3.2. ADVANCED TECHNOLOGY AND CRYOGENICS EXCELLENCE

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Overview

The Center for Advanced Technology and Cryogenics Excellence focuses on the design, assembly, and testing of cryogenic target systems for ICF. This year, we completed delivery of all components and subassemblies of the Deuterium Test System (D_2TS) to LLNL. This system will have the capability to fill targets by permeation to a pressure high enough that a full thickness fuel layer is generated upon cooling the targets. It will be the first apparatus available for conducting layering experiments on full-scale National Ignition Facility (NIF) indirect drive ignition targets, a crucial step in the ignition goal of Stockpile Stewardship.

We are an integral part of the design team for the NIF Cryogenic Target System (NCTS). The NCTS is the system that fills ignition targets with deuterium-tritium (DT) or other fuels, cools the targets to cryogenic temperature, layers the fuel in the target, inserts the target into the NIF target chamber and exposes the target for the shot. The system is being designed for both indirect and direct drive capsules, and for targets containing capsules made from polymers or beryllium (Be) alloys. The GA/Schafer team has been assigned the lead to develop the Target Insertion subsystem and the Layering subsystem. We have also been assigned to investigate the option of a Direct Drive/Indirect Drive Polymer Fill Cryostat for the Polymer Fill Systems subsystem. General design support was provided as requested on other portions of the NCTS.

During the last quarter of FY01, GA, under the leadership of LANL, developed a preconceptual design of the NIF Be Capsule DT Fill System. This system is designed to fill hollow Be capsules with high-pressure DT gas by bonding two machined hemispherical shells together in a high temperature, high pressure DT environment.

3.2.1. The Deuterium Test System (N. Alexander)

Ignition at NIF will require a uniform and smooth layer of solid fuel inside the capsule. Although considerable progress has been made over the past decade at understanding the conditions required to layer the fuel, no one has demonstrated an appropriately layered NIF capsule in the configuration likely to be used in actual experiments on NIF, i.e., a layered NIF capsule inside a hohlraum. Prior systems for indirect drive targets have filled target capsules through a fill tube to achieve a full thickness fuel layer. The fill tube introduced a thermal perturbation, which distorted the fuel layer as well as perturbing the implosion hydrodynamics.

The D_2TS will be the first apparatus available for performing layering experiments on full-scale NIF indirect drive ignition targets. The D_2TS project mission is to provide a test bed for engineering technologies that will be incorporated into the NCTS and to provide experimental data on D_2 layers formed in capsules without fill tubes.

This year the design of the D_2TS was completed (Fig. 3–1). All parts of the D_2TS were procured or manufactured and put into subassemblies (Fig. 3–2).

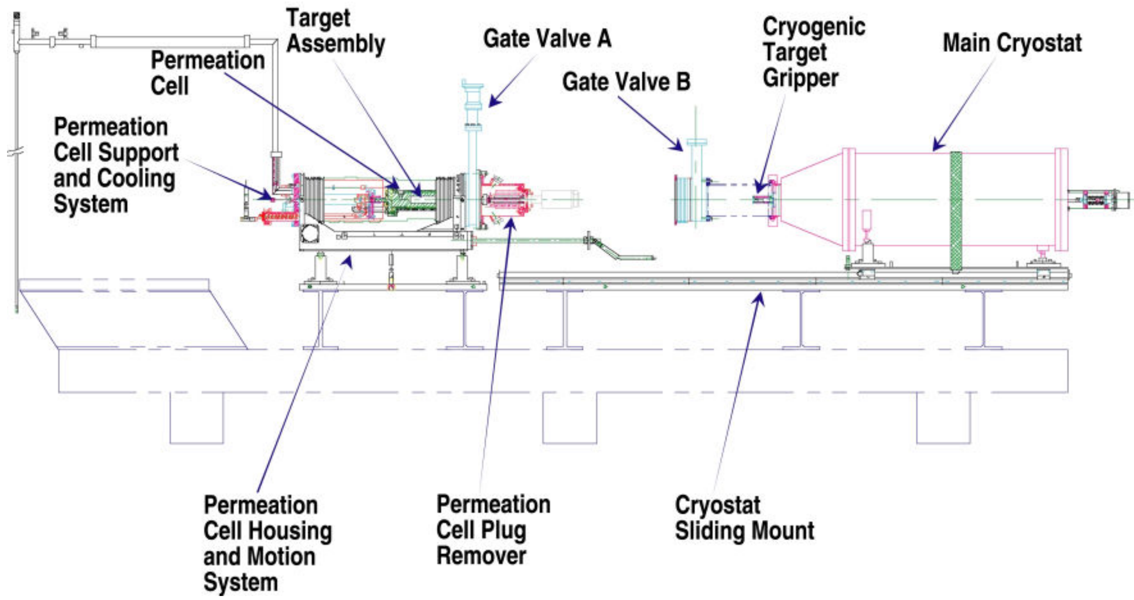

Fig. 3–1. The assembly layout of the D_2TS.

