J., Moses, E.I., Carlisle, K., Kilkenny, J., *The Ignition Target for the National Ignition Facility*, EUSPEN Conference, 2007

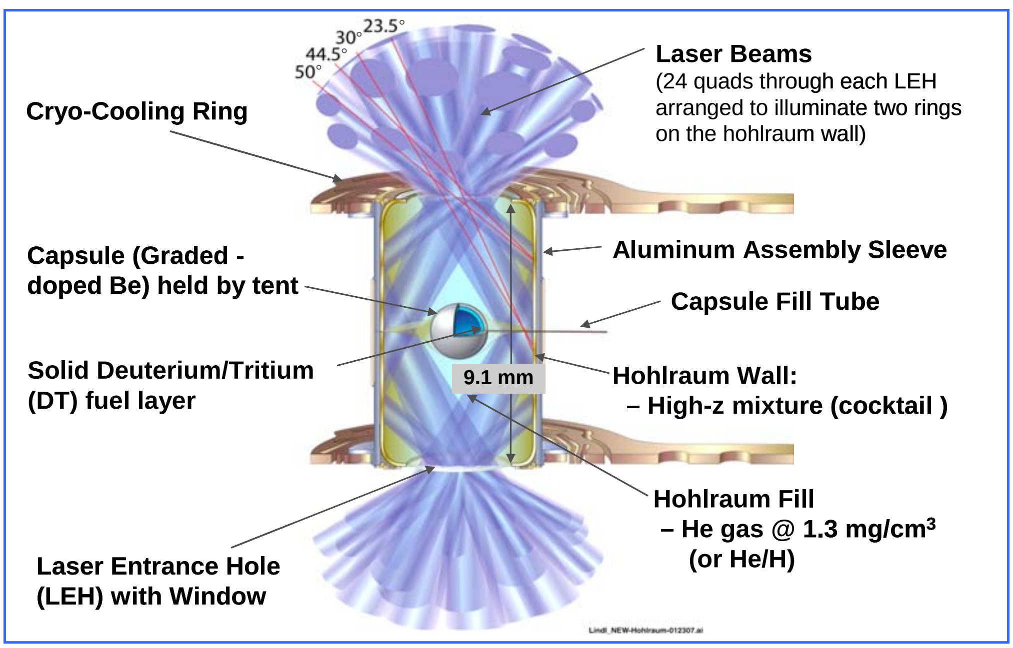
[2] Haid, B.J., *Helium Pot System for Maintaining Sample Temperature after Cryocooler Deactivation*, Advances in Cryogenic Engineering, V51A, 2005

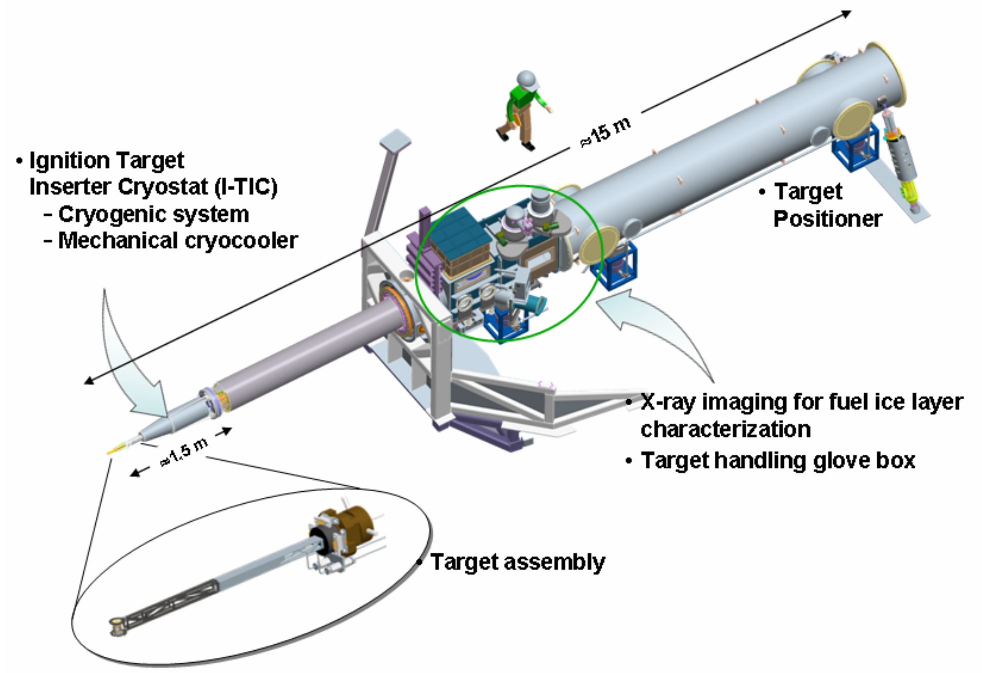
Figure 1. Schematic of the NIF cryogenic ignition target

