The SAMPLE Liquid Hydrogen Target User's Guide

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I. Overview

This document describes the liquid hydrogen target constructed at Caltech for use in the SAMPLE experiment at Bates. The target was designed by John Mark of the cryogenic target systems group at SLAC, and is basically the latest version of the targets which have been used for many experiments in End Station A [1]. The basic principles of operation are the same as the Bates High Power Liquid Deuterium Target, and many aspects are similarly designed to meet the Bates safety committee standards. (A detailed description of the Bates deuterium target can be found in ref [2]). The major difference in the design of the SAMPLE target over the Bates system is in the need to handle much higher beam power (500 W for 40 μA of electron beam current). In addition, there are several aspects of the SAMPLE target which are designed specifically to deal with the problems of measuring small parity-violating asymmetries.

An overview of the complete SAMPLE target system is shown in Figure I.1. Liquid hydrogen is circulated through a closed loop which sits inside a vacuum chamber connected to the beam line. A pump which drives the flow is immersed in the liquid, controlled by a 1/2 horsepower AC motor which sits in a warm hydrogen environment outside of the vacuum chamber. The flow is directed through a 40 cm long target cell longitudinal to the beam; the liquid hydrogen speed is estimated to be 10 m/sec in the target cell when the pump is running at full speed. The hydrogen in the target loop is cooled by a counterflow heat exchanger connected to a Process Systems International* model 1620 refrigeration system. The refrigerator delivers 16 psia of cold helium gas to the heat exchanger via 20 ft vacuum-jacketed transfer lines, and can deliver up to 800 watts of cooling power at 20 K with one Model RS compressor attached. Delivery of the hydrogen gas is controlled through a gas panel. A PC-based control system monitors the temperatures and pressures in the target system, as well as the status of all valves on the gas panel. A summary of useful parameters of the target is given in Table I.1.

* formerly Koch Process Systems, Inc.

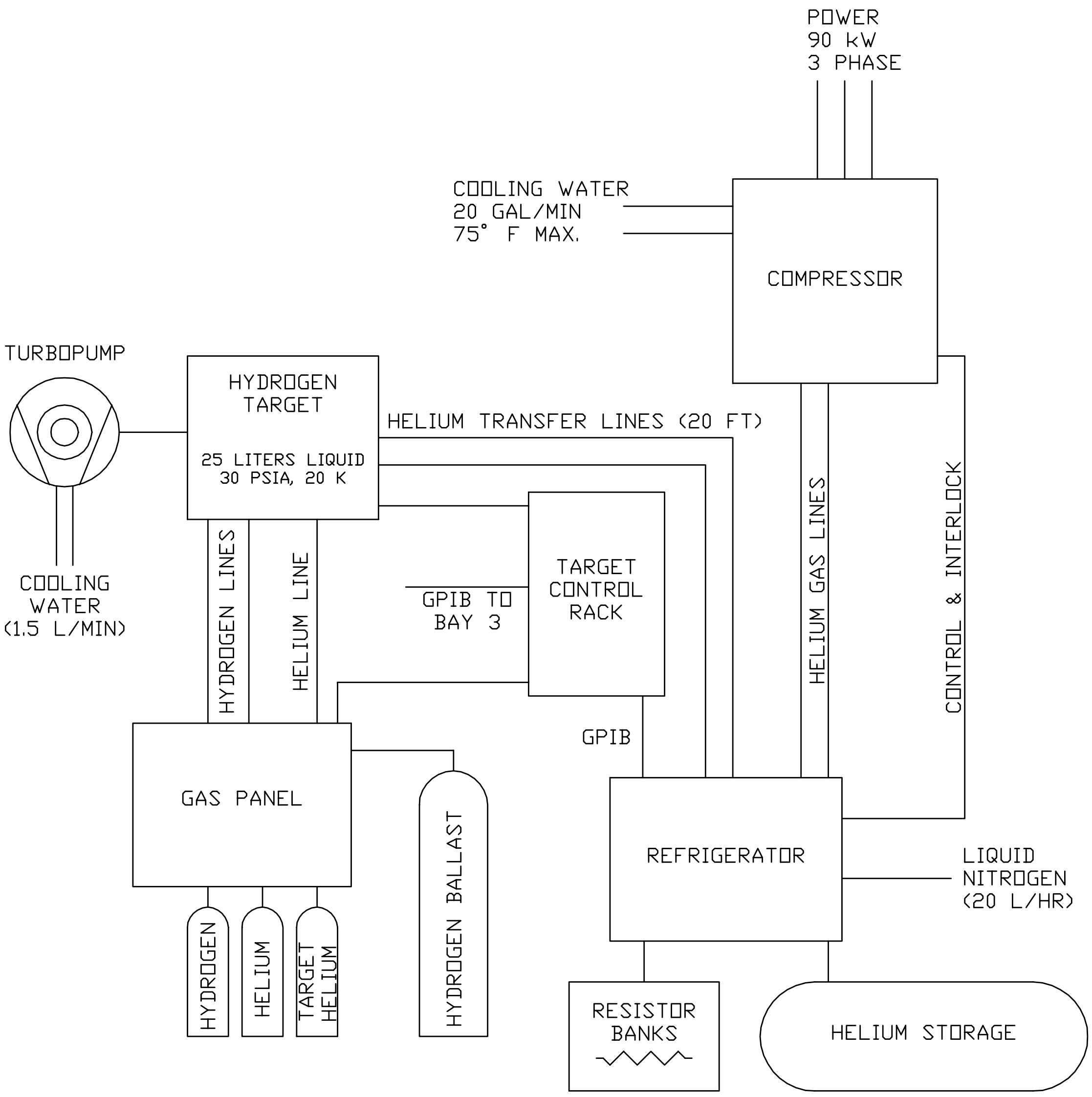

Figure I.1: Overview of the target system.

Table I.1

General operating parameters of the LH_2 target.

Volume of target loop	$\sim$ 25 liters
Volume of vacuum enclosure	7 m^3
Refrigeration capacity (without lN_2)	400 W
Refrigeration capacity (with lN_2)	700 W
Target heater capacity	1000 W (33 A, 33 V)
Operating temperature	20 K
Operating pressure	$\sim$30 psia
Density	0.07 g/cm^3
Target thickness	2.8 g/cm^2
Boiling point at 15 (30) psia	20 (23) K
Freezing point at 15 (30) psia	14 (14) K
Viscosity	130 μpoise
Specific heat	9.2 J/g-K
Thermal conductivity	1.18 mW/cm-K
20°C H_2: liquid H_2 volume ratio	$\sim$800: 1

The target loop is described in detail in section II. Section III describes the gas handling system and procedures for filling and emptying the target. Section IV contains general instructions for operating the refrigerator; a more detailed set of instructions can be found in the operations manual provided by the manufacturer. Section V is a description of the controls system. Appendix A contains a calculation of the boiloff rate of the target in the case of vacuum failure.

Emergency operating procedures are found in appendix B.

II. Target Loop and Vacuum Chamber

II.1 Target Loop

A schematic view of the target loop is shown in figure II.1. The loop consists of a heat exchanger, a pump, the target manifold and the target cell. The target manifold is made of 6061-T6 aluminum, as are the inner workings of the pump. The target cell is machined from 6061-T6 aluminum. All other parts are made of type 304 stainless steel. All joining parts are mated with conflat flanges, with the exception of one indium seal. When full, the target loop contains approximately 25 liters of liquid. Normal operating pressure of the hydrogen gas entering the system is 15-30 psia.

The heat exchanger is designed for very high throughput ($\sim$ 1 kg/sec) but low pressure. It consists of a corregated copper hose surrounded by a 6" diameter stainless steel pipe. Hydrogen flows through the inside of the copper hose, and helium flows in an annular path between the copper and the steel pipe, counterflow to the hydrogen.

When the pump is running, liquid hydrogen flows from the pump to the heat exchanger, and is delivered into the center of the target cell via a baffle in the manifold. The liquid flows longitudinally in the "beam upstream" direction along the center of the target and returns to the manifold along the outside of the target cell. The target cell and manifold are discussed in detail below.

The pump is connected to an AC motor via a long stainless steel shaft; its drive motor sits inside a can filled with room temperature hydrogen. There is one cold bearing near the pump and one warm bearing near the motor. The long shaft keeps the heat load from the motor at a minimum. The target loop and the motor can are isolated from each other by an O-ring seal so the motor can be serviced without disrupting the target loop. The motor typically runs at approximately 1800 RPM; its speed is controlled by a variable frequency motor controller. The speed of the motor is monitored with a tachometer.

A resistive heater is installed in the liquid just below the pump; it is used in a feedback loop with the electron beam current to keep the target cell at a constant temperature. The heater can deliver up to 1 kW of power into the liquid. The temperature of the target is monitored in four places within the loop with Lakeshore CGR-1-2000 carbon glass sensors. The four locations are before and after the pump, and on the inlet and outlet of the target manifold. During initial target studies, there were two more symmetric locations in the target nose. Two lines deliver hydrogen gas to the system from the gas panel, located before and after the pump.

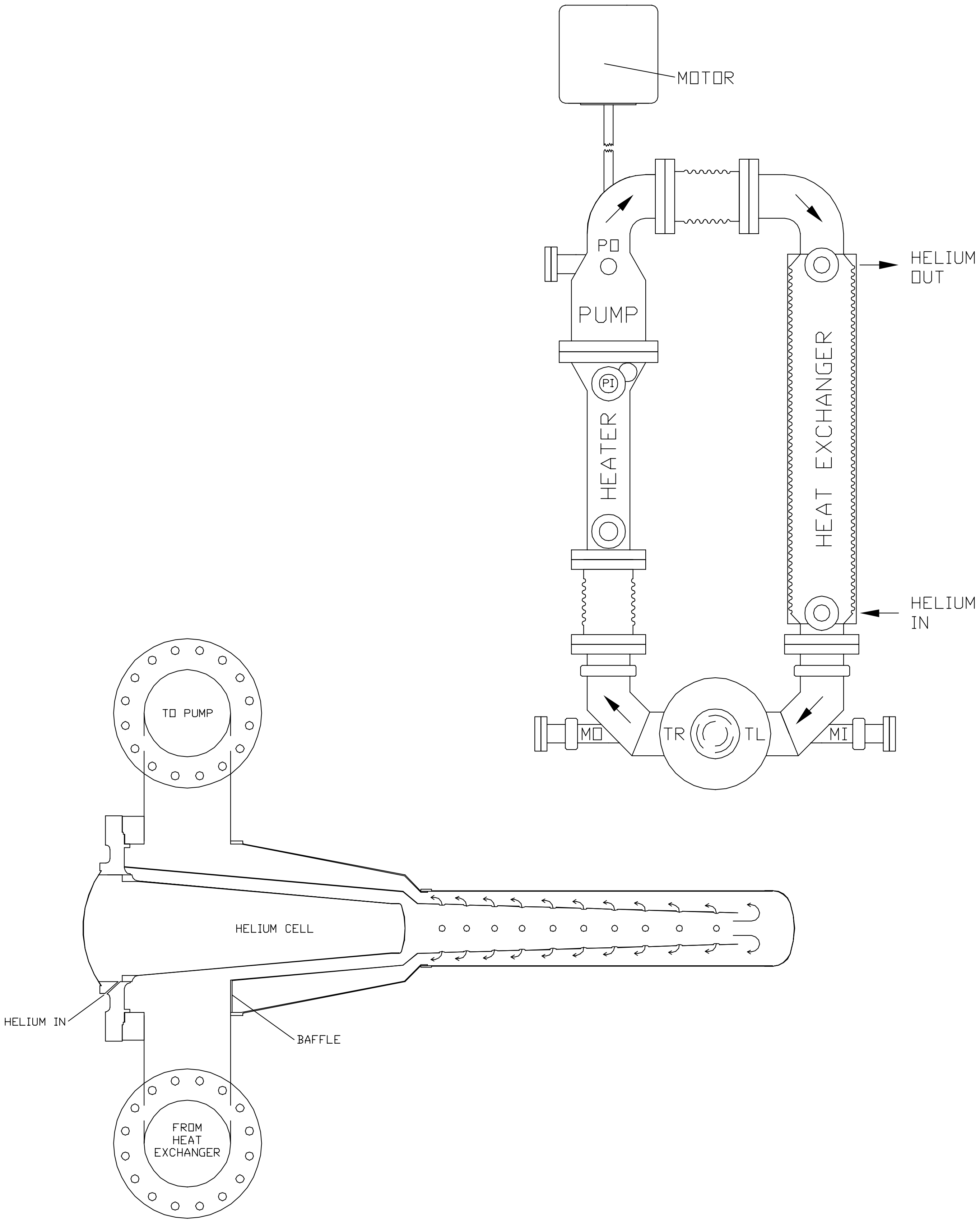

Figure II.1: Schematic view of the target loop and hydrogen flow manifold.

II.2 Target cell and manifold

The bottom of figure II.1 shows a more detailed view of the target cell and manifold. The outer wall is a 40 cm long, 7 cm diameter tube with a rounded beam entrance window. The outer target walls are 15 mils thick, and the inner tube is approximately 5 mils thick. Liquid hydrogen circulates from the manifold through the center tube and returns through the annulus formed by the inner and outer cell walls. The inner cylinder is tapered to 3 cm radius at the beam entrance point in order to keep the flow rate high. The holes in the walls of the inner tube introduce some transverse flow in order to help carry away heat deposited by the beam.

Changes in the target length as a function of beam position are an important consideration in the SAMPLE experiment. To maintain a constant target length as a function of transverse position, the exit window of the target has the same radius of curvature as the entrance window. The exit window curvature is maintained by a separate helium cell which backs the target cell. The pressure of the helium cell relative to the hydrogen is maintained at zero by a special regulator valve on the gas panel, R11. The electron beam exits the target through a window at the back of the helium cell. An aluminum flange with an indium seal holds the helium cell within the target manifold. Two sections of aluminum-stainless transition material are used to connect the manifold to the target loop. The entire loop is wrapped with 10 layers of superinsulation.

The target cell is attached to the manifold by a solder joint at the back of the cell. For safety considerations, the cell is hydraulically pressure tested to 100 psia before it is attached to the manifold. The target cell and manifold are then also pressure tested, as is the helium cell.

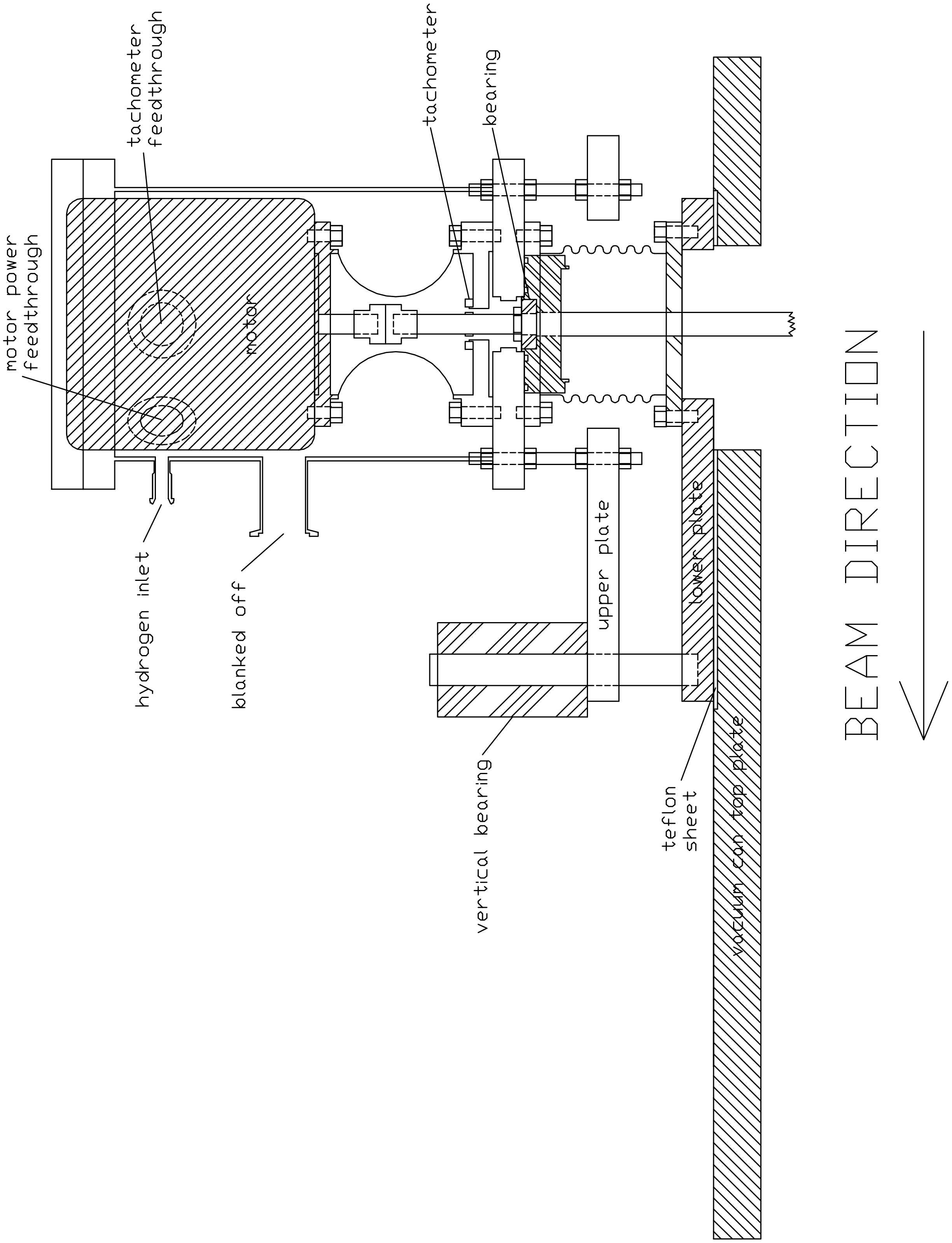

Figure II.2: Layout of the motor can and top of the vacuum chamber.

Table II.1

Required O-rings for Vacuum Chamber

All O-rings should be VITON. Where applicable, the Parker O-ring catalog numbers are included.

1:	57.875 DVL × 0.125		
2:	27.875 DVL × 0.125		
3:	142.00 DVL × 0.275		
4:	20.5 I.D. × 0.275		
5:	3-3/8 I.D. × 0.139	(-237)	
6:	4-1/8 I.D. × 0.139	(-243)	
7:	8" I.D. × 0.139	(-266)	(Norcal ASA)
8:	ISO-200-CR		(Norcal ISO)
9:	33.875 DVL × 0.125		
10:	5" I.D. × 0.125		
11:	9" I.D. × 0.139	(-270)	
12:	2" I.D. × 0.139	(-226)	
13:	3-7/8 I.D. × 0.139	(-241)	
14:	4-7/8 I.D. × 0.125		

II.3 Vacuum chamber

The target loop is enclosed in a rectangular aluminum vacuum chamber with 1" thick walls. A port on the dump pipe extension downbeam of the vacuum chamber is used for connecting a turbomolecular pump (Osaka Model TG1300) to the system. A pneumatic gate valve isolates the chamber from the turbopump in case of vacuum failure. There are two symmetrically placed ports with aluminum flanges at the back of the chamber.

The target loop is suspended from the top plate of the vacuum chamber: figure II.2 shows a schematic view. The target can be positioned within the chamber while it is cold and under vacuum by the use of a sliding teflon seal with an O-ring on either side. Two stepping motors allow remote control of the horizontal and vertical positions. All other degrees of freedom can be adjusted by hand.

All feedthrough connections are on a plate at the top of the vacuum chamber. The 1" i.d. helium transfer lines are connected to the target via 3" female bayonet connectors. The helium cell and hydrogen lines use VCR connectors with stainless steel gaskets. The temperature sensors

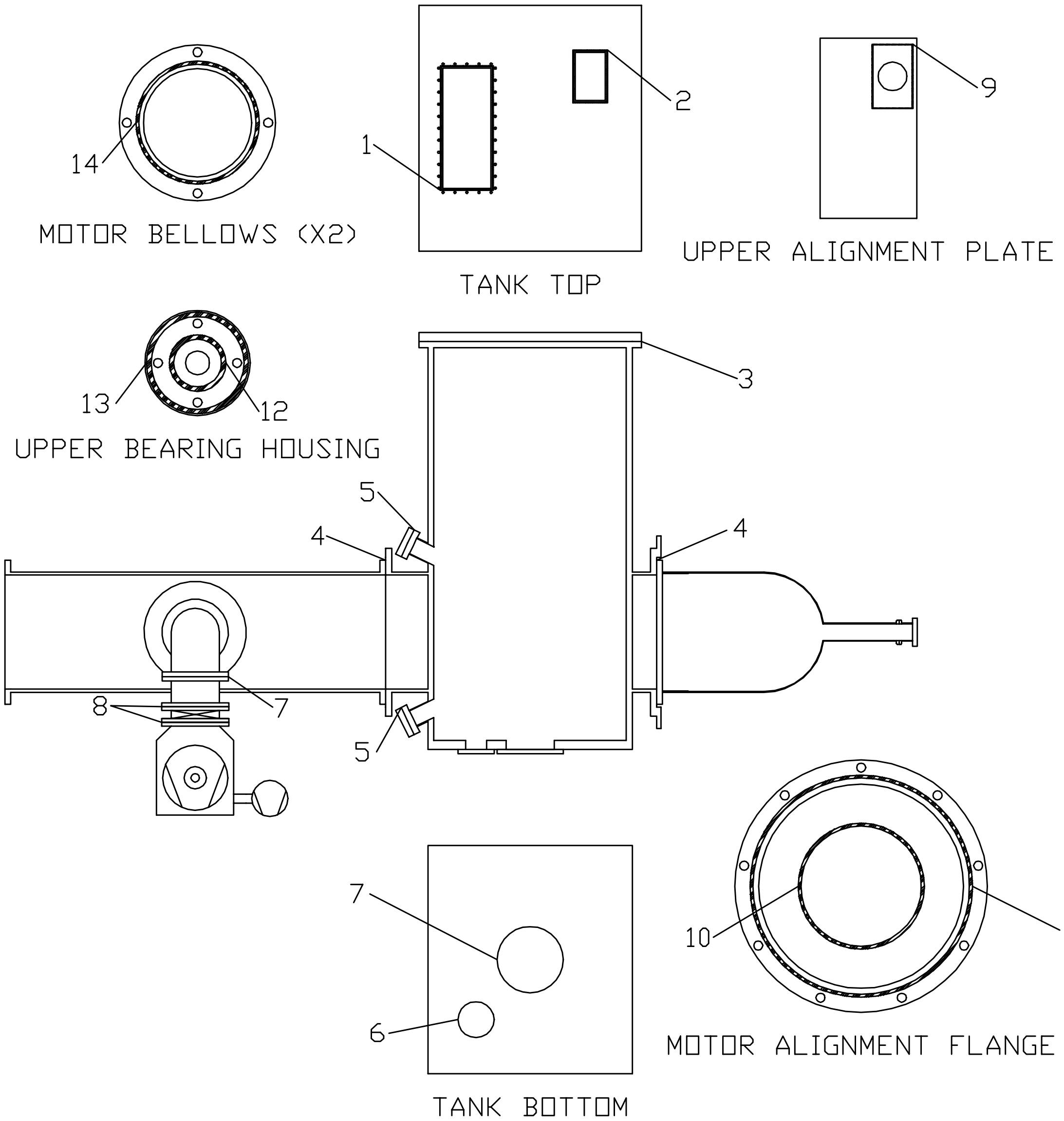

Figure II.3: Diagram showing locations of required Viton O-rings (see table II.1).

are connected via cryogenic 4-pin feedthrough connectors. The heater is connected via 4-pin high current feedthroughs.

Attached to the vacuum chamber is a scattering chamber with 1/8" aluminum walls. It is a cylinder with a hemisphere on the upstream end. The scattering chamber is axially symmetric and has no exit windows. Most of the scattering chamber is inside the light-tight skin which encloses the detector, whereas the vacuum chamber is located outside. A large flange on the vacuum chamber provides the connection to the light-tight skin. An aluminum-stainless transition piece with a 4.5" conflat flange couples the scattering chamber to the beam line on the upstream side. On the downstream side, the vacuum chamber is coupled to the beam line by a large spool piece with a 24" aluminum flange. All vacuum connections on the chamber are made with viton O-rings. Since many of these were custom made, a list of the the all of the necessary sizes is contained in Table II.1 (see also figure II.3).

III. Gas Handling System

III.1 Introduction

The gas handling system for SAMPLE is based on the system used for the Bates high power liquid hydrogen/deuterium target as described in Bates Internal Report 88–1. Central to the system is a valve panel providing interconnection among the target loop, hydrogen and helium source bottles, a vacuum pump and a ballast tank for hydrogen. With these valves the experimenter can purge air from the target and ballast, fill the target and ballast with hydrogen, liquify hydrogen in the target loop, and dispose of hydrogen while the target warms up. The panel also has several relief and check valves to ensure safe operation of the target.

Fig. III.1 is a schematic of the gas handling system. Components are labeled by abbreviations as follows:

CV	Check valve
GV	Gate valve
IG	Ionization gauge
MV	Manually operated valve
P	Pressure transducer or gauge
PS	Pressure switch
PV	Pneumatically operated valve
R	Regulator
RD	Rupture disc
RV	Relief valve
SV	Solenoid valve
TC	Thermocouple vacuum gauge
TMP	Turbomolecular pump
TWV	Three way valve
VP	Mechanical vacuum pump

When the target is in operation, liquid hydrogen at a temperature of 20 K is driven in a loop consisting of a pump, a heat exchanger, and the target cell (See Figure II.1.). The liquid is subcooled by a pressure head of 15 psig from a 2500 liter ballast tank of gaseous hydrogen. Downbeam from the hydrogen target cell is a truncated conical helium cell with thin convex entrance and exit windows. See Section II.1 for a more complete description of the target.