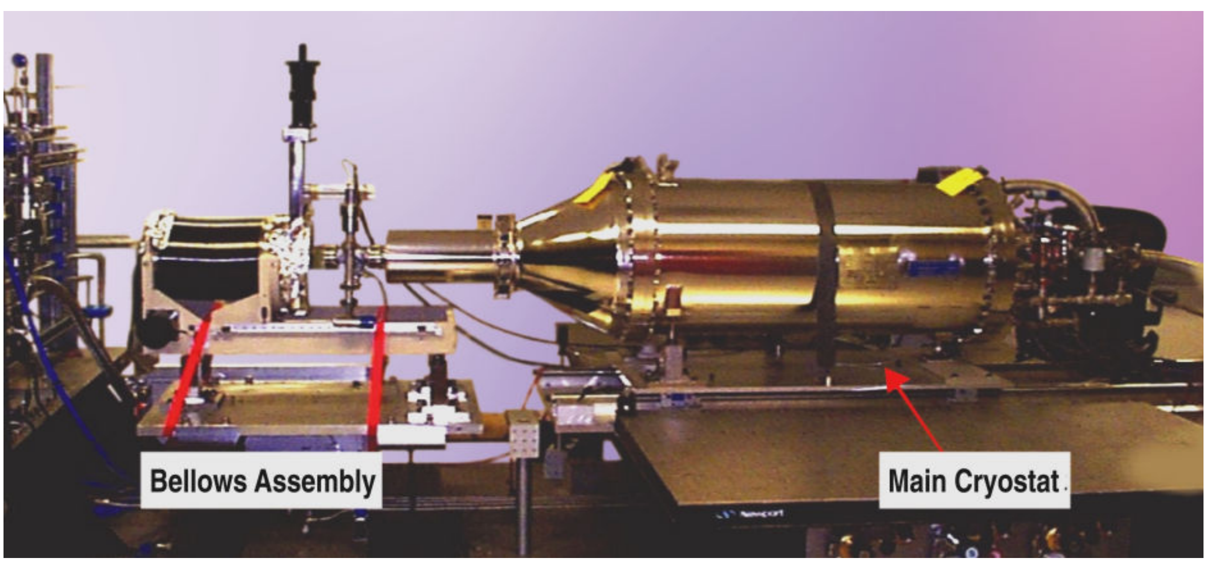

Fig. 3–2. Filled targets will be moved from the bellows assembly into the main cryostat. IR layering of the fuel takes place inside the main cryostat which holds the temperature constant to ±1 mK.

The centerpiece of the D_2TS is the main cryostat. It will retrieve full-scale, deuterium-filled targets into an IR layering and characterization station, and maintain them at a constant cold temperature of 18 K with a stability of ±0.001 K. Targets will be filled in a permeation cell located inside of the bellows assembly and then cooled. The main cryostat will couple to the bellows assembly and retrieve the cooled filled target from the bellows assembly through a vacuum lock. Layering experiments can then be conducted on the target.

For high-quality layering experiments, the desired temperature stability is ±1 mK over 10 minutes. Figure 3–3 shows that the main cryostat has achieved this level of performance. In this data, the standard deviation of the temperature is 0.7 mK.

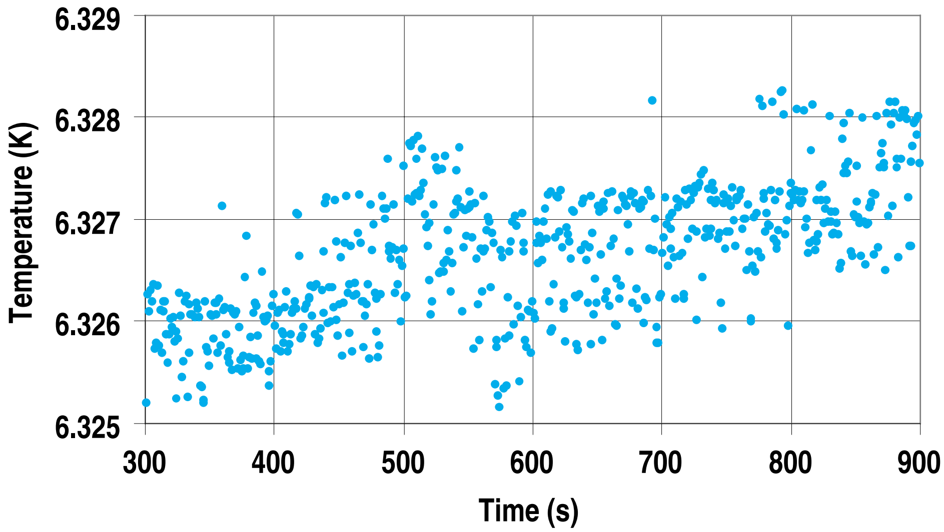

Fig. 3–3. The main cryostat maintained a surrogate target with a temperature stability of better than ±1 mK over a period of 10 minutes.

The permeation cell is shown in Fig. 3–4. The cell is designed to be pressurized with hydrogen isotopes and cooled down to cryogenic temperatures. The cell passed the pressure proof test and leak rate tests at 15,000 psi. (The photograph shown in Fig. 3–4 shows a permeation cell nearly identical to the one for the D_2TS. We are building the SFS for France which is nearly identical to the D_2TS. The photograph and the test results are from the SFS permeation cell.) The leak rate was ≤1.0×10^{-9} STD mbar liter/s (helium) for all pressures. This cell was successfully cooled to 15 K; meeting its base temperature requirement.

