S-AA-M-31

Cryogenic Target Handling System Operations Manual Volume IV–CTHS Description

Chapter 4: Moving Cryostat (MC) and Moving Cryostat Transfer Cart (MCTC)

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Chapter 4
Moving Cryostat (MC) and
Moving Cryostat Transfer Cart (MCTC)

4.1 INTRODUCTION

This chapter describes the moving cryostat transport cart (MCTC) and covers the objectives, design, and construction of the system.

Figures 4.4-1 and 4.1-2 illustrate the overall Cryogenic Target Handling System (CTHS) as it is integrated with the OMEGA facility. The MCTC enables the transfer of targets between the Fill/Transfer Station (FTS), the characterization station, and the OMEGA target chamber while maintaining the cryogenic temperature and vacuum pressure necessary to preserve the target.

Spherical cryogenic targets are produced by permeating deuterium or deuterium/tritium fuel into capsules at pressures of up to 1500 atm and then cooling them to below 20°K. This process is performed on four targets at a time in the FTS. A single frozen target is then transferred to a moving cryostat (MC) that is built into a MCTC. The MC maintains the cold evacuated environment around the target while it is layered, characterized, and then moved to the center of the target chamber.

The MCTC houses all of the cooling, vacuum, and control equipment required to maintain the MC at its low-temperature, high-vacuum conditions. A major feature of the MCTC is an evacuated umbilical spool that manages the electrical and fluid lines that connect the MC to the equipment on the

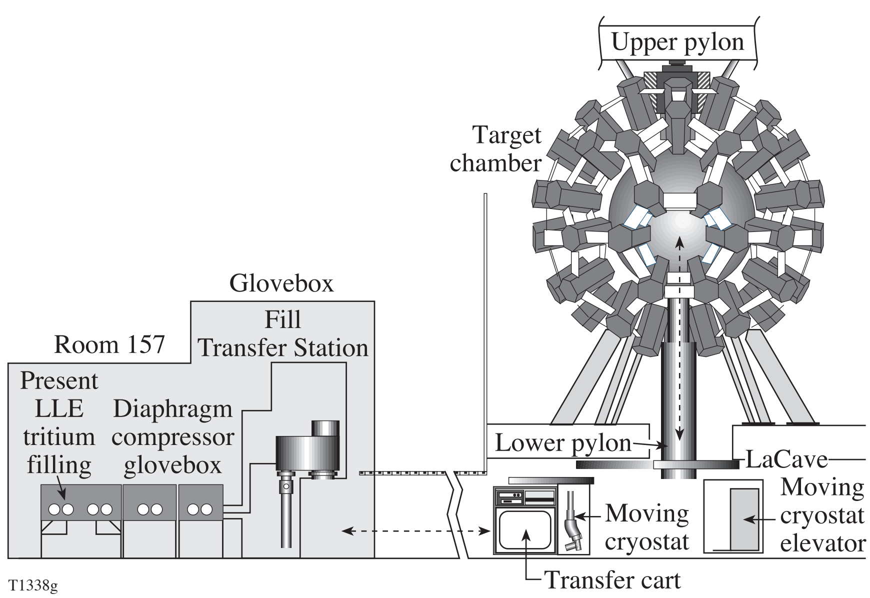

Figure 4.1-1
The CTHS consists of the Fill/Transfer Station, characterization station (not shown), moving cryostat transfer cart, lower pylon, chain locker, and the upper pylon. The pylon components are connected to the OMEGA target chamber.

cart. The entire MCTC is mounted on a pneumatic bearing system that allows operators to push it from place to place within the facility. Five MCTC's are in use. One MCTC (MCTC-4) is configured for planar cryogenic operations. The others are used for spherical cryogenic targets.

For target transfer the MCTC is docked at the FTS where targets are filled and cooled to cryogenic temperatures. Once docked the MC is inserted into the FTS, and a cryogenic target is transferred to it. The FTS is described in more detail in Chap. 7. The MCTC is then moved and docked at one of two characterization stations (CS) and the MC is raised into it.

The CS viewing system captures images of the cryogenic target through viewing ports in the MC. The images assist the CS operator in forming a uniform 100-μm-ice layer of deuterium or tritium. The CS is described in more detail in Chap. 8. The target is layered and the smoothness of the ice layer is measured; the MC is then lowered and the MCTC is moved to LaCave and docked at the lower pylon.

The MC is placed at the target chamber center (TCC) by the lower pylon (LP) equipment. (The lower pylon is described in more detail in Chap. 9.) When the MC arrives at TCC, the MC mates with the kinematic dock at the top of the lower pylon and is clamped into place. The target is then positioned to within 5 μm of TCC and the shot sequence is initiated at T–20, the upper pylon (UP) pull sequence is triggered, the upper shroud is pulled, and the target is shot. (The upper pylon is covered in more detail in Chap. 10.) The MCTC is returned to Room 157 and docked at the FTS where the target stalk is removed.

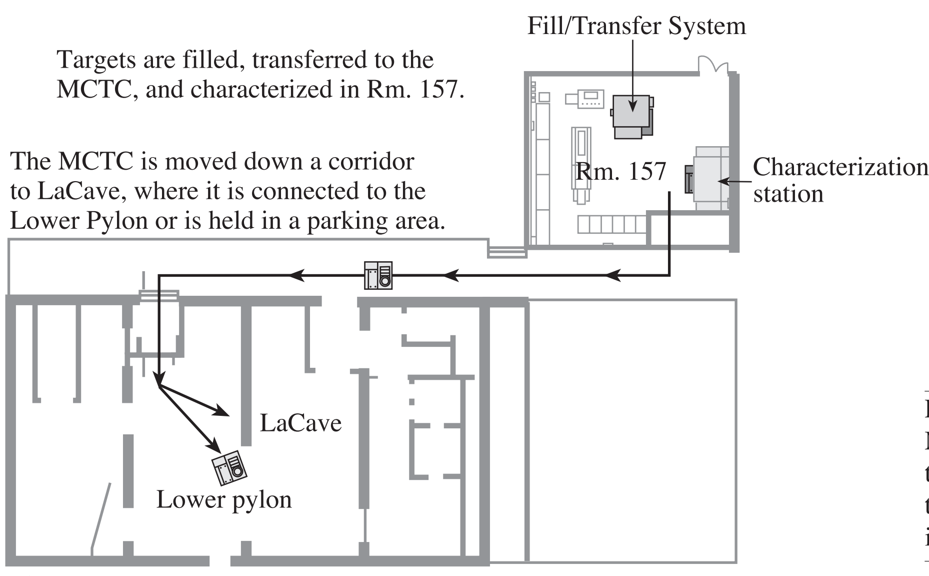

Figure 4.1-2
Movable cryostats are used to transport individual cryogenic targets within the laboratory and into the target chamber.

4.1.1 Equipment Overview

The MCTC (shown in Fig. 4.1-3) can be divided into two subsystems: the moving cryostat and the moving cryostat transfer cart. The MC houses the target in a vacuum cryogenic environment and the cart provides the cooling, vacuum, controls, and power services to the MC.

The parts of the MC are shown in Fig. 4.1-4: (a) the MC base and (b) the components that make up the upper shroud. The inner, middle, and outer shrouds shown in the figure are joined to form a single upper shroud assembly that can move in a vertical direction over the target and mate with the lower shrouds on the base. In this configuration, the target is centered in the "layering sphere." The layering sphere is a metal cylinder with an internal spherical cavity that is cooled to provide the low-temperature, spatially uniform radiation environment that promotes the formation of a smooth, concentric ice layer on the inside surface of the target capsule. Windows in the layering sphere and the shrouds allow the target to be viewed along two axes at the characterization station or by the Target Viewing System in the target chamber.

The MC can be driven vertically out of the MCTC up to 20 ft, via a chain drive and an umbilical containing hoses and wiring that provide cooling, electrical, and pneumatic power; laser power; and controls and data collection functions.

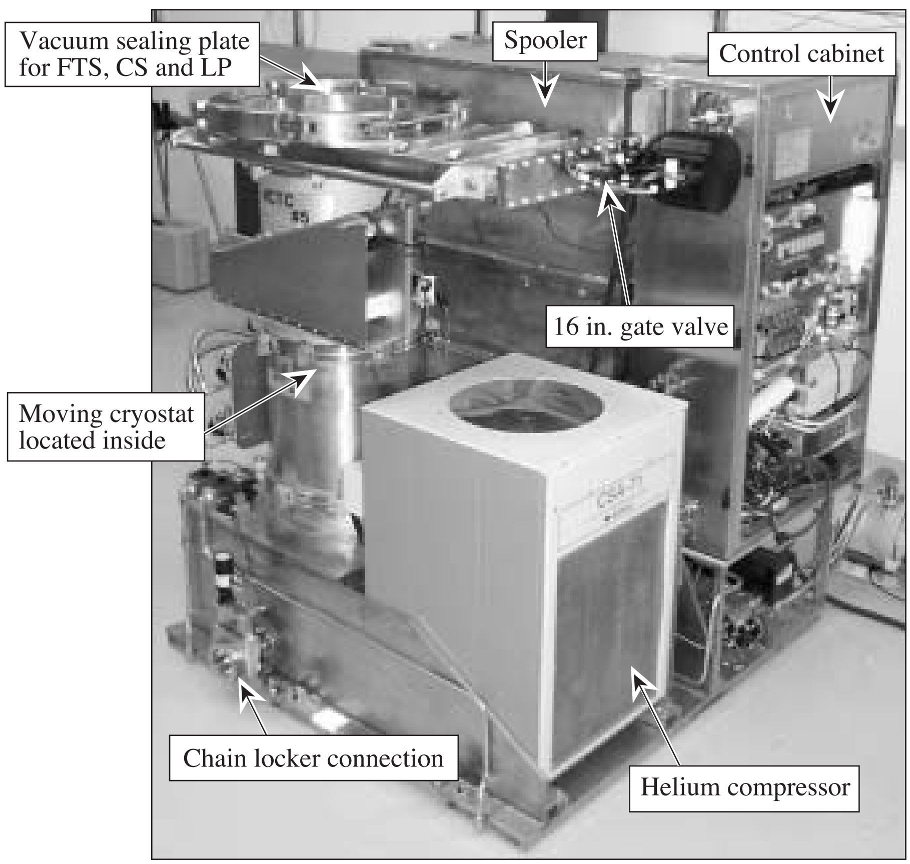

Figure 4.1-3
MCTC showing major components.

Figure 4.1-4
Parts of the moving cryostat: (a) the base includes the target positioner, a cooler, and the lower protective shrouds; (b) the upper shroud is a three-layer assembly. The layering sphere element that immediately surrounds the target provides a spatially uniform radiation environment that determines the properties of the ice.

The MC is comprised of the following major components:

- **Base Assembly:** This assembly consists of the frame for support, docking plate, backbone support for the short lift elevator, utility umbilical connections, and a cryocooler.
- **Four-Axis Fine Motion Assembly:** This assembly supports the target and allows the target to be positioned by providing the X, Y, Z, and θ motion.
- **Stalk Assembly:** The target stalk supports the target 26 in. above the fine motion assembly. It is designed to minimize heat transfer and vibrations.
- **Lower Shroud:** The lower shroud assembly provides the thermal link between the cryocooler and the upper shroud assembly.
- **Upper Shroud:** The upper shroud assembly encloses the target and stalk and provides an isothermal environment for the target.
- **Layering Sphere:** At the upper end of the upper shroud is the gold-plated copper layering sphere that surrounds the target and is conductively connected to the cold head at the base of the MC. IR energy from an external laser is uniformly diffused on the rough, gold-plated surface.

The MCTC transports and provides services (i.e., power, vacuum, laser energy…) to the MC. The MCTC supports the following systems:

- **Vacuum System:** A vacuum chamber encloses the MC, short-lift elevator, and the umbilical system. A turbo pump is used to generate vacuums to about 5×10^{-6} Torr.

- **Short-Lift Elevator:** A short-lift elevator with a dual-chain drive is used to vertically raise the MC out of the MCTC to a height of 48-in.

- **He Compressor:** This device supplies pressurized helium at up to 300 psig to the coldhead.

- **Gas Manifold:** This device provides gas for pressurizing and evacuating the parting joint finger bellows, for valve operation, and for the exchange gas in the layering sphere.

- **Umbilical System:** The umbilical connects the cart services to the MC. The umbilical system uses a spooler that allows the umbilical to extend and retract as the MC is raised or lowered. The spooler consists of a scissors-like structure that rises and falls as the umbilical is retracted/extended.

4.1.2 Target Overview

LLE targets are grouped into two main classes: spherical and planar. These two categories are subdivided into room-temperature and cryogenic targets (see Fig. 4.1-5 for views of the spherical and planar cryogenic targets in use on OMEGA). Cryogenic targets are mounted in an MC to maintain the cryogenic temperatures. These targets have different cooling and filling requirements and require different moving cryostat designs.

The spherical targets require a low mass support and requires the use of helium exchange gas to provide cooling between the target and the spherical MC. The spherical targets are filled by diffusing high-pressure, hydrogen gas up to 1500-atm through the capsule wall at room temperature and then

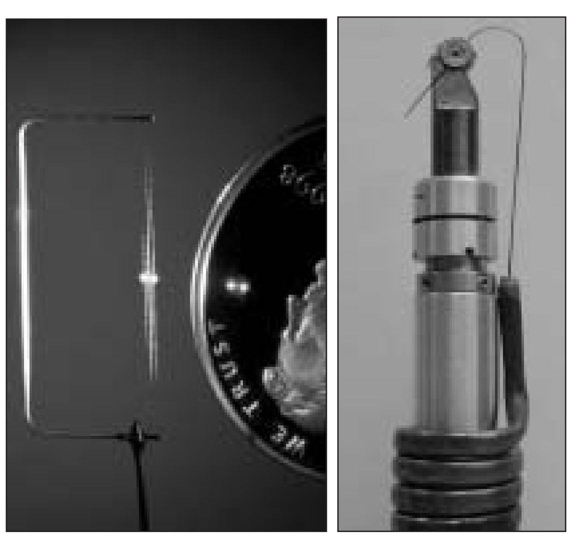

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Figure 4.1-5
Views of spherical and planar cryogenic targets in use on OMEGA.

cooling the target before the pressure is removed from the outside of the target. These steps are accomplished in the FTS. The cold spherical target is then transferred to a cold MC housed in an MCTC.

The planar targets are cooled by direct conduction to the copper support structure of the target and the planar moving cryostat (PMC). The planar targets (DD only) are filled at room temperature to a sub-atmospheric pressure. These targets are hand loaded into the PMC at ambient temperature, then cooled after the PMC is lowered into the MCTC and a high vacuum is established. The PMC is designed for rapid thermal cycling to allow several targets to be loaded and shot during a typical day.

4.2 SPHERICAL MOVING CRYOSTAT (MC) COMPONENT DESCRIPTION

As seen in Fig.4.2-1, the MC is a cylindrical device with a 16 in.-diameter and is approximately 30 in. long. The frozen target is mounted on a stalk and centered within an integrating sphere. The integrating sphere and stalk are insulated by a series of nested shrouds that act as heat sinks and thermal shields to remove heat in a controlled fashion.

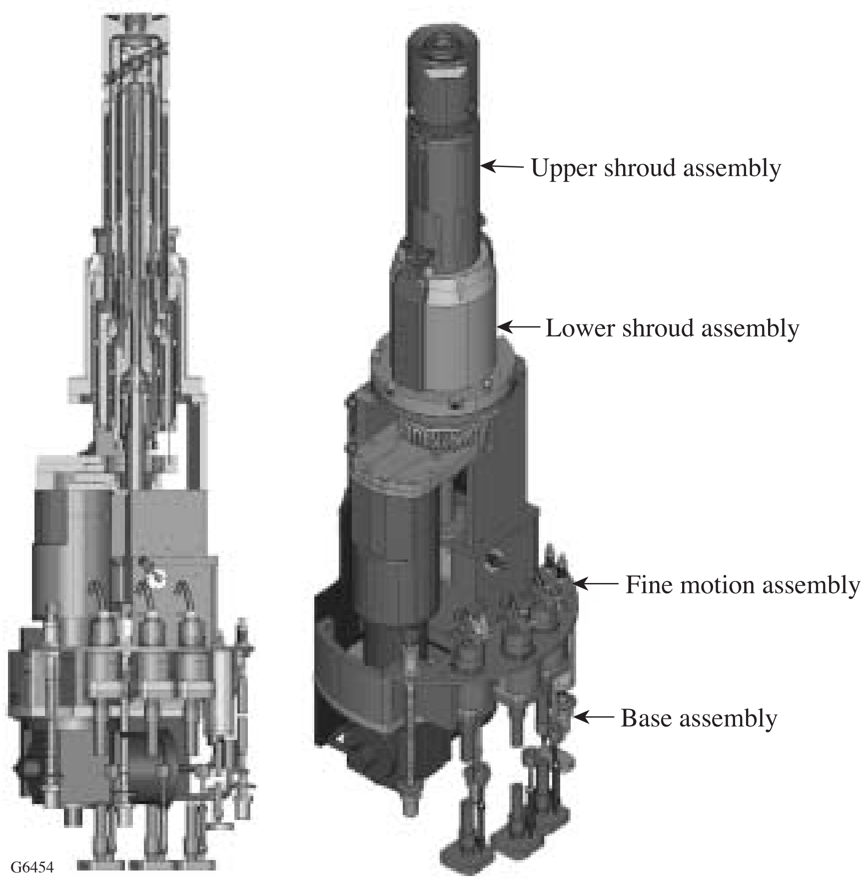

Figure 4.2-1
The major components of the spherical moving cryostat.