III.2 General Gas Handling Procedures

The handles of the manual valves on the panel are color-coded to indicate their function: those with a red handle carry hydrogen, those with orange carry helium, and those with black go to a vacuum pump. Most of the valves on the panel are equipped with microswitches to sense whether the valve is open or closed. These microswitches drive a bicolor LED next to the valve; green means the valve is open, red means closed. The state of these valves is also read by the computer.

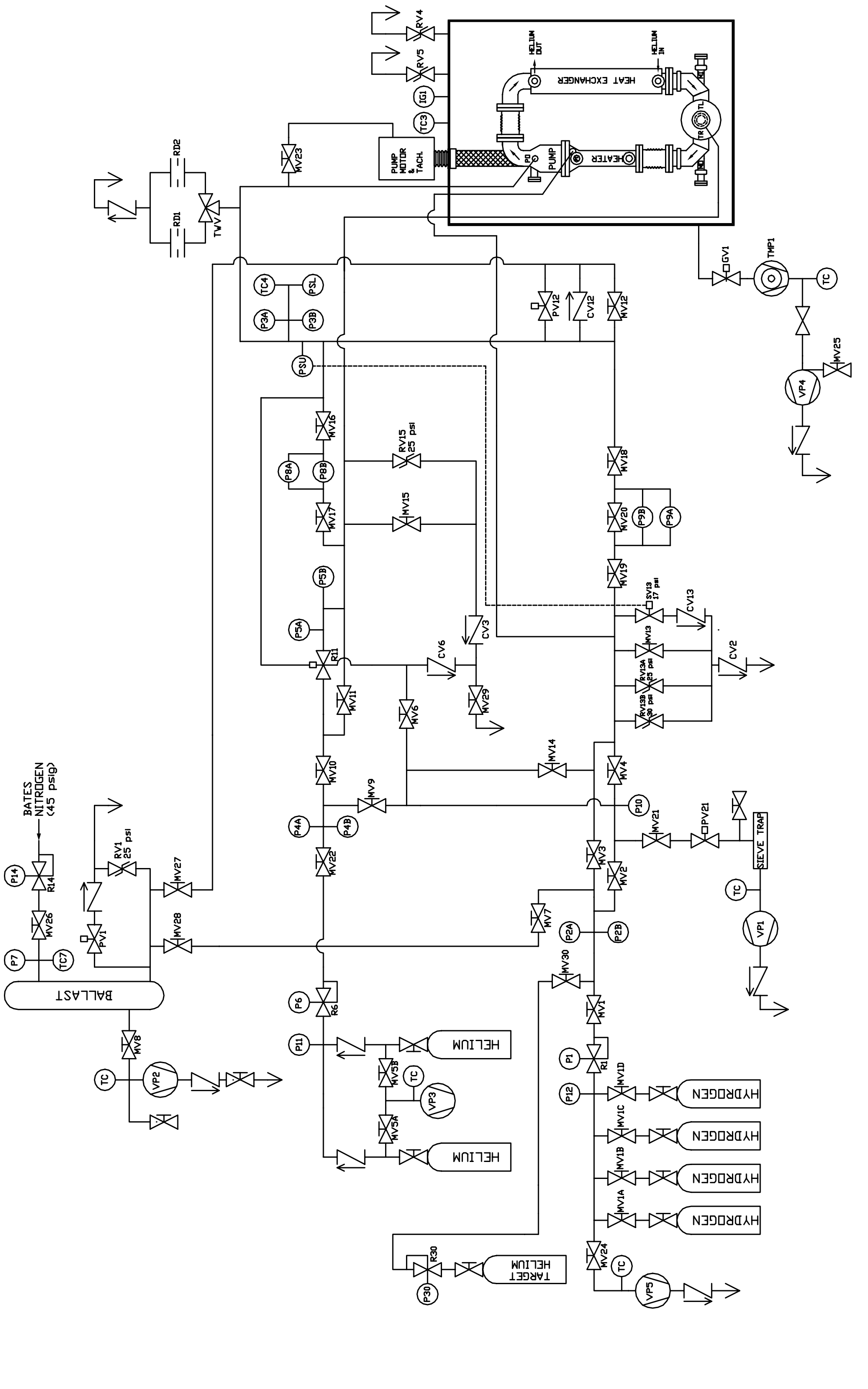

Figure III.1: Layout of the gas handling system.

The hydrogen bottle regulator R1, the helium bottle regulator R6 and the target helium regulator R30 each have an output valve with a round black handle. These valves are not indicated on the gas handling diagram (Figure III.1) and they should always be open unless the experimenter chooses to momentarily close them while changing the output setting of the regulator. When the instructions refer to closing a regulator it means backing out (counterclockwise) the regulator output setting to minimum pressure. Similarly, an instruction to open a regulator without a specification of output pressure means to turn the regulator output setting handle a few turns clockwise. This is only done to aid in evacuating the gas lines all the way back to the bottle valve. "Helium" refers to helium admitted through valve MV22 into the target backing cell; "target helium" is helium admitted through valve MV30 into the target loop for beam runs on a helium target.

Although Figure III.1 indicates five mechanical vacuum pumps, only two pumps are used for the SAMPLE target and are moved from place to place as needed. One of the pumps is equipped with an HPS vacuum sentry valve which closes in the event of a power failure and then vents the pump to air. It is this pump which should be used to back turbomolecular pump TMP1. The other mechanical pump requires manual venting through the small plug valve near its inlet whenever it is turned off.

IT IS IMPERATIVE that the hydrogen pressure in the target never exceed the helium pressure in the helium cell by more than 1 psid or else the helium cell may be damaged. The *helium* pressure may exceed the *hydrogen* by as much as 15 psid. This differential pressure may be read by gauge P8A or transducer P8B. Valves MV16 and MV17 are always kept open so that P8A and P8B are always reading this pressure. The detailed procedures in this section ensure that these limits are not exceeded.

IT IS ALSO IMPERATIVE that the vacuum chamber be evacuated before pumping on the target loop. The target cell is very thin and will implode if the pressure outside it exceeds the pressure inside. Pneumatic valve PV21 is interlocked to thermocouple TC3 to prevent pumping on the target loop unless the vacuum chamber is evacuated.

The first step in operating the target is the removal of all air from the target, ballast tank and associated plumbing. To do this, the entire system is repeatedly evacuated and backfilled with pure gas. The first backfill of any part of the system is with helium to reduce the possibility of mixing air and hydrogen. Subsequent backfills of the target loop or ballast tank use hydrogen. The full procedure for purging the ballast tank is in section III.A. The procedure for purging the target loop and helium cell is in section III.E.

The target may be filled and cooled after it has been evacuated and flushed. This procedure is described in section III.F. Hydrogen from the supply bottles is introduced into the evacuated system through pressure regulator R1. The output pressure of the regulator is monitored by P1. The hydrogen then passes through valve MV3 to the target loop. Similarly, helium regulated by R6 may be allowed into the evacuated helium cell. As noted, the helium cell must always be kept at a higher pressure than the target loop.

An alternative procedure for running the target loop with cold gaseous helium is described in Sections III.L and III.M.

Before cooling the target, it should be filled to its operating pressure of 15 psig. It is important that the helium pressure not exceed the hydrogen by more than 15 psid, so the filling of the target from vacuum to operating pressure is done in two stages — first from vacuum to 0 psig, then to 15 psig. The target loop pump should be running while the refrigerator is on to make the heat exchange more efficient. While the pump is running, valve MV20 must be kept closed and valves MV18 and MV19 kept open so the differential pressure generated by the pump may be read on gauge P9A and transducer P9B.

As the target cools, it will require more hydrogen and helium due to contraction. As more gas enters, the pressure difference across the convex entrance window to the helium cell is kept at 0 psid by pneumatic relay R11. It is a regulator that controls the pressure of a slave gas (helium) by the pressure of a master gas (hydrogen), keeping them in balance automatically. Gauge P5A monitors the helium output pressure.

There is a small constant venting of helium through CV6 and MV29. This venting is inherent in the design of pneumatic relay R11. It is important to monitor the helium bottle pressure and switch in a new bottle before the helium is depleted.

When the loop is full of liquid hydrogen, the operating pressure of 15 psig is maintained by the large volume of hydrogen in the ballast tank. The loop and the tank are connected through pneumatic valve PV12.

Table III.1

Parameters which are controlled through the vacuum interlock box. If the beam line vacuum is HIGHER than 10 mTorr as read on the thermocouple for VP4, the following will occur:

- Beam is disabled (master alarm panel in Bay 3).
- Target loop cannot be pumped out (PV21 closed).
- Ballast tank is closed off from gas panel (PV12 closed).
- Gate valves on beam line close (GV1 and SV5).
- Target heater is disabled.

Table III.2

Interlocks which must be satisfied for beam in the North Hall.

SAMPLE interlocks:

- The target cannot be in motion (no signal from "ENERGIZE" switch on target actuator controllers).
- The refrigerator must be ON (relay from refrigerator circuit).
- The target pump must be circulating.
- The target pressure must be between 7 psig and 18 psig (two pressure indicators).
- The gas panel must be in proper state for target operation (TTL output from computer).
- The target control computer is on and producing a heartbeat signal.

CCR interlocks:

- Beam line vacuum must be less than 10 mTorr (TC vacuum gauge trip-point relay).
- All hydrogen sniffers must give negative signal (control in CCR).

III.3 Emergency Operation

In the event of a power failure, vacuum failure or refrigerator failure it is possible that liquid hydrogen could evaporate and create a potentially hazardous hydrogen pressure in the target. To prevent this, relief valves RV13A and RV13B provide a redundant path to the laboratory venting system. They would open at pressures of 25 psig and 30 psig respectively. Should these both fail, manual valve MV13 could be used to vent the target. As a last line of defense, rupture disc RD1 would burst at a pressure of 40 psig. In a power failure, pneumatic valve PV12 would close, preventing the ballast tank from venting through any possible leak that might open in the target. In the event of a target rupture, evaporating hydrogen would vent from the vacuum chamber into the lab vent system through relief valves RV4 and RV5. RV4 is a one-inch valve that opens at 1-2 psig and RV5 is a four-inch flapper valve.

If the refrigerator were to trip off, an audible alarm would alert the operator. The restart procedure cannot be carried out remotely, so an access to the North Hall would be necessary. Detailed emergency operating procedures are provided in appendix B.

Interlocks for the target fall into two categories. First, certain steps may not be carried out if the beam line vacuum is not sufficiently low. These steps are controlled through a vacuum interlock box. A list of interlocks is shown in table III.1. Second, the beam may not be turned on unless the target related interlocks in table III.2 are satisfied. (Additional beam interlocks exist related to radiation safety and are not listed in this table.)

III.A. Evacuation and flushing of ballast tank

Initial state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed
☐	MV9	closed
☐	MV10	closed
☐	MV11	closed
☐	PV12	closed
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	closed
☐	MV17	closed
☐	MV18	closed
☐	MV19	closed
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	closed
☐	MV23	not in use
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	closed
☐	MV28	closed
☐	MV29	closed
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	all closed
☐	R1	closed
☐	P1	not in use
☐	Helium bottles	both closed
☐	R6	closed
☐	P6	not in use
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	closed
☐	P14	not in use
☐	TWV	To RD1 or RD2
☐	VP1	off
☐	TC for VP1	not in use
☐	VP2	off
☐	TC for VP2	not in use
☐	VP3	off
☐	TC for VP3	not in use
☐	VP4	off
☐	TC for VP4	not in use
☐	VP5	off
☐	TC for VP5	not in use
☐	Turbopump	off
☐	Target loop pump	off
☐	TC3	not in use
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	not in use
☐	P2A	not in use
☐	P3A	not in use
☐	P4A	not in use
☐	P5A	not in use
☐	P7	not in use
☐	P8A	not in use
☐	P9A	not in use
☐	P10	not in use
☐	GV1	closed
☐	SV5	not in use

III.A. Evacuation and flushing of ballast tank

1. Make sure all valves on the valve panel, vacuum chamber, gas bottles and ballast tank are closed initially. The hydrogen should be 99.9% pure for the flushes. One bottle at valve MV1A should be sufficient.

2. Turn on mechanical pump VP2.

3. Open valves MV1, MV30, MV7, MV16, MV17 and MV28.

4. Make sure the target helium and hydrogen bottles are closed, then open MV1A.

5. Open target helium regulator R30 and hydrogen regulator R1 by turning their handles fully clockwise.

   First evacuation of ballast tank:

6. Open valve MV8 and pump out the ballast tank and connecting lines to 100 mtorr as read on VP2's thermocouple gauge. The pressure on gauge P7 will drop from 0 psig to 30 in. Hg.

7. Sequentially close and reopen valves MV1, MV30, MV7, MV8, MV28 and MV1A to pump out a small dead space in each valve.

8. Close valves MV8 and MV30.

9. Close target helium regulator R30 by turning its handle fully counterclockwise.

10. Open the target helium bottle valve and adjust its regulator R30 to 0 psig.

    Helium backfill of ballast tank:

11. Open valve MV30 to fill the evacuated ballast tank to ~25 in. Hg helium as read on gauge P7.

12. Close valve MV30 and the target helium bottle valve.

13. Close target helium regulator R30 by turning its handle fully counterclockwise.

    Second evacuation of ballast tank:

14. Open valve MV8 and pump out the ballast tank and connecting lines to 100 mtorr as read on VP2's thermocouple gauge. The pressure on gauge P7 will drop from 25 in. Hg to 30 in. Hg.

15. Sequentially close and reopen valves MV1, MV7, MV8, MV28 and MV1A to pump out a small dead space in each valve.

16. Close valves MV1 and MV8.

17. Adjust nitrogen regulator R14 to 5 psig.

18. Close hydrogen regulator R1 by turning its handle fully counterclockwise.

19. Open the hydrogen bottle valve and adjust its regulator R1 to 0 psig.

    First hydrogen backfill of ballast tank:

20. Open valve MV1 to fill the evacuated ballast tank to ~25 in. Hg hydrogen as read on gauge P7.

21. Close valve MV1.

Third evacuation of ballast tank:

22. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.
23. Open valve MV8 and pump out the ballast tank and connecting lines to 100 mtorr as read on VP2's thermocouple gauge. The pressure on gauge P7 will drop from 25 in. Hg to 30 in. Hg.
24. Sequentially close and reopen valves MV7, MV8 and MV28 to pump out a small dead space in each valve.
25. Close valve MV8.

Second hydrogen backfill of ballast tank:

26. Open valve MV1 to fill the evacuated ballast tank to 25 in. Hg hydrogen as read on gauge P7.
27. Close the hydrogen bottle valve.
28. Open hydrogen regulator R1 by turning its handle fully clockwise.

Fourth evacuation of ballast tank:

29. Open valve MV8 and pump out the ballast tank and connecting lines to 100 mtorr as read on VP2's thermocouple gauge. Continue pumping until you are ready to fill the ballast tank with its charge of hydrogen. At that time perform the following steps:
30. Close valve MV8 and remove its handle.
31. Turn off mechanical pump VP2. Make sure the pump is vented.
32. Remove mechanical pump VP2 and cap off the inlet to valve MV8.
33. Close valve MV1A.
34. Confirm that all final conditions for procedure A are met.

III.A. Evacuation and flushing of ballast tank

Final state:

- ☐ MV1 .... open
- ☐ MV1A .... closed
- ☐ MV1B .... closed
- ☐ MV1C .... closed
- ☐ MV1D .... closed
- ☐ MV2 .... closed
- ☐ MV3 .... closed
- ☐ MV4 .... closed
- ☐ MV5A .... closed
- ☐ MV5B .... closed
- ☐ MV6 .... closed
- ☐ MV7 .... open
- ☐ MV8 .... closed, handle removed
- ☐ MV9 .... closed
- ☐ MV10 .... closed
- ☐ MV11 .... closed
- ☐ PV12 .... closed
- ☐ MV12 .... closed
- ☐ SV13 .... closed
- ☐ MV13 .... closed
- ☐ MV14 .... closed
- ☐ MV15 .... closed
- ☐ MV16 .... open
- ☐ MV17 .... open
- ☐ MV18 .... closed
- ☐ MV19 .... closed
- ☐ MV20 .... closed
- ☐ MV21 .... closed
- ☐ PV21 .... closed
- ☐ MV22 .... closed
- ☐ MV23 .... not in use
- ☐ MV24 .... closed and capped
- ☐ MV25 .... closed and capped
- ☐ MV26 .... closed
- ☐ MV27 .... closed
- ☐ MV28 .... open
- ☐ MV29 .... closed
- ☐ MV30 .... closed
- ☐ PV1 .... closed

- ☐ Hydrogen bottles .... all closed
- ☐ R1 .... open
- ☐ P1 .... 30 in. Hg
- ☐ Helium bottles .... both closed
- ☐ R6 .... closed
- ☐ P6 .... not in use
- ☐ Target helium bottle .... closed
- ☐ R30 .... closed
- ☐ P30 .... not in use
- ☐ R14 .... 5 psig
- ☐ P14 .... 5 psig
- ☐ TWV .... To RD1 or RD2
- ☐ VP1 .... not in use
- ☐ TC for VP1 .... not in use
- ☐ VP2 .... off and removed
- ☐ TC for VP2 .... not in use
- ☐ VP3 .... not in use
- ☐ TC for VP3 .... not in use
- ☐ VP4 .... not in use
- ☐ TC for VP4 .... not in use
- ☐ VP5 .... not in use
- ☐ TC for VP5 .... not in use
- ☐ Turbopump .... not in use
- ☐ Target loop pump .... off
- ☐ TC3 .... not in use
- ☐ TC4 .... not in use
- ☐ TC7 .... not in use
- ☐ IG1 .... not in use
- ☐ P2A .... 30 in. Hg
- ☐ P3A .... not in use
- ☐ P4A .... not in use
- ☐ P5A .... not in use
- ☐ P7 .... 30 in. Hg
- ☐ P8A .... not in use
- ☐ P9A .... not in use
- ☐ P10 .... not in use
- ☐ GV1 .... not in use
- ☐ SV5 .... not in use

III.B. Filling the ballast tank with hydrogen

Initial state:

- [ ] MV1 .... open
- [ ] MV1A .... closed
- [ ] MV1B .... closed
- [ ] MV1C .... closed
- [ ] MV1D .... closed
- [ ] MV2 .... closed
- [ ] MV3 .... closed
- [ ] MV4 .... closed
- [ ] MV5A .... closed
- [ ] MV5B .... closed
- [ ] MV6 .... closed
- [ ] MV7 .... open
- [ ] MV8 .... closed, handle removed
- [ ] MV9 .... closed
- [ ] MV10 .... closed
- [ ] MV11 .... closed
- [ ] PV12 .... closed
- [ ] MV12 .... closed
- [ ] SV13 .... closed
- [ ] MV13 .... closed
- [ ] MV14 .... closed
- [ ] MV15 .... closed
- [ ] MV16 .... open
- [ ] MV17 .... open
- [ ] MV18 .... closed
- [ ] MV19 .... closed
- [ ] MV20 .... closed
- [ ] MV21 .... closed
- [ ] PV21 .... closed
- [ ] MV22 .... closed
- [ ] MV23 .... not in use
- [ ] MV24 .... closed and capped
- [ ] MV25 .... closed and capped
- [ ] MV26 .... closed
- [ ] MV27 .... closed
- [ ] MV28 .... open
- [ ] MV29 .... closed
- [ ] MV30 .... closed
- [ ] PV1 .... closed
- [ ] Hydrogen bottles .... all closed
- [ ] R1 .... open
- [ ] P1 .... 30 in. Hg
- [ ] Helium bottles .... both closed
- [ ] R6 .... closed
- [ ] P6 .... not in use
- [ ] Target helium bottle .... closed
- [ ] R30 .... closed
- [ ] P30 .... not in use
- [ ] R14 .... 5 psig
- [ ] P14...................... 5 psig
- [ ] TWV .... To RD1 or RD2
- [ ] VP1 .... not in use
- [ ] TC for VP1.............. not in use
- [ ] VP2 .... off and removed
- [ ] TC for VP2.............. not in use
- [ ] VP3 .... not in use
- [ ] TC for VP3.............. not in use
- [ ] VP4 .... not in use
- [ ] TC for VP4.............. not in use
- [ ] VP5 .... not in use
- [ ] TC for VP5.............. not in use
- [ ] Turbopump.............. not in use
- [ ] Target loop pump .... off
- [ ] TC3 .... not in use
- [ ] TC4 .... not in use
- [ ] TC7 .... not in use
- [ ] IG1...................... not in use
- [ ] P2A .... 30 in. Hg
- [ ] P3A .... not in use
- [ ] P4A .... not in use
- [ ] P5A .... not in use
- [ ] P7....................... 30 in. Hg
- [ ] P8A .... not in use
- [ ] P9A .... not in use
- [ ] P10...................... not in use
- [ ] GV1 .... not in use
- [ ] SV5 .... not in use

III.B. Filling the ballast tank with hydrogen

1. Evacuate and flush the ballast tank as described in section A. Confirm that all initial conditions for procedure B are met. They are the same as the final conditions for procedure A.
2. Close valve MV1.
3. Replace the 99.9% hydrogen with four bottles of grade 5 hydrogen.
4. Turn on mechanical pump VP5. Wait until its thermocouple gauge reads less than 50 mtorr.
5. Open valves MV1A, MV1B, MV1C and MV1D.
6. Open valve MV24 and pump until the thermocouple gauge reads less than 50 mtorr.
7. Close valve MV24.
8. Close hydrogen regulator R1 by turning its handle fully counterclockwise.
9. Open the hydrogen bottle valve connected to valve MV1A and adjust its regulator R1 to 10 psig.
10. Turn off mechanical pump VP5 and vent it.
11. Cap off the inlet to valve MV24.
12. Close valves MV1B, MV1C and MV1D.

    <u>Filling ballast tank with its full charge of hydrogen</u>:

13. Open valve MV1 to fill the evacuated ballast tank to 10 psig hydrogen as read on gauge P2A. Increase the output pressure on hydrogen regulator R1 if necessary to attain this pressure. Switch to another hydrogen bottle if the one in use gets below 100 psig.
14. Close the hydrogen bottle valve.
15. Close valves MV7, MV1A (and any other hydrogen manifold valves that may be open), MV28 and MV1.
16. Close hydrogen regulator R1 by turning its handle fully counterclockwise.
17. Confirm that all final conditions for procedure B are met.

III.B. Filling the ballast tank with hydrogen

Final state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	closed
☐	MV11	closed
☐	PV12	closed
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	closed
☐	MV19	closed
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	closed
☐	MV23	not in use
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	closed
☐	MV28	closed
☐	MV29	closed
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	all closed
☐	R1	closed
☐	P1	not in use
☐	Helium bottles	both closed
☐	R6	closed
☐	P6	not in use
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	not in use
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	not in use
☐	TC for VP4	not in use
☐	VP5	not in use
☐	TC for VP5	not in use
☐	Turbopump	not in use
☐	Target loop pump	off
☐	TC3	not in use
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	not in use
☐	P2A	not in use
☐	P3A	not in use
☐	P4A	not in use
☐	P5A	not in use
☐	P7	10 psig
☐	P8A	not in use
☐	P9A	not in use
☐	P10	not in use
☐	GV1	not in use
☐	SV5	not in use

III.C. Replacing depleted hydrogen bottles

Initial state:

☐ MV1	closed	☐ Hydrogen bottles	all closed
☐ MV1A	closed	☐ R1	closed
☐ MV1B	closed	☐ P1	not in use
☐ MV1C	closed	☐ Helium bottles	both closed
☐ MV1D	closed	☐ R6	closed
☐ MV2	closed	☐ P6	not in use
☐ MV3	closed	☐ Target helium bottle	closed
☐ MV4	closed	☐ R30	closed
☐ MV5A	closed	☐ P30	not in use
☐ MV5B	closed	☐ R14	5 psig
☐ MV6	closed	☐ P14	5 psig
☐ MV7	closed	☐ TWV	To RD1 or RD2
☐ MV8	closed, handle removed	☐ VP1	not in use
☐ MV9	closed	☐ TC for VP1	not in use
☐ MV10	closed	☐ VP2	off and removed
☐ MV11	closed	☐ TC for VP2	not in use
☐ PV12	closed	☐ VP3	not in use
☐ MV12	closed	☐ TC for VP3	not in use
☐ SV13	closed	☐ VP4	not in use
☐ MV13	closed	☐ TC for VP4	not in use
☐ MV14	closed	☐ VP5	not installed
☐ MV15	closed	☐ TC for VP5	not in use
☐ MV16	open	☐ Turbopump	not in use
☐ MV17	open	☐ Target loop pump	off
☐ MV18	closed	☐ TC3	not in use
☐ MV19	closed	☐ TC4	not in use
☐ MV20	closed	☐ TC7	not in use
☐ MV21	closed	☐ IG1	not in use
☐ PV21	closed	☐ P2A	not in use
☐ MV22	closed	☐ P3A	not in use
☐ MV23	not in use	☐ P4A	not in use
☐ MV24	closed and capped	☐ P5A	not in use
☐ MV25	closed and capped	☐ P7	10 psig
☐ MV26	closed	☐ P8A	not in use
☐ MV27	closed	☐ P9A	not in use
☐ MV28	closed	☐ P10	not in use
☐ MV29	closed	☐ GV1	not in use
☐ MV30	closed	☐ SV5	not in use
☐ PV1	closed		

III.C. Replacing depleted hydrogen bottles

1. Fill the hydrogen ballast tank as described in section B. Confirm that all initial conditions for procedure C are met. They are the same as the final conditions for procedure B.
2. Remove all hydrogen bottles that were depleted in filling the ballast tank (procedure B). Replace them with full bottles.
3. Vent the hydrogen manifold to air by opening MV24, then closing it.
4. Turn on mechanical pump VP5. Wait until its thermocouple gauge reads less than 50 mtorr.
5. Gradually open valve MV24 and pump until the thermocouple gauge reads less than 50 mtorr.
6. Open the manifold valves (MV1A, MV1B, MV1C and/or MV1D) for all bottles that have been replaced. Wait until the thermocouple gauge reads less than 50 mtorr.
7. Close valve MV24.
8. Momentarily open one of the new bottles to pressurize the manifold, and then close it.
9. Close all manifold valves that are open.
10. Turn off pump VP5 and remove it.
11. Cap off valve MV24.
12. The conditions are now the same as at the beginning of this procedure except that all the hydrogen bottles are now full.
13. Confirm that all final conditions for procedure C are met.