All significant components of the D_2TS were delivered to LLNL. It is being assembled and placed into operation at the Target Area Technology experimental facilities at LLNL. More discussion of the operation and integration is in Section 3.6.4.

3.2.2. NIF Cryogenic Target System Development and Engineering (N. Alexander)

The NCTS is the system that fills ignition targets with DT or other fuels, cools the targets to cryogenic temperature, layers the fuel in the target, inserts the target into the NIF target chamber and exposes the target for the shot (Fig. 3–5). It also includes systems for nonignition cryogenic targets. The system is being designed for both indirect and direct drive capsules and for targets containing capsules made from polymers or Be alloys.

GA and Schafer are assisting LLNL, LANL, UR/LLE, and NRL in developing the NCTS. We are assigned the lead to develop the Target Insertion subsystem and the Layering subsystem. We have also been assigned to investigate the option of a Direct Drive/Indirect Drive Polymer Fill Cryostat for the Polymer Fill Systems subsystem and to design and build the fill station for Be capsules. General design support is also provided as requested on other portions of the NCTS.

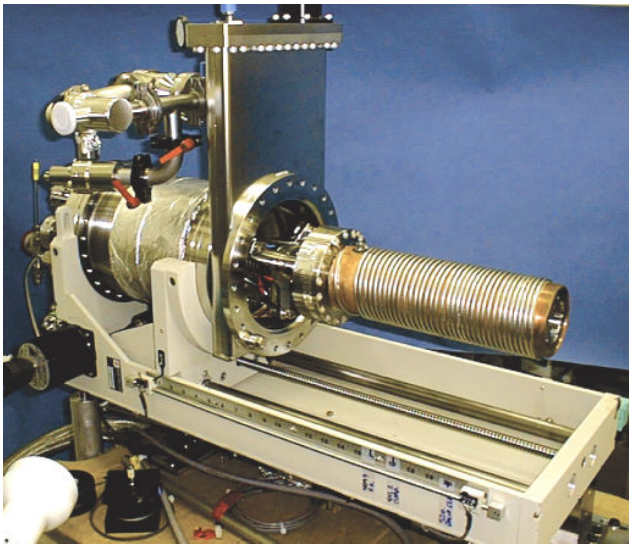

Fig. 3–4. The permeation cell for a system nearly identical to that of D_2TS (cell shown here with the bellows withdrawn) has passed pressure proof and leak tests up to 15,000 psi. The cell has been cooled to 16 K.

This year, activity focused on investigating design concepts for the NCTS and estimating cost and schedule. These activities are being conducted in preparation for the official start of the NCTS conceptual design. In the following sections, we report our activities on:

- The Target Cryostats System, where we concentrated on the Target Insertion Cryostat (TIC).
- The Direct Drive Polymer Fill Cryostat, a fill station for polymer targets.
- The Be Capsule Fill Station, which must fill the capsule with DT while simultaneously sealing two hollowed hemispheres of Be to make a perfect capsule.

3.2.2.1. The Target Cryostats System. The Target Cryostats System allows filled cryotargets to be moved from the fill facility, to the layering and characterization facility, to the center of the NIF target chamber. The Target Cryostats System provides a thermal environment, in conjunction with the shroud, that permits layering of the DT or other fuel in the target. At the NIF target chamber center, the shroud retractor removes the shroud from the Target Cryostats System, exposing the target for the laser shot. The Target Cryostats System has the capability to position the target at NIF target chamber center and elsewhere as needed. The Target Cryostats System also provides utilities to the cryotarget such as electrical leads, infrared light, and a tamping gas line. The work breakdown structure (WBS) is shown in Fig. 3–6.