The MC can be driven out of the MCTC 48 in. vertically by the short-lift elevator or up to 22 ft via a chain drive system. The MC itself is not a pressure vessel although a small pressure differential (50 to 100 mTorr) is maintained between the MC exchange gas region and the high vacuum interior of the MCTC.

4.2.1 Performance and Functionality

The MC has several critical functions and performance specifications:

- Maintains targets from 14 K to 20 K with a resolution and stability of 0.001 K.
- Maintains a 20- to 50-mTorr pressure of helium within the layering sphere to provide thermal coupling between the target and the layering sphere.
- Minimizes target vibration during characterization of the target and during target implosions within the OMEGA TC to less than ±10 μm.
- Allows 360° rotation of the target about the vertical Z axis.
- Controls the position of the target in three planes to within 5 μm.
- Provides windows in the thermal shrouds along the axes of the OMEGA Target Viewing System to allow alignment and characterization of the target.
- Enables the layering of the fuel within the targets through the use of an onboard laser system and electrical heaters.
- Provides rapid exposure of the target to the OMEGA laser via rapid removal of the upper shroud assembly from the MC.
- Provides for the transfer of targets to the MC from the FTS through shroud detachment and target placement atop the stalk.

4.2.2 MC Overview

The MC is comprised of four subassemblies; the base, fine motion assembly, lower shroud, and upper shroud. The base assembly provides the interfaces between the MCTC and the other MC subassemblies, including the cryocooler that provides the cooling for the shroud assemblies. The fine motion assembly provides support for the target and allows fine movement of the target, relative to the shrouds, in the X, Y, Z, and θ axes. The lower shroud assembly provides the thermal link between the cryocooler in the base assembly and the upper shroud assembly. Three tooling balls on the lower shroud assembly provide the docking interface to the FTS, the characterization stations, and the lower pylon. The upper shroud assembly provides the thermal environment for the target, interfaces to the lower shroud assembly through the parting joint, and provides the attachment to the upper pylon gripper for shroud retraction. The parting joint provides a thermal path to the lower shroud and allows a low-force separation of the upper and lower shroud assemblies during the shot sequence.

4.2.3 Base Assembly

The base assembly (shown in Fig. 4.2-2) consists of the frame, backbone, umbilical connection plate, a cryocooler, and a termination assembly for the umbilical. The umbilical cables provide supply and return helium for the cryocooler, three electrical cables, two optical fibers for the optical parametric oscillator (OPO) laser, the exchange gas, and the parting joint gas.

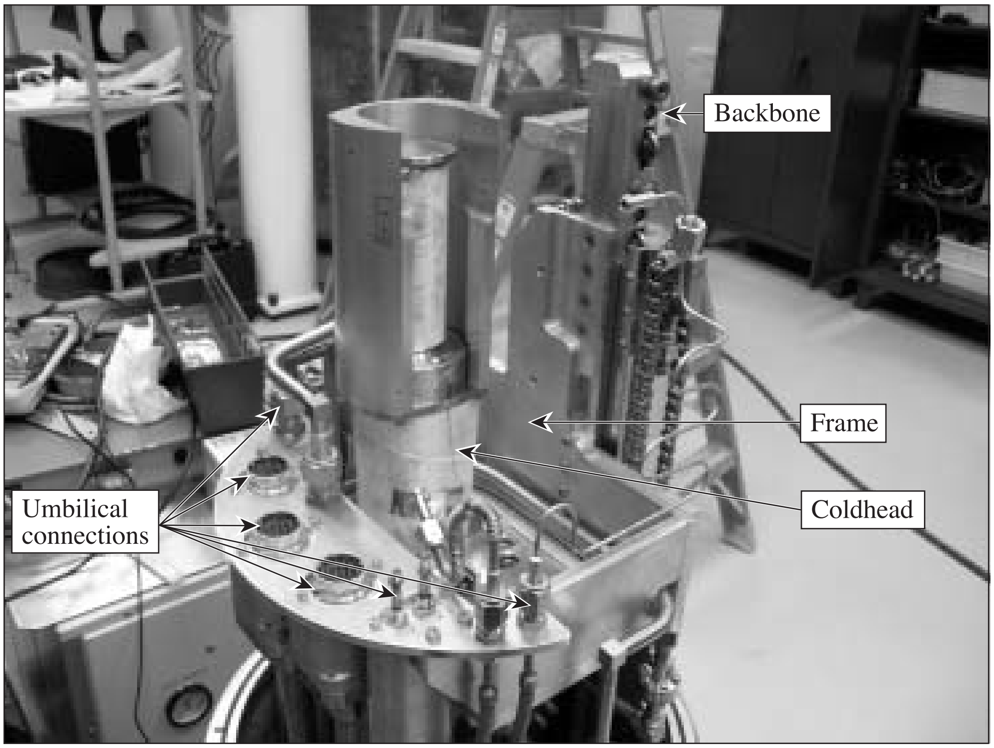

Figure 4.2-2
The spherical MC base assembly supports two other MC components and provides the interface for the umbilical lines.

4.2.3.1 Backbone

The frame is supported by the backbone, which interfaces to the rail of the short-lift elevator in the MCTC and short rail sections in the FTS and CS's. A longer section of rail is located in the LP to guide the MC to the center of the OMEGA target chamber. This backbone (shown in Fig. 4.2-3) provides support for the cantilevered loads of the MCTC umbilical. The frame also provides the interface to the short-lift elevator in the MCTC as detailed in Fig. 4.2-3.

This interface consists of a hook on each side of the base assembly that engages a link in each of the two chains of the short-lift elevator. This interface also allows the LP chain to lift the MC frame from the short-lift elevator during the insertion of the MC to TCC. The base assembly backbone provides the interface to the LP chain as shown in Fig. 4.2-4.

4.2.3.2 Cryocooler

The device that provides the cold temperatures necessary to achieve cryogenic conditions within the MC (and elsewhere in the Fill/Transfer Station) is a "cryocooler" or "cold head" (Figs. 4.2-5 and 4.2-6). This unit provides cryogenic surfaces on its first- and second-stage "cold heads." The inner and intermediate heat paths are thermally connected to the first and second stages of the cryocooler.

The cryocooler in the MC is a Sumitomo Heavy Industries model SRDK-408D cryocooler (Fig. 4.2-7). It is designed to provide a temperature range of 25°K to 40°K in the first stage and 3.5°K to 4.2°K in the second stage. The cold head has three major components: the motor drive unit, the cylinder, and the displacer–regenerator assembly located inside the cylinder.

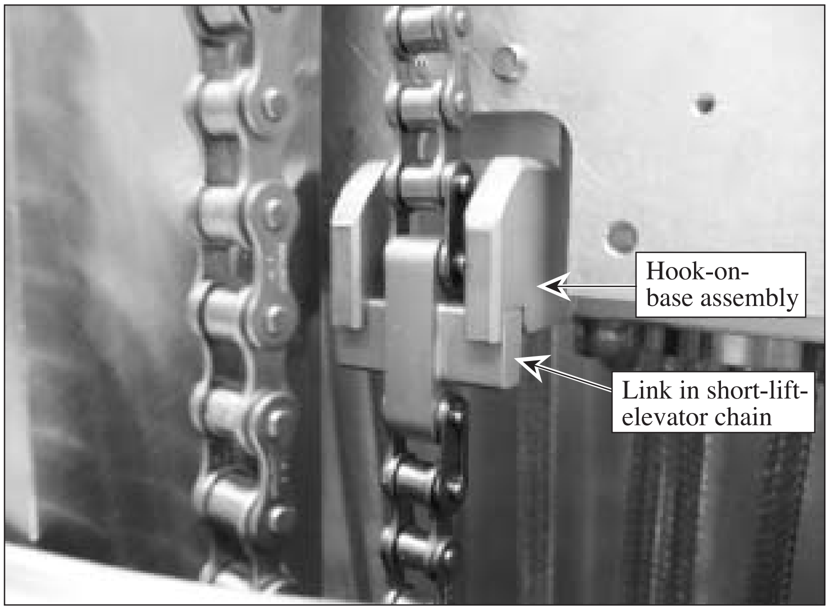

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Figure 4.2-3
Detail of one of two short-lift elevator interfaces to the MC base assembly.

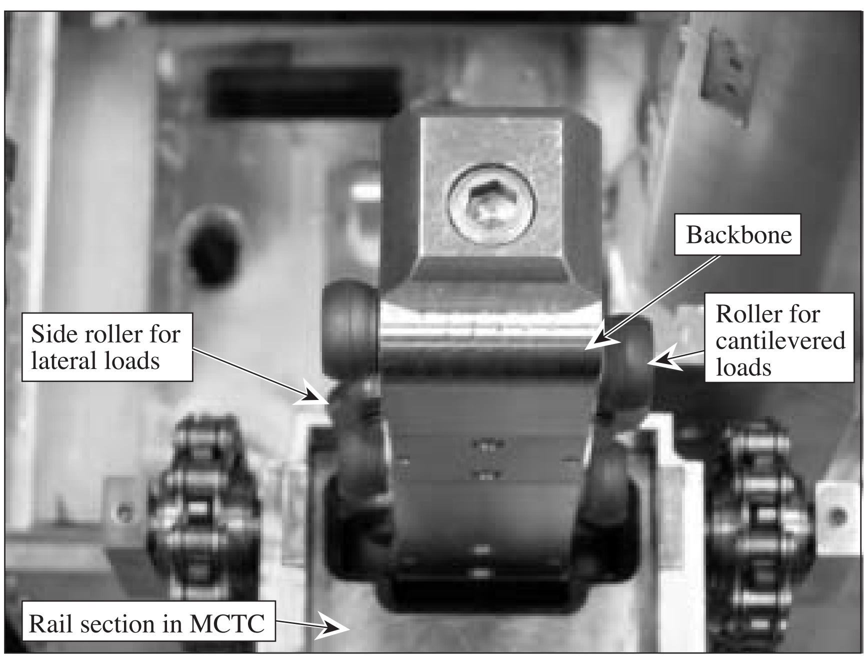

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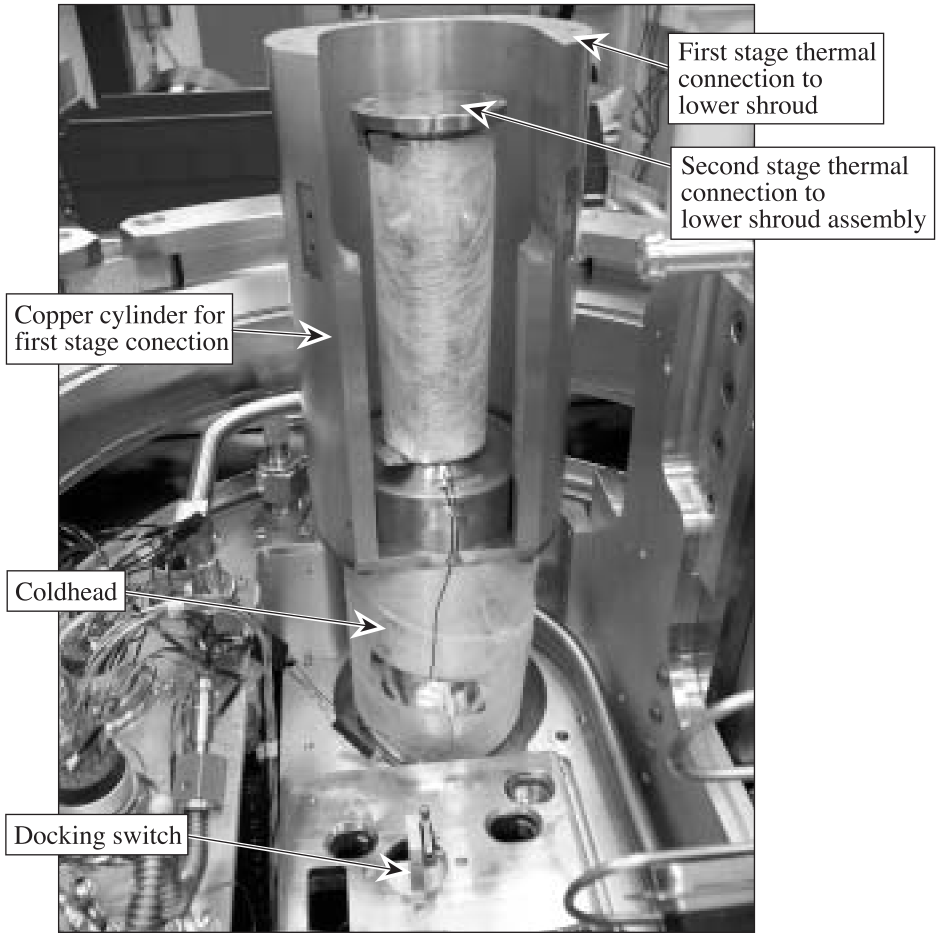
Figure 4.2-4
Detail of the backbone from a top view.

Figure 4.2-5
Coldhead connections in the base assembly.



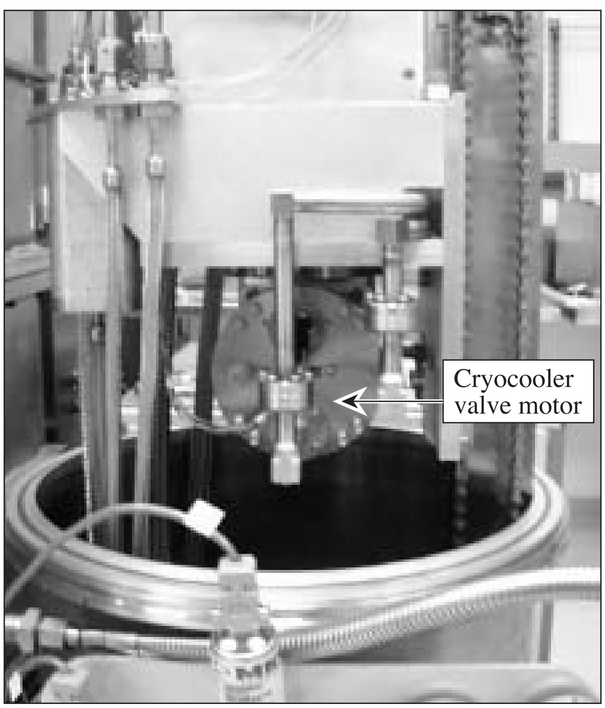


Figure 4.2-6
The cryocooler is mounted on the MC and can be seen when the MC is raised out of the MCTC.

The cold head implements the Gifford–McMahon cycle by expanding high-pressure helium to low pressure. This is accomplished through a reciprocating piston, which allows the helium to expand in two stages: first to approximately 40°K and then to 5°K [Fig. 4.2-7]. Helium is then returned to the external compressor through a second transfer line, at a pressure of 65 to 95 psia. A rotary valve controls gas flow into and out of the cold head. The umbilical supplies compressed helium to the cryocooler. Power is also supplied through the umbilical. The system requires a vacuum of 4×10^{-5} Torr to provide adequate insulation.

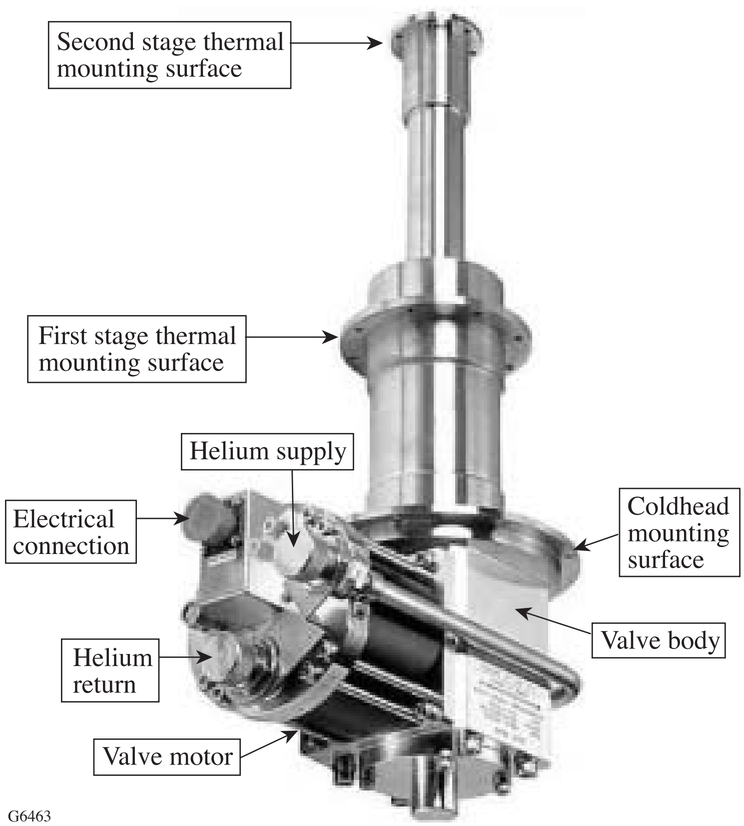


Figure 4.2-7
Sumitomo model RD-210W coldhead.