III.C. Replacing depleted hydrogen bottles

Final state:

☐	MV1	closed	☐	Hydrogen bottles	all closed
☐	MV1A	closed	☐	R1	closed
☐	MV1B	closed	☐	P1	not in use
☐	MV1C	closed	☐	Helium bottles	both closed
☐	MV1D	closed	☐	R6	closed
☐	MV2	closed	☐	P6	not in use
☐	MV3	closed	☐	Target helium bottle	closed
☐	MV4	closed	☐	R30	closed
☐	MV5A	closed	☐	P30	not in use
☐	MV5B	closed	☐	R14	5 psig
☐	MV6	closed	☐	P14	5 psig
☐	MV7	closed	☐	TWV	To RD1 or RD2
☐	MV8	closed, handle removed	☐	VP1	not in use
☐	MV9	closed	☐	TC for VP1	not in use
☐	MV10	closed	☐	VP2	off and removed
☐	MV11	closed	☐	TC for VP2	not in use
☐	PV12	closed	☐	VP3	not in use
☐	MV12	closed	☐	TC for VP3	not in use
☐	SV13	closed	☐	VP4	not in use
☐	MV13	closed	☐	TC for VP4	not in use
☐	MV14	closed	☐	VP5	off and removed
☐	MV15	closed	☐	TC for VP5	not in use
☐	MV16	open	☐	Turbopump	not in use
☐	MV17	open	☐	Target loop pump	off
☐	MV18	closed	☐	TC3	not in use
☐	MV19	closed	☐	TC4	not in use
☐	MV20	closed	☐	TC7	not in use
☐	MV21	closed	☐	IG1	not in use
☐	PV21	closed	☐	P2A	not in use
☐	MV22	closed	☐	P3A	not in use
☐	MV23	not in use	☐	P4A	not in use
☐	MV24	closed and capped	☐	P5A	not in use
☐	MV25	closed and capped	☐	P7	10 psig
☐	MV26	closed	☐	P8A	not in use
☐	MV27	closed	☐	P9A	not in use
☐	MV28	closed	☐	P10	not in use
☐	MV29	closed	☐	GV1	not in use
☐	MV30	closed	☐	SV5	not in use
☐	PV1	closed			

III.D. Evacuation of vacuum chamber

Initial state:

- ☐ MV1 .... closed
- ☐ MV1A .... closed
- ☐ MV1B .... closed
- ☐ MV1C .... closed
- ☐ MV1D .... closed
- ☐ MV2 .... closed
- ☐ MV3 .... closed
- ☐ MV4 .... closed
- ☐ MV5A .... closed
- ☐ MV5B .... closed
- ☐ MV6 .... closed
- ☐ MV7 .... closed
- ☐ MV8 .... closed, handle removed
- ☐ MV9 .... closed
- ☐ MV10 .... closed
- ☐ MV11 .... closed
- ☐ PV12 .... closed
- ☐ MV12 .... closed
- ☐ SV13 .... closed
- ☐ MV13 .... closed
- ☐ MV14 .... closed
- ☐ MV15 .... closed
- ☐ MV16 .... open
- ☐ MV17 .... open
- ☐ MV18 .... closed
- ☐ MV19 .... closed
- ☐ MV20 .... closed
- ☐ MV21 .... closed
- ☐ PV21 .... closed
- ☐ MV22 .... closed
- ☐ MV23 .... not in use
- ☐ MV24 .... closed and capped
- ☐ MV25 .... closed and capped
- ☐ MV26 .... closed
- ☐ MV27 .... closed
- ☐ MV28 .... closed
- ☐ MV29 .... closed
- ☐ MV30 .... closed
- ☐ PV1 .... closed
- ☐ Hydrogen bottles .... all closed
- ☐ R1 .... closed
- ☐ P1 .... not in use
- ☐ Helium bottles .... both closed
- ☐ R6 .... closed
- ☐ P6 .... not in use
- ☐ Target helium bottle .... closed
- ☐ R30 .... closed
- ☐ P30 .... not in use
- ☐ R14 .... 5 psig
- ☐ P14...................... 5 psig
- ☐ TWV..................... To RD1 or RD2
- ☐ VP1...................... not in use
- ☐ TC for VP1.............. not in use
- ☐ VP2...................... off and removed
- ☐ TC for VP2.............. not in use
- ☐ VP3...................... not in use
- ☐ TC for VP3.............. not in use
- ☐ VP4...................... not in use
- ☐ TC for VP4.............. not in use
- ☐ VP5...................... off and removed
- ☐ TC for VP5.............. not in use
- ☐ Turbopump.............. not in use
- ☐ TC3...................... not in use
- ☐ TC3...................... not in use
- ☐ TC4...................... not in use
- ☐ TC7...................... not in use
- ☐ IG1...................... not in use
- ☐ P2A...................... not in use
- ☐ P3A...................... not in use
- ☐ P4A...................... not in use
- ☐ P5A...................... not in use
- ☐ P7........................ 10 psig
- ☐ P8A...................... not in use
- ☐ P9A...................... not in use
- ☐ P10...................... not in use
- ☐ GV1...................... not in use
- ☐ SV5...................... not in use

III.D. Evacuation of vacuum chamber

1. Confirm that all initial conditions for procedure D are met. They are the same as the final conditions for procedure C.
2. Turn on the forepump/isolation valve controller and bypass its interlock.
3. Open isolation valve GV1.
4. Turn on forepump VP4 to evacuate the chamber.
5. Continue pumping on the vacuum chamber until the pressure has reached 300 mtorr as read on thermocouple gauge TC3.
6. Turn on the turbopump.
7. Turn off the interlock bypass when the chamber pressure is down to 10^{-4} torr as read on IG1.
8. Continue pumping on the chamber during all procedures involving the target loop.
9. Confirm that all final conditions for procedure D are met.

III.D. Evacuation of vacuum chamber

Final state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	closed
☐	MV11	closed
☐	PV12	closed
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	closed
☐	MV19	closed
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	closed
☐	MV23	not in use
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	closed
☐	MV28	closed
☐	MV29	closed
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	all closed
☐	R1	closed
☐	P1	not in use
☐	Helium bottles	both closed
☐	R6	closed
☐	P6	not in use
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	not in use
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	$<$ 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	off
☐	TC3	$<$ 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	not in use
☐	P4A	not in use
☐	P5A	not in use
☐	P7	10 psig
☐	P8A	not in use
☐	P9A	not in use
☐	P10	not in use
☐	GV1	open
☐	SV5	not in use

III.E. Evacuation and flushing of the target and filling lines with hydrogen

Initial state:

- [ ] MV1 .... closed
- [ ] MV1A .... closed
- [ ] MV1B .... closed
- [ ] MV1C .... closed
- [ ] MV1D .... closed
- [ ] MV2 .... closed
- [ ] MV3 .... closed
- [ ] MV4 .... closed
- [ ] MV5A .... closed
- [ ] MV5B .... closed
- [ ] MV6 .... closed
- [ ] MV7 .... closed
- [ ] MV8 .... closed, handle removed
- [ ] MV9 .... closed
- [ ] MV10 .... closed
- [ ] MV11 .... closed
- [ ] PV12 .... closed
- [ ] MV12 .... closed
- [ ] SV13 .... closed
- [ ] MV13 .... closed
- [ ] MV14 .... closed
- [ ] MV15 .... closed
- [ ] MV16 .... open
- [ ] MV17 .... open
- [ ] MV18 .... closed
- [ ] MV19 .... closed
- [ ] MV20 .... closed
- [ ] MV21 .... closed
- [ ] PV21 .... closed
- [ ] MV22 .... closed
- [ ] MV23 .... not in use
- [ ] MV24 .... closed and capped
- [ ] MV25 .... closed and capped
- [ ] MV26 .... closed
- [ ] MV27 .... closed
- [ ] MV28 .... closed
- [ ] MV29 .... closed
- [ ] MV30 .... closed
- [ ] PV1 .... closed
- [ ] Hydrogen bottles .... all closed
- [ ] R1 .... closed
- [ ] P1 .... not in use
- [ ] Helium bottles .... both closed
- [ ] R6 .... closed
- [ ] P6 .... not in use
- [ ] Target helium bottle .... closed
- [ ] R30 .... closed
- [ ] P30 .... not in use
- [ ] R14 .... 5 psig
- [ ] P14...................... 5 psig
- [ ] TWV .... To RD1 or RD2
- [ ] VP1 .... off
- [ ] TC for VP1.............. not in use
- [ ] VP2 .... off and removed
- [ ] TC for VP2.............. not in use
- [ ] VP3 .... not in use
- [ ] TC for VP3.............. not in use
- [ ] VP4 .... on
- [ ] TC for VP4.............. $<$ 300 mtorr
- [ ] VP5 .... off and removed
- [ ] TC for VP5.............. not in use
- [ ] Turbopump.............. on
- [ ] Target loop pump .... off
- [ ] TC3 .... $<$ 5 mtorr
- [ ] TC4 .... not in use
- [ ] TC7 .... not in use
- [ ] IG1...................... $< 10^{-4}$ torr
- [ ] P2A .... not in use
- [ ] P3A .... not in use
- [ ] P4A .... not in use
- [ ] P5A .... not in use
- [ ] P7....................... 10 psig
- [ ] P8A .... not in use
- [ ] P9A .... not in use
- [ ] P10...................... not in use
- [ ] GV1 .... open
- [ ] SV5 .... not in use

III.E. Evacuation and flushing of the target and filling lines with hydrogen

1. Confirm that all initial conditions for procedure E are met. They are the same as the final conditions for procedure D.
2. The vacuum chamber must be under vacuum before proceeding. The turbopump must be on with gate valve GV1 open. DO NOT pump on the target unless the chamber is at a pressure of 10^{-4} torr or less as read on ion gauge IG1.
3. Turn on mechanical pump VP1.
4. Open pneumatic valve PV21 at the master vacuum interlock box.
5. Open valves MV1, MV30, MV19, MV20, MV18, MV29 and MV23.
6. Make sure all hydrogen bottles are closed, then open valves MV1A, MV1B, MV1C and MV1D.
7. Open valve MV21. Gauge P10 will drop from 0 psig to 30 in. Hg.
8. Gradually open valve MV2.
9. Gradually open target helium regulator R30 by turning its handle fully clockwise.
10. Gradually open hydrogen regulator R1 by turning its handle fully clockwise. Wait until VP1's thermocouple gauge reaches 100 mtorr.

    First evacuation of target loop:

11. Gradually open valve MV4 to evacuate the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess. Gauge P3A will go from 0 to 30 in. Hg.
12. Open valves MV7 and MV12.
13. Gradually switch TWV to the other rupture disk.

    First evacuation of helium cell:

14. When VP1's thermocouple gauge reads 500 mtorr or less, gradually open valve MV6 to evacuate the helium cell. Gauge P8A will return to 0 psid. Gauge P5A will drop from 0 psig to 30 in. Hg.
15. Open solenoid valve SV13 for several seconds to pump the space between it and check valve CV13. Push the button next to SV13 to do this.
16. Open valves MV10, MV11 and MV22.
17. Make sure both helium bottles are closed, then gradually open helium regulator R6 by turning its handle fully clockwise.
18. Open valve MV9.
19. Continue pumping on the target loop, helium cell and plumbing until VP1's thermocouple gauge reaches 100 mtorr.
20. Sequentially close and reopen valves MV1, MV30, MV2, MV7, MV21, MV4, MV19, MV20, MV18, MV12, MV22, MV9, MV10, MV11, MV6, MV29, MV17, MV16, MV1A, MV1B, MV1C, MV1D and MV23 to pump out a small dead space in each valve.

21. Close valves MV6, MV9 and MV22.

22. Close helium regulator R6 by turning its handle fully counterclockwise.

23. Open both helium bottle valves and adjust their regulator R6 to 0 psig.

24. Close one of the helium bottles.

First backfill of helium cell with helium:

25. Gradually open valve MV22 to fill the helium cell. Gauge P5A will go from 30 in. Hg to 0 psig. Gauge P8A will go from 0 psid to full scale helium excess.

26. Close valve MV22.

27. Close valves MV21 and MV30.

28. Close target helium regulator R30 by turning its handle fully counterclockwise.

29. Open the target helium bottle and adjust its regulator R30 to 0 psig.

Backfill of target loop with helium:

30. Gradually open valve MV30 to fill the target loop with helium. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

31. Close valve MV30 when gauge P8A reaches 0 psid.

32. Close the target helium bottle and its regulator R30.

33. Gradually switch TWV to the other rupture disk.

34. Open solenoid valve SV13 momentarily to introduce helium into the space between it and check valve CV13. Push the button next to SV13 to do this.

35. Pause at this point if the target is not to be filled with hydrogen right away. To pause, close valve MV30 and the helium bottle. Do not change the setting of helium regulator R6. Open valve MV9 to guarantee the target and the helium cell will be at the same pressure. When you want to resume flushing with hydrogen, close valve MV9 and open valve MV30 and the helium bottle. Ignore this entire step is no pause is desired.

Second evacuation of target loop:

36. Gradually open valve MV21 to pump out the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess.

37. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

38. Open solenoid valve SV13 for several seconds to pump the space between it and check valve CV13. Push the button next to SV13 to do this.

39. Gradually switch TWV to the other rupture disc.

40. Close MV1 and MV21.

41. Close hydrogen regulator R1 by turning its handle fully counterclockwise.

42. Open the hydrogen bottle valve connected to valve MV1A and adjust its regulator R1 to 0 psig.

43. Close valves MV1B, MV1C and MV1D.

<u>First backfill of target loop with hydrogen</u>:

44. Gradually open valve MV1 to fill the target loop with hydrogen. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

45. Close valve MV1 when gauge P8A reaches 0 psid.

46. Gradually switch TWV to the other rupture disc.

47. Open solenoid valve SV13 momentarily to introduce hydrogen to the space between it and check valve CV13. Push the button next to SV13 to do this.

48. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.

<u>Third evacuation of target loop</u>:

49. Gradually open valve MV21 to pump out the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess.

50. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

51. Open solenoid valve SV13 for several seconds to pump the space between it and check valve CV13. Push the button next to SV13 to do this.

52. Gradually switch TWV to the other rupture disc.

53. Close valve MV21.

<u>Second backfill of target loop with hydrogen</u>:

54. Gradually open valve MV1 to fill the target loop with hydrogen. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

55. Close valve MV1 when gauge P8A reaches 0 psid.

56. Gradually switch TWV to the other rupture disc.

57. Open solenoid valve SV13 momentarily to introduce hydrogen to the space between it and check valve CV13. Push the button next to SV13 to do this.

58. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.

<u>Fourth evacuation of target loop</u>:

59. Gradually open valve MV21 to pump out the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess.

60. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

61. Close valves MV2 and MV4.

Second evacuation of helium cell:

62. Gradually open valve MV9 to pump out the helium cell and plumbing. Gauge P8A will go from full scale helium excess to 0 psid.

63. Close valve MV9 when VP1's thermocouple gauge has reached 100 mtorr.

Second backfill of helium cell with helium:

64. Gradually open valve MV22 to fill the helium cell with helium. Gauge P8A will go from 0 to full scale helium excess.

65. Close valve MV22.

Third evacuation of helium cell:

66. Gradually open valve MV9 to pump out the helium cell and plumbing. Gauge P8A will go from full scale helium excess to 0 psid.

67. Close valve MV9 when VP1's thermocouple gauge has reached 100 mtorr.

Third backfill of helium cell with helium:

68. Gradually open valve MV22 to fill the helium cell with helium. Gauge P8A will go from 0 to full scale helium excess.

69. Close valve MV22.

Fourth evacuation of helium cell:

70. Gradually open valve MV9 to pump out the helium cell and plumbing. Gauge P8A will go from full scale helium excess to 0 psid.

71. Gradually open valves MV2 and MV4 to resume pumping on the target loop. Monitor gauge P8A to ensure there is never a hydrogen excess while opening these valves.

72. Confirm that all final conditions for procedure E are met.

73. Go to Section F to fill and cool the target.

III.E. Evacuation and flushing of the target and filling lines with hydrogen

Final state:

☐	MV1	closed	☐	Hydrogen bottles	one open
☐	MV1A	open	☐	R1	0 psig
☐	MV1B	closed	☐	P1	0 psig
☐	MV1C	closed	☐	Helium bottles	one open
☐	MV1D	closed	☐	R6	0 psig
☐	MV2	open	☐	P6	0 psig
☐	MV3	closed	☐	Target helium bottle	closed
☐	MV4	open	☐	R30	closed
☐	MV5A	closed	☐	P30	not in use
☐	MV5B	closed	☐	R14	5 psig
☐	MV6	closed	☐	P14	5 psig
☐	MV7	open	☐	TWV	To RD1 or RD2
☐	MV8	closed, handle removed	☐	VP1	on
☐	MV9	open	☐	TC for VP1	< 100 mtorr
☐	MV10	open	☐	VP2	off and removed
☐	MV11	open	☐	TC for VP2	not in use
☐	PV12	closed	☐	VP3	not in use
☐	MV12	open	☐	TC for VP3	not in use
☐	SV13	closed	☐	VP4	on
☐	MV13	closed	☐	TC for VP4	< 300 mtorr
☐	MV14	closed	☐	VP5	off and removed
☐	MV15	closed	☐	TC for VP5	not in use
☐	MV16	open	☐	Turbopump	on
☐	MV17	open	☐	Target loop pump	off
☐	MV18	open	☐	TC3	< 5 mtorr
☐	MV19	open	☐	TC4	< 100 mtorr
☐	MV20	open	☐	TC7	not in use
☐	MV21	open	☐	IG1	$< 10^{-4}$ torr
☐	PV21	open	☐	P2A	30 in. Hg
☐	MV22	closed	☐	P3A	30 in. Hg
☐	MV23	open	☐	P4A	30 in. Hg
☐	MV24	closed and capped	☐	P5A	30 in. Hg
☐	MV25	closed and capped	☐	P7	15 psig
☐	MV26	closed	☐	P8A	0 psid
☐	MV27	closed	☐	P9A	0 psid
☐	MV28	closed	☐	P10	30 in. Hg
☐	MV29	open	☐	GV1	open
☐	MV30	closed	☐	SV5	not in use
☐	PV1	closed			

III.F. Filling and cooling the target with hydrogen

Initial state:

- ☐ MV1 .... closed
- ☐ MV1A .... open
- ☐ MV1B .... closed
- ☐ MV1C .... closed
- ☐ MV1D .... closed
- ☐ MV2 .... open
- ☐ MV3 .... closed
- ☐ MV4 .... open
- ☐ MV5A .... closed
- ☐ MV5B .... closed
- ☐ MV6 .... closed
- ☐ MV7 .... open
- ☐ MV8 .... closed, handle removed
- ☐ MV9 .... open
- ☐ MV10 .... open
- ☐ MV11 .... open
- ☐ PV12 .... closed
- ☐ MV12 .... open
- ☐ SV13 .... closed
- ☐ MV13 .... closed
- ☐ MV14 .... closed
- ☐ MV15 .... closed
- ☐ MV16 .... open
- ☐ MV17 .... open
- ☐ MV18 .... open
- ☐ MV19 .... open
- ☐ MV20 .... open
- ☐ MV21 .... open
- ☐ PV21 .... open
- ☐ MV22 .... closed
- ☐ MV23 .... open
- ☐ MV24 .... closed and capped
- ☐ MV25 .... closed and capped
- ☐ MV26 .... closed
- ☐ MV27 .... closed
- ☐ MV28 .... closed
- ☐ MV29 .... open
- ☐ MV30 .... closed
- ☐ PV1 .... closed
- ☐ Hydrogen bottles .... one open
- ☐ R1 .... 0 psig
- ☐ P1 .... 0 psig
- ☐ Helium bottles .... one open
- ☐ R6 .... 0 psig
- ☐ P6 .... 0 psig
- ☐ Target helium bottle .... closed
- ☐ R30 .... closed
- ☐ P30 .... not in use
- ☐ R14 .... 5 psig
- ☐ P14 .... 5 psig
- ☐ TWV .... To RD1 or RD2
- ☐ VP1 .... on
- ☐ TC for VP1 .... < 100 mtorr
- ☐ VP2 .... off and removed
- ☐ TC for VP2 .... not in use
- ☐ VP3 .... not in use
- ☐ TC for VP3 .... not in use
- ☐ VP4 .... on
- ☐ TC for VP4 .... < 300 mtorr
- ☐ VP5 .... off and removed
- ☐ TC for VP5 .... not in use
- ☐ Turbopump .... on
- ☐ Target loop pump .... off
- ☐ TC3 .... < 5 mtorr
- ☐ TC4 .... < 100 mtorr
- ☐ TC7 .... not in use
- ☐ IG1 .... $< 10^{-4}$ torr
- ☐ P2A .... 30 in. Hg
- ☐ P3A .... 30 in. Hg
- ☐ P4A .... 30 in. Hg
- ☐ P5A .... 30 in. Hg
- ☐ P7 .... 15 psig
- ☐ P8A .... 0 psid
- ☐ P9A .... 0 psid
- ☐ P10 .... 30 in. Hg
- ☐ GV1 .... open
- ☐ SV5 .... not in use

III.F. Filling and cooling the target with hydrogen

1. Evacuate and flush the target and filling lines as described in section E.
2. Confirm that all initial conditions for section F are met. They are the same as the final conditions for section E.
3. Close valves MV9, MV2 and MV4.
4. Open valve MV3.

   Fill helium cell to one absolute atmosphere of helium:

5. Gradually open valve MV22 to fill the helium cell. Gauge P5A will go from vacuum to 0 psig. Gauge P8A will go from 0 psid to full scale helium excess.
6. Close valve MV22.
7. Close valve MV21.
8. Close pneumatic valve PV21 at the master vacuum interlock box.
9. Turn off mechanical pump VP1 and vent it.
10. Remove pump VP1 and cap off the inlet to pneumatic valve PV21.

    Fill target loop to one absolute atmosphere hydrogen:

11. Gradually open valve MV1 to reduce gauge P8A from 15 psid to 0 psid. DO NOT let gauge P8A go to hydrogen excess.
12. Close MV1.
13. Increase the helium regulator R6 to 10 psig.
14. Close valve MV29.

    Fill helium cell to two absolute atmospheres helium:

15. Gradually open valve MV22 until gauge P5A increases from 0 to 10 psig. Gauge P8A will increase to 10 psid helium excess. Do not close MV22.
16. Increase the hydrogen regulator R1 to 10 psig.

    Fill target loop to two absolute atmospheres hydrogen:

17. Gradually open valve MV1 until gauge P8A is reduced from full scale to 0 psid helium excess, and then close MV1. DO NOT let gauge P8A go to hydrogen excess.
18. Close valve MV11.
19. Increase the helium regulator R6 to 40 psig.
20. Gradually open valve MV29. You may hear some helium vent through check valve CV6. This is OK.
21. Open valve MV1. Increase the output pressure on hydrogen regulator R1 if necessary to get gauge P2A up to 10 psig. Do not close valve MV1.

22. Close valve MV20.

23. Gradually open valve MV27. This will equalize the hydrogen pressures in the target loop and the ballast tank.

24. Open valve MV28.

25. Close valve MV3.

<u>Cooling the target loop</u>:

26. Turn on the target loop pump. As the hydrogen cools gauge P9A will rise very slowly.

27. Begin cooling the target loop with the refrigerator as described in section IV. Put the temperature setpoint of the refrigerator at 25 K. As the loop cools, hydrogen will be drawn from the bottle to maintain 15 psig in the loop. When a hydrogen bottle has less than 100 psig, close its valve and its manifold valve and switch to another bottle. Put an “empty” bottle tag on the depleted bottle.

28. When the target loop temperatures are all 25 K, reduce the temperature setpoint of the refrigerator to 24.5 K. After the loop temperatures equilibrate, reduce the setpoint to 24 K. Continue in this manner to 21.5 K, when liquifaction will begin.

<u>Signs that the target is full:</u>

a) Consumption of hydrogen levels off. This is monitored on the computer as the hydrogen bottle pressure (P12) vs. time.

b) The loop pressure (P2B) will rise to, or above, the hydrogen regulator pressure (P1) before filling began.

c) The refrigerator heater power will rise to ~700 W.

29. Close valve MV7 when the loop is full of liquid hydrogen. Change the refrigerator setpoint to 19.8 K. Set the engine speed to 220 RPM.

30. Cooling to 19.8 K will reduce the loop pressure. Restore it by opening valve MV7 as long as necessary, and then close MV7.