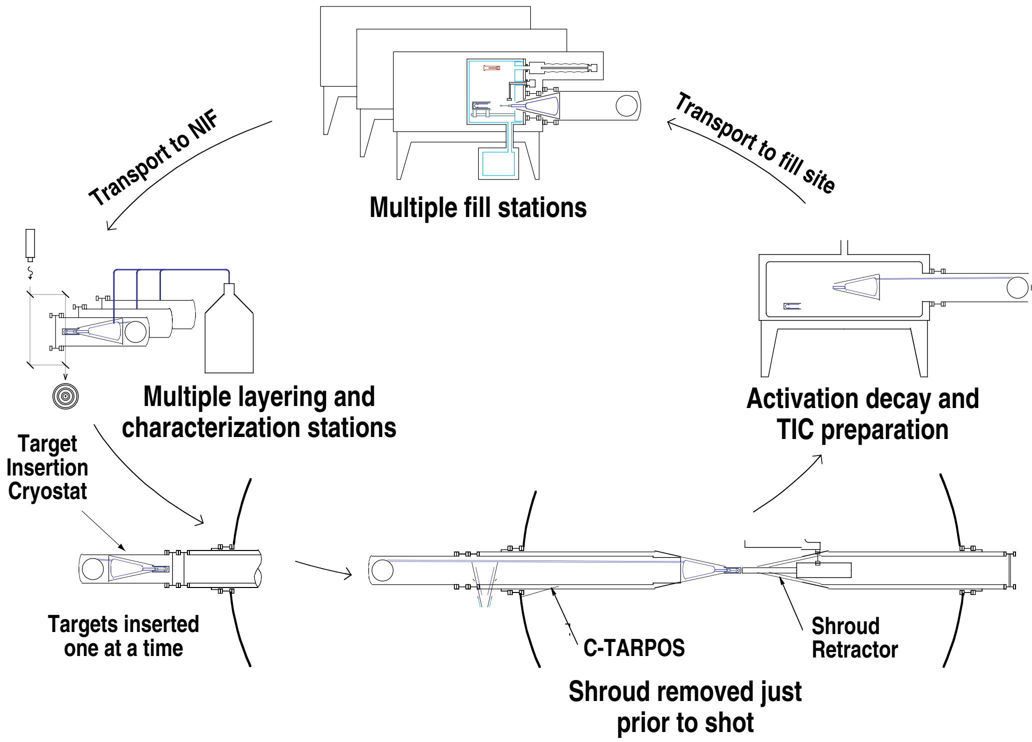

Fig. 3–5. The NCTS will take a target, fill it with DT (or other fuel), cryogenically layer and characterize the fuel, insert the layered target into the center of the NIF target chamber, and expose the target just before the laser beams hit it. Afterwards, part of the system will be set aside, until radioactive decay subsides, before being used for another shot.

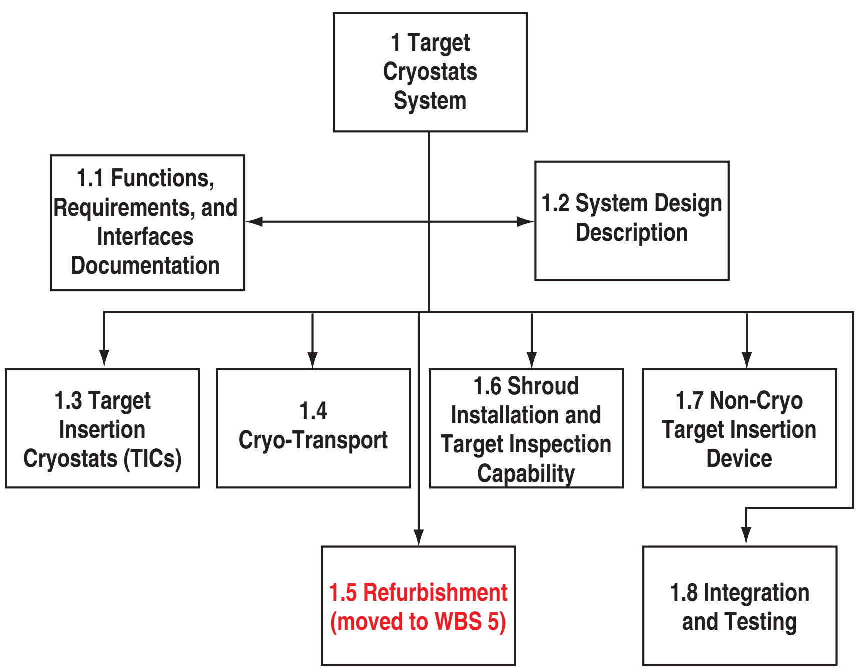

Fig. 3–6. The WBS for the Target Cryostats System.

There are four hardware subsystems in the Target Cryostats System:

1. Target Insertion Cryostats (WBS 1.3), which received the most effort this year.
2. CryoTransport (WBS 1.4).
3. Shroud Installation and Target Inspection Capability (WBS 1.6).
4. NonCryoTarget Insertion Device (WBS 1.7).

3.2.2.2. Target Insertion Cryostat. Our major efforts on the Targets Cryostats System was in developing a conceptual design for the TIC. Several acronyms are used in the following text:

- TIC — Target Insertion Cryostat.
- TIC Transporter — The transportation cart that houses a TIC and moves it between stations.
- TARPOS — TARget POSitioner, currently being built for NIF, it will hold the first targets.
- CTARPOS — Cryogenic TARget POSitioner, planned for the NCTS.
- HIRC — Hydrogen Isotopes Research Center, a refurbished building, B331, at LLNL.

The TIC retrieves a filled, cooled target from the fill station in the fill facility located in the HIRC (B331), holds the target through the various processing steps, and continues to hold it until the target is shot. The TIC contains a gripper for the target assembly holder, a liquid helium cryogen tank, neutron shielding, and a fine motion TARPOS known as a hexapod.

The basic TIC will have two versions; one for indirect drive and one for direct drive targets. Each of these will be made in a low activation variant and a standard materials variant (for ignition and non-ignition shots respectively). Thus, there will be a total of four variants of the TICs. The direct and indirect drive versions will be the same except for the design of the nose cone. The nose cone is the region between the shroud and the hexapod (see Fig. 3–7). The indirect and direct drive targets use very different shrouds so the interface to the shroud will be completely different.