4.2.3.3 Base Docking

The spring-loaded base plate on the four-axis positioner provides compliance when the MC engages the docking geometry at the LP, FTS, or CS. This allows the MC base assembly to move upward several tenths of an inch after the docking geometry is engaged. This motion is used to trip the docking switch [Figs. 4.2-5 and 4.2-8] on the base assembly, which prohibits further motion of the MCTC short-lift elevator or the chain locker.

The LP and CS use electric clamps to preload the docking geometry joint, and once these clamps are engaged, the base assembly is lowered approximately 0.5 in. to provide clearance between the base assembly and the spring-loaded base plate on the fine motion assembly. This clearance reduces target vibration by removing mechanical coupling between the base assembly, which includes the cryocooler, and the combined assembly of the fine motion assembly, lower shroud assembly and the upper shroud assembly, which is rigidly coupled to the docking plate in the LP or CS.

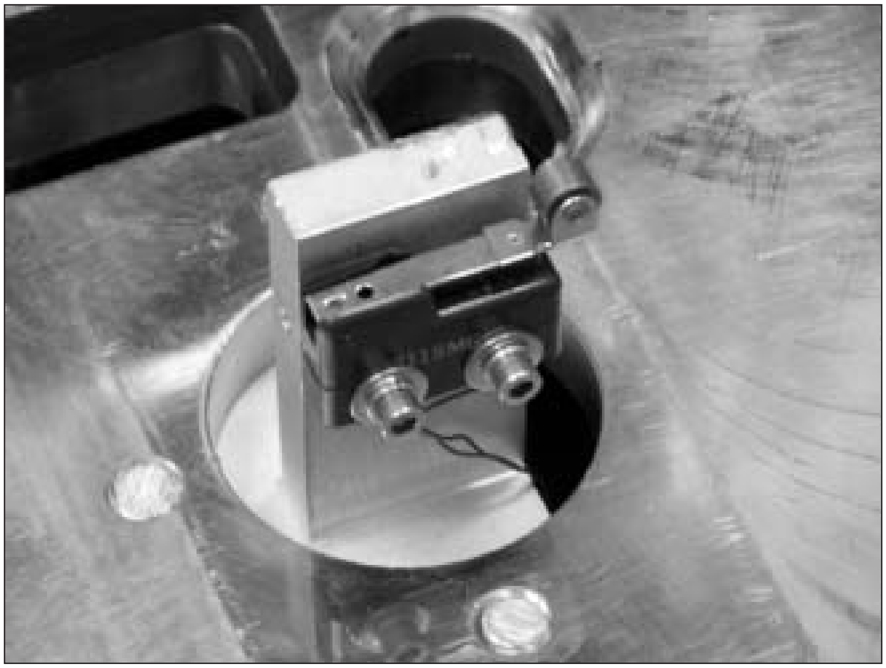


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Figure 4.2-8
Base-assembly docking switch.

The docking mechanism at the FTS uses the force of the spring-loaded base plate to provide the preload and clamps are not used. In this situation, the base assembly is not lowered, and a significant mechanical coupling remains between the cryocooler and the target.

4.2.4 Fine-Motion Assembly

The fine-motion assembly (shown in Fig. 4.2-9) supports the target and allows the target to be positioned at TCC by providing X, Y, Z, and θ motions of the target relative to the shrouds. The X and Y motion is created by moving the lower end of the stalk in a lateral direction, and the stalk rotates about the pivot to create lateral motion at the target. The pivot provides rigid support to the stalk at the midpoint (see Fig. 4.2-10 for details of the pivot).

4.2.4.1 Four-Axis Box

The four-axis positioner is located in the fine motion box. This assembly is referred to as the four-axis box (or 4AB) (Fig. 4.2-10). The stalk connection to the θ axis is a gimbal, so the lower end of the stalk is free to pivot slightly during the lateral motion of the 4AB. Position feedback is provided with linear potentiometers for X, Y, and Z and a rotary potentiometer for the θ axis.

4.2.5 Stalk Assembly

The target stalk (shown in Fig. 4.2-9) supports the target 26 in. above the positioning stages. It is designed to minimize heat transfer to the target and to minimize vibration of the target. It is fabricated from thin-walled stainless steel tubing and contains internal and external damping to minimize ringing of modes induced in the stalk by cryocooler operation and by the forces associated with the upper shroud retraction. The top of the stalk has a threaded interface to a spindle that positively and repeatably

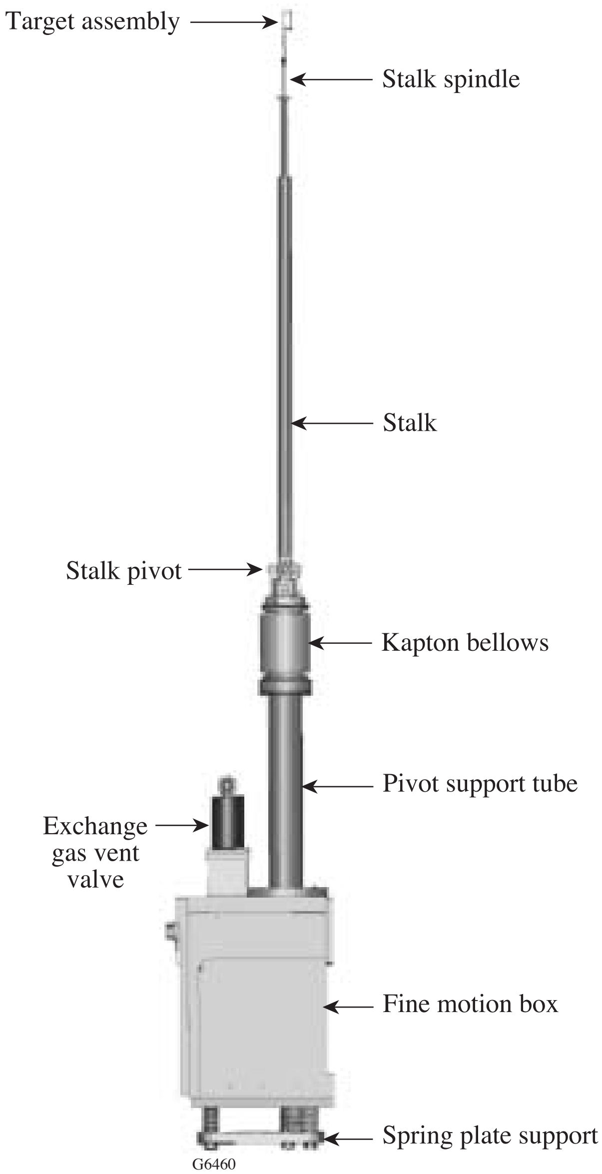

Figure 4.2.-9
Fine-motion assembly.

locates the target base relative to the stalk. This spindle uses a Samarium Cobalt permanent magnet to provide a preload on the tapered joint between the spindle and the target base. This material was chosen for the magnet because it will operate at cryogenic temperatures.

The interior of the 4AB is part of the exchange gas region of the MC. The exchange gas is supplied at room temperature to the 4AB from the umbilical. The gas flows upward through the pivot support tube into the lower shroud assembly. During this transition the gas is cooled to 15°K, so the pivot support tube and the stalk need to support a thermal gradient from 300°K to 15°K over this distance of 11 in. The Kapton bellows at the pivot provides the gas seal between the fine motion assembly and the lower shroud assembly. An upper indium seal is located between the pivot support tube and the bellows, and a lower indium seal is located between the bellows and the lower shroud assembly (see Fig. 4.2-11).

During shot operations, the exchange gas is vented to the lower pylon approximately 6 to 8 s before the shot. This is accomplished by opening the exchange gas vent valve (see Fig. 4.2-9), which is located on the top of the 4AB. This valve is operated in parallel with the thermal parting joint between the upper and lower shroud assemblies. (See Sec. 4.2.6.2 for further information on the parting-joint operation.)

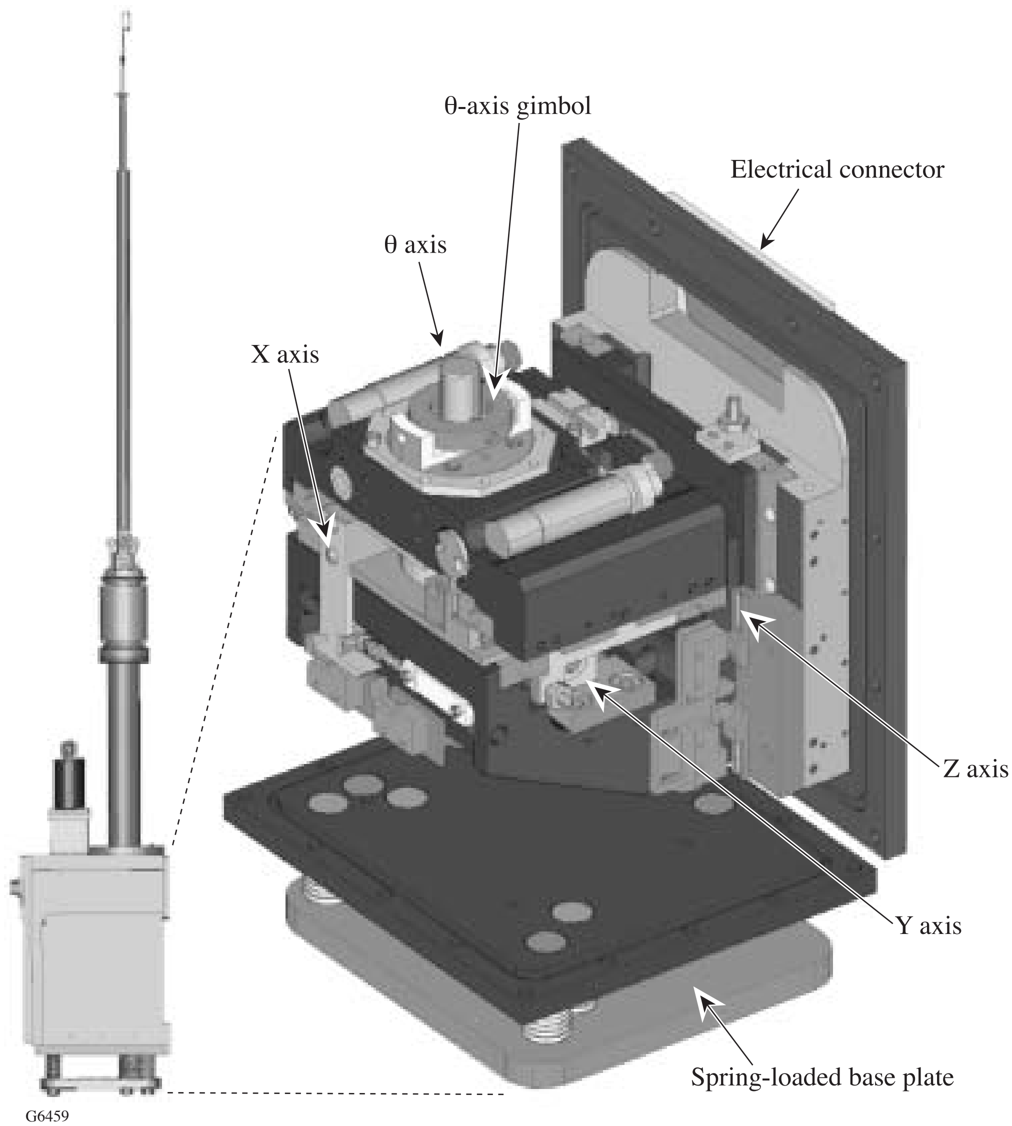

Figure 4.2-10
Four-axis box (4AB) showing each fine motion stage.

4.2.5.1 Stalk Pivot

The stalk is supported at the pivot with two rigid rollers at 90° from each other, so they form a vee for the cylindrical surface of the stalk. Two spring-loaded rollers, opposing these rigid bearings, provide preload of this joint between the pivot and stalk. The stalk can move in the vertical direction through these four rollers, and the stalk can pivot about these rollers to provide *X* and *Y* motion at the target. The assembly of these four rollers and the stalk can rotate about the vertical axis on the two rotation bearings shown in Fig. 4.2-11.

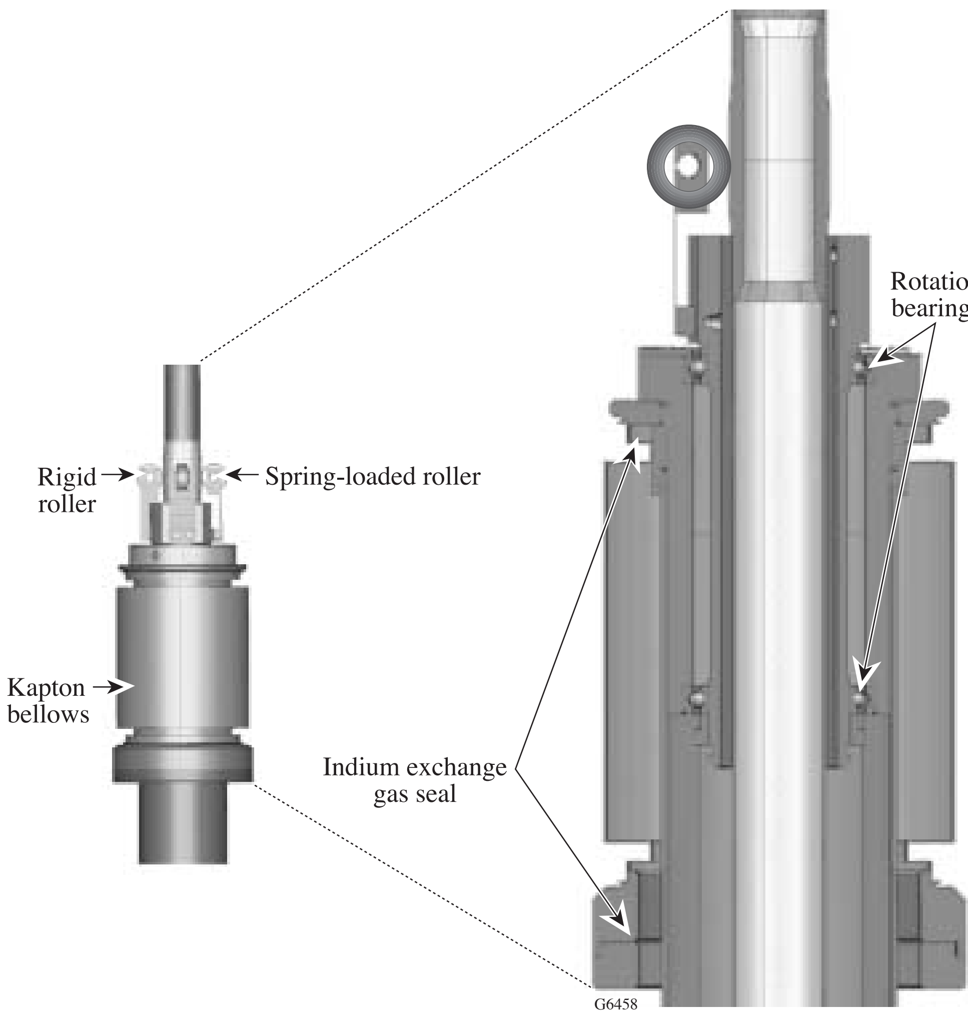

Figure 4.2-11
Stalk pivot detail.

4.2.5.2 Target Assembly

The fuel capsule is approximately 900 μm in diameter with a wall thickness of 3 to 5 μm. This capsule is supported by four spider silks to produce a low-mass mount [Fig. 4.2-12]. The spider silks are stretched across the staple-shaped beryllium wire, which is used to minimize obstruction of the laser beams hitting the target, while minimizing the mass near the capsule. The staple is supported by two boron fibers that are each 300 μm in diameter. The boron fibers are used to provide a low-mass, stiff support for the staple. The boron fibers are epoxied into the target base using a precision fixture. (See Vol. IV, Chap. 1 for additional information on the target assembly.) The joint between the target assembly and the stalk is a tapered geometry, which is preloaded with a samarium cobalt (SmCo) magnet located in the stalk spindle that attracts a steel plug in the target base. This preloaded joint ensures repeatable target alignment and sufficient joint stiffness to prevent motion of this joint during upper shroud retraction.