Figure 2. The CTS provides the systems necessary to field the NIF ignition target.

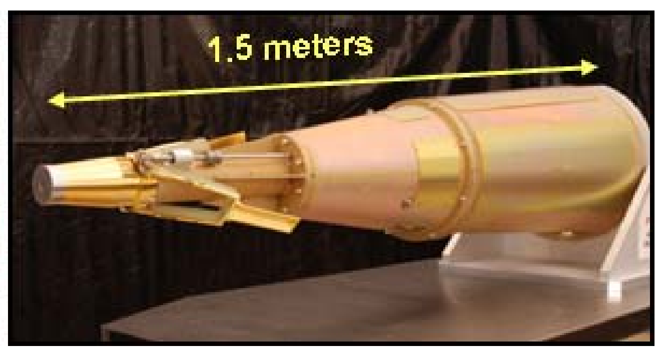
Figure 3. The cryogenic system (left) is assembled into the ITIC (right).

Figure 4. The required ±1mK temperature stability has been demonstrated in the lab.

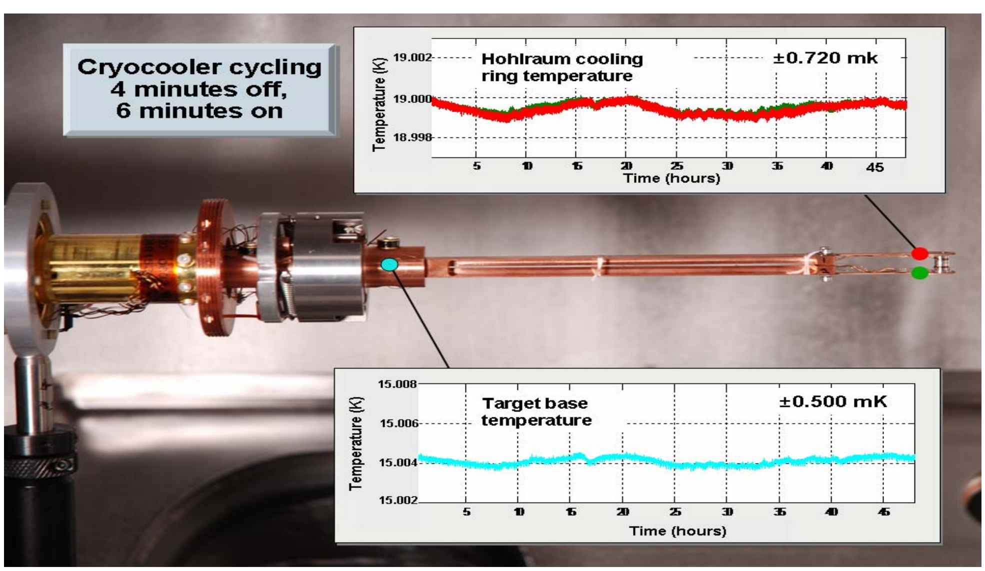




• Ignition Target
Inserter Cryostat (I-TIC)
- Cryogenic system
- Mechanical cryocooler
≈15 m
• Target
Positioner
≈1.5 m
• X-ray imaging for fuel ice layer
characterization
• Target handling glove box
• Target assembly



1.5 meters



Cryocooler cycling
4 minutes off,
6 minutes on
Hohlraum cooling
ring temperature
±0.720 mk
Temperature (K)
19.002
19.000
18.998
Time (hours)
Target base
temperature
±0.500 mK
15.008
15.006
15.004
15.002
Time (hours)