31. Open pneumatic valve PV12 at the master vacuum interlock box.

32. Close valve MV12.

33. Close valve MV1 and the hydrogen bottle valve.

34. Close all valves on the hydrogen manifold.

35. Open gate valve SV5 before putting beam on the target.

36. Continue to monitor the helium bottle. Replace it when its pressure falls below 200 psig. See section G for this procedure.

37. Confirm that all final conditions for procedure F are met.

III.F. Filling and cooling the target with hydrogen

Final state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	open
☐	MV11	closed
☐	PV12	open
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	open
☐	MV19	open
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	open
☐	MV23	open
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	open
☐	MV28	open
☐	MV29	open
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	all closed
☐	R1	15 psig
☐	P1	not in use
☐	Helium bottles	one open
☐	R6	40 psig
☐	P6	40 psig
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	off and removed
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	< 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	on
☐	TC3	< 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	10 psig
☐	P4A	40 psig
☐	P5A	10 psig
☐	P7	10 psig
☐	P8A	0 psid
☐	P9A	> 0 psid
☐	P10	not in use
☐	GV1	open
☐	SV5	open for beam

III.G. Replacing the helium bottle

Initial state:

- [ ] MV1 .... closed
- [ ] MV1A .... closed
- [ ] MV1B .... closed
- [ ] MV1C .... closed
- [ ] MV1D .... closed
- [ ] MV2 .... closed
- [ ] MV3 .... closed
- [ ] MV4 .... closed
- [ ] MV5A .... closed
- [ ] MV5B .... closed
- [ ] MV6 .... closed
- [ ] MV7 .... closed
- [ ] MV8 .... closed, handle removed
- [ ] MV9 .... closed
- [ ] MV10 .... open
- [ ] MV11 .... closed
- [ ] PV12 .... open
- [ ] MV12 .... closed
- [ ] SV13 .... closed
- [ ] MV13 .... closed
- [ ] MV14 .... closed
- [ ] MV15 .... closed
- [ ] MV16 .... open
- [ ] MV17 .... open
- [ ] MV18 .... open
- [ ] MV19 .... open
- [ ] MV20 .... closed
- [ ] MV21 .... closed
- [ ] PV21 .... closed
- [ ] MV22 .... open
- [ ] MV23 .... open
- [ ] MV24 .... closed and capped
- [ ] MV25 .... closed and capped
- [ ] MV26 .... closed
- [ ] MV27 .... open
- [ ] MV28 .... open
- [ ] MV29 .... open
- [ ] MV30 .... closed
- [ ] PV1 .... closed
- [ ] Hydrogen bottles .... all closed
- [ ] R1 .... 15 psig
- [ ] P1 .... not in use
- [ ] Helium bottles .... one open
- [ ] R6 .... 40 psig
- [ ] P6 .... 40 psig
- [ ] Target helium bottle .... closed
- [ ] R30 .... closed
- [ ] P30 .... not in use
- [ ] R14 .... 5 psig
- [ ] P14 .... 5 psig
- [ ] TWV .... To RD1 or RD2
- [ ] VP1 .... off and removed
- [ ] TC for VP1 .... not in use
- [ ] VP2 .... off and removed
- [ ] TC for VP2 .... not in use
- [ ] VP3 .... not in use
- [ ] TC for VP3 .... not in use
- [ ] VP4 .... on
- [ ] TC for VP4 .... < 300 mtorr
- [ ] VP5 .... off and removed
- [ ] TC for VP5 .... not in use
- [ ] Turbopump .... on
- [ ] Target loop pump .... on
- [ ] TC3 .... < 5 mtorr
- [ ] TC4 .... not in use
- [ ] TC7 .... not in use
- [ ] IG1 .... $< 10^{-4}$ torr
- [ ] P2A .... not in use
- [ ] P3A .... 10 psig
- [ ] P4A .... 40 psig
- [ ] P5A .... 10 psig
- [ ] P7 .... 10 psig
- [ ] P8A .... 0 psid
- [ ] P9A .... > 0 psid
- [ ] P10 .... not in use
- [ ] GV1 .... open
- [ ] SV5 .... open for beam

III.G. Replacing the helium bottle

1. The helium bottle being used to fill the helium cell is constantly being bled by pneumatic relay R11. It must be replaced when its pressure falls below 200 psig.
2. The target loop is at operating temperature and contains liquid hydrogen as described in section F.
3. Confirm that all initial conditions for section G are met. They are the same as the final conditions for section F.
4. Open the full helium bottle that is in reserve on the manifold. Make sure the regulator pressure of R6 remains at 40 psig.
5. Close the expended helium bottle valve.
6. Replace the expended helium bottle with a full one.
7. Turn on mechanical pump VP3. Wait until its thermocouple gauge reads less than 50 mtorr.
8. Open the pump valve (either MV5A or MV5B) to the new bottle that was just placed on the manifold. Pump until the thermocouple gauge reads less than 50 mtorr, then close the pump valve.
9. Momentarily open the new bottle to pressurize the small volume up to its check valve.
10. Close the new bottle.
11. Turn off pump VP3 and vent it.
12. The conditions are now the same as at the beginning of this procedure except that a full helium bottle is being used rather than a depleted one.
13. Confirm that all final conditions for procedure G are met.

III.G. Replacing the helium bottle

Final state:

- [ ] MV1 .... closed
- [ ] MV1A .... closed
- [ ] MV1B .... closed
- [ ] MV1C .... closed
- [ ] MV1D .... closed
- [ ] MV2 .... closed
- [ ] MV3 .... closed
- [ ] MV4 .... closed
- [ ] MV5A .... closed
- [ ] MV5B .... closed
- [ ] MV6 .... closed
- [ ] MV7 .... closed
- [ ] MV8 .... closed, handle removed
- [ ] MV9 .... closed
- [ ] MV10 .... open
- [ ] MV11 .... closed
- [ ] PV12 .... open
- [ ] MV12 .... closed
- [ ] SV13 .... closed
- [ ] MV13 .... closed
- [ ] MV14 .... closed
- [ ] MV15 .... closed
- [ ] MV16 .... open
- [ ] MV17 .... open
- [ ] MV18 .... open
- [ ] MV19 .... open
- [ ] MV20 .... closed
- [ ] MV21 .... closed
- [ ] PV21 .... closed
- [ ] MV22 .... open
- [ ] MV23 .... open
- [ ] MV24 .... closed and capped
- [ ] MV25 .... closed and capped
- [ ] MV26 .... closed
- [ ] MV27 .... open
- [ ] MV28 .... open
- [ ] MV29 .... open
- [ ] MV30 .... closed
- [ ] PV1 .... closed
- [ ] Hydrogen bottles .... all closed
- [ ] R1 .... 15 psig
- [ ] P1 .... not in use
- [ ] Helium bottles .... one open
- [ ] R6 .... 40 psig
- [ ] P6 .... 40 psig
- [ ] Target helium bottle .... closed
- [ ] R30 .... closed
- [ ] P30 .... not in use
- [ ] R14 .... 5 psig
- [ ] P14 .... 5 psig
- [ ] TWV .... To RD1 or RD2
- [ ] VP1 .... off and removed
- [ ] TC for VP1 .... not in use
- [ ] VP2 .... off and removed
- [ ] TC for VP2 .... not in use
- [ ] VP3 .... not in use
- [ ] TC for VP3 .... not in use
- [ ] VP4 .... on
- [ ] TC for VP4 .... < 300 mtorr
- [ ] VP5 .... off and removed
- [ ] TC for VP5 .... not in use
- [ ] Turbopump .... on
- [ ] Target loop pump .... on
- [ ] TC3 .... < 5 mtorr
- [ ] TC4 .... not in use
- [ ] TC7 .... not in use
- [ ] IG1 .... $< 10^{-4}$ torr
- [ ] P2A .... not in use
- [ ] P3A .... 10 psig
- [ ] P4A .... 40 psig
- [ ] P5A .... 10 psig
- [ ] P7 .... 10 psig
- [ ] P8A .... 0 psid
- [ ] P9A .... > 0 psid
- [ ] P10 .... not in use
- [ ] GV1 .... open
- [ ] SV5 .... open for beam

III.H. Warming the hydrogen-filled target to room temperature

Initial state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	open
☐	MV11	closed
☐	PV12	open
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	open
☐	MV19	open
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	open
☐	MV23	open
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	open
☐	MV28	open
☐	MV29	open
☐	MV30	closed
☐	PV1	closed
☐	Hydrogen bottles	all closed
☐	R1	15 psig
☐	P1	not in use
☐	Helium bottles	one open
☐	R6	40 psig
☐	P6	40 psig
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	off and removed
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	< 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	on
☐	TC3	< 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	10 psig
☐	P4A	40 psig
☐	P5A	10 psig
☐	P7	10 psig
☐	P8A	0 psid
☐	P9A	> 0 psid
☐	P10	not in use
☐	GV1	open
☐	SV5	open for beam

III.H. Warming the hydrogen-filled target to room temperature

1. The target is filled with circulating liquid hydrogen as described in section F.

2. Turn off the beam and set the interlock so beam may not be put on the target.

3. Take the target heater out of automatic control and slowly turn the heater down to 0 in steps of 100 W.

4. Turn off the target heater voltage.

   At this point it will be necessary to enter the North Hall. Install the target computer there.

5. Confirm that all initial conditions for procedure H are met. They are the same as the final conditions for section F or G.

6. Close gate valve SV5 from the master vacuum interlock box.

7. Close off the refrigerator LN_2 supply by turning off LC-1 and closing the supply valve V806. Also close the LN_2 tank supply valve.

   <u>NOTE</u>: The target circulating pump should be ON ($>$ 20 Hz) during the boiloff process. If the pump has shut off for some reason, DO NOT turn the pump back on until the liquid has completely boiled away. If the pump is turned on in the middle of the boiloff process it may cause a sudden pressure surge and damage the He cell.

8. Open the refrigerator bypass valve V360 fully. Some helium will continue to flow to the target loop but most will go back to the compressor. The target should immediately begin to warm up.

9. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.

10. Close V361 approximately 4 turns so that it is open about $\frac{1}{2}$ turn. Watch the pressure in the target either on the computer screen (in the counting bay) or at gauge P3A on the gas panel. As the target starts to boil its pressure will increase. When the target pressure reaches 17 psig, pressure switch PSU will cause solenoid valve SV13 to open and the target should begin to vent. The target pressure should stabilize once SV13 is open. **If the target pressure continues to rise**, open V361 a little more to send more cooling to the target. Use V361 as a throttle valve to control the boiloff rate of the target. A full target should take no less than 20 minutes to boil completely away. When the target has completed boiling the pressure will quickly drop. SV13 will close when the target pressure drops to 14 psig.

11. Close pneumatic valve PV12 after the target has stopped boiling and SV13 is closed.

12. Once all liquid has boiled away, the target will slowly warm up to room temperature. This process may be accelerated by turning on the target heater to 50–100 watts.

13. Change the helium bottle going to the helium cell if the bottle pressure drops below 200 psig (see section III.G to change the helium bottle).

    <u>NOTE</u>: When the target temperature is approximately 30 K, the vacuum chamber pressure will rise by about a factor of 10–50 from its cold value. If the ion gauge IG1 gets high on the 10^{-4} range the turbopump interlock should be bypassed to keep it from tripping off and the gate valve GV1 from closing. As the target continues to warm the vacuum should return to the warm value.

14. Once the target has reached 40 K, the refrigerator may be turned off. **Follow the instructions in section IV.4.** Do not shut down the compressor at this time.

15. It may also be desirable to speed up the warming process by backfilling the vacuum system with helium. If you desire to do this, turn off the ion gauge controller. This will close gate valve GV1 and trip off the turbopump and forepump. Bypass the isolation valve interlock and open GV1. Wait 30 minutes for the turbopump to spin down. Connect a regulated helium bottle with a valve to valve MV25. Slowly introduce helium to the vacuum system until thermocouple gauge TC3 reads about 1 torr, and then close MV25. However, the chamber will have to be pumped out again before backfilling the target with helium.

16. When the target reaches 100 K, set the target heater to 0 W and turn off the power supply.

17. When the target is close to room temperature, the compressor may be shut down. Follow the instructions in section IV.5.

18. Turn off the target loop pump.

19. Slightly crack open valve MV13. Gauge P3A will drop from 15 psig to 0 psig.

20. Close valve MV13.

21. If the vacuum system was backfilled with helium, pump the vacuum system out again, following steps 2 through 8 in section III.D.

22. Proceed to section I to purge hydrogen from the target loop.

23. It may also be necessary to purge hydrogen from the ballast tank. Ask the safety officer on duty if this is necessary.

24. Confirm that all final conditions for procedure H are met.

III.H. Warming the hydrogen-filled target to room temperature

Final state:

☐	MV1	closed	☐	Hydrogen bottles	all closed
☐	MV1A	closed	☐	R1	10 psig
☐	MV1B	closed	☐	P1	not in use
☐	MV1C	closed	☐	Helium bottles	one open
☐	MV1D	closed	☐	R6	40 psig
☐	MV2	closed	☐	P6	40 psig
☐	MV3	closed	☐	Target helium bottle	closed
☐	MV4	closed	☐	R30	closed
☐	MV5A	closed	☐	P30	not in use
☐	MV5B	closed	☐	R14	5 psig
☐	MV6	closed	☐	P14	5 psig
☐	MV7	closed	☐	TWV	To RD1 or RD2
☐	MV8	closed, handle removed	☐	VP1	off and removed
☐	MV9	closed	☐	TC for VP1	not in use
☐	MV10	open	☐	VP2	off and removed
☐	MV11	closed	☐	TC for VP2	not in use
☐	PV12	closed	☐	VP3	not in use
☐	MV12	closed	☐	TC for VP3	not in use
☐	SV13	closed	☐	VP4	on
☐	MV13	closed	☐	TC for VP4	$<$ 300 mtorr
☐	MV14	closed	☐	VP5	off and removed
☐	MV15	closed	☐	TC for VP5	not in use
☐	MV16	open	☐	Turbopump	on
☐	MV17	open	☐	Target loop pump	off
☐	MV18	open	☐	TC3	$<$ 5 mtorr
☐	MV19	open	☐	TC4	not in use
☐	MV20	closed	☐	TC7	not in use
☐	MV21	closed	☐	IG1	$< 10^{-4}$ torr
☐	PV21	closed	☐	P2A	not in use
☐	MV22	open	☐	P3A	0 psig
☐	MV23	open	☐	P4A	40 psig
☐	MV24	closed and capped	☐	P5A	0 psig
☐	MV25	closed and capped	☐	P7	10 psig
☐	MV26	closed	☐	P8A	0 psid
☐	MV27	open	☐	P9A	0 psid
☐	MV28	open	☐	P10	not in use
☐	MV29	open	☐	GV1	open
☐	MV30	closed	☐	SV5	closed
☐	PV1	closed			

Note: This table assumes that step 15, backfilling the vacuum chamber, was not carried out

III.I. Purging hydrogen from the target loop

Initial state:

- [ ] MV1 .... closed
- [ ] MV1A .... closed
- [ ] MV1B .... closed
- [ ] MV1C .... closed
- [ ] MV1D .... closed
- [ ] MV2 .... closed
- [ ] MV3 .... closed
- [ ] MV4 .... closed
- [ ] MV5A .... closed
- [ ] MV5B .... closed
- [ ] MV6 .... closed
- [ ] MV7 .... closed
- [ ] MV8 .... closed, handle removed
- [ ] MV9 .... closed
- [ ] MV10 .... open
- [ ] MV11 .... closed
- [ ] PV12 .... closed
- [ ] MV12 .... closed
- [ ] SV13 .... closed
- [ ] MV13 .... closed
- [ ] MV14 .... closed
- [ ] MV15 .... closed
- [ ] MV16 .... open
- [ ] MV17 .... open
- [ ] MV18 .... open
- [ ] MV19 .... open
- [ ] MV20 .... closed
- [ ] MV21 .... closed
- [ ] PV21 .... closed
- [ ] MV22 .... open
- [ ] MV23 .... open
- [ ] MV24 .... closed and capped
- [ ] MV25 .... closed and capped
- [ ] MV26 .... closed
- [ ] MV27 .... open
- [ ] MV28 .... open
- [ ] MV29 .... open
- [ ] MV30 .... closed
- [ ] PV1 .... closed
- [ ] Hydrogen bottles .... all closed
- [ ] R1 .... 10 psig
- [ ] P1 .... not in use
- [ ] Helium bottles .... one open
- [ ] R6 .... 40 psig
- [ ] P6 .... 40 psig
- [ ] Target helium bottle .... closed
- [ ] R30 .... closed
- [ ] P30 .... not in use
- [ ] R14 .... 5 psig
- [ ] P14 .... 5 psig
- [ ] TWV .... To RD1 or RD2
- [ ] VP1 .... off and removed
- [ ] TC for VP1 .... not in use
- [ ] VP2 .... off and removed
- [ ] TC for VP2 .... not in use
- [ ] VP3 .... not in use
- [ ] TC for VP3 .... not in use
- [ ] VP4 .... on
- [ ] TC for VP4 .... < 300 mtorr
- [ ] VP5 .... off and removed
- [ ] TC for VP5 .... not in use
- [ ] Turbopump .... on
- [ ] Target loop pump .... off
- [ ] TC3 .... < 5 mtorr
- [ ] TC4 .... not in use
- [ ] TC7 .... not in use
- [ ] IG1 .... $< 10^{-4}$ torr
- [ ] P2A .... not in use
- [ ] P3A .... 0 psig
- [ ] P4A .... 40 psig
- [ ] P5A .... 0 psig
- [ ] P7 .... 10 psig
- [ ] P8A .... 0 psid
- [ ] P9A .... 0 psid
- [ ] P10 .... not in use
- [ ] GV1 .... open
- [ ] SV5 .... closed

III.I. Purging hydrogen from the target loop

1. The hydrogen must be removed from the target loop before working on the loop or putting it aside for a substantial length of time.
2. Make sure that the target loop has been warmed to room temperature as described in section H.
3. Confirm that all initial conditions for procedure I are met. They are the same as the final conditions for procedure H.
4. Re-install pump VP1 and turn it on.
5. Open valve PV21 at the master vacuum interlock box.
6. Close valves MV27 and MV28.
7. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.
8. Make sure all hydrogen bottles are closed, then open valves MV21, MV1, MV1A, MV1B, MV1C, MV1D, MV7, MV20 and MV12.
9. Gradually open valve MV2.
10. Wait until the pressure at gauge P1 has dropped to 0 psig, then open hydrogen regulator R1 by turning its handle fully clockwise.
11. Wait until the pressure at the thermocouple gauge for pump VP1 has reached 50 mtorr.
12. Close valves MV10 and MV29.

    First evacuation of target loop:

13. Gradually open valve MV4 to evacuate the target loop. Gauge P3A will go from 0 psig to 30 in. Hg. Gauge P8A will go from 0 psid to full scale helium excess.
14. Close helium regulator R6 by turning its handle fully counterclockwise.
15. Close valves MV2 and MV4.
16. Gradually open valve MV9 to pump out back to the helium regulator R6. Pump until the thermocouple gauge for pump VP1 reads 50 mtorr.
17. Close valve MV22.
18. Adjust the helium regulator R6 to 0 psig.
19. Close valve MV21.
20. Open valves MV2 and MV4.

    First backfill of target loop with helium:

21. Gradually open valve MV22 until gauge P8A goes from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.
22. Close valve MV22.

<u>Second evacuation of target loop</u>:

23. Gradually open valve MV21 to evacuate the target loop. Gauge P3A will go from 0 psig to 30 in. Hg. Gauge P8A will go from 0 psid to full scale helium excess.
24. Wait until the pressure at the thermocouple gauge for pump VP1 has reached 50 mtorr.
25. Close valve MV21.

<u>Second backfill of target loop with helium</u>:

26. Gradually open valve MV22 until gauge P8A goes from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.
27. Close valve MV22.
28. Close valve MV9.
29. Increase helium regulator R6 to 5 psig.
30. Open valves MV10 and MV11.
31. Crack open valve MV22 until gauge P5A reads 5 psig, and then close MV22. Gauge P8A will go to 5 psid helium excess.
32. Close valve MV10.
33. Open valves MV9 and MV13.
34. Crack open valve MV22 until you hear helium venting through check valve CV2, and then close MV22.
35. Close valve MV13.
36. Open valve MV29 to vent the helium cell down to 0 psig.
37. Open valve MV10 to equalize the pressures in the target loop and the helium cell.
38. Close pneumatic valve PV21 at the master vacuum interlock box.
39. Close valves MV1, MV1A, MV1B, MV1C and MV1D.
40. Turn off mechanical pump VP1 and vent it.
41. Close hydrogen regulator R1 by turning its handle fully counterclockwise.
42. Close the helium bottle valve.
43. Close helium regulator R6 by turning its handle fully counterclockwise.
44. Confirm that all final conditions for procedure I are met.
45. Go to procedure J to purge hydrogen from the ballast tank and backfill it with nitrogen.
46. Go to procedure K if you want to vent the vacuum chamber.

III.I. Purging hydrogen from the target loop

Final state:

- [ ] MV1 .... closed
- [ ] MV1A .... closed
- [ ] MV1B .... closed
- [ ] MV1C .... closed
- [ ] MV1D .... closed
- [ ] MV2 .... open
- [ ] MV3 .... closed
- [ ] MV4 .... open
- [ ] MV5A .... closed
- [ ] MV5B .... closed
- [ ] MV6 .... closed
- [ ] MV7 .... open
- [ ] MV8 .... closed, handle removed
- [ ] MV9 .... open
- [ ] MV10 .... open
- [ ] MV11 .... open
- [ ] PV12 .... closed
- [ ] MV12 .... open
- [ ] SV13 .... closed
- [ ] MV13 .... closed
- [ ] MV14 .... closed
- [ ] MV15 .... closed
- [ ] MV16 .... open
- [ ] MV17 .... open
- [ ] MV18 .... open
- [ ] MV19 .... open
- [ ] MV20 .... open
- [ ] MV21 .... closed
- [ ] PV21 .... closed
- [ ] MV22 .... closed
- [ ] MV23 .... open
- [ ] MV24 .... closed and capped
- [ ] MV25 .... closed and capped
- [ ] MV26 .... closed
- [ ] MV27 .... closed
- [ ] MV28 .... closed
- [ ] MV29 .... open
- [ ] MV30 .... closed
- [ ] PV1 .... closed
- [ ] Hydrogen bottles .... all closed
- [ ] R1 .... closed
- [ ] P1 .... not in use
- [ ] Helium bottles .... closed
- [ ] R6 .... closed
- [ ] P6 .... not in use
- [ ] Target helium bottle .... closed
- [ ] R30 .... closed
- [ ] P30 .... not in use
- [ ] R14 .... 5 psig
- [ ] P14 .... 5 psig
- [ ] TWV .... To RD1 or RD2
- [ ] VP1 .... off
- [ ] TC for VP1 .... not in use
- [ ] VP2 .... off and removed
- [ ] TC for VP2 .... not in use
- [ ] VP3 .... not in use
- [ ] TC for VP3 .... not in use
- [ ] VP4 .... on
- [ ] TC for VP4 .... < 300 mtorr
- [ ] VP5 .... off and removed
- [ ] TC for VP5 .... not in use
- [ ] Turbopump .... on
- [ ] Target loop pump .... off
- [ ] TC3 .... < 5 mtorr
- [ ] TC4 .... not in use
- [ ] TC7 .... not in use
- [ ] IG1 .... $< 10^{-4}$ torr
- [ ] P2A .... not in use
- [ ] P3A .... 0 psig
- [ ] P4A .... not in use
- [ ] P5A .... 0 psig
- [ ] P7 .... 10 psig
- [ ] P8A .... 0 psid
- [ ] P9A .... 0 psid
- [ ] P10 .... not in use
- [ ] GV1 .... open
- [ ] SV5 .... closed

III.J. Purging hydrogen from the ballast tank

Initial state:

- ☐ MV1 .... closed
- ☐ MV1A .... closed
- ☐ MV1B .... closed
- ☐ MV1C .... closed
- ☐ MV1D .... closed
- ☐ MV2 .... open
- ☐ MV3 .... closed
- ☐ MV4 .... open
- ☐ MV5A .... closed
- ☐ MV5B .... closed
- ☐ MV6 .... closed
- ☐ MV7 .... open
- ☐ MV8 .... closed, handle removed
- ☐ MV9 .... open
- ☐ MV10 .... open
- ☐ MV11 .... open
- ☐ PV12 .... closed
- ☐ MV12 .... open
- ☐ SV13 .... closed
- ☐ MV13 .... closed
- ☐ MV14 .... closed
- ☐ MV15 .... closed
- ☐ MV16 .... open
- ☐ MV17 .... open
- ☐ MV18 .... open
- ☐ MV19 .... open
- ☐ MV20 .... open
- ☐ MV21 .... closed
- ☐ PV21 .... closed
- ☐ MV22 .... closed
- ☐ MV23 .... open
- ☐ MV24 .... closed and capped
- ☐ MV25 .... closed and capped
- ☐ MV26 .... closed
- ☐ MV27 .... closed
- ☐ MV28 .... closed
- ☐ MV29 .... open
- ☐ MV30 .... closed
- ☐ PV1 .... closed
- ☐ Hydrogen bottles .... all closed
- ☐ R1 .... closed
- ☐ P1 .... not in use
- ☐ Helium bottles .... closed
- ☐ R6 .... closed
- ☐ P6 .... not in use
- ☐ Target helium bottle .... closed
- ☐ R30 .... closed
- ☐ P30 .... not in use
- ☐ R14 .... 5 psig
- ☐ P14 .... 5 psig
- ☐ TWV .... To RD1 or RD2
- ☐ VP1 .... off
- ☐ TC for VP1 .... not in use
- ☐ VP2 .... off and removed
- ☐ TC for VP2 .... not in use
- ☐ VP3 .... not in use
- ☐ TC for VP3 .... not in use
- ☐ VP4 .... on
- ☐ TC for VP4 .... < 300 mtorr
- ☐ VP5 .... off and removed
- ☐ TC for VP5 .... not in use
- ☐ Turbopump .... on
- ☐ Target loop pump .... off
- ☐ TC3 .... < 5 mtorr
- ☐ TC4 .... not in use
- ☐ TC7 .... not in use
- ☐ IG1 .... $< 10^{-4}$ torr
- ☐ P2A .... not in use
- ☐ P3A .... 0 psig
- ☐ P4A .... not in use
- ☐ P5A .... 0 psig
- ☐ P7 .... 10 psig
- ☐ P8A .... 0 psid
- ☐ P9A .... 0 psid
- ☐ P10 .... not in use
- ☐ GV1 .... open
- ☐ SV5 .... closed

III.J. Purging hydrogen from the ballast tank

1. Confirm that all initial conditions for procedure J have been met. They are the same as the final conditions for procedure I.
2. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.
3. Open valve PV1 and bleed the ballast tank down to 0 psig hydrogen as read on gauge P7.
4. Close valve PV1.
5. Install mechanical pump VP2 and turn it on.
6. Open valve MV8 and pump out the ballast tank to 100 mtorr as read on VP2's thermocouple gauge. The pressure on gauge P7 will drop from 0 psig to 30 in. Hg.
7. Close valve MV8.
8. Open valve MV26 and fill the ballast tank with nitrogen. Gauge P7 will go from 30 in. Hg to 0 psig.
9. Close valve MV26.
10. Turn off pump VP2 and remove it.
11. Confirm that all final conditions for procedure J are met.