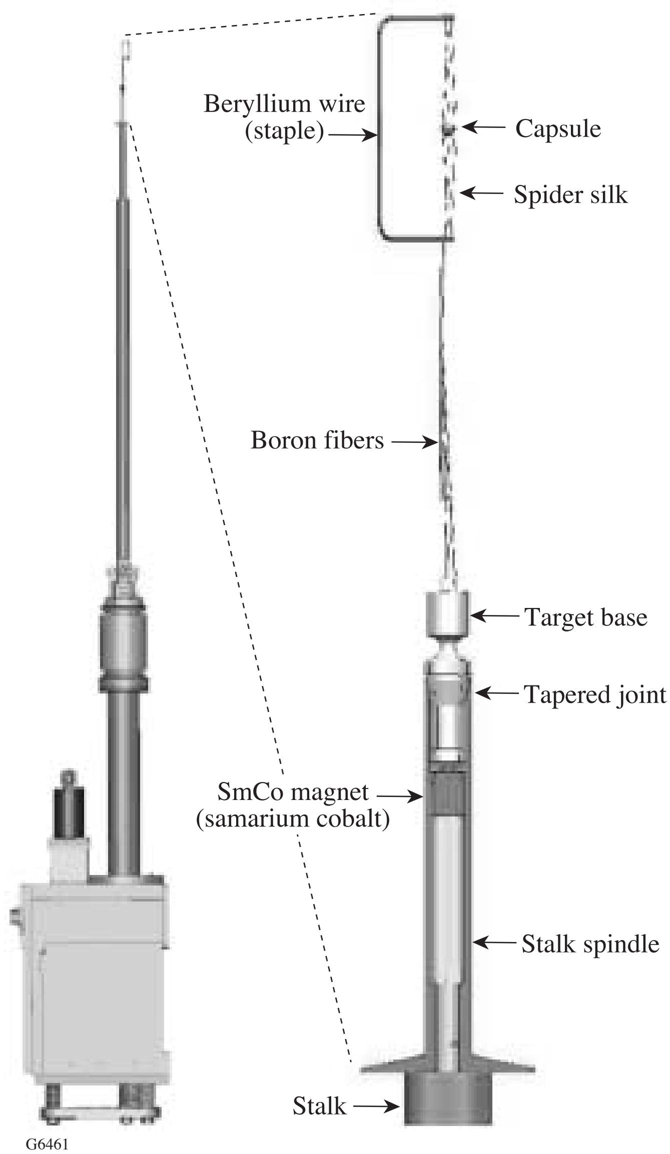

Figure 4.2-12
Target assembly for spherical cryogenic shots.

4.2.6 Lower Shroud Assembly

The lower shroud assembly provides the thermal link (parting joint) between the cryocooler and the upper shroud assembly. The lower shroud also houses the electrical and optical connections to the upper shroud assembly and is connected to and supported by the fine-motion assembly. The major parts of the lower shroud assembly are the inner heat path, exchange gas seal, intermediate heat path, outer housing, and the adapter housing [see Fig. 4.2-13]. The inner and intermediate heat paths are supported from the outer housing by stainless steel spacers for low thermal conductivity and rigid mechanical support.

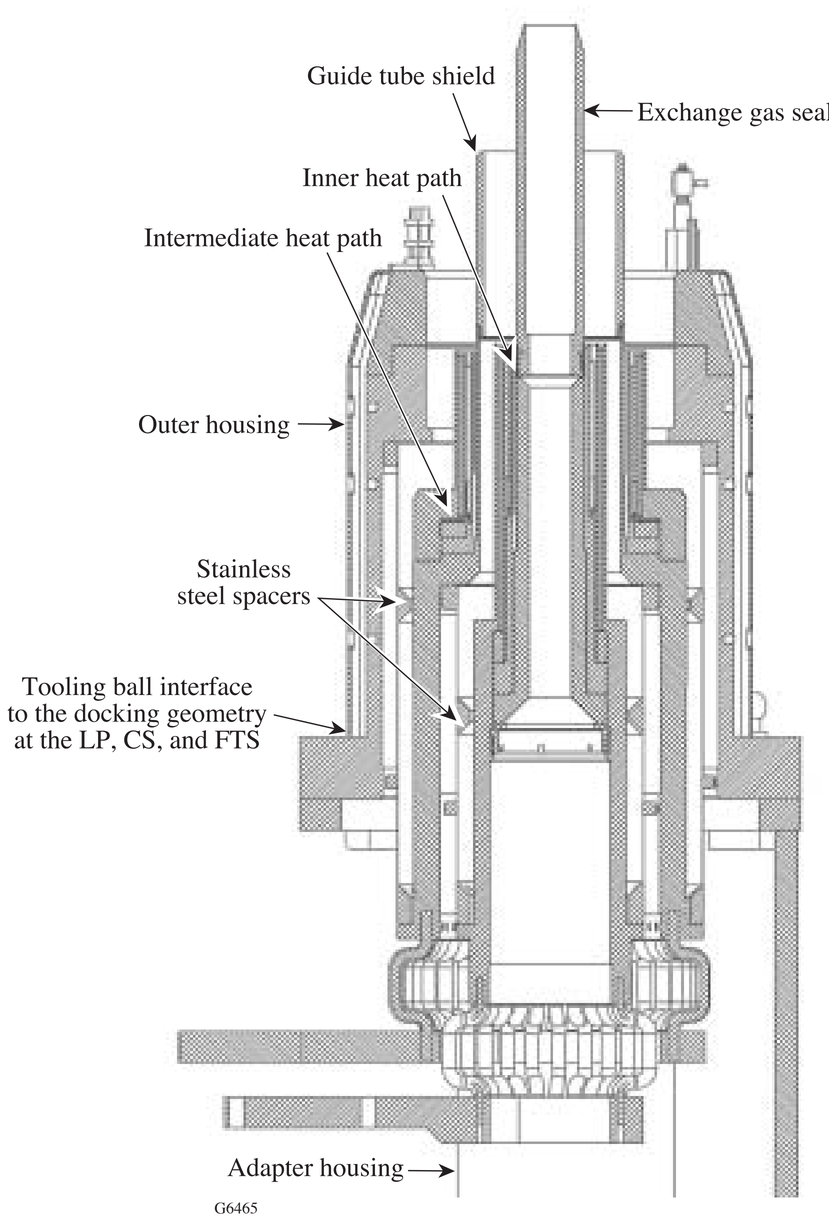

Figure 4.2-13
Lower shroud assembly.

4.2.6.1 Lower Shroud Heat Paths

The inner heat path (shown in Fig. 4.2-14) consists of the parting joint, threaded interface to the exchange gas seal, cylinder, thermal braids, and the plate connection to the coldhead second stage. The inner heat paths of the lower shroud engage the upper shroud at the parting joint (Fig. 4.2-15). The inner diameter at the bottom of the cylinder provides the sealing surface for the lower indium seal of the Kapton bellows in the fine motion assembly. This seal allows the exchange gas to travel upward through the inner heat path and exchange gas seal without leaking into the high-vacuum region of the MCTC.

The intermediate heat path (shown in Fig. 4.2-14) is similar in function to the inner heat path. In place of the exchange gas seal, the intermediate heat path has a guide tube and shield. This tube provides shielding to the parting-joint region during the shot and provides a guide to the upper shroud assembly during replacement after the shot. The inner and intermediate heat path assemblies are nested together and connected using the stainless steel spacer shown in Fig. 4.2-13. This assembly is in turn nested into the outer housing using a similar spacer. (See Fig. 4.2-15 for a top view of the lower shroud assembly.)

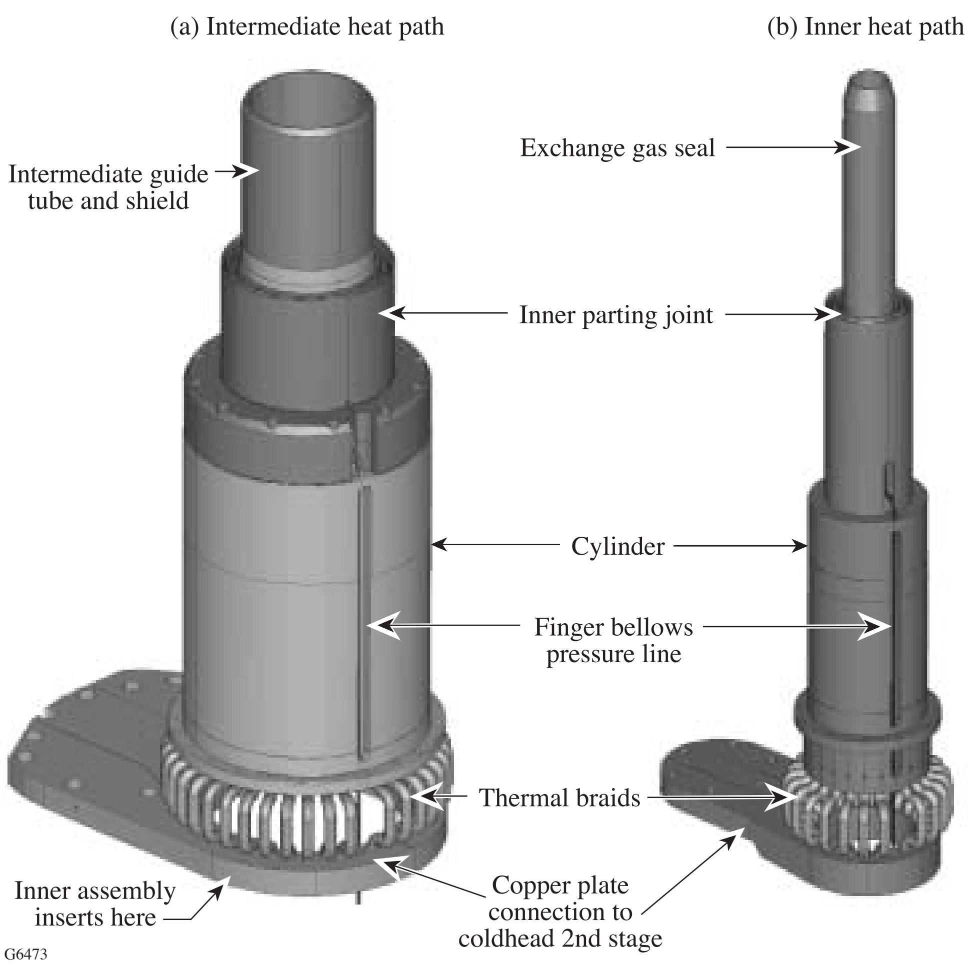

Figure 4.2-14
Inner heat path of the inner and intermediate shroud assemblies.

The thermal braids are soldered to the cylinder and the plate connection using a low-temperature indium solder. These braids provide a high thermal conductivity connection, while providing a compliant mechanical connection to minimize the transmission of vibration from the coldhead to the inner heat path. The plate connection surface is lapped to be flat and to have a fine surface finish, and this is bolted to the second stage of the coldhead, which has also been lapped flat with a fine surface finish. This copper-to-copper bolted connection has proven to be an excellent thermal joint and has none of the maintenance problems associated with the more-common use of indium foil between the mating copper surfaces. All bolted thermal joints in the MC are prepared in this manner.

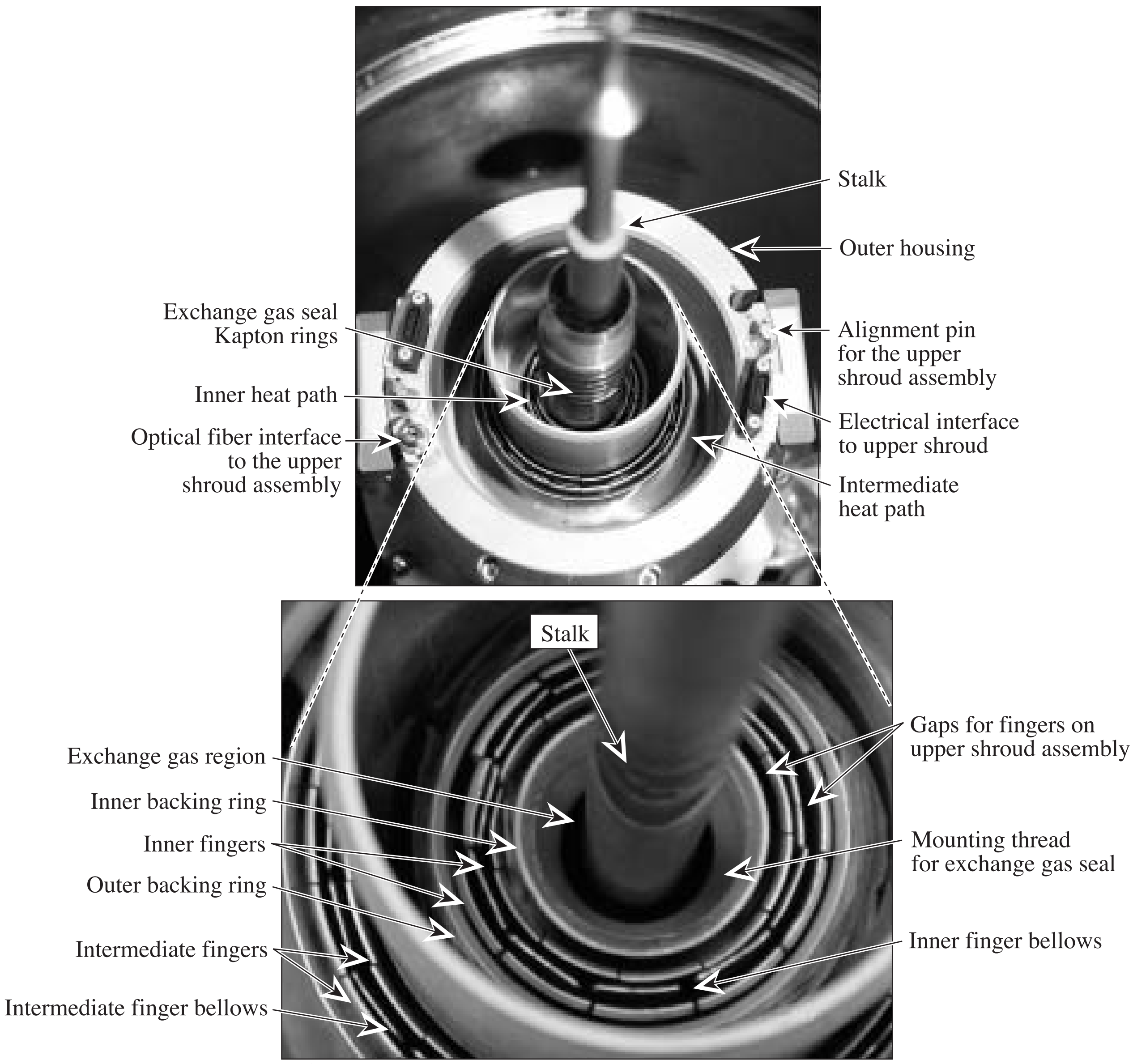

Figure 4.2-15
Lower-shroud-assembly parting joint.

4.2.6.2 Parting Joint

The parting joint (detailed in Fig. 4.2-15) consists of inner and outer backing rings and inner and outer fingers. The finger bellows, installed between the inner and outer fingers, is stainless steel and can be inflated to 100 psia. Inflation of the finger bellows (Fig. 4.2-16) pushes the lower fingers inward and outward into the upper shroud fingers, which in turn are pushed inward and outward against the backing rings. This provides a high-surface-area thermal joint with high mechanical preload for good thermal conductivity. Deflating the finger bellows allows the upper and lower fingers to relax and provide minimal retraction forces when the upper shroud is removed for the shot. Care must be used to maintain the concentricity of the fingers on both the lower and upper shrouds.

The exchange-gas seal minimizes the leakage of exchange gas between the upper and lower shroud assemblies. This seal is made of a series of Kapton rings as seen in Fig. 4.2-15. The rings are bonded to the exchange-gas seal and are sized to provide a seal to the inner surface of the upper shroud assembly, while also minimizing the retraction force during the removal of the upper shroud. The exchange-gas seal also provides a guide to the upper shroud assembly during replacement after the shot.