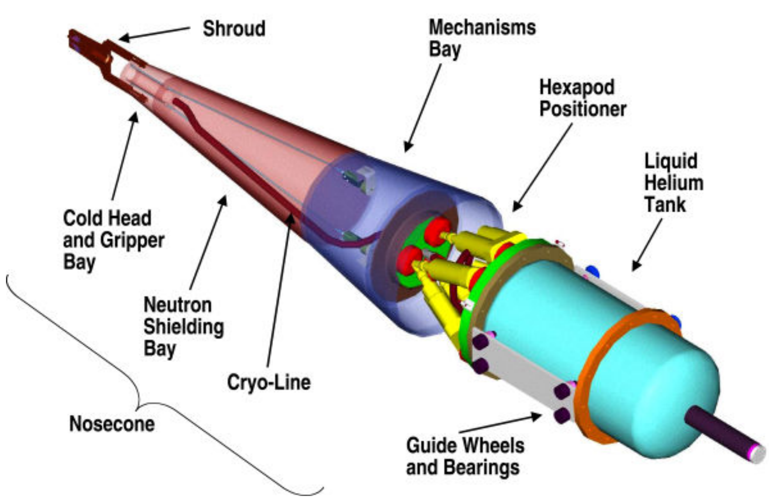

Fig. 3–7. The TIC hexapod attached to the helium tank positions the TIC nose cone and the target held in the gripper. The nose cone shown is for indirect drive targets.

The target gripper attaches to the base of the target assembly holder, which contains the target. The target gripper for indirect drive is more complex as it must accomplish a gas seal, attach electrical lines, and make mechanical and thermal connection to the target assembly base. The indirect drive target gripper is designed as a helium pneumatic actuated version of the gripper used on the D_2TS (Fig. 3–8).

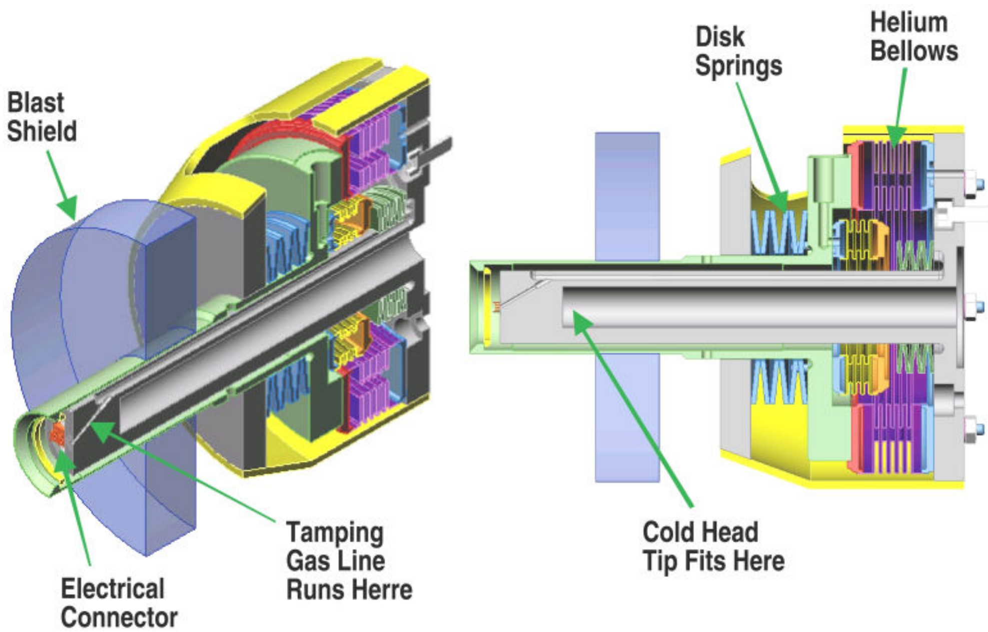

Fig. 3–8. The indirect drive target gripper makes a mechanical, thermal, and electrical connect to the base of the target assembly holder, which contains the target. It seals the tamping gas line to the base.

For direct drive targets, only a mechanical connection is required so a simple spring-loaded collet is sufficient for a gripper. An additional positioning mechanism must be added to the direct drive nose cone. This positioner allows the target to be positioned within the shroud so that the target can be centered in the layering sphere in the shroud and rotated for characterization. An XYZ-theta positioning stage is located in the mechanism bay to accomplish this (Fig. 3–9). The stage is attached to a long stepped rod that runs to the shroud to hold the gripper. The rod is also supported by a flexure with a rotary linear bearing to enhance the stability of the rod. The rod is stepped so that neutrons will not have a clear line of sight through the shielding. This target-in-shroud positioning system is not required for the indirect drive target TIC.

To couple to the differing shrouds, grippers, and positioners, the coldhead for the two types of TICs will have to be customized to each TIC type.

A hexapod positioner (Fig. 3–7) is included for positioning the gripper in the fill station during target extraction from the permeation cell and for fine positioning of the target in the layering and characterization station and in the NIF target chamber. A conceptual design model, position error budget, and stress analysis of the hexapod positioner has been done by a leading manufacturer of hexapods. This indicates that the position requirements can be met even with a 100 kg payload (a design requirement) on the hexapod.