III.J. Purging hydrogen from the ballast tank

Final state:

☐ MV1	closed	☐ Hydrogen bottles	all closed
☐ MV1A	closed	☐ R1	closed
☐ MV1B	closed	☐ P1	not in use
☐ MV1C	closed	☐ Helium bottles	closed
☐ MV1D	closed	☐ R6	closed
☐ MV2	open	☐ P6	not in use
☐ MV3	closed	☐ Target helium bottle	closed
☐ MV4	open	☐ R30	closed
☐ MV5A	closed	☐ P30	not in use
☐ MV5B	closed	☐ R14	5 psig
☐ MV6	closed	☐ P14	5 psig
☐ MV7	open	☐ TWV	To RD1 or RD2
☐ MV8	closed, handle removed	☐ VP1	off
☐ MV9	open	☐ TC for VP1	not in use
☐ MV10	open	☐ VP2	off and removed
☐ MV11	open	☐ TC for VP2	not in use
☐ PV12	closed	☐ VP3	not in use
☐ MV12	open	☐ TC for VP3	not in use
☐ SV13	closed	☐ VP4	on
☐ MV13	closed	☐ TC for VP4	$<$ 300 mtorr
☐ MV14	closed	☐ VP5	off and removed
☐ MV15	closed	☐ TC for VP5	not in use
☐ MV16	open	☐ Turbopump	on
☐ MV17	open	☐ Target loop pump	off
☐ MV18	open	☐ TC3	$<$ 5 mtorr
☐ MV19	open	☐ TC4	not in use
☐ MV20	open	☐ TC7	not in use
☐ MV21	closed	☐ IG1	$< 10^{-4}$ torr
☐ PV21	closed	☐ P2A	not in use
☐ MV22	closed	☐ P3A	0 psig
☐ MV23	open	☐ P4A	not in use
☐ MV24	closed and capped	☐ P5A	0 psig
☐ MV25	closed and capped	☐ P7	0 psig
☐ MV26	closed	☐ P8A	0 psid
☐ MV27	closed	☐ P9A	0 psid
☐ MV28	closed	☐ P10	not in use
☐ MV29	open	☐ GV1	open
☐ MV30	closed	☐ SV5	closed
☐ PV1	closed		

III.K. Venting the vacuum chamber

Initial state:

- ☐ MV1 .... closed
- ☐ MV1A .... closed
- ☐ MV1B .... closed
- ☐ MV1C .... closed
- ☐ MV1D .... closed
- ☐ MV2 .... open
- ☐ MV3 .... closed
- ☐ MV4 .... open
- ☐ MV5A .... closed
- ☐ MV5B .... closed
- ☐ MV6 .... closed
- ☐ MV7 .... open
- ☐ MV8 .... closed, handle removed
- ☐ MV9 .... open
- ☐ MV10 .... open
- ☐ MV11 .... open
- ☐ PV12 .... closed
- ☐ MV12 .... open
- ☐ SV13 .... closed
- ☐ MV13 .... closed
- ☐ MV14 .... closed
- ☐ MV15 .... closed
- ☐ MV16 .... open
- ☐ MV17 .... open
- ☐ MV18 .... open
- ☐ MV19 .... open
- ☐ MV20 .... open
- ☐ MV21 .... closed
- ☐ PV21 .... closed
- ☐ MV22 .... closed
- ☐ MV23 .... open
- ☐ MV24 .... closed and capped
- ☐ MV25 .... closed and capped
- ☐ MV26 .... closed
- ☐ MV27 .... closed
- ☐ MV28 .... closed
- ☐ MV29 .... open
- ☐ MV30 .... closed
- ☐ PV1 .... closed
- ☐ Hydrogen bottles .... all closed
- ☐ R1 .... closed
- ☐ P1 .... not in use
- ☐ Helium bottles .... closed
- ☐ R6 .... closed
- ☐ P6 .... not in use
- ☐ Target helium bottle .... closed
- ☐ R30 .... closed
- ☐ P30 .... not in use
- ☐ R14 .... 5 psig
- ☐ P14 .... 5 psig
- ☐ TWV .... To RD1 or RD2
- ☐ VP1 .... off
- ☐ TC for VP1 .... not in use
- ☐ VP2 .... off and removed
- ☐ TC for VP2 .... not in use
- ☐ VP3 .... not in use
- ☐ TC for VP3 .... not in use
- ☐ VP4 .... on
- ☐ TC for VP4 .... < 300 mtorr
- ☐ VP5 .... off and removed
- ☐ TC for VP5 .... not in use
- ☐ Turbopump .... on
- ☐ Target loop pump .... off
- ☐ TC3 .... < 5 mtorr
- ☐ TC4 .... not in use
- ☐ TC7 .... not in use
- ☐ IG1 .... $< 10^{-4}$ torr
- ☐ P2A .... not in use
- ☐ P3A .... 0 psig
- ☐ P4A .... not in use
- ☐ P5A .... 0 psig
- ☐ P7 .... 15 psig
- ☐ P8A .... 0 psid
- ☐ P9A .... 0 psid
- ☐ P10 .... not in use
- ☐ GV1 .... open
- ☐ SV5 .... closed

III.K. Venting the vacuum chamber

1. Backfill the target loop with helium as described in procedure I. Confirm that all initial conditions for procedure K are met. They are the same as the final conditions for procedure I.
2. Close gate valve SV5 from the master vacuum interlock box.
3. Bypass the interlock on the isolation valve controller.
4. Turn off the turbopump and mechanical pump VP4. Wait 30 minutes for the turbopump to spin down.
5. Vent the chamber with nitrogen by cracking open valve MV25 to a regulated nitrogen bottle. The chamber pressure may be monitored with the convection gauge.
6. Close valve MV25 after the chamber is filled with nitrogen.
7. Close gate valve GV1 to isolate the turbopump.
8. Blow air into the vacuum chamber before and during any human entry.
9. Confirm that all final conditions for procedure K are met.

III.K. Venting the vacuum chamber

Final state:

MV1	closed
MV1A	closed
MV1B	closed
MV1C	closed
MV1D	closed
MV2	open
MV3	closed
MV4	open
MV5A	closed
MV5B	closed
MV6	closed
MV7	open
MV8	closed, handle removed
MV9	open
MV10	open
MV11	open
PV12	closed
MV12	open
SV13	closed
MV13	closed
MV14	closed
MV15	closed
MV16	open
MV17	open
MV18	open
MV19	open
MV20	open
MV21	closed
PV21	closed
MV22	closed
MV23	open
MV24	closed and capped
MV25	closed and capped
MV26	closed
MV27	closed
MV28	closed
MV29	open
MV30	closed
PV1	closed

Hydrogen bottles	all closed
R1	0 psig
P1	not in use
Helium bottles	closed
R6	closed
P6	not in use
Target helium bottle	closed
R30	closed
P30	not in use
R14	5 psig
P14	5 psig
TWV	To RD1 or RD2
VP1	off
TC for VP1	not in use
VP2	off and removed
TC for VP2	not in use
VP3	not in use
TC for VP3	not in use
VP4	off
TC for VP4	not in use
VP5	off and removed
TC for VP5	not in use
Turbopump	off
Target loop pump	off
TC3	not in use
TC4	not in use
TC7	not in use
IG1	not in use
P2A	not in use
P3A	0 psig
P4A	not in use
P5A	0 psig
P7	15 psig
P8A	0 psid
P9A	0 psid
P10	not in use
GV1	closed
SV5	closed

III.L. Replenishing the target loop with hydrogen

Initial state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	open
☐	MV11	closed
☐	PV12	open
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	open
☐	MV19	open
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	open
☐	MV23	open
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	open
☐	MV28	open
☐	MV29	open
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	all closed
☐	R1	10 psig
☐	P1	not in use
☐	Helium bottles	one open
☐	R6	40 psig
☐	P6	40 psig
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	off and removed
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	< 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	on
☐	TC3	< 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	10 psig
☐	P4A	40 psig
☐	P5A	10 psig
☐	P7	10 psig
☐	P8A	0 psid
☐	P9A	> 0 psid
☐	P10	not in use
☐	GV1	open
☐	SV5	open for beam

III.L. Replenishing the target loop with hydrogen

1. If the target has warmed significantly due to refrigerator failure it may be necessary to replace hydrogen that has vented.
2. The target has been running as in section F.
3. Turn on the refrigerator to resume cooling the target.
4. Confirm that all initial conditions for section L are met. They are the same as the final conditions for section F.
5. Open one hydrogen bottle and its manifold valve. Hydrogen regulator R1 should still be set at 10 psig.
6. Open valve MV1. Gauge P2A should read 10 psig.
7. Open valve MV7 to admit hydrogen to the target.
8. Monitor the hydrogen and helium bottles to ensure they don't empty.
9. Close valve MV7 when the loop is full of liquid hydrogen.
10. Close valve MV1 and all hydrogen bottle and manifold valves.
11. Continue to monitor the helium bottle. Replace it when its pressure falls below 200 psig. See section G for this procedure.
12. The conditions are now the same as at the beginning of this procedure.
13. Confirm that all final conditions for procedure L are met.

III.L. Replenishing the target loop with hydrogen

Final state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	open
☐	MV11	closed
☐	PV12	open
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	open
☐	MV19	open
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	open
☐	MV23	open
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	open
☐	MV28	open
☐	MV29	open
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	all closed
☐	R1	10 psig
☐	P1	not in use
☐	Helium bottles	one open
☐	R6	40 psig
☐	P6	40 psig
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	off and removed
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	< 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	on
☐	TC3	< 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	10 psig
☐	P4A	40 psig
☐	P5A	10 psig
☐	P7	10 psig
☐	P8A	0 psid
☐	P9A	> 0 psid
☐	P10	not in use
☐	GV1	open
☐	SV5	open for beam

III.M. Evacuation and flushing of target and filling lines with helium

Initial state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	closed
☐	MV11	closed
☐	PV12	closed
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	closed
☐	MV19	closed
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	closed
☐	MV23	not in use
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	closed
☐	MV28	closed
☐	MV29	closed
☐	MV30	closed
☐	PV1	closed
☐	Hydrogen bottles	all closed
☐	R1	closed
☐	P1	not in use
☐	Helium bottles	both closed
☐	R6	closed
☐	P6	not in use
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	not in use
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	$<$ 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	off
☐	TC3	$<$ 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	not in use
☐	P4A	not in use
☐	P5A	not in use
☐	P7	0 psig
☐	P8A	not in use
☐	P9A	not in use
☐	P10	not in use
☐	GV1	open
☐	SV5	not in use

III.M. Evacuation and flushing of target and filling lines with helium

1. Confirm that all initial conditions for procedure M are met. They are the same as the final conditions for procedure D except that the ballast tank is filled with 0 psig nitrogen as read on P7.
2. The vacuum chamber must be under vacuum before proceding. The turbopump must be on with gate valve GV1 open. DO NOT pump on the target unless the vacuum chamber is at a pressure of 10^{-4} torr or less as read on ion gauge IG1.
3. Turn on mechanical pump VP1.
4. Open pneumatic valve PV21 at the master vacuum interlock box.
5. Open valves MV30, MV19, MV20, MV18, MV29 and MV23.
6. Open valve MV21. Gauge P10 will drop from 0 psig to 30 in. Hg.
7. Gradually open valve MV2.
8. Gradually open target helium regulator R30 by turning its handle fully clockwise. Wait until VP1's thermocouple gauge reaches 100 mtorr.

   <u>First evacuation of target loop</u>:

9. Gradually open valve MV4 to evacuate the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess.Gauge P3A will go from 0 to 30 in. Hg.
10. Open valves MV7 and MV12.
11. Gradually switch TWV to the other rupture disk.

    <u>First evacuation of helium cell</u>:

12. When VP1's thermocouple gauge reads 500 mtorr or less, gradually open valve MV6 to evacuate the helium cell. Gauge P8A will return to 0 psid. Gauge P5A will drop from 0 to 30 in. Hg.
13. Open solenoid valve SV13 for several seconds to pump out the space between it and check valve CV13. Push the button next to SV13 to do this.
14. Open valves MV10, MV11 and MV22.
15. Make sure both helium bottles are closed, then gradually open helium regulator R6 by turning its handle fully clockwise.
16. Open valve MV9.
17. Continue pumping on the target loop, helium cell and plumbing until VP1's thermocouple gauge reaches 100 mtorr.
18. Sequentially close and reopen valves MV30, MV2, MV7, MV21, MV4, MV19, MV20, MV18, MV12, MV22, MV9, MV10, MV11, MV6, MV29, MV17, MV16 and MV23 to pump out a small dead space in each valve.
19. Open and close valve MV3.

20. Close valves MV6, MV9 and MV22.

21. Close helium regulator R6 by turning its handle fully counterclockwise.

22. Open both helium bottle valves and adjust their regulator R6 to 0 psig.

23. Close the helium bottle valve that was not used in section III. A.

    First backfill of helium cell with helium:

24. Gradually open valve MV22 to fill the helium cell. Gauge P5A will go from 30 in. Hg to 0 psig. Gauge P8A will go from 0 psid to full scale helium excess.

25. Close valve MV22.

26. Close valves MV30 and MV21.

27. Close target helium regulator R30 by turning its handle fully counterclockwise.

28. Open the target helium bottle valve and adjust its regulator R30 to 0 psig.

    First backfill of target loop with helium:

29. Gradually open valve MV30 to fill the target loop with helium. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

30. Close valve MV30 when gauge P8A reaches 0 psid.

    Second evacuation of target loop:

31. Gradually open valve MV21 to pump out the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess.

32. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

33. Close valve MV21.

    Second backfill of target loop with helium:

34. Gradually open valve MV30 to fill the target loop with helium. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

35. Close valve MV30 when gauge P8A reaches 0 psid.

    Third evacuation of target loop:

36. Gradually open valve MV21 to pump out the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess.

37. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

38. Close valves MV2 and MV4.

    Second evacuation of helium cell:

39. Gradually open valve MV9 to pump out the helium cell and plumbing. Gauge P8A will go from full scale helium excess to 0 psid.

40. Close valve MV9 when VP1's thermocouple gauge has reached 100 mtorr.

    Second backfill of helium cell with helium:

41. Gradually open valve MV22 to fill the helium cell with helium. Gauge P8A will go from 0 to full scale helium excess.

42. Close valve MV22.

    Third evacuation of helium cell:

43. Gradually open valve MV9 to pump out the helium cell and plumbing. Gauge P8A will go from full scale helium excess to 0 psid.

44. Gradually open valves MV2 and MV4 to resume pumping on the target loop. Monitor gauge P8A to ensure it never goes to hydrogen excess while opening these valves.

45. Confirm that all final conditions for procedure M are met.

III.M. Evacuation and flushing of target and filling lines with helium

Final state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	open
☐	MV3	closed
☐	MV4	open
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	open
☐	MV8	closed, handle removed
☐	MV9	open
☐	MV10	open
☐	MV11	open
☐	PV12	closed
☐	MV12	open
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	open
☐	MV19	open
☐	MV20	open
☐	MV21	open
☐	PV21	open
☐	MV22	closed
☐	MV23	open
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	closed
☐	MV28	closed
☐	MV29	open
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	closed
☐	R1	closed
☐	P1	not in use
☐	Helium bottles	one open
☐	R6	0 psig
☐	P6	0 psig
☐	Target helium bottle	open
☐	R30	0 psig
☐	P30	0 psig
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	on
☐	TC for VP1	$<$ 100 mtorr
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	$<$ 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	off
☐	TC3	$<$ 5 mtorr
☐	TC4	$<$ 100 mtorr
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	30 in. Hg
☐	P3A	30 in. Hg
☐	P4A	30 in. Hg
☐	P5A	30 in. Hg
☐	P7	0 psig
☐	P8A	0 psid
☐	P9A	0 psid
☐	P10	30 in. Hg
☐	GV1	open
☐	SV5	not in use

III.N. Filling and cooling the target with helium

Initial state:

- [ ] MV1 .... closed
- [ ] MV1A .... closed
- [ ] MV1B .... closed
- [ ] MV1C .... closed
- [ ] MV1D .... closed
- [ ] MV2 .... open
- [ ] MV3 .... closed
- [ ] MV4 .... open
- [ ] MV5A .... closed
- [ ] MV5B .... closed
- [ ] MV6 .... closed
- [ ] MV7 .... open
- [ ] MV8 .... closed, handle removed
- [ ] MV9 .... open
- [ ] MV10 .... open
- [ ] MV11 .... open
- [ ] PV12 .... closed
- [ ] MV12 .... open
- [ ] SV13 .... closed
- [ ] MV13 .... closed
- [ ] MV14 .... closed
- [ ] MV15 .... closed
- [ ] MV16 .... open
- [ ] MV17 .... open
- [ ] MV18 .... open
- [ ] MV19 .... open
- [ ] MV20 .... open
- [ ] MV21 .... open
- [ ] PV21 .... open
- [ ] MV22 .... closed
- [ ] MV23 .... open
- [ ] MV24 .... closed and capped
- [ ] MV25 .... closed and capped
- [ ] MV26 .... closed
- [ ] MV27 .... closed
- [ ] MV28 .... closed
- [ ] MV29 .... open
- [ ] MV30 .... closed
- [ ] PV1 .... closed
- [ ] Hydrogen bottles .... closed
- [ ] R1 .... closed
- [ ] P1 .... not in use
- [ ] Helium bottles .... one open
- [ ] R6 .... 0 psig
- [ ] P6 .... 0 psig
- [ ] Target helium bottle .... open
- [ ] R30 .... 0 psig
- [ ] P30 .... 0 psig
- [ ] R14 .... 5 psig
- [ ] P14 .... 5 psig
- [ ] TWV .... To RD1 or RD2
- [ ] VP1 .... on
- [ ] TC for VP1 .... < 100 mtorr
- [ ] VP2 .... off and removed
- [ ] TC for VP2 .... not in use
- [ ] VP3 .... not in use
- [ ] TC for VP3 .... not in use
- [ ] VP4 .... on
- [ ] TC for VP4 .... < 300 mtorr
- [ ] VP5 .... off and removed
- [ ] TC for VP5 .... not in use
- [ ] Turbopump .... on
- [ ] Target loop pump .... off
- [ ] TC3 .... < 5 mtorr
- [ ] TC4 .... < 100 mtorr
- [ ] TC7 .... not in use
- [ ] IG1 .... $< 10^{-4}$ torr
- [ ] P2A .... 30 in. Hg
- [ ] P3A .... 30 in. Hg
- [ ] P4A .... 30 in. Hg
- [ ] P5A .... 30 in. Hg
- [ ] P7 .... 0 psig
- [ ] P8A .... 0 psid
- [ ] P9A .... 0 psid
- [ ] P10 .... 30 in. Hg
- [ ] GV1 .... open
- [ ] SV5 .... not in use

III.N. Filling and cooling the target with helium

1. Evacuate and flush the target and filling lines with helium as described in section M.
2. Confirm that all initial conditions for section N are met. They are the same as the final conditions for section M.
3. Close valves MV9, MV2 and MV4.
4. Open valve MV3.

Fill helium cell to one absolute atmosphere of helium:

5. Gradually open valve MV22 to fill the helium cell. Gauge P5A will go from vacuum to 0 psig. Gauge P8A will go from 0 psid to full scale helium excess.
6. Close valve MV22.
7. Close valve MV21.
8. Close pneumatic valve PV21 at the master vacuum interlock box.
9. Turn off mechanical pump VP1 and vent it.
10. Remove mechanical pump VP1 and cap off the inlet to pneumatic valve PV21.

Fill target loop to one absolute atmosphere helium:

11. Gradually open valve MV30 to reduce gauge P8A from full scale helium excess to 0 psid. DO NOT let gauge P8A go to "hydrogen" excess.
12. Close valve MV30.
13. Increase the helium regulator R6 to 15 psig.
14. Close valve MV29.

Fill helium cell to two absolute atmospheres helium:

15. Gradually open valve MV22 until gauge P5A increases from 0 to 15 psig. Gauge P8A will go from 0 to full scale helium excess. Do not close MV22.
16. Increase the target helium regulator R30 to 15 psig.

Fill target loop to two absolute atmospheres helium:

17. Gradually open valve MV30 until gauge P8A is reduced from full scale to 0 psid helium excess, and then close valve MV30. DO NOT let gauge P8A go to "hydrogen" excess.
18. Close valve MV11.
19. Increase the helium regulator R6 to 40 psig.
20. Gradually open valve MV29. You may hear some helium vent through check valve CV6. This is OK.
21. Open valve MV30. Increase the output pressure on the target helium regulator R30 if necessary to get gauge P2A up to 15 psig. Do not close MV30.

22. Close valve MV20.

    Cooling the target loop:

23. Turn on the target loop pump.
24. Cool the target loop with the refrigerator as described in section IV. As the loop cools helium will be drawn from the target helium bottle to maintain 15 psig in the loop.
25. Open gate valve SV5 before putting beam on the target.
26. Continue to monitor the helium bottle. Replace it when its pressure falls below 200 psig. See section G for this procedure.
27. Confirm that all final conditions for procedure N are met.

    NOTE: If the helium in the target is to be replaced with hydrogen while the target is cold (procedure O), the ballast tank should be evacuated in preparation for a hydrogen fill. Install mechanical pump VP2, open valve MV8, and pump on the ballast tank for the duration of the helium run.

III.N. Filling and cooling the target with helium

Final state:

☐	MV1	☐	closed
☐	MV1A	☐	closed
☐	MV1B	☐	closed
☐	MV1C	☐	closed
☐	MV1D	☐	closed
☐	MV2	☐	closed
☐	MV3	☐	open
☐	MV4	☐	closed
☐	MV5A	☐	closed
☐	MV5B	☐	closed
☐	MV6	☐	closed
☐	MV7	☐	open
☐	MV8	☐	closed, handle removed
☐	MV9	☐	closed
☐	MV10	☐	open
☐	MV11	☐	closed
☐	PV12	☐	closed
☐	MV12	☐	open
☐	SV13	☐	closed
☐	MV13	☐	closed
☐	MV14	☐	closed
☐	MV15	☐	closed
☐	MV16	☐	open
☐	MV17	☐	open
☐	MV18	☐	open
☐	MV19	☐	open
☐	MV20	☐	closed
☐	MV21	☐	closed
☐	PV21	☐	closed
☐	MV22	☐	open
☐	MV23	☐	open
☐	MV24	☐	closed and capped
☐	MV25	☐	closed and capped
☐	MV26	☐	closed
☐	MV27	☐	closed
☐	MV28	☐	closed
☐	MV29	☐	open
☐	MV30	☐	open
☐	PV1	☐	closed

☐	Hydrogen bottles	all closed
☐	R1	closed
☐	P1	not in use
☐	Helium bottles	one open
☐	R6	40 psig
☐	P6	40 psig
☐	Target helium bottle	open
☐	R30	15 psig
☐	P30	15 psig
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	off and removed
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	$<$ 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	on
☐	TC3	$<$ 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	15 psig
☐	P4A	40 psig
☐	P5A	15 psig
☐	P7	0 psig
☐	P8A	0 psid
☐	P9A	$>$ 0 psid
☐	P10	not in use
☐	GV1	open
☐	SV5	open for beam

III.O. Replacing helium with hydrogen while the target is cold

Initial state:

☐	MV1	closed	☐	Hydrogen bottles	all closed
☐	MV1A	closed	☐	R1	closed
☐	MV1B	closed	☐	P1	not in use
☐	MV1C	closed	☐	Helium bottles	one open
☐	MV1D	closed	☐	R6	40 psig
☐	MV2	closed	☐	P6	40 psig
☐	MV3	open	☐	Target helium bottle	open
☐	MV4	closed	☐	R30	15 psig
☐	MV5A	closed	☐	P30	15 psig
☐	MV5B	closed	☐	R14	5 psig
☐	MV6	closed	☐	P14	5 psig
☐	MV7	open	☐	TWV	To RD1 or RD2
☐	MV8	open	☐	VP1	off and removed
☐	MV9	closed	☐	TC for VP1	not in use
☐	MV10	open	☐	VP2	on
☐	MV11	closed	☐	TC for VP2	$\leq$ 100 mtorr
☐	PV12	closed	☐	VP3	not in use
☐	MV12	open	☐	TC for VP3	not in use
☐	SV13	closed	☐	VP4	on
☐	MV13	closed	☐	TC for VP4	$<$ 300 mtorr
☐	MV14	closed	☐	VP5	off and removed
☐	MV15	closed	☐	TC for VP5	not in use
☐	MV16	open	☐	Turbopump	on
☐	MV17	open	☐	Target loop pump	on
☐	MV18	open	☐	TC3	$<$ 5 mtorr
☐	MV19	open	☐	TC4	not in use
☐	MV20	closed	☐	TC7	$\leq$ 100 mtorr
☐	MV21	closed	☐	IG1	$< 10^{-4}$ torr
☐	PV21	closed	☐	P2A	not in use
☐	MV22	open	☐	P3A	15 psig
☐	MV23	open	☐	P4A	40 psig
☐	MV24	closed and capped	☐	P5A	15 psig
☐	MV25	closed and capped	☐	P7	30 in. Hg
☐	MV26	closed	☐	P8A	0 psid
☐	MV27	closed	☐	P9A	$>$ 0 psid
☐	MV28	closed	☐	P10	not in use
☐	MV29	open	☐	GV1	open
☐	MV30	open	☐	SV5	open for beam
☐	PV1	closed			

III.O. Replacing helium with hydrogen while the target is cold

1. The target is filled with circulating helium as described in section N.
2. Turn off the beam and set the interlock so beam may not be put on the target.
3. Take the target heater out of automatic control and slowly turn the heater down to 0 in steps of 100 W.
4. Turn off the target heater voltage.