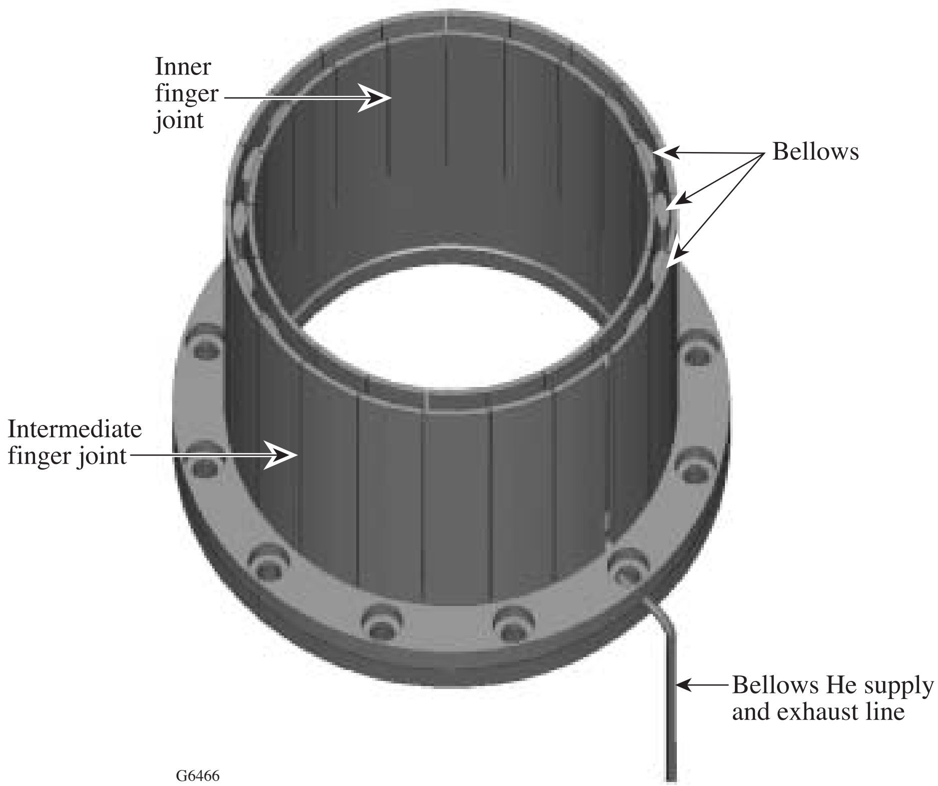

Figure 4.2-16
Detail of the parting joint and bellows.

4.2.6.3 Outer Housing

The outer housing supports the lower-shroud assembly components and is rigidly connected to the fine-motion assembly via the adaptor housing as shown in Fig. 4.2-13. As shown in Fig. 4.2-17, three tooling balls are mounted at the base of the outer housing to mate with radial grooves on the docking plates at the FTS, CS, and LP. These features act as a kinematic mount that locates the MC and the docking plate structures relative to each other while avoiding stresses that would result from an over-constrained interface.

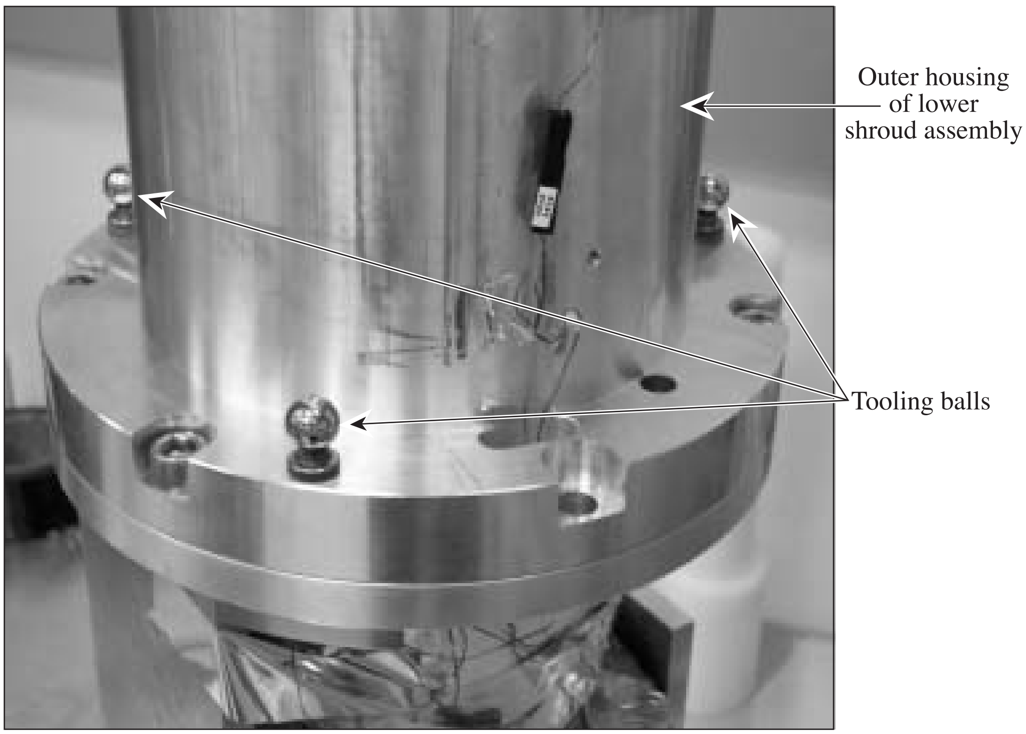

Figure 4.2-17
Detail of docking features on lower shroud assembly.

4.2.7 Upper Shroud Assembly

The upper shroud assembly is comprised of the inner and intermediate heat paths and the outer housing along with the stainless steel spacers that join these parts into one assembly. Each heat path has a cap, cylinder, and fingers (see Fig. 4.2-18). The outer housing has a cap and the upper pylon gripper and cylinder as well as the electrical, optical, and mechanical interfaces to the lower shroud assembly. The three caps include view ports, aligned to the viewing axes in the OMEGA target chamber (Fig. 4.2-19). These view ports allow fine alignment of the target at TCC and allow the fuel layer in the target to be characterized for uniformity prior to the shot. In addition, the inner heat path cap forms the layering sphere (Fig. 4.2-19) and the exchange gas region around the target to provide the isothermal environment required for a uniform fuel layer in the target.

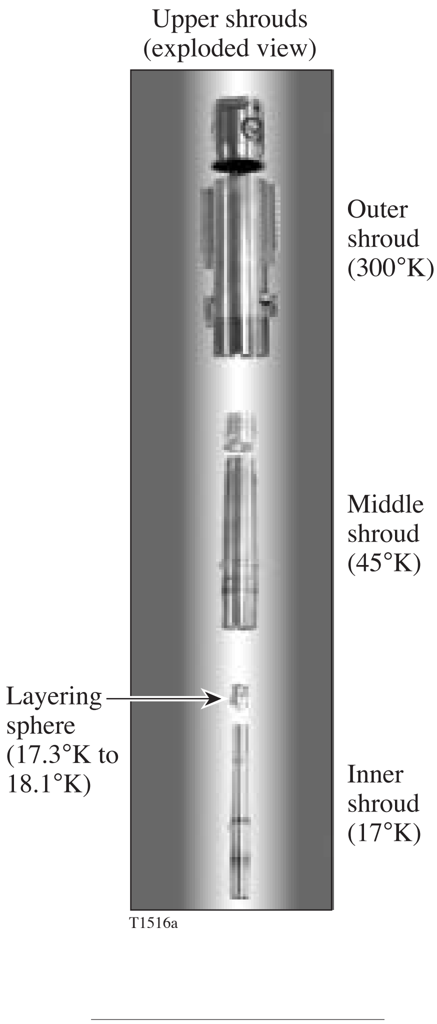

Figure 4.2-18
Exploded view of upper shroud assembly.

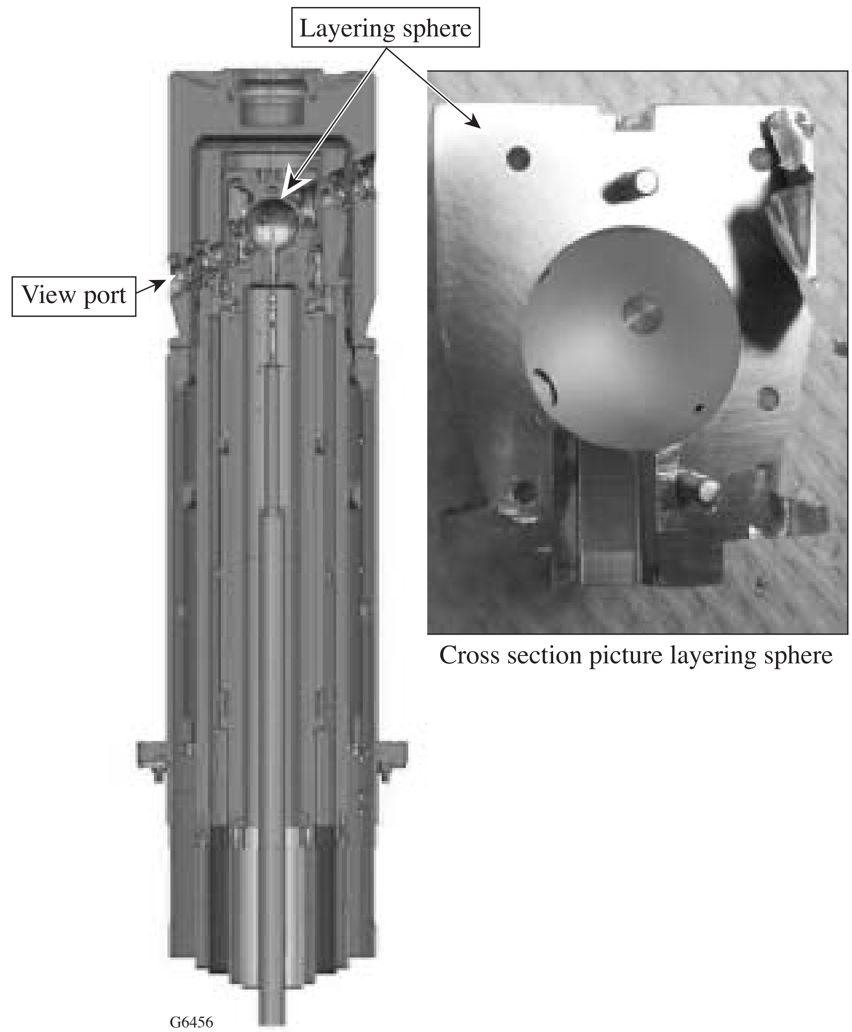

Figure 4.2-19
Cross section of upper shroud.

4.2.8 Layering

The fuel in a spherical cryogenic capsule must be formed into a frozen layer that is extremely smooth and uniform. Typically the fuel layer needs to be in the range of 1- to 2-μm-rms roughness. This requires that the target be located in a very isothermal environment. The layering sphere located in the inner heat path of the upper shroud provides this environment. Using temperature control and applied laser energy, the ice inside the target can be melted, refrozen, and sublimed. This heating/cooling process, called "layering," results in internal ice layers that are very smooth and uniform.

The temperature of the layering sphere is controlled by the combination of heaters and cooling from the coldhead. On the outside of the inner cylinder near the layering sphere are two heaters. The cryocooler is always operating at 100% power and the heaters are cycled to provide control of the layering-sphere temperature. The exchange gas is supplied at 20 to 50 mTorr to provide thermal coupling between the target and the layering sphere.

While targets that contain tritium will experience self-heating due to radioactive decay, pure-deuterium targets require a supplemental energy source to provide the thermal energy required to form the precise fuel layers. The laser that is used for this energy source is an Aculight Model 1100 IR OPO Laser (Fig. 4.2-20) with adjustable wavelength capability. The primary OPO system components are mounted on the exterior of the MCTC (as illustrated in Fig. 4.2-20) and include a personal computer (PC brick mounted in panel), LCD controls display (Fig. 4.2-20) laser, and secondary controller.

The laser energy is delivered to the layering sphere via an optical fiber that runs through the umbilical system to the MC. A signal from a diode sensor mounted inside the layering sphere is fed back to the secondary controller. The wavelength of the laser is set at optimal wavelength to match the absorption peak of the molecular species being layered (3.16 μm for deuterium). Uniform heating of the target is achieved by plating the inner surface of the layering sphere with a diffused layer of gold so that the incoming OPO IR beam is diffusely reflected to uniformly illuminate the target with the radiation.

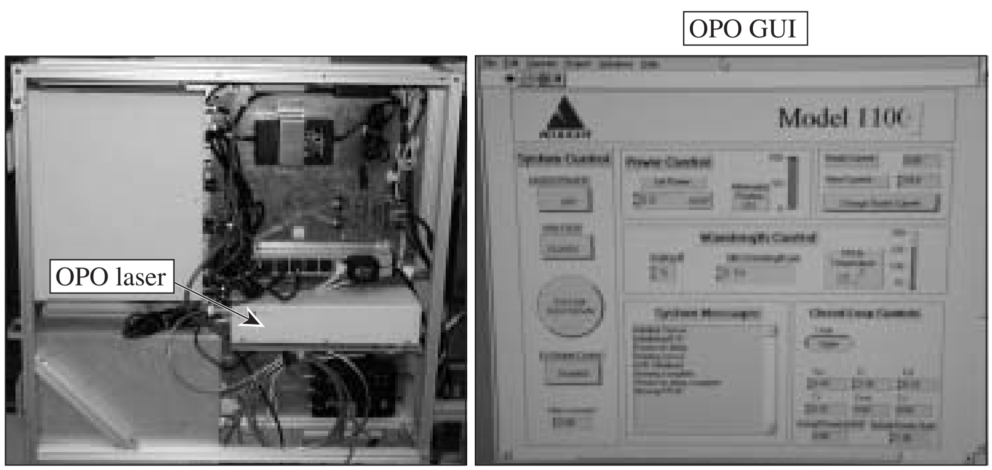

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Figure 4.2-20
(a) The OPO laser mounted in the MCTC control cabinet.
(b) The OPO GUI on the MCTC flat panel display.

4.2.8.1 Layering Sphere

Figure 4.2-21 shows the details of the layering sphere. When the MC is docked into the characterization station, targets in the MC can be observed through the shroud view ports. Each view port consists of optical windows in the shroud assembly's outer cylinder, intermediate cylinder, and layering sphere. The windows are vacuum insulated from each other. Each window is flat to 1/10 wave over 25 mm. The outer windows are made of 1-mm-thick borosilicate glass and are at room temperature. The windows in the intermediate cylinder are made of 3-mm-thick borosilicate glass and absorb the thermal radiation from the outer windows and reradiate at 45°K. This minimizes the ambient thermal radiation incident on the capsule due to the window openings. The inner windows are made of 3-mm-thick sapphire to provide high thermal conductivity to minimize any lateral thermal gradients, but they pass the 45˚K thermal radiation from the intermediate windows. The sapphire is oriented to minimize birefringence.

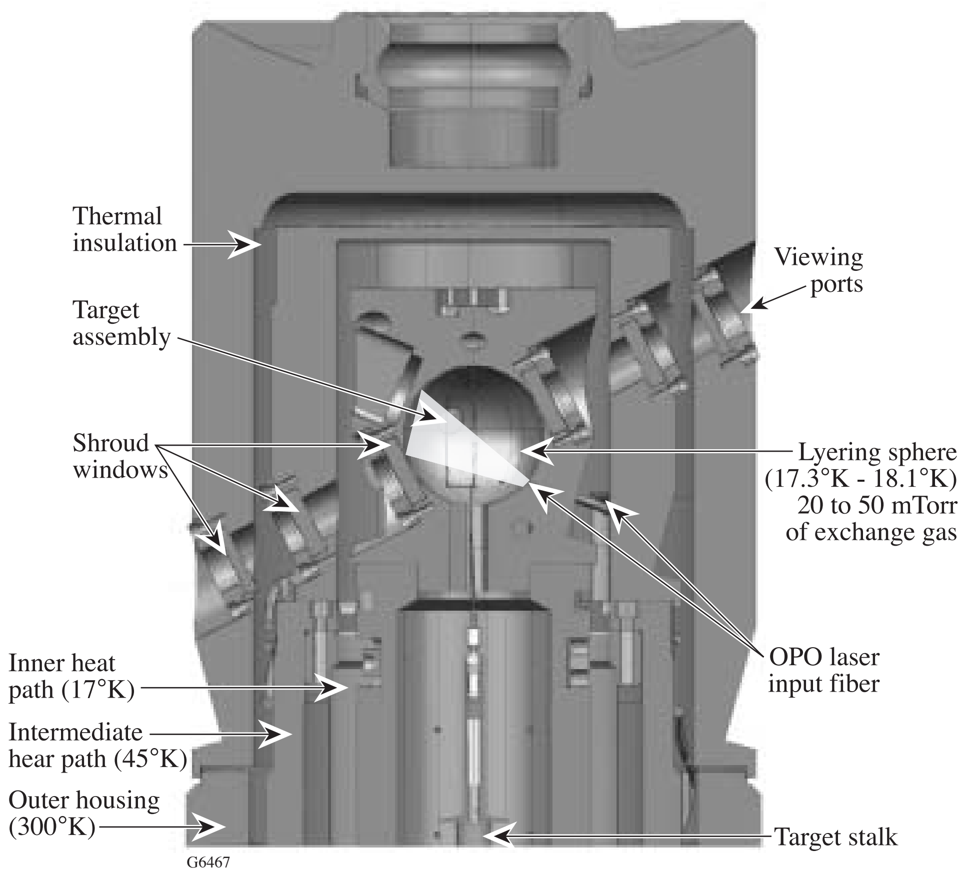

Figure 4.2-21
Details of the layering sphere region.