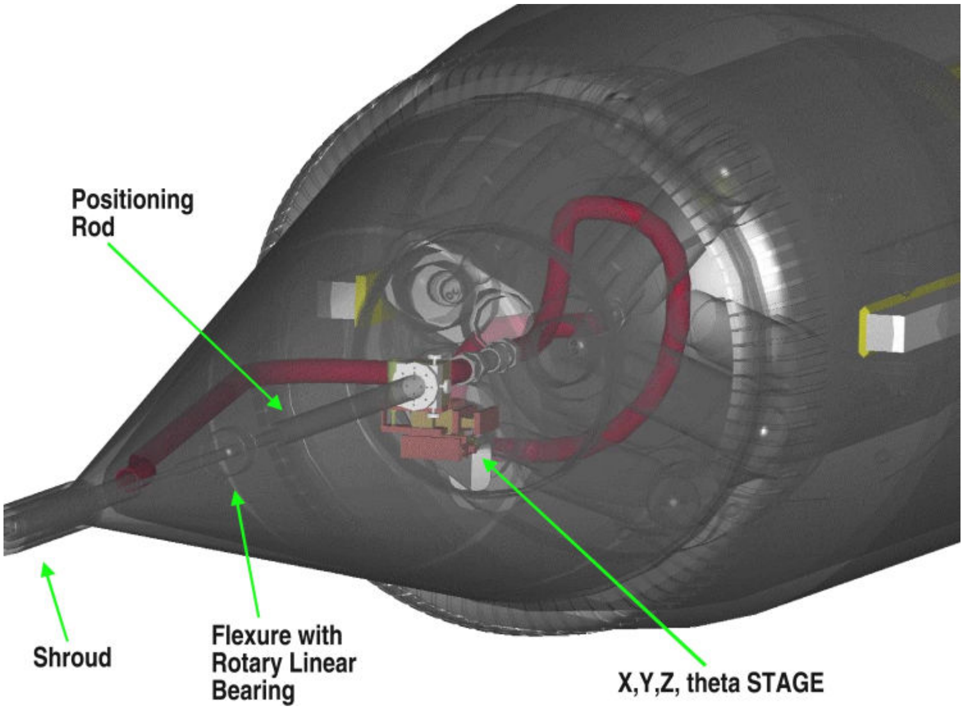

Fig. 3–9. In the direct drive TIC, the positioner stages used to locate the target in the shroud are located in the mechanisms bay (see Fig. 3–7).

3.2.2.3. The TIC Transporter. The TIC is housed in a subsystem of CryoTransport, the "TIC Transporter". Instrumentation, controllers, lasers, and vacuum pumps are housed on the TIC Transporter where utilities required by the target are passed through to the TIC by a utilities line spooler. The TIC Transporter can float on air castors for local transport of the TIC and fine maneuvering required to attach the TIC Transporter/TIC to the various workstations that the target must be taken to (fill station, layering and characterization station, and CTARPOS). The CryoTransport also includes a specially designed truck that is used to move the TIC Transporter/TIC between the fill facility and the NIF.

The Shroud Installation and Target Inspection Capability is located in the fill facility. It is used to install the shroud on the TIC and allows the target to be inspected for damage after the DT fill procedure. For indirect drive, the shroud installation capability is housed in a separate station adjacent to the fill station. For direct drive, the shroud installation capability is located inside of the fill station's fill cryostat; along with the permeation cell used to fill the target with DT.

In operation, the Target Cryostats System first retrieves a filled, cooled target (held by the target assembly holder) from the fill station in the fill facility located in the HIRC (B331). The TIC Transporter is attached to the fill station and extends the nose of the TIC into the fill station. The gripper at the tip of the TIC engages the base of the target assembly holder. For direct drive, the shroud installer installs the shroud while the TIC is still within the fill station cryostat. For indirect drive, the TIC is withdrawn into the TIC Transporter, the TIC Transporter is attached to the shroud installation station, and the shroud installed over the target. With the target and shroud in place, the TIC Transporter/TIC is floated to the fill facility loading dock on air castors. A truck transports the TIC Transporter to the NIF and deposits the TIC Transporter into the elevator. The TIC Transporter is first taken to the layering and characterization laboratory and attached to the characterization station. The DT is layered using the IR lasers onboard the TIC Transporter. Once the target layer has been formed and well characterized, the TIC is withdrawn into the TIC Transporter and floated to the CTARPOS in the NIF target bay. The TIC Transporter pushes the TIC out into the rail system of the CTARPOS. The TIC is then pushed to the end of the CTARPOS boom where it engages a kinematic mount. The target is positioned to the laser beam convergence and the shroud retractor attached to the shroud from the opposite side of the chamber. The TIC releases the shroud and the shroud is removed quickly by the shroud retractor and the target shot.

3.2.2.4. The Direct Drive Polymer Fill Cryostat. The baseline design of the NIF Direct Drive Polymer Fill System is based directly on the OMEGA Cryogenic Target Handling System (OCTHS) at UR/LLE. The OCTHS has been operational since late 2000 and is now routinely used to fill cryogenic direct drive targets.

A sketch of the preconceptual baseline design of the NIF Direct Drive Polymer Fill System is given in Fig. 3–10. A detailed description of the vari ous components of the DD Polymer Fill System is presented in the NCTS Baseline Document to be issued by the end of CY01.