   At this point it will be necessary to enter the North Hall. Install the target computer there. Turn on the beacon at the entrance to indicate hydrogen will be in the hall.
5. Confirm that all initial conditions for procedure O are met. They are the same as the final conditions for section N except that valve MV8 is open and mechanical pump VP2 is pumping on the ballast tank.
6. Close gate valve SV5 from the master vacuum interlock box.
7. Close valves MV30, MV3 and the target helium bottle valve.
8. Close the target helium regulator R30 by turning its handle fully counterclockwise.
9. Close valve MV8. Remove its handle.
10. Turn off mechanical pump VP2 and remove it.
11. Reinstall mechanical pump VP1 and turn it on.
12. Open pneumatic valve PV21 at the master vacuum interlock box.
13. Open valves MV2 and MV21. Gauge P10 will go to 30 in. Hg.
14. Make sure all the hydrogen bottles are closed, then open valves MV1A, MV1B, MV1C and MV1D.
15. Open valve MV1.
16. Open hydrogen regulator R1 by turning its handle fully clockwise. Continue pumping until pump VP1's thermocouple gauge reaches 100 mtorr.
17. Close valves MV2, MV1, MV1B, MV1C and MV1D.
18. Close hydrogen regulator R1 by turning its handle fully counterclockwise.
19. Open the hydrogen bottle attached to manifold valve MV1A.
20. Adjust hydrogen regulator R1 to 10 psig.
21. Open valve MV28.

<u>Fill ballast tank with its full charge of hydrogen</u>:

22. Open valve MV1 to fill the evacuated ballast tank to 10 psig hydrogen as read on gauge P2A. Switch to another hydrogen bottle if the one in use gets below 100 psig.

23. Close valves MV1, MV7 and MV28.

24. Close hydrogen regulator R1 and all hydrogen bottles and their associated manifold valves. Replace any bottles that have been emptied as described in section C.

<u>Warm the target to 80K</u>:

25. Reset the refrigerator temperature setpoint to 80K. As the target warms, its pressure will increase. When the target pressure reaches 17 psig, pressure switch PSU will cause solenoid valve SV13 to open and the target will begin to vent. SV13 will close when the target pressure drops to 14 psig.

    <u>NOTE</u>: When the target temperature is approximately 30 K, the vacuum chamber pressure will rise by about a factor of 10–50 from its cold value. The vacuum should improve as the target warms past this point. Bypass the turbopump interlock if it looks like the ion gauge may trip off due to high pressure. If thermocouple gauge TC3 gets too high, pneumatic valve PV21 may close.

26. Change the helium bottle going to the helium cell if the bottle pressure drops below 200 psig. See section G for instructions.

27. Turn off the target loop pump when the target temperature has reached 80K.

28. Slightly crack open valve MV13. Gauge P3A will drop from 15 psig to 0 psig. Gauge P5A will do the same.

29. Close valve MV13.

30. Open valves MV20 and MV7.

<u>First evacuation of target loop</u>:

31. Gradually open valve MV4 to evacuate the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess. Gauge P3A will go from 0 to 30 in. Hg.

32. Gradually open valves MV2 and MV1. Wait until VP1's thermocouple gauge reaches 100 mtorr.

33. Close helium regulator R6 by turning its handle fully counterclockwise.

34. Gradually open valve MV9. Gauge P6 will drop from 40 psig to 30 in. Hg.

35. Close valves MV22 and MV9.

36. Adjust helium regulator R6 to 0 psig.

37. Open valve MV22.

38. Open solenoid valve SV13 for several seconds to pump out the space between it and check valve CV13. Push the button next to SV13 to do this.

39. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

40. Close valves MV21 and MV1.

41. Open valves MV1A, MV1B, MV1C and MV1D.

42. Open the hydrogen bottle connected to valve MV1A and adjust its regulator R1 to 0 psig.

43. Close valves MV1B, MV1C and MV1D.

<u>First backfill of target loop with hydrogen</u>:

44. Gradually open valve MV1 to fill the target loop with hydrogen. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

45. Close valve MV1 when gauge P8A reaches 0 psid.

46. Open solenoid valve SV13 momentarily to introduce hydrogen to the space between it and check valve CV13. Push the button next to SV13 to do this.

47. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.

<u>Second evacuation of target loop</u>:

48. Gradually open valve MV21 to evacuate the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess. Gauge P3A will go from 0 to 30 in. Hg.

49. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

50. Close valve MV21.

<u>Second backfill of target loop</u>:

51. Gradually open valve MV1 to fill the target loop with hydrogen. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

52. Close valve MV1 when gauge P8A reaches 0 psid.

<u>Third evacuation of target loop</u>:

53. Gradually open valve MV21 to evacuate the target loop and plumbing. Gauge P8A will go from 0 to full scale helium excess. Gauge P3A will go from 0 to 30 in. Hg.

54. Continue pumping on the target loop and plumbing until VP1's thermocouple gauge reaches 100 mtorr.

55. Close valve MV21.

<u>Third backfill of target loop</u>:

56. Gradually open valve MV1 to fill the target loop with hydrogen. Gauge P8A will go from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.

57. Close valve MV1 when gauge P8A reaches 0 psid.

58. Close valves MV22 and MV29.

59. Open valve MV11.

60. Adjust helium regulator R6 to 10 psig.

Fill helium cell to two absolute atmospheres helium:

61. Gradually open valve MV22 until gauge P5A increases from 0 to 10 psig. Gauge P8A will go from 0 to 10 psid helium excess. Do not close MV22.

62. Increase the hydrogen regulator R1 to 10 psig.

63. Close valve MV20.

64. Turn on the target loop pump.

Fill target loop to two absolute atmospheres hydrogen:

65. Gradually open valve MV1 until gauge P8A is reduced from full scale helium excess to 0 psid, and then close MV1. DO NOT let gauge P8A go to hydrogen excess.

66. Close valve MV11.

67. Increase the helium regulator R6 to 40 psig.

68. Gradually open valve MV29. You may hear some helium vent through check valve CV6. This is OK.

69. Open valve MV1. Increase the output pressure on hydrogen regulator R1 if necessary to get gauge P2A up to 10 psig. Do not close MV1.

70. Gradually open valve MV27. This will equalize the hydrogen pressures in the target loop and the ballast tank.

71. Open valve MV28.

72. Close valve MV2 and MV4.

Resume cooling the target loop:

73. Open the liquid nitrogen supply valve and set the refrigerator fill switch to "automatic." Change the temperature setpoint of the refrigerator to 25 K. As the loop cools, hydrogen will be drawn from the bottle to maintain 10 psig in the loop. When a hydrogen bottle has less than 200 psig, close its valve and its manifold valve and switch to another bottle. Put an "empty" bottle tag on the depleted bottle.

74. Close pneumatic valve PV21.

75. Turn off mechanical pump VP1 and vent it.

76. Remove pump VP1 and cap off the inlet to pneumatic valve PV21.

77. When the target loop temperatures are all 25 K, reduce the temperature setpoint of the refrigerator to 24.5 K. After the loop temperatures equilibrate, reduce the setpoint to 24 K. Continue in this manner to 21.5 K, when liquification will begin.

Signs that the target is full:

a) Consumption of hydrogen levels off. This is monitored on the computer as the hydrogen bottle pressure (P12) vs. time.

b) The loop pressure (P2B) will rise to, or above, the hydrogen regulator pressure (P1) before filling began.

c) The refrigerator heater power will rise to ~700 W.

78. Close valve MV7 when the loop is full of liquid hydrogen. Change the refrigerator setpoint to 19.8 K. Set the engine speed to 220 rpm.
79. Cooling to 19.8 K will reduce the loop pressure. Restore it by opening valve MV7 as long as necessary, and then close MV7.
80. Open pneumatic valve PV12 at the master vacuum interlock box.
81. Close valve MV12.
82. Close valve MV1 and the hydrogen bottle valve.
83. Close all valves on the hydrogen manifold.
84. Open gate valve SV5 before putting beam on the target and enable the target heater.
85. Continue to monitor the helium bottle. Replace it when its pressure falls below 200 psig. See section G for this procedure.
86. Confirm that all final conditions for procedure O are met.

III.O. Replacing helium with hydrogen while the target is cold

Final state:

☐	MV1	closed	☐	Hydrogen bottles	all closed
☐	MV1A	closed	☐	R1	15 psig
☐	MV1B	closed	☐	P1	not in use
☐	MV1C	closed	☐	Helium bottles	one open
☐	MV1D	closed	☐	R6	40 psig
☐	MV2	closed	☐	P6	40 psig
☐	MV3	closed	☐	Target helium bottle	closed
☐	MV4	closed	☐	R30	closed
☐	MV5A	closed	☐	P30	not in use
☐	MV5B	closed	☐	R14	5 psig
☐	MV6	closed	☐	P14	5 psig
☐	MV7	closed	☐	TWV	To RD1 or RD2
☐	MV8	closed, handle removed	☐	VP1	off and removed
☐	MV9	closed	☐	TC for VP1	not in use
☐	MV10	open	☐	VP2	off and removed
☐	MV11	closed	☐	TC for VP2	not in use
☐	PV12	open	☐	VP3	not in use
☐	MV12	closed	☐	TC for VP3	not in use
☐	SV13	closed	☐	VP4	on
☐	MV13	closed	☐	TC for VP4	< 300 mtorr
☐	MV14	closed	☐	VP5	off and removed
☐	MV15	closed	☐	TC for VP5	not in use
☐	MV16	open	☐	Turbopump	on
☐	MV17	open	☐	Target loop pump	on
☐	MV18	open	☐	TC3	< 5 mtorr
☐	MV19	open	☐	TC4	not in use
☐	MV20	closed	☐	TC7	not in use
☐	MV21	closed	☐	IG1	$< 10^{-4}$ torr
☐	PV21	closed	☐	P2A	not in use
☐	MV22	open	☐	P3A	10 psig
☐	MV23	open	☐	P4A	40 psig
☐	MV24	closed and capped	☐	P5A	10 psig
☐	MV25	closed and capped	☐	P7	10 psig
☐	MV26	closed	☐	P8A	0 psid
☐	MV27	open	☐	P9A	> 0 psid
☐	MV28	open	☐	P10	not in use
☐	MV29	open	☐	GV1	open
☐	MV30	closed	☐	SV5	open for beam
☐	PV1	closed			

III.P. Replacing hydrogen with helium while the target is cold.

Initial state:

☐	MV1	closed
☐	MV1A	closed
☐	MV1B	closed
☐	MV1C	closed
☐	MV1D	closed
☐	MV2	closed
☐	MV3	closed
☐	MV4	closed
☐	MV5A	closed
☐	MV5B	closed
☐	MV6	closed
☐	MV7	closed
☐	MV8	closed, handle removed
☐	MV9	closed
☐	MV10	open
☐	MV11	closed
☐	PV12	open
☐	MV12	closed
☐	SV13	closed
☐	MV13	closed
☐	MV14	closed
☐	MV15	closed
☐	MV16	open
☐	MV17	open
☐	MV18	open
☐	MV19	open
☐	MV20	closed
☐	MV21	closed
☐	PV21	closed
☐	MV22	open
☐	MV23	open
☐	MV24	closed and capped
☐	MV25	closed and capped
☐	MV26	closed
☐	MV27	open
☐	MV28	open
☐	MV29	open
☐	MV30	closed
☐	PV1	closed

☐	Hydrogen bottles	all closed
☐	R1	15 psig
☐	P1	not in use
☐	Helium bottles	one open
☐	R6	40 psig
☐	P6	40 psig
☐	Target helium bottle	closed
☐	R30	closed
☐	P30	not in use
☐	R14	5 psig
☐	P14	5 psig
☐	TWV	To RD1 or RD2
☐	VP1	off and removed
☐	TC for VP1	not in use
☐	VP2	off and removed
☐	TC for VP2	not in use
☐	VP3	not in use
☐	TC for VP3	not in use
☐	VP4	on
☐	TC for VP4	$<$ 300 mtorr
☐	VP5	off and removed
☐	TC for VP5	not in use
☐	Turbopump	on
☐	Target loop pump	on
☐	TC3	$<$ 5 mtorr
☐	TC4	not in use
☐	TC7	not in use
☐	IG1	$< 10^{-4}$ torr
☐	P2A	not in use
☐	P3A	10 psig
☐	P4A	40 psig
☐	P5A	10 psig
☐	P7	10 psig
☐	P8A	0 psid
☐	P9A	$>$ 0 psid
☐	P10	not in use
☐	GV1	open
☐	SV5	open for beam

III.P. Replacing hydrogen with helium while the target is cold.

1. The target is filled with circulating liquid hydrogen as described in section F or O.
2. Turn off the beam and set the interlock so beam may not be put on the target.
3. Take the target heater out of automatic control and slowly turn the heater down to 0 in steps of 100 W.
4. Turn off the target heater voltage.

   At this point it will be necessary to enter the North Hall. Install the target computer there. Turn on the beacon at the entrance to indicate hydrogen is in the hall.

5. Confirm that all initial conditions for procedure H are met. They are the same as the final conditions for section F or O.
6. Close gate valve SV5 from the master vacuum interlock box.
7. Close off the refrigerator LN_2 supply by turning off LC-1 and closing the supply valve V806. Also close the LN_2 tank supply valve.

   NOTE: The target circulating pump should be ON ($>$ 20 Hz) during the boiloff process. If the pump has shut off for some reason, DO NOT turn the pump back on until the liquid has completely boiled away. If the pump is turned on in the middle of the boiloff process it may cause a sudden pressure surge and damage the He cell.

8. Open the refrigerator bypass valve V360 fully. Some helium will continue to flow to the target loop but most will go back to the compressor. The target should immediately begin to warm up.
9. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.
10. Close V361 approximately 4 turns so that it is open about $\frac{1}{2}$ turn. Watch the pressure in the target either on the computer screen or at gauge P3A on the gas panel. As the target starts to boil its pressure will increase. When the target pressure reaches 17 psig, pressure switch PSU will cause solenoid valve SV13 to open and the target should begin to vent. The target pressure should stabilize once SV13 is open. **If the target pressure continues to rise**, open V361 a little more to send more cooling to the target. Use V361 as a throttle valve to control the boiloff rate of the target. A full target should take no less than 20 minutes to boil completely away. When the target has completed boiling the pressure will quickly drop. SV13 will close when the target pressure drops to 14 psig.
11. Close pneumatic valve PV12 after the target has stopped boiling and SV13 is closed.
12. Once all liquid has boiled away, the target will slowly warm up. This process may be accelerated by turning on the target heater to 50–100 watts.
13. Change the helium bottle going to the helium cell if the bottle pressure drops below 200 psig (see section III.G to change the helium bottle).

   NOTE: When the target temperature is approximately 30 K, the vacuum chamber pressure will rise by about a factor of 10–50 from its cold value. As the target continues to warm the vacuum should return to the warm value.

14. When the target reaches 100 K, set the target heater to 0 W and turn off the power supply. Reset the refrigerator set point to 80 K.

15. Slightly crack open valve MV13. Gauge P3A will drop from 15 psig to 0 psig.

16. Close valve MV13.

17. Re-install pump VP1 and turn it on.

18. Open valve PV21 at the master vacuum interlock box.

19. Close valves MV27 and MV28.

20. Notify the chief operator that the hydrogen sniffer in the vent line will be detecting hydrogen.

21. Make sure all hydrogen bottles are closed, then open valves MV21, MV1, MV1A, MV1B, MV1C, MV1D, MV7, MV20 and MV12.

22. Gradually open valve MV2.

23. Wait until the pressure at gauge P1 has dropped to 0 psig, then open hydrogen regulator R1 by turning its handle fully clockwise.

24. Turn off the loop pump.

25. Wait until the pressure at the thermocouple gauge for pump VP1 has reached 50 mtorr.

26. Make sure target helium regulator R30 is closed by turning its handle fully counterclockwise.

<u>First evacuation of target loop</u>:

27. Gradually open valve MV4 to evacuate the target loop. Gauge P3A will go from 0 psig to 30 in. Hg. Gauge P8A will go from 0 psid to full scale helium excess.

28. Open valve MV30.

29. Pump until the thermocouple gauge for pump VP1 reads 50 mtorr, then close valve MV21.

30. Close valve MV30.

31. Open the target helium bottle and set its regulator R30 to 0 psig.

<u>First backfill of target loop with helium</u>:

32. Gradually open valve MV30 until gauge P8A goes from full scale helium excess to 10 psid. DO NOT let gauge P8A go to hydrogen excess.

33. Close valve MV30.

<u>Second evacuation of target loop</u>:

34. Gradually open valve MV21 to evacuate the target loop. Gauge P3A will go from 20 in. Hg. to 30 in. Hg. Gauge P8A will go from 10 psid to full scale helium excess.

35. Wait until the pressure at the thermocouple gauge for pump VP1 has reached 50 mtorr.

36. Close valve MV21.

Second backfill of target loop with helium:

37. Gradually open valve MV30 until gauge P8A goes from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.
38. Close valve MV30.

Third evacuation of target loop:

39. Gradually open valve MV21 to evacuate the target loop. Gauge P3A will go from 20 in. Hg to 30 in Hg. Gauge P8A will go from 10 psid to full scale helium excess.
40. Wait until the pressure at the thermocouple gauge for pump VP1 has reached 50 mtorr.
41. Close valve MV21.

Third backfill of target loop with helium:

42. Open valve MV30 until gauge P8A goes from full scale helium excess to 0 psid. DO NOT let gauge P8A go to hydrogen excess.
43. Close valve MV30.
44. Close valves MV1, MV1A, MV1B, MV1C and MV1D.
45. Close hydrogen regulator R1 by turning its handle fully counterclockwise.
46. Close valve MV22.
47. Gradually open valve MV11 to bleed gauge P4A down to 0 psig.
48. Close valve MV29.
49. Gradually crack open valve MV22 until gauge P8A reads 15 psid, then close valve MV22.
50. Close valve MV11.
51. Set target helium regulator R30 to 10 psig.
52. Open valve MV30. Gauge P8A will go to 5 psid helium excess. DO NOT let gauge P8A go to hydrogen excess. Do not close valve MV30.
53. Open valve MV29.
54. Open valve MV22.
55. Close valve MV20.
56. Open valve MV3.
57. Close valves MV2, MV4 and pneumatic valve PV21.
58. Turn on the target loop pump.
59. Open refrigerator valve V361 fully.
60. Close refrigerator bypass valve V360.

Resume cooling the target loop:

61. Reset the refrigerator setpoint to 20 K and resume cooling the target. As the loop cools gauge P9A will rise very slowly.

62. Turn off mechanical pump VP1 and remove it. Cap the inlet to pneumatic valve PV21.

63. Open gate valve PV5 before putting beam on the target.

64. Continue to monitor the helium bottle. Replace it when its pressure falls below 200 psig. See section G for this procedure.

65. Purge the ballast tank of hydrogen if no further hydrogen running is contemplated. See section J for these instructions.

66. Confirm that all final conditions for procedure P are met.

III.P. Replacing hydrogen with helium while the target is cold.

Final state:

- ☐ MV1 .... closed
- ☐ MV1A .... closed
- ☐ MV1B .... closed
- ☐ MV1C .... closed
- ☐ MV1D .... closed
- ☐ MV2 .... closed
- ☐ MV3 .... open
- ☐ MV4 .... closed
- ☐ MV5A .... closed
- ☐ MV5B .... closed
- ☐ MV6 .... closed
- ☐ MV7 .... open
- ☐ MV8 .... closed, handle removed
- ☐ MV9 .... closed
- ☐ MV10 .... open
- ☐ MV11 .... closed
- ☐ PV12 .... closed
- ☐ MV12 .... open
- ☐ SV13 .... closed
- ☐ MV13 .... closed
- ☐ MV14 .... closed
- ☐ MV15 .... closed
- ☐ MV16 .... open
- ☐ MV17 .... open
- ☐ MV18 .... open
- ☐ MV19 .... open
- ☐ MV20 .... closed
- ☐ MV21 .... closed
- ☐ PV21 .... closed
- ☐ MV22 .... open
- ☐ MV23 .... open
- ☐ MV24 .... closed and capped
- ☐ MV25 .... closed and capped
- ☐ MV26 .... closed
- ☐ MV27 .... closed
- ☐ MV28 .... closed
- ☐ MV29 .... open
- ☐ MV30 .... open
- ☐ PV1 .... closed
- ☐ Hydrogen bottles .... all closed
- ☐ R1 .... closed
- ☐ P1 .... not in use
- ☐ Helium bottles .... one open
- ☐ R6 .... 40 psig
- ☐ P6 .... 40 psig
- ☐ Target helium bottle .... open
- ☐ R30 .... 10 psig
- ☐ P30 .... 10 psig
- ☐ R14 .... 5 psig
- ☐ P14...................... 5 psig
- ☐ TWV..................... To RD1 or RD2
- ☐ VP1...................... off and removed
- ☐ TC for VP1.............. not in use
- ☐ VP2...................... off and removed
- ☐ TC for VP2.............. not in use
- ☐ VP3...................... not in use
- ☐ TC for VP3.............. not in use
- ☐ VP4...................... on
- ☐ TC for VP4.............. < 300 mtorr
- ☐ VP5...................... off and removed
- ☐ TC for VP5.............. not in use
- ☐ Turbopump.............. on
- ☐ Target loop pump .... on
- ☐ TC3...................... < 5 mtorr
- ☐ TC4...................... not in use
- ☐ TC7...................... not in use
- ☐ IG1...................... $< 10^{-4}$ torr
- ☐ P2A...................... not in use
- ☐ P3A...................... 10 psig
- ☐ P4A...................... 40 psig
- ☐ P5A...................... 10 psig
- ☐ P7........................ not in use
- ☐ P8A...................... 0 psid
- ☐ P9A...................... > 0 psid
- ☐ P10...................... not in use
- ☐ GV1...................... open
- ☐ SV5...................... open for beam

III.Q. Warming the helium-filled target to room temperature

Initial state:

MV1	closed
MV1A	closed
MV1B	closed
MV1C	closed
MV1D	closed
MV2	closed
MV3	open
MV4	closed
MV5A	closed
MV5B	closed
MV6	closed
MV7	open
MV8	closed, handle removed
MV9	closed
MV10	open
MV11	closed
PV12	closed
MV12	open
SV13	closed
MV13	closed
MV14	closed
MV15	closed
MV16	open
MV17	open
MV18	open
MV19	open
MV20	closed
MV21	closed
PV21	closed
MV22	open
MV23	open
MV24	closed and capped
MV25	closed and capped
MV26	closed
MV27	closed
MV28	closed
MV29	open
MV30	open
PV1	closed

Hydrogen bottles	all closed
R1	closed
P1	not in use
Helium bottles	one open
R6	40 psig
P6	40 psig
Target helium bottle	open
R30	15 psig
P30	15 psig
R14	5 psig
P14	5 psig
TWV	To RD1 or RD2
VP1	off and removed
TC for VP1	not in use
VP2	off and removed
TC for VP2	not in use
VP3	not in use
TC for VP3	not in use
VP4	on
TC for VP4	< 300 mtorr
VP5	off and removed
TC for VP5	not in use
Turbopump	on
Target loop pump	on
TC3	< 5 mtorr
TC4	not in use
TC7	not in use
IG1	$< 10^{-4}$ torr
P2A	not in use
P3A	15 psig
P4A	40 psig
P5A	15 psig
P7	30 in Hg or 0 psig
P8A	0 psid
P9A	> 0 psid
P10	not in use
GV1	open
SV5	open for beam

III.Q. Warming the helium-filled target to room temperature

1. The target is filled with circulating helium as described in section N.

2. Turn off the beam and set the interlock so beam may not be put on the target.

3. Make sure the target heater is off.

   At this point it will be necessary to enter the North Hall. Install the target computer there.

4. Confirm that all initial conditions for procedure Q are met. They are the same as the final conditions for section N.

5. Close gate valve SV5 from the master vacuum interlock box.

6. Close off the refrigerator LN_2 supply by turning off LC-1 and closing the supply valve V806. Also close the LN_2 tank supply valve.