4.2.8.2 Optical Parametric Oscillation Laser (OPO)

The optical parametric oscillation laser (OPO) is a nonlinear process in which a single laser beam, referred to as the "pump beam," is transformed into two lower-energy beams known as the "signal beam" and the "idler beam" (Fig. 4.2-22). The delivered power is controlled by a rotational wave plate, which acts as a variable attenuator. A look-up table is used to determine the correct motor position for each power setting. This nonlinear process enables a single fixed wavelength to be converted into other wavelengths. The wavelengths of the three beams can be determined by the following relationship:

$$1/\lambda_{\text{pump}} = 1/\lambda_{\text{signal}} + 1/\lambda_{\text{idler}}.$$

Periodically poled devices that generate the wavelengths have a nonlinear conversion technique known as "quasi-phase-matching" (QPM). Figure 4.2-23 shows an example of a periodic poling crystal. QPM technology has a high nonlinear drive and large angular acceptance. This results in the ability to convert diode-pumped, high-repetition-rate, *Q*-switched, and cw solid-state lasers over a broad wavelength range.

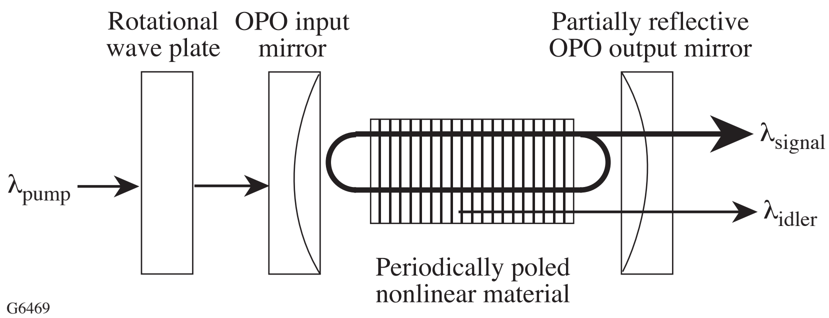

Figure 4.2-22
Optical parametric oscillation laser.

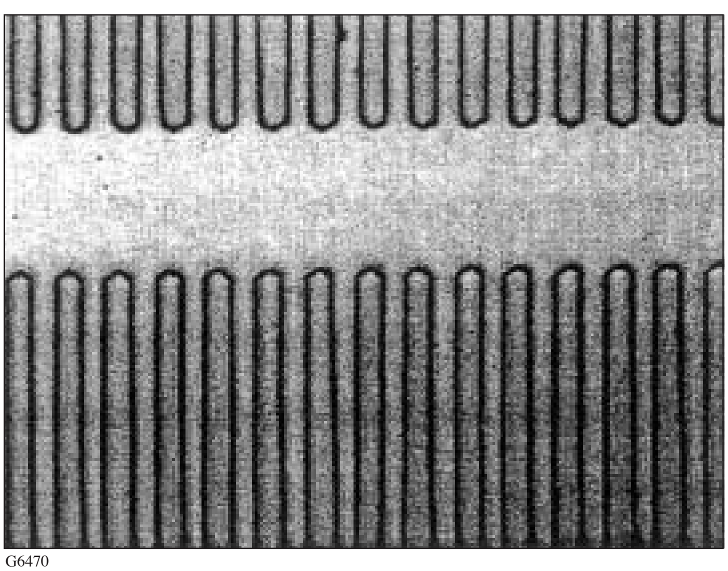

Figure 4.2-23
Image of periodically poled nonlinear crystal.

The PPLN crystal has eight different gratings, each of which has a different poling period. The different gratings are the means for the coarse wavelength tuning. Fine wavelength tuning is accomplished by varying the crystal temperature. Thus, the wavelength tuning is accomplished by means of both PPLN temperature and position.

The PPLN crystal is mounted in an oven, which in turn is mounted on a motorized translation stage. When the user inputs a wavelength set point, the crystal is moved to the correct grating and the temperature is increased or decreased as required. If the PPLN crystal is exposed to 1.064-μm light when it is cold, it will sustain permanent damage. Thus, the PPLN crystal requires heating to temperatures above 80°C. The controlled temperature is varied between 85°C and 150°C. The eight gratings are 1 mm wide and are separated by unpoled regions. No OPO conversion will take place if the beam is propagating through an unpoled region. The system uses a look-up table to determine the correct grating and temperature to generate a given wavelength.

An InSb detector is used inside the layering sphere to detect the OPO laser power; this signal is used as feedback to the OPO closed-loop laser power control system. The signal gain is very weak; therefore, a high-gain commercial SRS phase-locked amplifier provides phase synchronous amplification. The amplifier output drives both the feedback loop and data acquisition PC.

Indium antimonide (InSb) photodiodes generate current when exposed to infrared radiation. The detector utilizes a single-crystal p–n junction technology and provides response in the 1- to 5.5-μm-wavelength region. The OPO laser energy delivered to the layering sphere is measured by the InSb detector and used by the closed-loop control system. The detector is mounted in the layering sphere and looks through a sapphire window.

4.2.8.3 Temperature Measurement

Two types of temperature sensors are used on the cart: Cernox™ sensors and silicon diodes (Fig. 4.2-24). Cernox™ thin-film resistance temperature sensors provide highly accurate (±5°mK at 4.2°K) temperature measurements from 100°mK to 420°K. This accuracy is required for layering

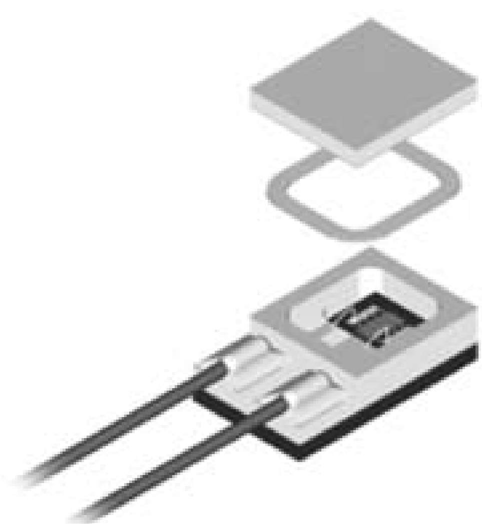

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Figure 4.2-24
Lakeshore temperature sensors.

(controlling to the triple point). These sensors have excellent heat transfer curves, yielding a characteristic thermal response time of 1.5 ms at 4.2 K and 50 ms at 77 K. They have a low magnetoresistance and are resistant to ionizing radiation.

Silicon diodes are used for general-purpose cryogenic temperature sensing. The sensors are interchangeable (they follow a standard curve) and are inexpensive. The silicon-diode accuracy is ±12 mK at 4.2 K. The sensors have a wide temperature range—1.4 K to 500 K—and a thermal response of 10 ms at 4.2 K and 100 ms at 77 K. These sensors are sensitive to magnetic fields and radiation (tolerant of low levels of radiation).

Both of the Cernox™ and silicon-diode Lakeshore temperature sensors are packaged with direct sensor to sapphire base mounting, hermetic seal, and brazed Kovar leads. This package design is such that the heat coming down the leads bypasses the chip. They have a life cycle of several thousand hours at 500°K and are compatible with ultrahigh-vacuum applications.

4.3 PLANAR MOVING CRYOSTAT (PMC) – TO BE SUPPLIED

4.4 MCTC STRUCTURE AND MC UTILITY SYSTEMS

The moving cryostat transport cart (MCTC) (shown in Figs. 4.4-1 and 4.4-2) is the device that transports and maintains the operation of the moving cryostat (MC). The MCTC is a mobile vacuum chamber accompanied by all of the equipment needed to support the MC. These systems allow the MC to maintain the required low-temperature, high-vacuum environment for the target while it is moved from the Fill/Transfer Station (FTS) to the characterization station, the lower pylon, and ultimately at the center of the target chamber. The target status can be seen via the on-cart Viewing System.

The block diagram shown in Fig. 4.4-3 identifies the major components of the MCTC and their interfaces. The MCTC houses the MC, the He compressor, the umbilical spooler, the 16-in. gate valve, the docking assembly, the control system, and the vacuum system. An external chain at the lower pylon also interfaces with the MC base and drives the MC 22 ft to TCC. The MC is serviced by the umbilical, which is wrapped around the spooler. The spooler pays out and retrieves the service lines to the MC as it is inserted and retracted.

An aluminum-base weldment is the foundation for the MCTC. It supports all of the main components, including the spooler cover that houses the umbilical and the cylindrical spools and a 16-in. gate valve that house the MC. Together, these items form the entire vacuum envelope for the MCTC. Sixteen-inch gate valves provide the vacuum interface to the FTS, lower pylon, and characterization station.

The MC is powered through the umbilical, a 50-ft-long collection of cables and hoses that provides all of the necessary services for maintaining the operation of the cryostat. The umbilical is necessary to allow the MC to be raised out of the MCTC.

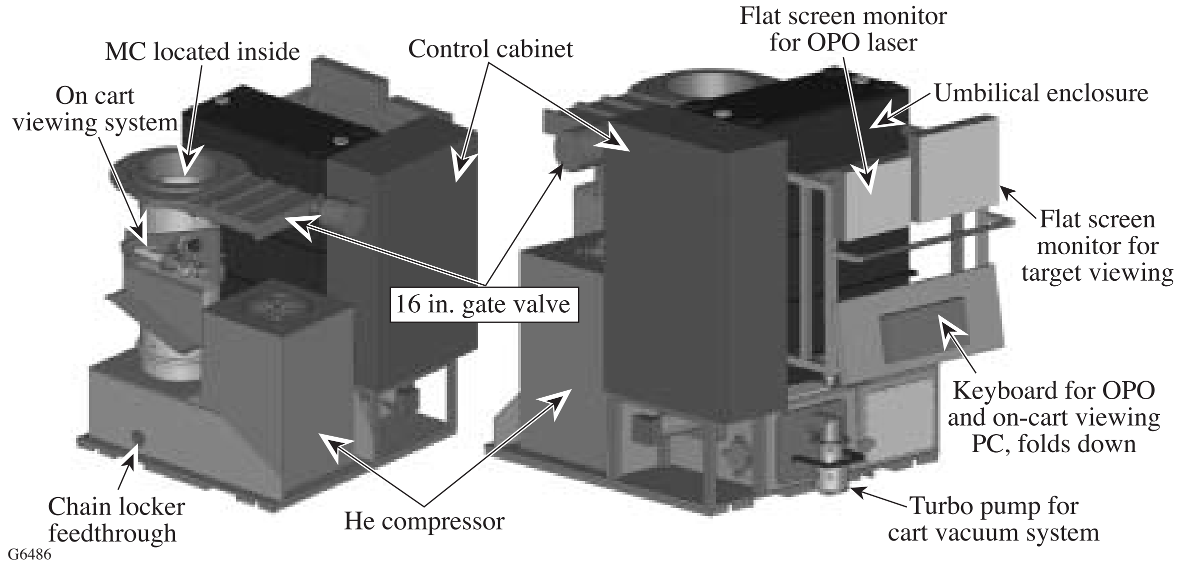

Figure 4.4-1
Moving cryostat transport cart.

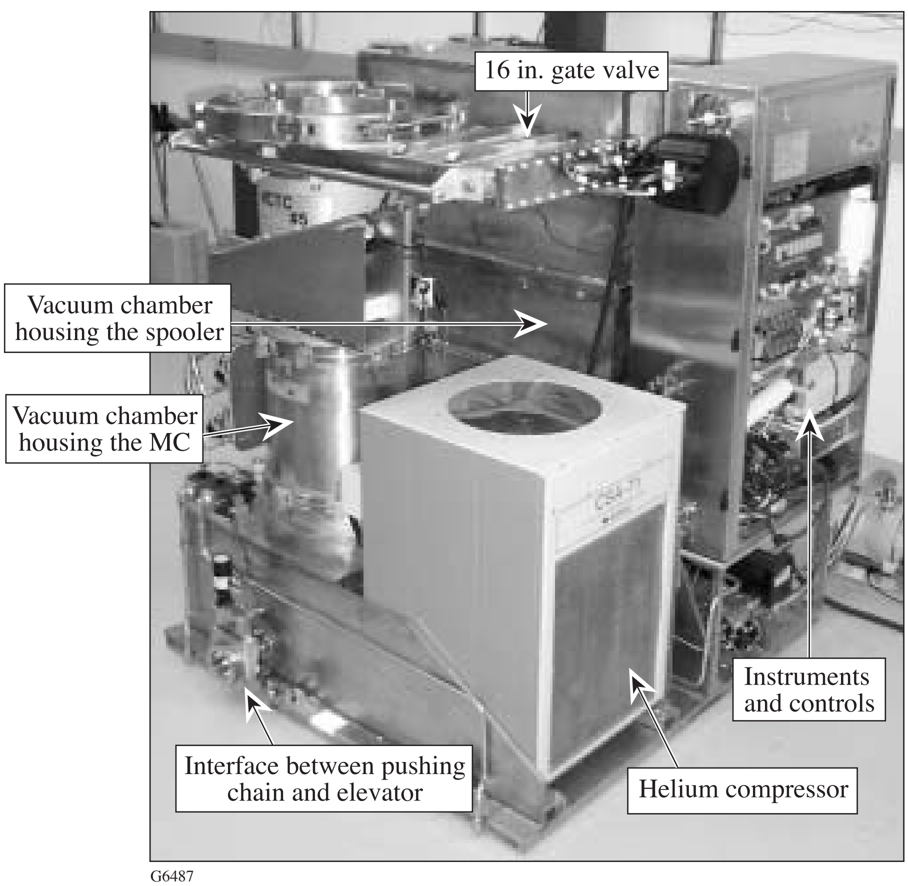

Figure 4.4-2
Moving cryostat transport cart in Room 157.

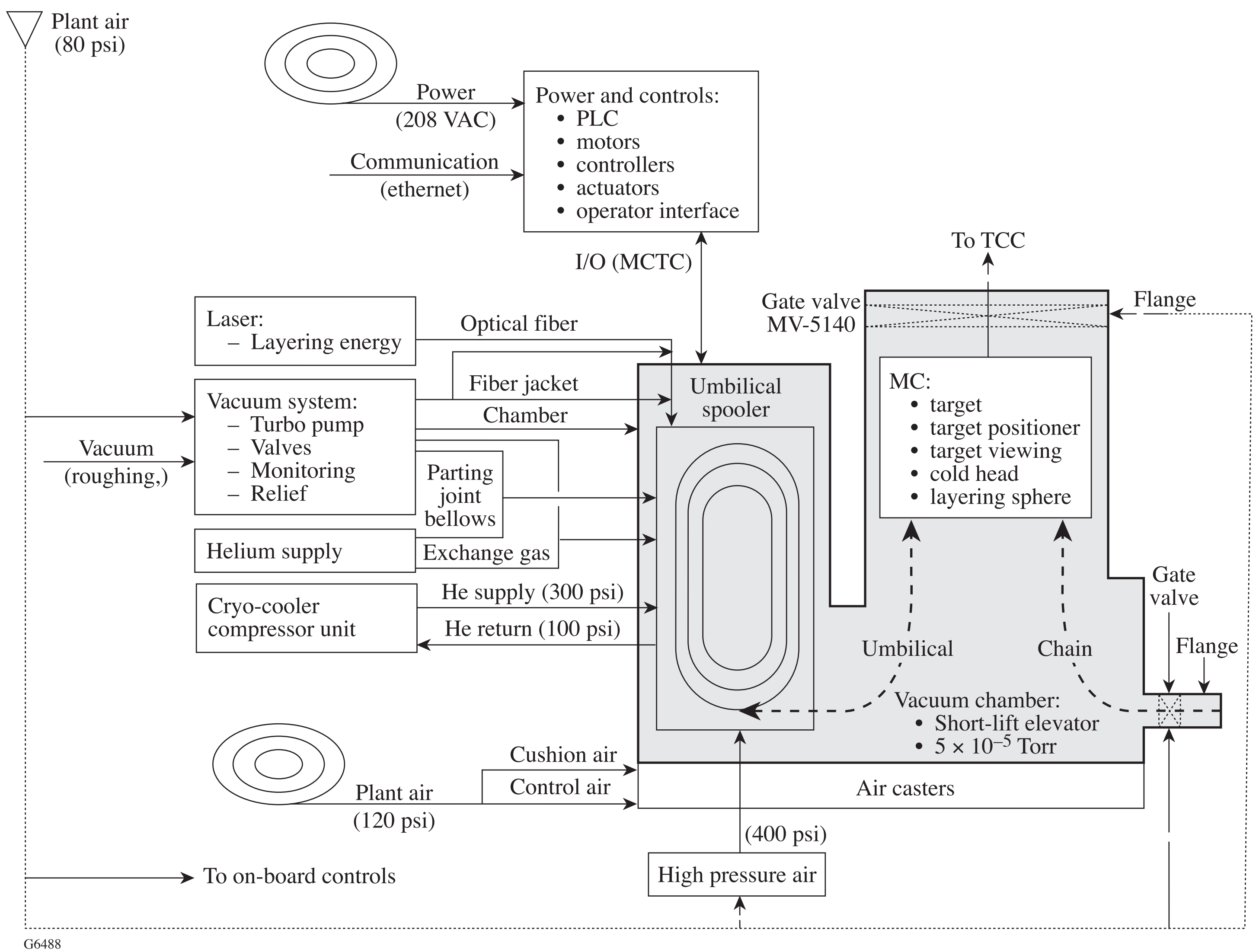

Figure 4.4-3
MCTC block diagram. The MCTC consists of several major systems to facilitate cryogenic target transport and insertion, including power and controls, a vacuum system, a helium supply, the cryocooler compressor unit, and a high-pressure air supply.