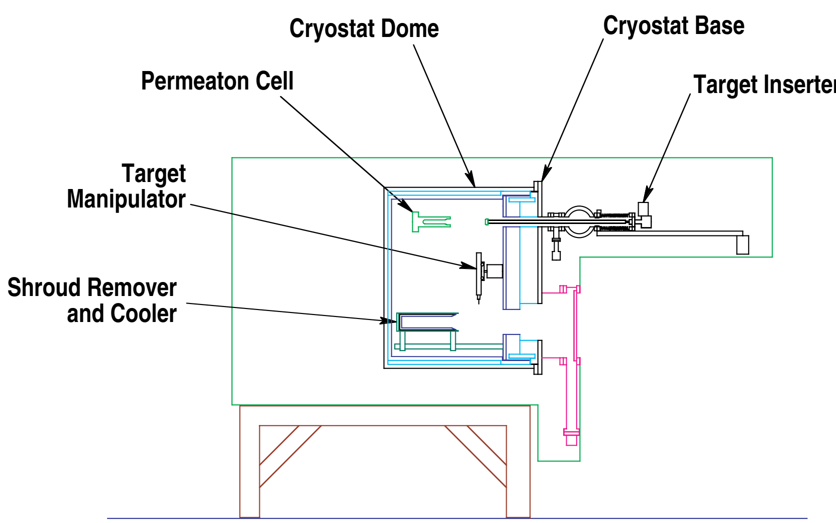

Fig. 3–10. Baseline design of NIF DD Polymer Fill System.

3.2.3. Design of Beryllium Capsule DT Fill Station (C. Gibson)

During the last quarter of FY01, the team of LANL and GA developed a preconceptual design of the NIF Be Capsule DT Fill System. This system is designed to produce hollow Be capsules filled with high-pressure DT gas. Although many methods to produce filled Be capsules have been discussed, the design we conceived is to bond two machined hemispherical shells together in a high pressure DT environment.

The Be Capsule DT Fill System has the following major components: the DT Supply System, the DT Compression System, the Be Capsule Fill Station, the Control System and the Weapons Engineering Tritium Facility (WETF) Support System (located at LANL). GA has responsibility for the DT Compression System and the Be Capsule Fill Station. These two areas are discussed below.

3.2.3.1. DT Compression System. The DT Compression System simultaneously compresses DT and helium gas to the pressures required during target fill. The design of the compressor system is based on existing syringe and diaphragm pump designs, such as those used successfully at the University of Rochester's OCTHS and at WETF with tritium for the past 10 years.

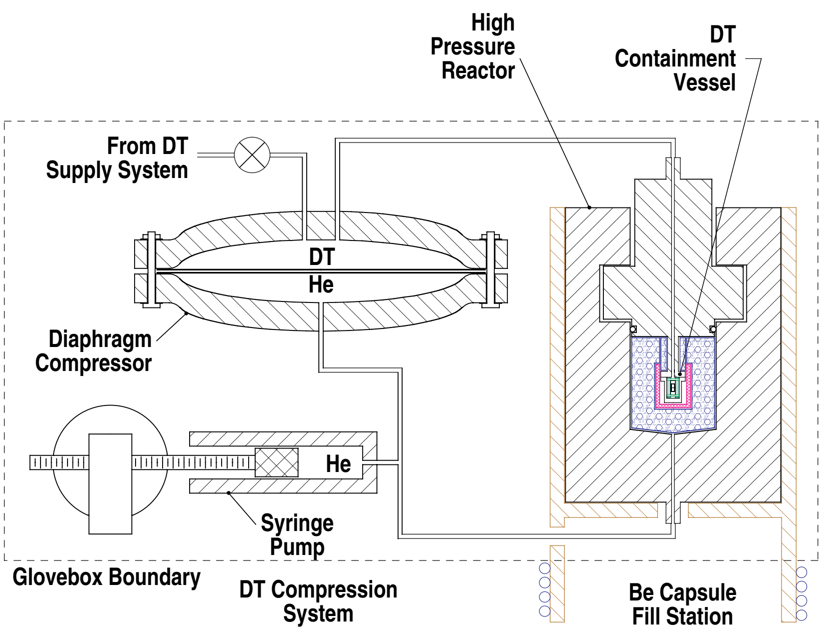

Fig. 3–11. The DT Compression System and Be Capsule Fill Station are composed of two parts. The left side controls the pressure; the DT fill gas and equalizing helium gas are controlled and balanced by the by the syringe pump and the diaphragm compressor. The right side holds and heats Be cylinders with hollowed hemispherical ends, sealing DT gas into an interior cavity.

The basic design of the DT Compression System is shown on the left side of Fig. 3–11. It consists of two distinct plumbing systems, one for DT gas and one for helium gas. The two gas systems are separated from each other by the diaphragm of a diaphragm compressor. Since the diaphragm has little structural strength, any difference in pressure across it will cause the diaphragm to deflect, thereby eliminating the ΔP. This arrangement ensures that the DT and helium gas will always be at approximately the same pressure and, therefore, the DT Containment Vessel inside the Be Capsule Fill Station will see little pressure difference across its wall.