   NOTE: The target circulating pump should be ON ($>$ 20 Hz) during the warming process.

7. Open the refrigerator bypass valve V360 fully. Some helium will continue to flow to the target loop but most will go back to the compressor. The target should immediately begin to warm up.

8. Close V361 approximately 4 turns so that it is open about $\frac{1}{2}$ turn. Watch the pressure in the target either on the computer screen (in the counting bay) or at gauge P3A on the gas panel. As the target starts to warm its pressure will increase. When the target pressure reaches 17 psig, pressure switch PSU will cause solenoid valve SV13 to open and the target should begin to vent. The target pressure should stabilize once SV13 is open. **If the target pressure continues to rise**, open V361 a little more to send more cooling to the target. Use V361 as a throttle valve to control the warming rate of the target. SV13 will close when the target pressure drops to 14 psig.

   NOTE: When the target temperature is approximately 30 K, the vacuum chamber pressure will rise by about a factor of 10–50 from its cold value. If the ion gauge IG1 gets high on the 10^{-4} range the turbopump interlock should be bypassed to keep it from tripping off and the gate valve GV1 from closing. As the target continues to warm the vacuum should return to the warm value.

9. The target will slowly warm up to room temperature. This process may be accelerated by turning on the target heater to 50–100 watts.

10. Change the helium bottle going to the helium cell if the bottle pressure drops below 200 psig (see section III.G to change the helium bottle).

11. Once the target has reached 40 K, the refrigerator may be turned off. **Follow the instructions in section IV.4.** Do not shut down the compressor at this time.

12. It may also be desirable to speed up the warming process by backfilling the vacuum system with helium. If you desire to do this, turn off the ion gauge controller. This will close gate valve GV1 and trip off the turbopump and forepump. Bypass the isolation valve interlock and open GV1. Wait 30 minutes for the turbopump to spin down. Connect the Bates nitrogen line to valve MV25. Slowly introduce nitrogen to the vacuum system until thermocouple gauge TC3 reads about 1 torr, and then close MV25. However, the chamber will have to be pumped out again before backfilling the target with helium.

13. When the target reaches 100 K, set the target heater to 0 W and turn off the power supply.
14. When the target is close to room temperature, the compressor may be shut down. Follow the instructions in section IV.5.
15. Turn off the target loop pump.
16. Close valve MV30.
17. Open valve MV13. Gauge P3A will drop from 15 psig to 0 psig.
18. Open valve MV4.
19. Open valve MV9.
20. Open valves MV2, MV11 and MV20.
21. Close regulators R30 and R6 by turning their handles fully counterclockwise.
22. Close the helium and target helium bottles.
23. If the vacuum system was backfilled with helium, pump the vacuum system out again following steps 2 through 8 in section III.D.
24. Confirm that all final conditions for procedure Q are met.

III.Q. Warming the helium-filled target to room temperature

Final state:

☐	MV1 .... closed		☐	Hydrogen bottles .... all closed	
☐	MV1A .... closed		☐	R1 .... closed	
☐	MV1B .... closed		☐	P1 .... not in use	
☐	MV1C .... closed		☐	Helium bottles .... both closed	
☐	MV1D .... closed		☐	R6 .... closed	
☐	MV2 .... open		☐	P6 .... 40 psig	
☐	MV3 .... open		☐	Target helium bottle .... closed	
☐	MV4 .... open		☐	R30 .... closed	
☐	MV5A .... closed		☐	P30 .... 15 psig	
☐	MV5B .... closed		☐	R14 .... 5 psig	
☐	MV6 .... closed		☐	P14 .... 5 psig	
☐	MV7 .... open		☐	TWV .... To RD1 or RD2	
☐	MV8 .... closed, handle removed		☐	VP1 .... off and removed	
☐	MV9 .... open		☐	TC for VP1 .... not in use	
☐	MV10 .... open		☐	VP2 .... off and removed	
☐	MV11 .... open		☐	TC for VP2 .... not in use	
☐	PV12 .... closed		☐	VP3 .... not in use	
☐	MV12 .... open		☐	TC for VP3 .... not in use	
☐	SV13 .... closed		☐	VP4 .... on	
☐	MV13 .... open		☐	TC for VP4 .... $<$ 300 mtorr	
☐	MV14 .... closed		☐	VP5 .... off and removed	
☐	MV15 .... closed		☐	TC for VP5 .... not in use	
☐	MV16 .... open		☐	Turbopump .... on	
☐	MV17 .... open		☐	Target loop pump .... off	
☐	MV18 .... open		☐	TC3 .... $<$ 5 mtorr	
☐	MV19 .... open		☐	TC4 .... not in use	
☐	MV20 .... open		☐	TC7 .... not in use	
☐	MV21 .... closed		☐	IG1 .... $< 10^{-4}$ torr	
☐	PV21 .... closed		☐	P2A .... not in use	
☐	MV22 .... open		☐	P3A .... 15 psig	
☐	MV23 .... open		☐	P4A .... 40 psig	
☐	MV24 .... closed and capped		☐	P5A .... 15 psig	
☐	MV25 .... closed and capped		☐	P7 .... 30 in Hg or 0 psig	
☐	MV26 .... closed		☐	P8A .... 0 psid	
☐	MV27 .... closed		☐	P9A .... $>$ 0 psid	
☐	MV28 .... closed		☐	P10 .... not in use	
☐	MV29 .... open		☐	GV1 .... open	
☐	MV30 .... closed		☐	SV5 .... open for beam	
☐	PV1 .... closed				

IV. Refrigerator

For the SAMPLE experiment, hydrogen is liquified by a PSI model 1620–S helium gas refrigerator. A schematic diagram of the refrigeration cycle is shown in figure IV.1. He gas at approximately 230 psig is delivered to the refrigerator from the RS compressor. If the liquid nitrogen precooling system is in use, part of the gas will enter the LN_2 loop (E81) via valve V806. The remainder passes through the first stage of heat exchanger (E30). All of the gas then passes through a second heat exchanger (E31), after which point the He temperature is approximately 80 K. Charcoal adsorbers (E36 A or B) remove impurities from the gas before it goes through the main heat exchanger cycles (E32 and E33). Finally, two expansion engines (E39 and E37) expand the gas isentropically to bring the gas to 12 K before delivering it to the cryogenic transfer lines (through valve V361) at a pressure of about 16 psia. The return line from the target is used as the coolant in all of the heat exchangers. Also shown in figure IV.1 are the relevant pressure and temperature indicators at various points in the refrigerator.

A vacuum chamber encloses the expansion engines, the heat exchangers, charcoal adsorbers and all cold piping of the refrigerator. When warm, the chamber can be pumped out with a small mechanical pump to about 50 mTorr. When cold, the chamber will cryopump to approximately 10^{-5} Torr.

Two feedback cycles control the performance of the refrigerator. The engines can be run in an automatic feedback loop with helium supply pressure. The main purpose of this loop is to keep the engines from working harder than that required to maintain the necessary cooling capacity, thus saving on electrical power. In most cases we will be interested in leaving the engines in MANUAL speed control in order to maximize the output capacity of the refrigerator. The other feedback loop is between the refrigerator's internal heater and the load return temperature. The temperature in the return line to the refrigerator is monitored with a Si-diode sensor (TE-3). The refrigerator will maintain this temperature at the given set point (nominally 20 K) by adjusting an internal heater, providing up to 1000 W of internal heat. In principal this cycle could be used to control the target temperature. However, in practice it has been found that changes in beam current are too rapid to allow this system to respond effectively; the target temperature is better controlled via the feedback loop between the target heater and average beam current.

The following sections provide an instruction set for starting up the refrigerator to cooling the target, as well as for warming the target and shutting down the refrigerator. A more complete description of the refrigerator and operating instructions can be found in the manuals provided by the manufacturer. In general, it is expected that only experienced personnel will be responsible for operation of the refrigerator. Any situation which requires more than the minimum instruction set provided here should be left to experienced staff.

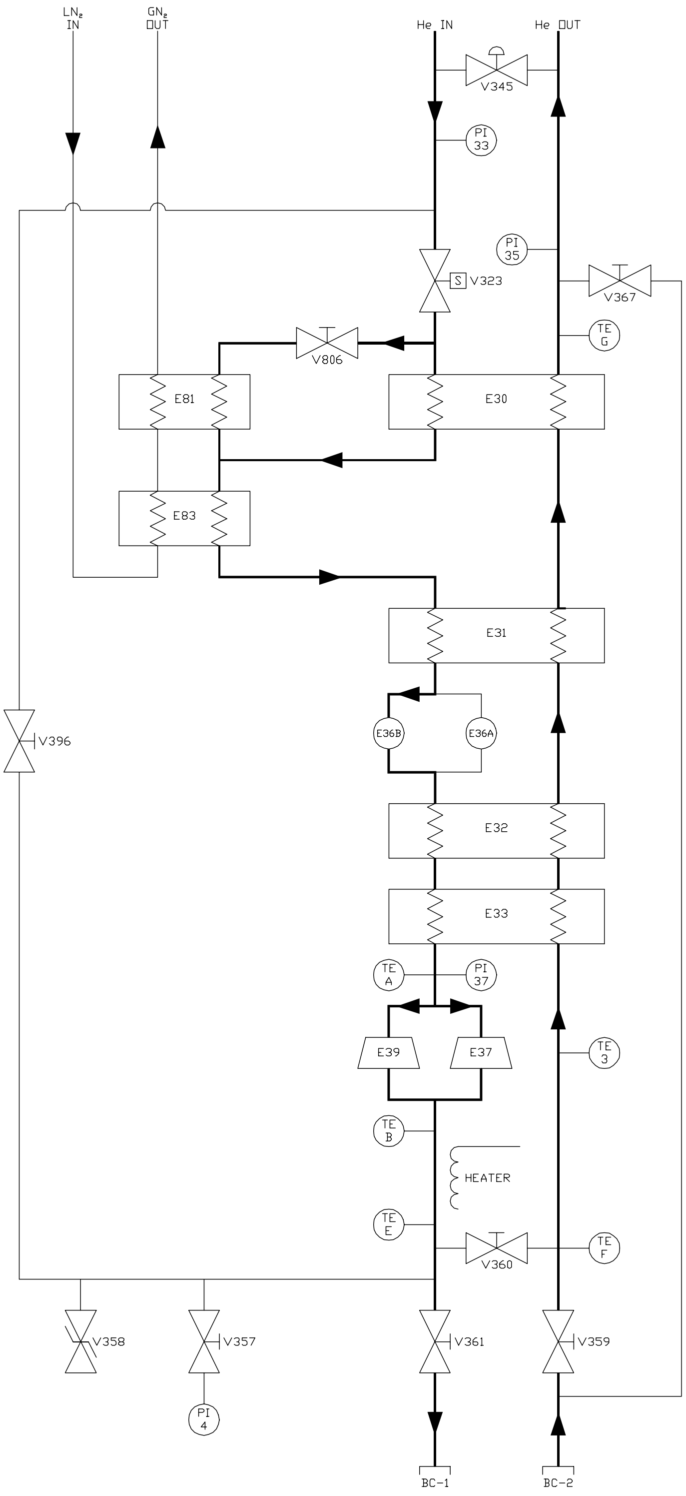

Figure IV.1: Flow diagram of the model 1620 refrigeration cycle.

IV.1 Preparation of the target for cooldown

Prepare the target for cooling as described in section III.F of the gas handling system instructions. These instructions should be followed through F.25.

IV.2 Startup of the Refrigerator

These instructions should only be followed after the refrigerator and compressor have been thoroughly checked by an experienced operator. For more detailed information, refer to the instructions in section 4.1 of the refrigerator's operations manual.

IV.2.1 Preliminary Checks

Verify the conditions as listed below and make any necessary corrections.

1. All switches on the control panel are off.
2. The flywheel locking bar is in place.
3. When using liquid nitrogen for precooling, ensure that the LN_2 supply is ready for use.
4. Load supply valve V361, load return valve V359 and load bypass valve V360 are all closed.
5. Valves V312, V397, V339, V35, V36, V42, V43, V44, V396, V341 and V367 are closed.
6. Valves (either V31 and V32 or V33 and V34) isolating the charcoal adsorbers (either E36A or E36B) not being used are closed.
7. Valve V806 is partially open (approximately two turns).
8. Valve V379 is partially open (approximately two turns).
9. Vacuum on vacuum indicator VI45 is below 50 microns, vacuum valve V336 is closed.
10. A pure helium, makeup gas source is open with a minimum pressure of 100 psig.

IV.2.2 Blowdown of the Heat Exchanger

1. Open valve V312 and decrease the pressure in the refrigerator to approximately 5 psig as shown on pressure gauge PI37.
2. Turn compressor cooling water to "auto".
3. Open valve V341 and start the compressor.
4. Press the ENGINE START button to energize solenoid valves V323, V334 and V374 to allow gas to enter the system to operating pressure (230 psi) as indicated on PI37.

5. Press ENGINE STOP button to de-energize solenoid valves V323, V334 and V374.

6. Open valve V312 to one-half (1/2) turn to blow down the main heat exchanger.

7. Close valve V312 when PI37 is between 10 psig or less.

   NOTE: If there is any possibility that water still remains in the heat exchanger, repeat steps (4) through (7) three times. If it is dry, proceed to step (8). If the refrigerator has been turned off for less than 24 hours it is normally sufficient to blowdown the heat exchanger only once.

8. Valve V312 should be closed and PI37 should be 10 psig or less.

9. Remove locking bar from flywheel.

10. Install engine covers.

IV.2.3 Cooldown of the Refrigerator and Target

DO NOT proceed with this step until steps IV.2.1 and IV.2.2 have been completed and verified. In addition, verify that the target is ready to be cooled by referring to section III.F, through step 25. At this point the target pump motor should also be turned on.

1. Open load bypass valve V360. Load supply valve V361 and load return valve V359 should be closed.

2. The compressor should already be running. If not, open valve V341 and start the COMPRESSOR. Observe that the compressor starts and the supply pressure gauge PI33 reads the set point pressure of the external bypass regulator V345, approximately 230 psig.

3. Set the ENGINE SPEED control switch to AUTO and start the engine. SIC and PIC ENGINE SPEED CONTROLS will set the engine speed. The engine start switch also activates helium supply solenoid valves V334, V374 and V323.

   CAUTION: DO NOT OPERATE WITHOUT ENGINE COVERS IN PLACE.

4. Close valve V341.

5. Open the supply valve from the Bates liquid nitrogen dewar. This valve is on the wall behind the refrigerator. Open liquid nitrogen feed solenoid valve V805 by turning to the AUTO position switch on the LN_2 control (LC-1). V806 should be open two (2) turns.

   CAUTION: DO NOT ALLOW NITROGEN SUPPLY PRESSURE TO EXCEED 30 PSIG AS RELIEF VALVE V807 WILL OPEN.

6. The system is now ready to begin cooling the target. Slowly open V359.

7. Slowly open V361.

8. Close V360.

9. Allow the refrigerator and target to cool to the desired temperature, as set by the load return temperature TE-3 on the refrigerator's heater control circuit. Under normal operation of the SAMPLE target, TE-3 should be set to 20 K.

10. Turn on the heater control circuit.

11. As the system cools and helium gas density increases, makeup gas will be required to maintain normal operating pressures. Monitor the pure gas supply during cooldown. After approximately one hour of operation, the COMPRESSOR LOAD button on the refrigerator should be pushed to allow additional gas to be supplied to the compressor.

12. Once TE-3 is close to operating temperature the engine speed of the refrigerator will cut back in order to save electrical power. At this point the ENGINE SPEED control should be set to MANUAL. Turn the control pot labelled SPEED control counterclockwise before setting the speed control to MANUAL. Then increase the engine speed by slowly turning the pot clockwise until the engine speed reaches approximately 180 RPM, without letting the SUPPLY PRESSURE PI33 drop below 230 psig.

IV.3 Preparation of the Target for Warmup

1. Verify that the beam is off and interlocked.

2. Verify that the target heater is off.

   At this point it will be necessary to enter the North Hall.

3. Proceed to section III.H of the gas handling system to begin the target warmup procedure. When the target has reached approximately 40 K the refrigerator may be shut down. Follow the procedures in section IV.4 at that time.

IV.4 Shutting down the refrigerator

1. Verify that the target liquid has completely boiled away and its temperature is greater than 40 K.

2. Open throttle valve V379 two more turns (to a total of four turns).

3. Press the ENGINE STOP button to shut down the expansion engines. Solenoid valves V323, V334 and V374 will also close.

4. Gas will be recovered from the system into the helium storage tank. When all helium has been recovered, the storage tank pressure and the supply pressure PI39 will read approximately the same value. At this point the compressor may be shut down, but it is convenient to leave it running to supply warm He gas to the target loop to aid in warming the target.

   NOTE: If the storage tank pressure reaches 240 psi, the compressor may be shut down by its overpressure interlock at 265 psi. If the tank pressure does not reach 240 psi, the compressor will continue to operate until shut down manually.

5. When the excess He gas is dumped to the pure storage tank, close V379 back down two turns (it should then be open a total of two turns).

6. Set the refrigerator/compressor system into "bypass" mode to circulate He gas through the target heat exchanger. Open valve V367, then close valve V359. Slowly crack open V396 until PI4 reads approximately 10 psi. If V396 is opened too far, blowoff valve V358 will open.

7. Open valve V361 fully so that warm gas from the compressor will circulate through the target loop.

8. Proceed to step 14 of section III.H to finish warming the target.

9. When the target has reached room temperature, proceed to shut down the compressor following step IV.5.

IV.5 Shutdown of the compressor

When the target is at room temperature the compressor can be shut down.

1. Close V396.

2. Verify that bypass valve V360 is open.

3. Close V367, then close V361. Valve V359 should already be closed, so the transfer lines are now isolated from the refrigerator and may be removed if required.

4. Open throttle valve V379 two more turns (to a total of four turns).

5. Press the COMPRESSOR STOP button at the refrigerator. Additional gas will be dumped to the pure storage tank.

6. Open valve V312 and vent the engine inlet pressure to less than 10 psi in order to prevent the engines from restarting accidentally.

7. Put the engine locking bar in place.

8. Close the helium makeup supply cylinder.

9. If the transfer lines are not going to be removed from the refrigerator, open load return valve V359 to allow the gas warming in the transfer lines to expand without building up excess pressure.

V. Controls and Instrumentation

V.1 Overview

The Sample Target Control and Monitoring System consists of several GPIB devices connected to a personal computer. This system performs several functions, the most important of which is to monitor the state of the gas handling system as well as the temperature, pressure and position of the target. This information is communicated in a compressed form to the SAMPLE CAMAC/VAX data acquisition system through digital I/O registers. The control system is written in the LABVIEW and runs under Windows 95 on a 486, 66 MHz DX2 PC with 32 MB RAM. LABVIEW is a graphical programming language that creates "virtual instruments" (VI's) that consist of "front panels" through which the user interacts with the program and "circuit diagrams" where the program is drawn graphically. The front panel consists of switches, buttons, dials, and displays that the user controls with a mouse in a manner similar to controlling a real instrument. The SAMPLE VI is the virtual instrument that controls and monitors the SAMPLE cryotarget. Its functions are to:

1. Monitor target temperatures, pressures, position, valve status.
2. Sound an alarm if key temperatures, pressures, or valve states are outside proper operating conditions.
3. Trip beam interlock and sound an alarm if target parameters have entered dangerous conditions.
4. Record the target state at regular intervals to log files.
5. Provide an abridged target status word for the CAMAC fast data acquisition to read into the data stream event by event.
6. Control target loop heater with either manual heater settings or automatically set loop heater power to keep total heat load on target constant.
7. Control target motion remotely.

A detailed, up-to-date description of the controls system and operating procedures are provided in a separate document

parity$disk:[sample.target]controls- spring98.tex.

A general description will be presented here. There are 9 GPIB devices that are controlled by the computer.

GPIB address	name	device
8	DMM1	Keithley Model 199/1992 Digital Multimeter
9	DAC	IOtech DAC488/4
10	LS	Lakeshore Model 820 Cryogenic Thermometer
11	DMM2	Keithley Model 199/1992 Digital Multimeter
12	IO40	IOtech Digital488/40
14	ADC1	IOtech ADC488/16
15	ADC2	IOtech ADC488/16
18	IO80	IOtech DIO488/80A
26	Fridge	Refrigerator

GPIB Devices used by SAMPLE cryogenic target

The multimeter DMM1 is used to read back the position sensors of the target. It is generally not used during operation with beam. The DAC controls a Sorensen DC power supply and two Compumotor stepper motor controllers. The stepper motor controllers allow remote target motion and are normally disabled during operation of the target with beam. The Sorenson power supply (33V/33A max) provides power to the target internal heater used to stabilize the target temperature. The Lakeshore thermometer (LS) and the DMM2 multimeter provide two alternate methods of monitoring target temperature. The DMM2 was implemented as backup temperature readout because of frequent failures of the Lakeshore device. There is a button in the software to switch from one temperature readout to the other. The digital IO40 reads the status of the valves (2 bits per valve) on the valve panel. With two bits it is possible to distinguish between four possible states: fully open, fully closed, ambiguous and power failure. The state of the valves must satisfy a proper condition truth table in order for the beam interlock to be satisfied. The two ADCs read values for various pressure transducers, the beam current, the internal heater voltage and current, and two vacuum gauges. The IO80A is used to send critical target information from the target computer to the main SAMPLE data acquisition, such as temperature and pressure. Finally, the refrigerator is equipped with a GPIB device which sends temperature information to the target controls.

V.2 Displays

V.2.1 Main Control Panel

The main control panel displays six strip charts showing the time evolution of target pressures and temperatures, vacuum pressure, refrigerator temperatures, and heat loads. To the right of the strip charts is a vapor pressure plot showing the status of the target cryogen with respect to the vapor pressure curve. Below the vapor pressure curve is a status region indicating the status of target monitoring. Below the strip charts is a message display and controls for scrolling the strip charts. At the bottom of the display are a row of buttons. The leftmost button is used to stop the program, the others select control panels and displays for target subsystems. The various functions of the controls on the main panel are listed below. See the more extensive writeup for detailed operating instructions.

STOP: Click on this button to stop the target monitoring. A dialog box will confirm the intention before shutting off the program.

Pause Charts: Stops the charts from scrolling. The button turns red when the charts are stopped, and is green when scrolling is enabled. After the scrolling is stopped, a scroll bar appears that allows the charts to be scrolled back in time.

Chart Width: selects the width of the charts in minutes. Although any value can be selected, the chart memory is really only about 80 minutes long.

Clear Charts: Clears all the strip charts.

Heater: Controls the target loop heater.

Logging: Allows turning on/off the logging and changing the logging parameters.

Devices: Allows enabling/disabling of the GPIB devices.

Position: Controls the target position.

Gas Panel: Shows a schematic layout of the gas panel and indicates the valve status. Also shows the pressures and temperatures in the system.

Fridge: Shows a schematic layout of the refrigerator and displays temperatures and pressures at various points in the system.

Alarms: Allows enabling/disabling of alarms and beam interlocks.

Monitor: Opens a GPIB device monitor to show the raw GPIB data.

Simulation: Allows variation of the parameters used in the simulation of the GPIB devices.

Settings: Allows the parameters to be saved to a file.

Valves: Displays the valve status for the gas panel.

V.2.2 Secondary Control Panels

V.2.2.1 Gas Panel

The Gas Panel shows a schematic layout of the target and gas valve panel. The state of the valves and the readouts of the pressures and temperatures are displayed.

V.2.2.2 Heater Control Panel

The Heater Control Panel adjusts the power settings for the target loop heater. If the heater is on when the program is stopped, a dialog box asks if it is intended to leave the heater on before exiting the program. If the heater is on when the program starts, a dialog asks if the heater is to be left alone before continuing the startup.

Heater Mode: is a 4 position switch used to set the heater control mode. The options are:

OFF: Default heater setting. The heater current is set to zero.

MANUAL: Heater puts out a constant power which is set by the **Manual Heater Power Setting** input. The input power is allowed to vary from 0 to **Maximum Target Power**.

AUTO: The heater power setting is adjusted to keep the heat load on the target constant. This is done by taking the measured beam power and subtracting this from the **Auto Power Setting** to determine the necessary heater power. This is calculated after each read of the GPIB devices and the power setting of the heater set.

BYPASS: Bypass tells the computer to do **NOTHING** to the DAC used to set the heater power. This mode is set if the DAC was left on when the program was last exited or stopped. When the program starts again, it asks if it should leave the DAC alone and come up in BYPASS mode. The user must explicitly change the setting out of BYPASS mode.

Manual Power Setting: The user inputs the desired heater power level during manual operation. The maximum allowed setting is 1000 W or **Maximum Target Power**, whichever is smaller. The power can only be set in 10W increments.

Auto Power Setting: For automatic adjustment of the heater to compensate for the power deposition by the beam. The heater is set by,

$$P_{htr} = P_{auto} - P_{beam}$$

Maximum Target Power: The maximum power allowed on the heater. It is limited by setting the maximum allowed voltage on the heater power supply. This parameter is saved to the parameter file by the Settings SAVE option.

Heater Voltage Set: shows the voltage to be set on the heater

Heater Current Set: shows the current to be set on the heater

Voltage DAC Set: shows the DAC setting necessary to set the heater voltage. This is not the same as the **Heater Voltage Set** value because a 0 to 5 VDC reference voltage set by the DAC corresponds to a 0 to 33 VDC output voltage on the heater power supply.

Current DAC Set: shows the DAC setting necessary to set the heater current. This is not the same as the **Heater Current Set** value because a 0 to 5 VDC reference voltage set by the DAC corresponds to a 0 to 33 Amp output current on the heater power supply.