A helium compressor resides on the MCTC and provides compressed helium gas at room temperature to the MC cryocooler, in a closed loop. A dedicated source of helium is used to operate the cryogenic valves and to provide the exchange gas. A separate manifold distributes facility-compressed air from a single connection point to support the other on-cart functions including valves and the umbilical spooler.

Power for the operation of the MCTC is supplied through the power switch, a pair of detachable electrical connectors, and a switching device. The MCTC is transported on air casters supplied with high-pressure air. A power cable and air hose connected to the MCTC allow travel from location to location.

An onboard PLC controls the MCTC and communicates status information with remote computers. A touch panel allows operators to control the operation of the MCTC and read status information.

4.4.1 Performance and Functionality

Critical functions and performance specifications of the MCTC include the following:

- Provide high-vacuum atmosphere ($<1 \times 10^{-5}$ Torr).
- Allow easy movement with two people via air casters and power/air interfaces.
- Provide the MC with compressed helium for valve actuation and temperature control.
- Provide vertical travel of the MC up to 50 in. (self-contained elevator).
- Provide a vacuum interface between the MCTC and the FTS, lower pylon, or characterization station.
- Provide a mechanical interface for repeatable location at the FTS, LP, and CS.
- Provide secondary tritium containment.
- Provide temperature control for the integrating sphere (<5 mK).
- Provide laser energy to the integrating sphere.
- Provide 20- to 50-mTorr exchange gas to the layering sphere.
- Enable the vertical movement of the MC up to a distance of 20 ft through the use of a internally wound umbilical.
- Provide diagnostic information to the LLE intranet about the location and status of the cart.

4.4.2 Vacuum System

The vacuum chamber encloses the MC, the short-lift elevator, and the umbilical and represents a volume of about 0.5 m^3. There are two main sections to the vacuum chamber: The larger, rectangular section houses the umbilical and umbilical spooler; the smaller cylindrical section houses the MC and short-lift elevator. The umbilical travels through an open volume that connects these two sections.

The MCTC Edwards Turbo-Molecular Pump can achieve about a 5×10^{-6}-Torr vacuum. A roughing pump must back the turbo-molecular pump; therefore, the MCTC is connected to a vacuum manifold system at each of the docking locations; this manifold provides turbo backing and initial roughing services. In LaCave, the OMEGA Vacuum Pump System supports these tasks. In Room 157, the air and low DT vacuum manifolds are used on the DT system and the backing and roughing manifolds are used on the D_2 system.

An onboard 2-l cylinder, maintained at vacuum, accepts the effluent from the turbo-molecular pump when it is disconnected from the vacuum manifold system. The MCTC can operate in this manner for a duration of only a few minutes. When the MCTC vacuum exhaust port is again opened to vacuum, the contents of the cylinder are evacuated. The cylinder is shown in Fig. 4.4-4.

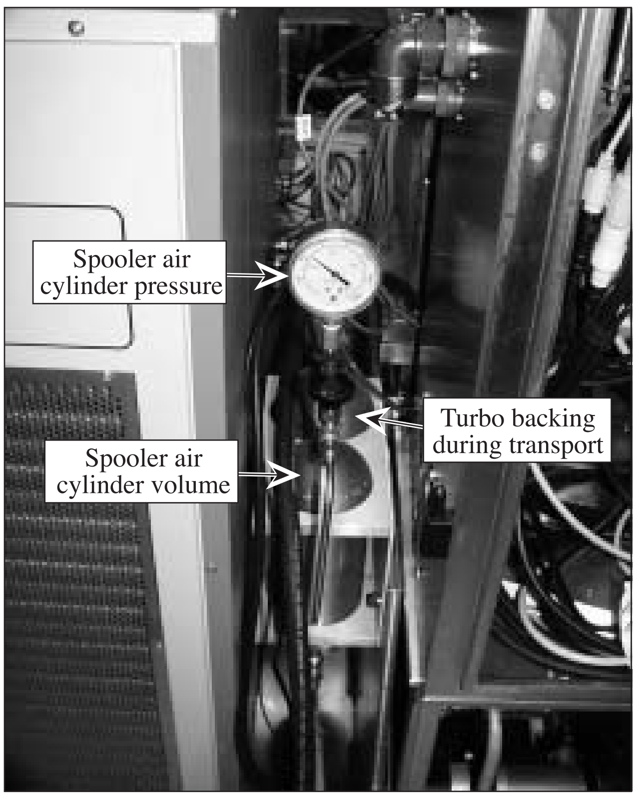

Figure 4.4-4
MCTC spooler air cylinder volume and turbo backing volume.

4.4.3 Short-Lift Elevator

A short-lift elevator with a dual-chain drive and driving motor is used in the cylindrical section of the MCTC vacuum chamber. The elevator can vertically raise the MC out of the MCTC to a height of 36 in. without any external support or to 50 in. with added external guide rails. The elevator is used in a stand-alone fashion when inserting the MC into either the characterization station or the Fill/Transfer Station (FTS). The elevator can also be used to raise the MC above the MCTC gate valve so that personnel can access it. A high-torque, gear-reduced motor drives a dual-chain system that raises and lowers the MC. (See Fig. 4.4-5 for a detail of the interface of the short-lift elevator to the base assembly.)

A pneumatic 16-in. gate valve provides access to the MC and facilitates docking to the FTS, Lower Pylon and Characterization Station. The gate valve is large enough to accommodate the MC as it is driven vertically out of the MCTC.

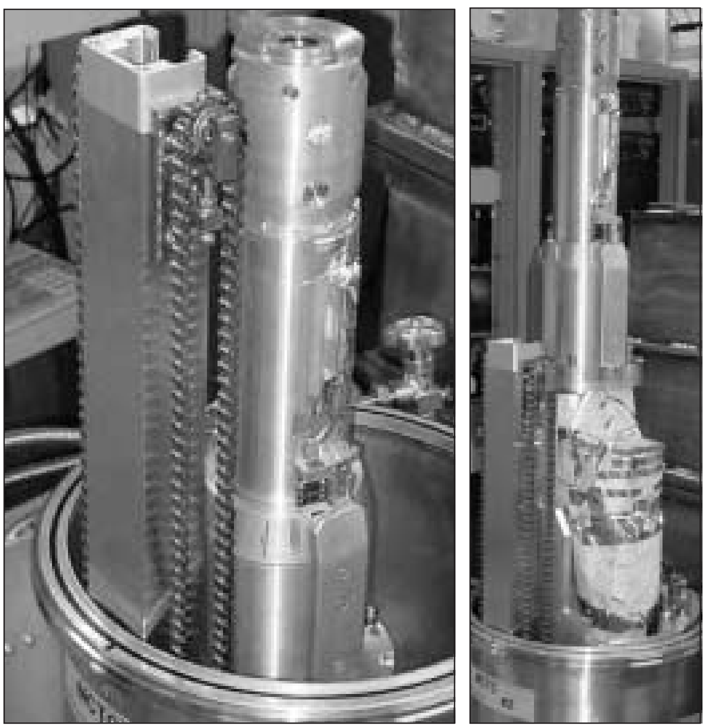

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Figure 4.4-5
Short-lift elevator, MC with spool and the gate valve removed.

4.4.4 3-in. Gate Valve and External Elevators (Chain Locker)

The MC can be raised higher at the lower pylon using an external chain drive. The chain drive is contained within the chain locker, and it interfaces with the MCTC through the 3-in. gate valve of the remote elevator interface. (The chain locker is discussed in more detail in Chap. 9.)

4.4.5 Helium Compressor

The compressor subsystem is a Sumitomo Heavy Industries CSA-71 (A) compressor (see Fig. 4.4-2). This device supplies pressurized helium to the cold head at up to 300 psig. The power consumption of the unit is 7.5 KW (10 Hp). This air-cooled unit is composed of a scroll pump (to pressurize gas), an adsorber (removes condensables), gas cooler, and a storage tank. Stainless steel braided hoses, which are part of the assembly, transport the helium to and from the cold head.

4.4.6 Umbilical and Spooler

The spooler is the device that manages the umbilical line and allows them to extend and retract with the MC, while maintaining a constant preload. The spooler consists of a scissors-like structure that rises and falls as the umbilical is retracted/extended. Sets of rollers on the top and bottom of the spooler allow the umbilical to coil/uncoil with little friction (Fig. 4.4-6).

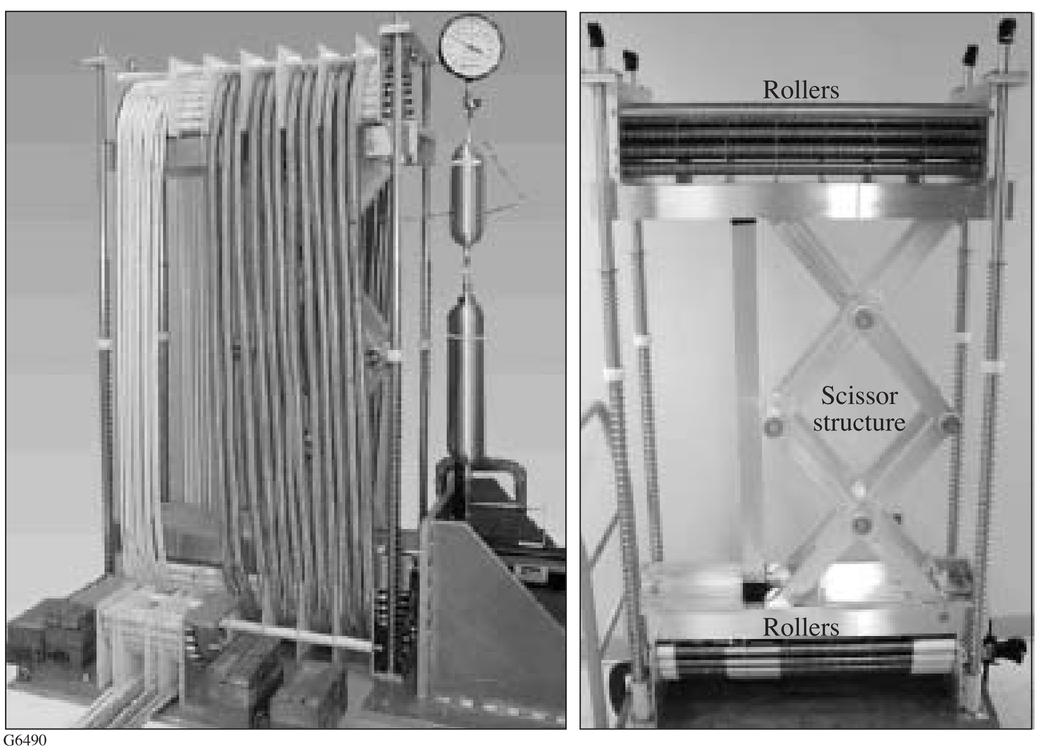

Figure 4.4-6
Detail of the umbilical spooler.

As the MC rises vertically, it pulls more of the umbilical from the spooler and the scissors structure collapses accordingly, shortening each coil. As the umbilical is spooled out, the total number of coils remains the same, but the length of the coils on the spooler changes as the roller sections move closer together (see Fig. 4.4-7).

Constant tension is maintained on the umbilical by a combination of an air cylinder acting on the scissor assembly and coil springs acting on the upper roller assembly. The pressure for the air cylinder is provided by a nitrogen gas cylinder resident on the MCTC. The air cylinder is charged to about 120 to 130 psi when the umbilical is fully retracted (see Fig. 4.4-4).

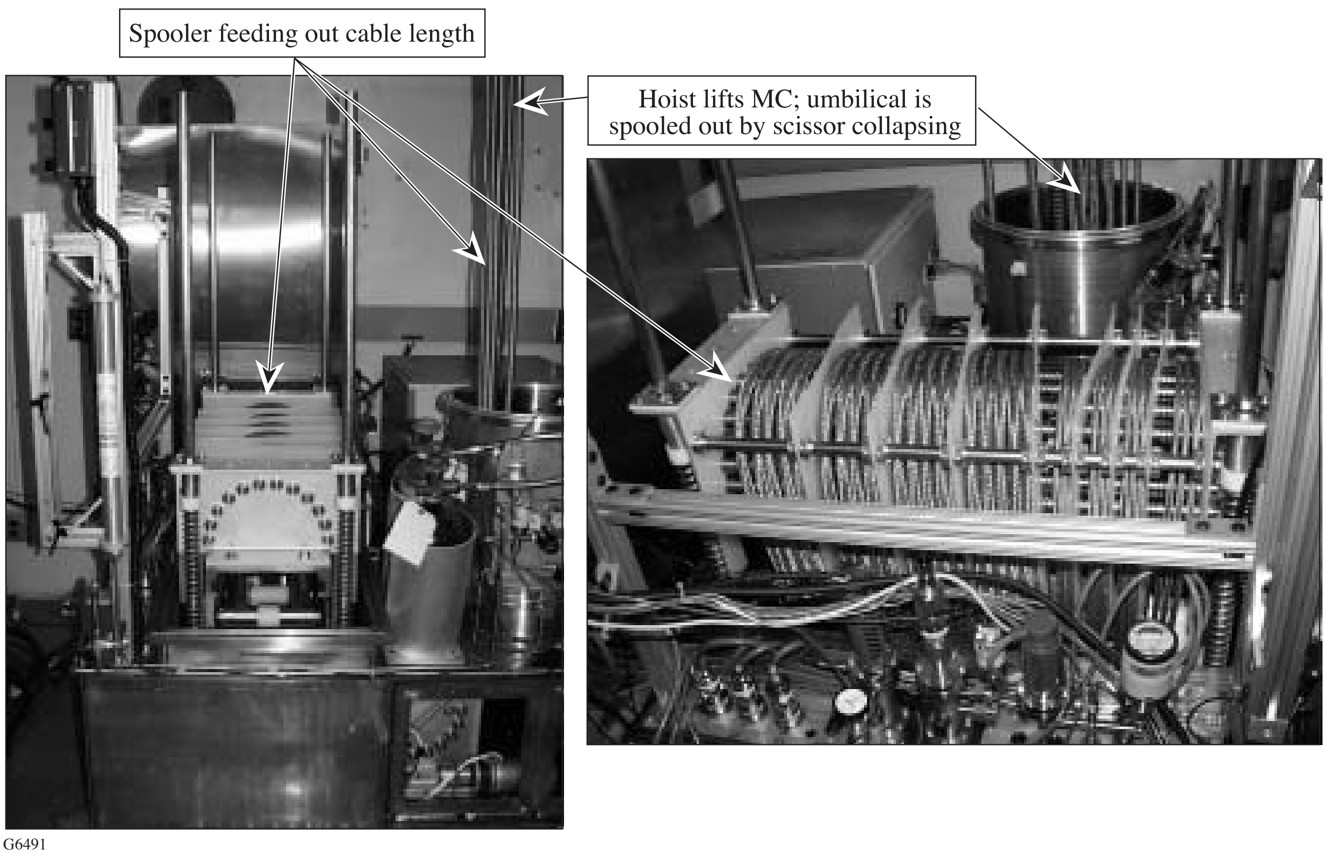

Figure 4.4-7
The scissor is contracted providing ~20 ft of umbilical to the MC.