A commercially available syringe pump, installed on the helium stream, is used to increase or decrease the system pressure. These syringe pumps are available from Fluitron, Inc. at working pressures up to 40,000 psi and piston volumes up to 1 liter.

The following discussion gives the steps required to operate the DT Compression System so that it simultaneously supplies high pressure DT and helium gas to the Be Capsule Filling Station. Prior to starting, both the DT and helium piping is evacuated and the syringe pump piston is placed in its maximum volume position. DT gas is then added to the DT side at the maximum pressure that the DT Supply System is capable of providing. The next step is to add helium gas, at the same pressure as the DT, to the helium side of the system. The syringe pump piston is now moved towards its minimum volume position, thereby increasing the helium gas pressure. As the helium gas pressure is increased, the diaphragm deflects to equalize the pressure between the DT and helium gas. To decrease the gas pressure, the piston travel is simply reversed.

3.2.3.2. Be Capsule Fill Station. The baseline design of the Be Capsule Fill Station is shown on the right side of Fig. 3–11. The innermost components are shown in Fig. 3–12. At the center of the fill system are two Be cylinders which, after filling, bonding and machining, will become the filled capsule. These Be cylinders have hemispherical cavities machined into one end. They are arranged so that the two hemispherical cavities are aligned, thereby forming a spherical cavity.

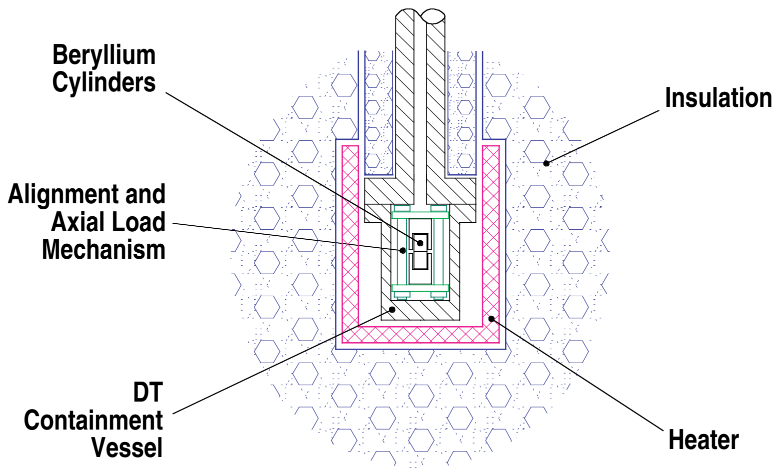

Fig. 3–12. Inner components of the Be Capsule Fill Station heat, compress, and seal together the ends of two Be cylinders that have hollowed hemispherical cavities machined into them. Helium on the outside, maintained at the same pressure as DT on the inside, keeps the containment vessel from exploding.

The two Be cylinders are held and aligned by a precision mechanism. This mechanism also applies an axially compressive load to the cylinders during the fill process in order to bond them together. Many options have been proposed to apply this load, including the use of an external feed through or a pressure actuated diaphragm. Our basic design, however, uses the differential coefficient of thermal expansion of different parts of the mechanism to apply the load. This is done by fabricating the mechanism using materials with different coefficients of thermal expansion. As the temperature of the mechanism is raised from room temperature to the bonding temperature, the materials will expand by different amounts. By careful design, this effect can be used to apply the required load to the Be cylinders.

The DT Containment Vessel surrounds the load applying mechanism and the Be cylinders. This small vessel is connected to the DT piping coming from the diaphragm compressor. To allow bonding temperatures up to 900°C, it is fabricated from a high melting point metal, such as tantalum. The seal must also be fabricated from a metal which can withstand these high temperatures.

The DT Containment Vessel is surrounded by a helium atmosphere. The DT Compression System, discussed in the previous section, is designed so that the helium pressure is approximately the same as the DT pressure. This allows the wall of the DT

Containment Vessel to be designed to only withstand the high bonding temperature and not the high fill pressure.

There are two additional components in the helium environment: the heater and the thermal insulation. The heater is used to raise the DT Containment Vessel and the components inside to the required bonding temperature. The insulation is designed to isolate the High Pressure Reactor from the high temperature of the internal components. The ceramic insulation will be made of a porous material so that the high pressure helium gas will not crush it. Since the thermal conductivity of gas is not a strong function of pressure, the insulation will be effective even though it is filled with high-pressure helium gas.

All of the above components are located inside a high pressure reactor. This reactor is commercially available from companies such as High Pressure Equipment Co. at inside diameters up to 10 in. and pressures up to 100,000 psi. The reactor will be actively cooled with water to maintain its temperature at slightly above room temperature. To avoid the potential hazards of a water leak, the cooling water tubes will not go inside the glove box. Instead, the reactor is thermally connected to a high conductivity copper cylinder. This cylinder penetrates the glove box wall. The cooling water tubes are connected to the cylinder outside the glove box, thereby thermally connecting the cooling water to the reactor.

We estimated that six fill vessels will be needed to meet the requirements for delivering NIF ignition targets at a rate of 12 per week. This is based on performing two filling cycles with the six vessels in a one week period. During the conceptual design, more detailed analysis of the filling times will be performed to establish the number of fill vessels needed to meet the requirements for delivery of DT filled ignition targets to NIF.