The umbilical is a collection of hoses that contain electrical cables, fiber-optic cables, and helium gas at various pressures. The total length of each umbilical line is about 50 ft. This allows the MC to extend 20 ft above the MCTC when at target chamber center (TCC). The umbilical consists of the following:

Five Large Hoses

Electrical 1: sensors and power (i.e., temperatures, MC positioner, and electric cables)
Electrical 2: sensors and power (i.e., temperatures, MC positioner, and electric cables)
Electrical 3: sensors and power (i.e., temperatures, MC positioner, and electric cables)
Cold-head helium supply
Cold-head helium return

Three Small Hoses

Parting-joint helium supply
Helium exchange gas supply
Two fiber-optic cables to supply laser energy to the layering sphere

4.4.7 Gas Manifolds

The gas manifold (Fig. 4.4-8) provides helium gas for pressurizing the parting joint finger bellows and for the exchange gas in the layering sphere. This manifold also allows evacuation of the

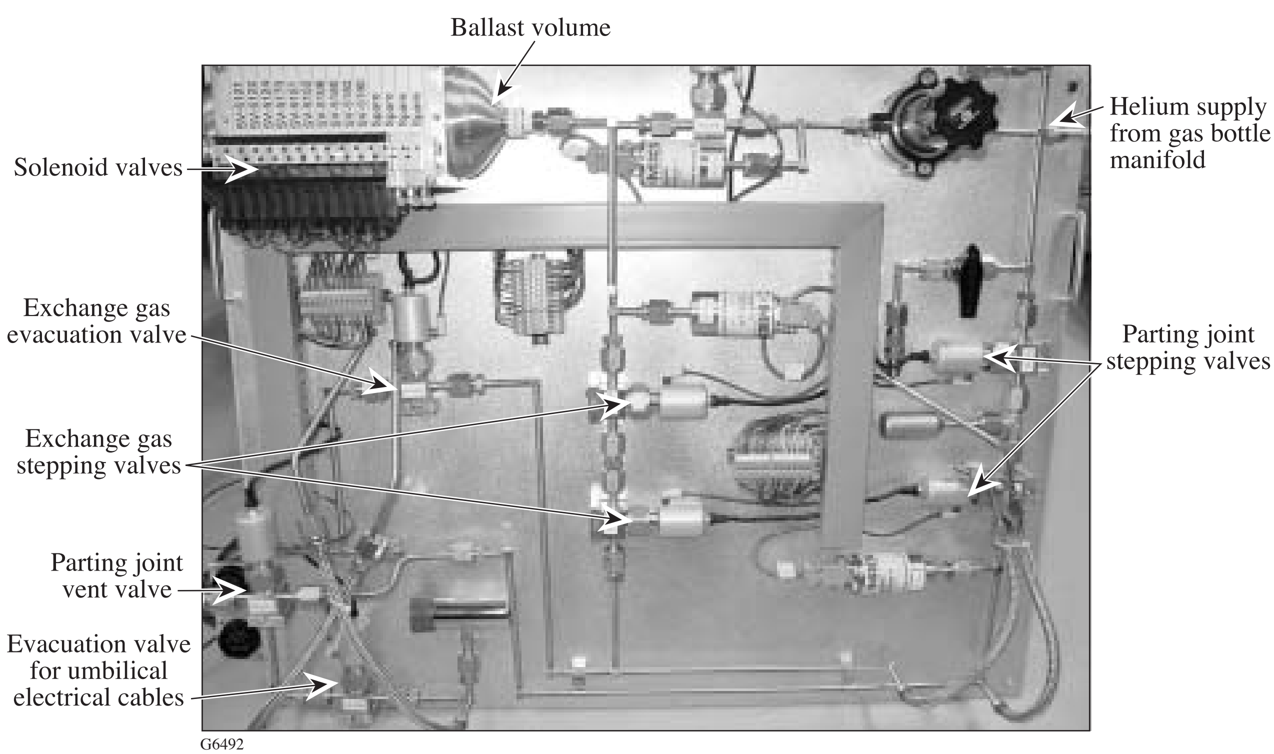

Figure 4.4-8
MCTC helium manifold.

exchange gas volume and the umbilical hoses that contain electrical cables, using the MCTC vacuum system. This manifold also provides an evacuation valve used to exhaust the parting joint gas using an external vacuum source. This eliminates the risk of back-streaming this high-pressure helium throughout the vacuum system turbo pump into the high vacuum region of the MCTC. The solenoid valves on the MCTC are gas operated using nitrogen gas. A small nitrogen bottle on the MCTC provides an onboard nitrogen supply that is used when the cart is in transit. When docked, nitrogen is provided externally and a valve for the onboard bottle is closed (see Fig. 4.4-9).

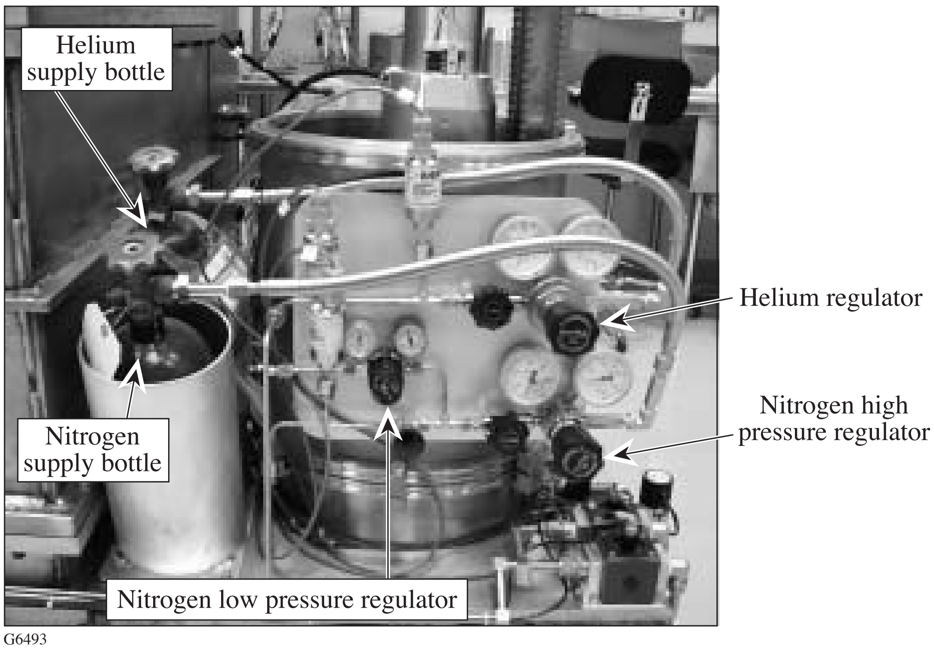

Figure 4.4-9
MCTC gas bottle manifold.

4.4.8 On-Cart Target Viewing System

The On-Cart Viewing System (Figs. 4.4-10 and 4.4-11) allows for qualitative examination of a target while the cart is not docked at a characterization station. While it is useful for determining that a target is present and for determining its general condition (frozen, melted, or layered), vibration and optical limitations prevent using this system to characterize a target.

On-cart viewing uses a pulsed LED (light-emitting diode) (Fig. 4.4-12) to backlight the target. This diode is mounted in a pivot mount on the end of a retractable extension arm. When the on-cart viewing is not being used, the diode is pulled back into an access port in the MCTC top spool piece. This allows the MC to travel though the gate valve without hitting the diode. The diode is aligned when the MCTC is warm so that it points though the shroud windows.

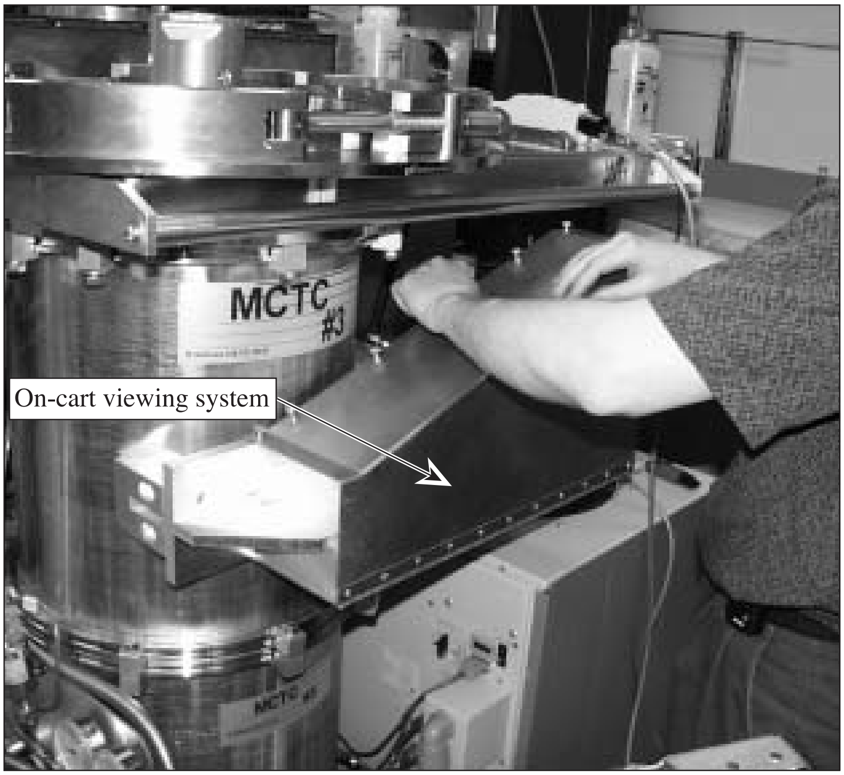

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Figure 4.4-10
The MCTC On-Cart Viewing System.

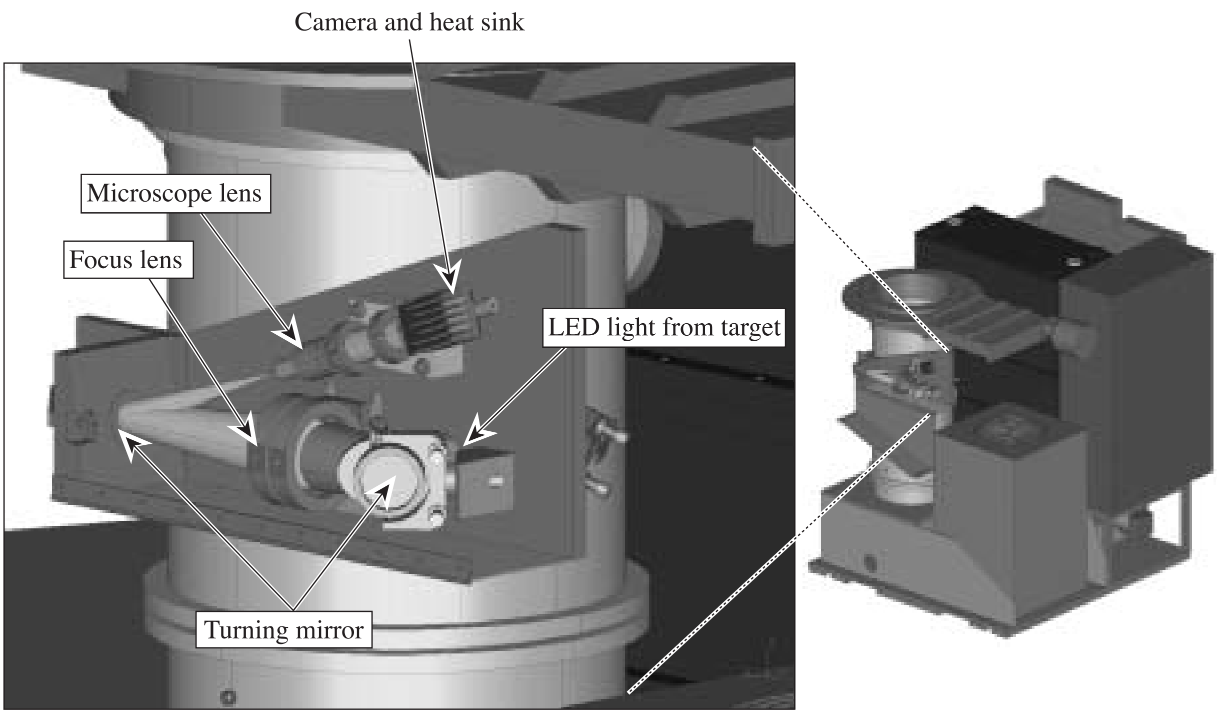

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Figure 4.4-11
On-Cart Viewing System location, optical path, and CCD camera.

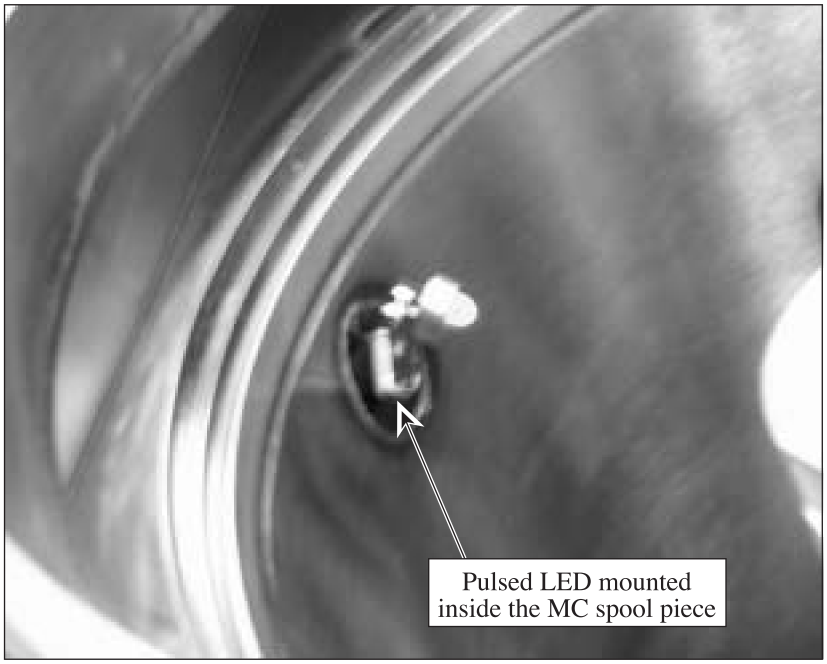

Figure 4.4-12
The On-Cart Viewing System retractable LED light source.

Turning mirrors are then used to direct the image of the target to a Pulnix camera (Fig. 4.4-13). The focusing optics are mounted on the outside of the spool piece with the camera. The mirrors, which point the image after it passes through the vacuum windows on the spool, allow a limited adjustment to center the target in the field of view.

The camera is connected to a PC mounted in the MCTC electronics cabinet. The image is routed to the flat panel display mounted on the front of the cart. The same Cryoview software that is used at the characterization stations is used on the carts.

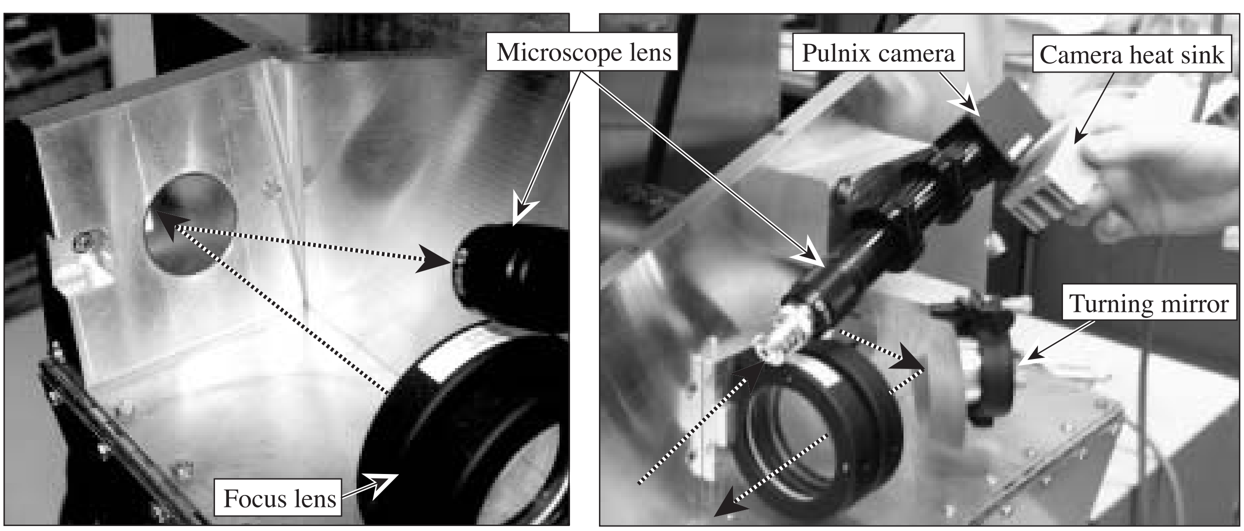

Figure 4.4-13
Detailed view of the on-cart viewing system optical path and CCD camera.

4.4.9 Air Casters

The MCTC has a pneumatic-bearing system that allows an operator to push the cart on a cushion of air from place to place within the facility. Four air casters allow the 5000-lb MCTC to be easily pushed by two people (Fig. 4.4-14). These air casters use compressed air at 120 psig to overcome friction and lift the MCTC a few tenths of an inch off the ground. The compressed air is supplied via a dedicated screw compressor located in the LLE Fan Room.

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Figure 4.4-14
The MCTC being moved from Rm 157 to LaCave via the pneumatic-bearing system.

4.4.10 MCTC Power Supply

The MCTC can remain connected to three-phase 208-V ac at all times via a power-switching system, which allows power to be supplied to the MCTC as it is being transported from station to station over long distances. This is accomplished by providing two onboard power connections, an onboard switch box, and power supply stations with 50-ft-long power cables along the cart transport route. The power connections are equipped with four BCD encoded switches that inform the MCTC of its current location. Various interlocks are enabled and disabled based on this BCD location input.

As the MCTC is transported from station to station, there are several zones where the power (and air supply) can be switched from one source to another. Indicator lights on the MCTC switching system inform the operators about the status of the individual power sources. The MCTC also steps down the voltage of the 208-V ac to single-phase 110 V to power various instruments.