Beam Power: shows the beam power deposited in the target.

Heater Set Power Output: shows the power level the program is attempting to set on the Heater.

Heater Output Power shows the power being output from heater as measured from the voltage and current readouts on the Heater power supply.

*** Note***: Because the heater control provides a critical function to keep the target temperature stable, a manual override circuit has been implemented in case of computer control failure. Detailed instructions for switching from computer control to manual override are in the target controls document. The more extensive document contains detailed instructions on how to set up the manual override circuit.

V.2.2.3 Logging Control Panel

The Logging Control Panel controls the logging of the target data to disk. Logging consists of averaging the variables over some number of data samples and then writing to disk. The number of writes to disk is adjustable.

Data Logging: Enables/disables the data logging. This parameter is loaded from the parameter file.

Samples Averaged: The number of samples averaged over before writing to disk. Loaded from the parameter file

Records Per File: The number of records written to the data file. This parameter is loaded from the parameter file.

log path: The file that the information about the data logging is written to.

data path: The name of the data file

number of samples: The current number of samples read.

number of writes: The number of writes that have so far been written to the data file.

dat: The data from the current read.

sum: The sum of the data.

ave: The average data being written to the data file.

V.2.2.4 Devices Control Panel

The Devices Control Panel allows the user to individually enable or disable each of the 9 GPIB devices. Also shown are the GPIB addresses of each device. Both the address and enable are read from the parameter file. The Lakeshore thermometer also has separate enable buttons for each of the 6 resistors.

V.2.2.5 Position Control Panel

The target motion is controlled from this panel. The possible motions are "stopped", "single step" and "continuous". The direction of motion is controlled from the upper left box where the possible motions are STOP, UP, DOWN, LEFT or RIGHT. If the endstop in the direction of motion is reached, the endstop Indicator lights up and the motion in that direction is halted. The position of the target is indicated on the graph on the right of the panel and on the numerical indicators below the graph. The target will not move if the ACTION switch is in the off position. The target is always halted when exiting the position control panel. This panel is normally used only for alignment of the target prior to a data taking period.

V.2.2.6 Alarms Control Panel

There are two types of warning indicator: alarms and beam interlocks. Alarms indicate something that needs attention. They generate a red message with one warning bell. The alarms available are: MV13 or SV13 open; Helium bottle pressure out of bounds, or the Helium — Hydrogen pressure difference out of bounds plus others. Beam interlocks are events that warrant turning off the beam. They are indicated by a pink message and three warning bells. Events that cause an interlock trip are: valves not the expected values for running; target temperature out of bounds; or target loop pressure out of bounds. In the case of the valves, because there is a problem with the valve read, occasionally a valve reads falsely. This is fixed by reading the valves three times. If the test is failed three times in a row the interlock is tripped. Alarms are generated after each failure however.

All the alarms and interlocks can be disabled and the trip points for the temperatures and pressures can be adjusted. The settings for the alarms and interlocks are read from the parameter file when the program is started and can be saved with the SETTINGS SAVE function.

V.2.2.7 Settings Control Panel

The settings control panel has one function. The save button saves the current parameters to a file. The default file is SAMPLE.PAR.

V.2.2.8 Monitor Control Panel

The monitor control panel displays the GPIB traffic. It shows the latest GPIB commands for each device, the raw data string written to or read from the device and the extracted raw data for each channel.

V.2.2.9 Simulation Control Panel

It is possible to run the control program with no connection to the GPIB with simulated data. The simulation panel supplies inputs and input noise for all the GPIB devices. The simulation is started and stopped at run time.

March 23, 1999

List of References

1. J. Mark
2. C.F. Williamson, Bates Internal Report # 88-1.
3. W.M. Schmitt and C.F. Williamson, Bates Internal Report # 90-02.

Appendix A: Boiloff Rate in Catastrophic Vacuum Failure

In the case of a vacuum leak in the beam line, the target loop will be warmed by the surrounding gas pressure and will begin to boil away. The boiloff rate and mass flow rate of other Bates cryogenic target systems were calculated in Bates Internal Report # 90-02 [3]. Here the same procedure is followed using the parameters of the SAMPLE target system.

There are two scenarios under which the target may be rapidly boiled.

(1) The vacuum chamber has a catastrophic leak. Room temperature air will warm the target cell.

(2) The target cell leaks, and cold H_2 gas warms the target.

Of these two possibilities, the first is more severe and is calculated here, following the same procedure as in the Bates Report 90-02. The target would be warmed by convective and conductive heat transfer:

$$q = U\,(T_g - T_L)\ , \tag{A.1}$$

where U is the heat transfer coefficient, T_g is the temperature of the warm gas and T_L is the temperature of the boiling liquid. The heat transfer coefficient will have three sources: film boiling at the target wall, conduction through the target wall, and convective heat transfer by gas on the outside of the wall:

$$U = \frac{1}{h_B} + \frac{1}{k} + \frac{1}{h_c} \tag{A.2}$$

where h_B is the film-boiling heat transfer coefficient, k is the heat transfer coefficient of the target wall, and h_c is the convective heat transfer coefficient.

A.1 Film boiling

The film boiling coefficient can be written as:

$$\frac{1}{h_B} = \frac{\left[d\,(T_i - T_L)\right]^{\frac{1}{4}}}{h'_B}\,, \tag{A.3}$$

where

$$\frac{1}{h'_B} = 1.61\left[\frac{\mu_v}{k_v^3 \rho_v\,(\rho_L - \rho_v)\,g h_v}\right]^{\frac{1}{4}} \tag{A.4}$$

and T_i is the temperature of the inner gas wall. The physical properties of hydrogen, deuterium and air are taken from 99-02 and listed in table A.1. For hydrogen at 25 K,

$$\frac{1}{h'_B} = 5.72 \times 10^{-3}\,.$$

Table A.1

Properties of H_2, D_2 and Air (copied from Bates Internal Report (ref. 3), p. 5).

Quantity	Hydrogen	Deuterium	Air
k_V (25 K)	0.0220	0.0155	
ρ_V (25 K)	3.12	6.2	
μ_V (25 K)	1.4×10^{-6}	1.7×10^{-6}	
c_{pV} (25 K)	13815	5860	
ρ_L (25 K)	66	160	
c_{pL} (25 K)	1.1×10^{4}	6.7×10^{3}	
h_V (25 K)	4.3×10^{5}	3.07×10^{5}	
k_g (277 K)	0.174	0.130	0.0244
β_V (277 K)	3.66×10^{-3}	3.66×10^{-3}	3.67×10^{-3}
ρ_g (273 K)	0.0893	0.179	1.224
c_{pg} (273 K)	14307	7294	1005
μ_g (273 K)	8.35×10^{-6}	1.20×10^{-5}	1.80×10^{-5}

k_V = thermal conductivity of vapor (W/m/K)
ρ_V = density of vapor (kg/m^3)
μ_V = viscosity of vapor (kg/m/sec)
c_{pV} = specific heat of vapor (J/kg/K)
ρ_L = density of liquid (kg/m^3)
c_{pL} = specific heat of liquid (J/kg/K)
h_V = enthalpy of vaporization (J/kg)
k_g = thermal conductivity of gas (W/m/K)
β_V = volume thermal expansitivy of gas (1/K)
ρ_g = density of gas (kg/m^3)
c_{pV} = specific heat of gas (J/kg/K)
μ_g = viscosity of gas (kg/m/sec)

A.2 Conduction through target wall

The thermal resistance of the target wall is written as

$$\frac{1}{k} = \frac{x}{k'}\,, \tag{A.5}$$

where x is the wall thickness and k' is the thermal conductivity in W/m/K. The target loop is made of both 6061-T6 Al and stainless steel; the worst case is the Al target cell wall which has $x = 6$ mils. For 6061-T6 Al at 70 K, $k' \sim 65$ W/m/K so

$$\frac{1}{k} = 2.3 \times 10^{-6}\,.$$

A.3 Convective Heat transfer from the surrounding gas

This term may be written as

$$\frac{1}{h_c} = \frac{d^{(1-3n)}}{(T_g - T_o)^n\, h'_c}\,, \tag{A.6}$$

where

$$h'_c = Ck_g \left[\frac{g\beta\rho_g^2 C_{pg}}{\mu_g k_g}\right]^n\,. \tag{A.7}$$

The dimensionless parameters C and n are determined empirically based on the surface geometry, orientation and nature of film flow. Here it is assumed that all surfaces are vertical and the flow is laminar. This is the most conservative assumption, and is this case $C = 12.0$ and $n = 1/4/$ T_g is the surrounding gas temperature and T_o is the outside wall temperature. In the case of the SAMPLE target,

$$\frac{1}{h'_c} = 3.24 \times 10^{-2}\,.$$

A.4 Boiloff Rate

The boiloff rate can now be calculated. Assuming conservation of energy,

$$q = \frac{h'_b\,(T_i - T_L)^{\frac{3}{4}}}{d^{\frac{1}{4}}} = \frac{k'\,(T_o - T_i)}{x} = h'_c d^{(3n-1)}\,(T_g - T_o)^{n+1}\,. \tag{A.8}$$

The gas-liquid temperature difference is

$$(T_g - T_L) = \left(\frac{d^{\frac{1}{3}}}{h_B'^{\frac{4}{3}}}\right) q^{\frac{4}{3}} + \left(\frac{x}{k'}\right) q + \left(\frac{d^{1-3n}}{h'_c}\right)^{\frac{1}{(n+1)}} q^{\frac{1}{(n+1)}}\,. \tag{A.9}$$

In the case of the SAMPLE target, $d = 9$ cm and one may write

$$(T_g - T_L) = A_1 q^{\frac{4}{3}} + A_2 q + A_3 q^{0.8}\,, \tag{A.10}$$

where

$$A_1 = 4.59 \times 10^{-4}$$
$$A_2 = 2.3 \times 10^{-6}$$
$$A_3 = 4.0 \times 10^{-2}\,.$$

This equation can be solved iteratively to find a value for q. Assuming a temperature difference $\Delta T = 250$ K, the solution is

$$q = 1.46 \times 10^4\,.$$

Using this, the boiloff rate is calculated via

$$\Delta t = h_V \left(\frac{\rho_L}{q}\right)\left(\frac{\Delta V}{\Delta A}\right)\,, \qquad (A.11)$$

and the mass evolution rate

$$w = \rho_l \left(\frac{\Delta V}{\Delta t}\right) = q\left(\frac{\Delta A}{h_V}\right)\,. \qquad (A.12)$$

The target volume–to–area ratio is approximately $d/4 = 0.023$ m. This gives a boiloff rate and mass evolution rate of

$$\Delta t = 44\,\mathrm{secs}$$
$$w = .038\,\mathrm{kg/sec} = 83 \times 10^{-3}\,\mathrm{lbs/sec}\,.$$

A.5 Pressure Rise in Target

The pressure rise in the target will depend on how quickly the calculated mass flow can be carried away by the gas panel. This can be characterized by a resistance coefficient of the gas panel venting system, K:

$$K = f\left(\frac{L}{D}\right)\,, \qquad (A.13)$$

where f is a friction factor dependent upon the Reynolds number of the gas (see report 90-02, p. 21), and L/D is the effective length/diameter ratio for the gas piping. From the mass evolution rate the Reynolds number is calculated to be

$$\mathrm{Re} = \frac{48w}{\pi\mu d} = 1.7 \times 10^6$$

which is highly turbulent flow. From Bates report 90-02, the friction factor $f = 0.011$. Figure A.1 shows an approximate schematic of the SAMPLE target gas panel from the target to the main vent in the North Hall. All piping on the gas panel is 1" OD copper tubing, which has an inner diameter of 0.94 inches. Table A.1 lists L/D for the various components of the gas panel. For a safety factor, an $L/D = 800$ is assumed here. Then $K = 8.0$. However, it is possible that K might be larger due to sudden changes in the diameter of the piping or check valves. For the purposes of this calculation, K will be increased to $K = 10$.* The flow of the gas through the vent piping can

* Note that in the Bates 90-02 report, $K = 23.5$, of which 21 was from the gas panel piping.

be described by Bernoulli's theorem and the Darcy formula as in pp. 23-27 of the 90-02 report. These equations allow one to calculate the maximum pressure drop in the pipe, beyond which the flow in the pipe becomes supersonic. Once it has been determined that the given mass evolution rate is below the sonic velocity, the pressure drop in the pipe can be calculated and the pressure rise in the target is then known. For the SAMPLE system and using the graph on p. 24 of 90-02,

$$x_{max} = \left(\frac{\Delta P}{P}\right)_{max} = 0.784\,,$$
$$m = 0.39 \qquad \text{and}$$
$$Y = 1 - m x_{max} = 0.695\,.$$

Table A.2

Effective L/D ratios for SAMPLE gas panel.

Component	Length (in.)	L/D
1" OD tubing (tgt)	370	394
1" OD tubing (vent)	180	192
3" vent piping	360	120
8 1" elbows		20
2 3/4" check valves		8
several 3" elbows		4
Total		740

The sonic velocity of the escaping gas is described by the Darcy formula

$$w_{sonic} = 0.1192 D^2 \left(1 - m x_{max}\right) \left(\frac{P_2}{1 - x_{max}}\right) \sqrt{\frac{M x_{max}}{KT}}\,, \tag{A.14}$$

where P_2 is the output gas pressure (15 psia), T is the output temperature (293 K), D is the inner diameter of the gas piping and M is the molecular weight of the gas. For the SAMPLE gas panel,

$$w_{sonic} = 117 \times 10^{-3}\,\mathrm{lb/sec}\,,$$

so the mass evolution rate is well below sonic velocity. The mass flow rate can thus be described by equation A.14, with $x = (P_1 - P_2)/P_1$ and $0 \le x \le x_{max}$. Squaring both sides leads to

$$x^3 + a x^2 + b x + c = 0\,, \tag{A.15}$$

where

$$
\begin{aligned}
a &= -\frac{\left(w^2 + 2Fm\right)}{Fm^2}\,, \\
b &= \frac{\left(F + 2w^2\right)}{Fm^2}\,, \\
c &= -\frac{w^2}{Fm^2} \qquad \text{and} \\
F &= 0.01423\left(\frac{MD^4P_2^2}{KT}\right)\,.
\end{aligned}
$$

The real root of this equation between 0 and x_{max} is $x = 0.68$, corresponding to

$$P_1 = \frac{P_2}{1-x} = 47\,\text{psia}\,.$$

The target cells, which are the weakest point of the target loop, are pressure tested to 100 psia, so this pressure rise does not represent a dangerous condition.

Appendix B: Emergency Operating Procedures

B.1. Failure of the Refrigeration System

If the refrigerator were to fail, the target would begin to boil, causing a rise in pressure in the target loop. This situation is actually not much different from a controlled warm–up of the target. However, it may be desirable to try to restart the refrigerator before the target liquid is completely lost. The refrigerator can only be operated locally at present so it is necessary to enter the North Hall to restart the refrigerator.

1. Verify that the beam is off. A refrigerator failure should trip the beam off via the master alarm panel in Bay 3. Verify that there is not a beam line vacuum failure (which might indicate a rupture of the target cell). Verify that it is safe to enter the North Hall.

2. Take the target heater out of automatic control and turn the power supply off.

3. **Attempt to restart the refrigerator** as described in in section B.5. *If the refrigerator cannot be restarted*, proceed to vent and warm the target in a controlled fashion following the steps below:

   3(a).Reduce the target pressure to 0 psig by the following procedure. First, verify that the hydrogen supply valve MV1 is closed. Close the ballast tank valve PV12. Slowly crack open vent valve MV13 while monitoring P3, P5 and P8. Both P3 and P5 should slowly drop from 15 to 0 psig, while P8 should remain at 0 psid.

   3(b).As the target warms up, the target pressure P3 will increase. At 18 psig, SV13 will open and vent gas. This cycle will continue until the target is warm. This process can be accelerated by opening mechanical vent valve MV13 somewhat more.

4. *If the refrigerator can be restarted*, check to see that the target is full of liquid by checking the status of temperature sensor PO (channel B) and target pressure P3 against the vapor pressure curve of hydrogen. Alternately, check the liquid level sensor (if installed). If the liquid level is low, hydrogen must be added to the target. Follow the procedures in step III.L.

B.2 General Power Failure

A power failure would mean loss of refrigeration and eventually loss of beam line vacuum. The target will begin to warm up, causing a rise in pressure in the target loop. Loss of beam line vacuum will accelerate this process. The gas panel is designed to vent the hydrogen gas in a controlled manner through valve SV13. However, because SV13 is normally closed in case of loss of power, it is run on uninterruptible power so that it will continue to operate. If SV13 fails to operate, the target will be vented through relief valves RV13A and RV13B. Gate valves GV1 and SV5 are normally closed, and close automatically in the event of a power failure.

Even if the target warms up in a safe manner during a power failure, it is important to be able to verify the status of the target. Therefore, the target controls rack in the North Hall is connected to uninterruptible power, as is the 10 V power supply used for the gas panel valve indicators and pressure transducers, along with the target control computer. The target pressure can therefore be monitored. The SAMPLE vacuum gauges are not on uninterruptible power, but vacuum gauges STC1 and STC3 in CCR will provide an indication of vacuum on either side of the target in the case of power failure.

In the event of a **power outage**, the target circulating pump will most likely trip off. DO NOT ATTEMPT TO RESTART THE PUMP UNLESS THE TARGET FLUID HAS COMPLETELY BOILED AWAY. Previous attempts to restart the pump while the target is only partially full have resulted in implosion of the helium cell. When power is restored both the pump and the refrigerator should remain off until manually reset.

If you are in the Counting Bay and the Hall is secured:

1. Verify that the beam is off and inform the Chief Operator that the target is going to boil away. The hazardous gas detector in the North Hall vent line should indicate the presence of hydrogen in the vent line. Verify that no other hazardous gas detectors have indicated the presence of hydrogen in the hall.

2. Determine the status of the beam line vacuum via the gauges STC1 and STC3 in CCR. A vacuum failure could be an indication that the target cell has ruptured.

3. Verify that the target refrigerator is off.

4. The target heater will have tripped off. Verify on the computer that the heater power is 0 and turn it off on the computer.

5. Notify the target expert on call that there has been a power outage.

6. If the beam line vacuum is intact, it is now safe to enter the North Hall. However, it is probably preferable to remain in the counting bay and monitor the status of the target from the control computer. If the beam line vacuum is not intact it is best to remain in the counting bay until the target has completely boiled.

7. At this point it is likely that the target will begin to boil. Evidence for target boiling will be rise in temperature and pressure in the loop. When the target pressure reaches 17 psig, solenoid valve SV13 should open and the target will begin to vent. This will continue for approximately 15 minutes. When both temperature sensors TMO and TMI have reached 24K, the target has completely boiled away. DO NOT PROCEED UNTIL THE TARGET HAS COMPLETELY BOILED AWAY.

8. While in the counting bay, turn the control for the circulating pump down to "10" and turn it on. Verify that the He-H differential pressure on the target has not indicated H excess. While monitoring the He-H differential pressure, slowly turn the circulating pump back up to 1800 RPM (about "50" on the dial). This will likely cause the target to vent because of the additional heat load deposited in the target by the pump.

9. At this point it will be necessary to enter the North Hall. Bring target control computer with you.

10. Attempt to restart the refrigerator as in steps B.1 and B.5. If the refrigerator cannot be restarted, wait until the target expert on call arrives. If the refrigerator can be restarted, then proceed with target reliquefaction. It is likely that hydrogen will have to be added to the target, so follow the procedures in section III.L.

In the event that there is a brief power glitch, some components may be off and some may be on. In this case, the most important step is to verify that the target circulating pump is still turning.

1. Verify that the beam is off and inform the operator that it may be necessary to enter the North Hall.

If the pump is NOT turning, DO NOT ATTEMPT TO RESTART IT. It will be necessary to boil the target and reliquefy. If the refrigerator is still on, then the most important thing to do at this point is just to keep the target from freezing.

2. Ask the operator for immediate access to the hall. Inform him/her that it is not an emergency but is time-critical.

3. Turn the refrigerator off by hitting the Engine Stop button on the front of the fridge.

4. Notify the target expert on call.

5. Return to the counting bay. If the target heater is still on, turn it down in steps of 100 W every 30 secs until it is all the way to 0.

6. If the compressor has tripped off, it is safe to attempt to restart it. This will help circulate warm helium through the target heat exchanger and warm the target.

7. If the target is warming in a controlled fashion, a small amount of heat (about 100 W) can be put on the target heater to help expedite the warmup.

If the circulating pump is STILL turning, then it is likely that the target can be recovered. Take the following steps.

8. Check the status of the target heater and the refrigerator. If the refrigerator is off, then it will be necessary to enter the North Hall. First check the status of the target heater. If the heater is still on, turn it down in steps of 100 W every 30 seconds until it is all the way down to 0 and manually disable the heater on the computer.

9. At this point it will be necessary to enter the North Hall and attempt to restart the refrigerator, following the steps in B.1 and B.5.

B.3. Loss of or Leak in Beam Line Vacuum

In the case of a vacuum leak in the beam line, the target loop will be warmed by the surrounding gas pressure and will begin to boil off. The boiloff rate and mass flow rate of the target system were calculated following the procedure in Bates Internal Report # 90-02. A description of the calculation for the SAMPLE target can be found in Appendix A. With a surrounding gas of air at STP, the target will boil off completely in about 45 seconds. The 1 inch OD tubing on the gas panel should safely vent the target gas at a rate below the sonic velocity, and the pressure in the target loop should be less than 50 psia. The weakest point in the target loop is the cell itself, which has been hydrostatically pressure tested to 100 psia.

If the beam line vacuum rises beyond 10 mTorr, the vacuum interlock system will cause the following to happen:

- Both gate valves GV1 and SV5 should close.
- The beam should trip off.
- The ballast tank valve PV12 should close, thus preventing the ballast volume from being released into the ventilation system.
- The target heaters should trip off.
- The target internal lighting will be disabled.
- Valve PV21 will close, precluding pumpout of the target loop. This valve will not reopen unless beam line vacuum is restored. Therefore the target loop will have to be purged with helium before the vacuum failure can be addressed.

These steps should be verified by the target operator.

If the vacuum failure is insufficient to trip the vacuum interlocks, but serious enough to prevent the target from properly operating, the following steps should be taken.

1. Turn off the beam.

2. Proceed with a controlled warmup of the target, following section IV-3, IV-4 and III.H.

3. Pump out the target loop and backfill with helium following procedure III.I.

It is now safe to open the vacuum system to atmosphere and address the vacuum leak.

B.4. Rupture of the target loop

A rupture of the target cell represents the most serious potential safety hazard, as the first layer of containment of hydrogen is now broken. A target cell rupture is indicated by *simultaneous* and *dramatic* loss of target pressure and rise in chamber vacuum. Each of these indicators will disable beam. Proceed with the following steps:

1. Announce over the paging system (dial "5", then speak) that the hydrogen cell has ruptured in the North Hall. Notify the chief operator on duty immediately.

2. If the beam line vacuum rises beyond 10 mTorr, the vacuum interlock system will cause the following to happen:
   • Both gate valves GV1 and SV5 should close.
   • The beam should trip off.
   • The ballast tank valve PV12 should close, thus preventing the ballast volume from being released into the ventilation system.
   • The target heaters should trip off.
   • The target internal lighting will be disabled.
   • Valve PV21 will close, precluding pumpout of the target loop. This valve will not reopen unless beam line vacuum is restored. Therefore the target loop will have to be purged with helium before the vacuum failure can be addressed.

   Verify that each of these steps has occurred.

3. If the vacuum failure is not sufficiently bad to cause the interlocks to trip, shut down the vacuum system via the following steps:

   3(a) Verify that the beam is off.

   3(b) Close beam line gate valve SV5 to isolate the expansion volume for hydrogen.

   3(c) Close pneumatic valve PV12 to prevent the contents of the ballast tank from being dumped into the vacuum system.

   3(d) Close gate valve GV1 to isolate the turbopump.

   3(e) Turn off the refrigerator.

   3(f) Turn off the target heaters. This can be done either from the computer or from the vacuum interlock box.

3(g) Verify that the target internal lighting is turned off.

3(h) Close valve PV21.

4. Turn off the target pump motor.
5. Place the North Hall under full fast purge for at least two hours.
6. After two hours, verify that it is safe to enter the North Hall with the chief operator. If so, purge the vacuum system with nitrogen for at least one hour or until the hazardous gas detector in the ventilation line no longer reads the presence of hydrogen gas.
7. Pump out the vacuum system until vacuum is safely restored. At this point the target loop will also be pumped. If the helium cell has also ruptured it will not be possible to restore vacuum unless the helium supply bottle is closed.
8. Backfill and purge the beam line with nitrogen at least twice. This will also purge the target loop.

The target can now be safely disassembled for repair.

B.5. Attempting to restart the refrigerator

The refrigerator can only be restarted locally, so IT IS IMPORTANT TO VERIFY THAT IT IS SAFE TO ENTER THE NORTH HALL before proceeding with the restart procedure.

1. Set the engine speed control switch to AUTO.

2. Open valve V341 to allow the maximum possible flow of He gas from the storage tank.

3. If the compressor has also tripped off, restart the compressor and push the COMPRESSOR LOAD button for about 15 seconds to fully load the compressor with helium gas. If the compressor cannot be restarted, do not attempt to go any further.

4. Start the expansion engines.

5. Close valve V341.

6. Turn on the heater control circuit. It may take several minutes for the refrigerator to stabilize.

7. Set the engine speed control to MANUAL.

The refrigerator should now be operational and should continue to cool the target.

Appendix C: Parts for Valve Panel

MV1	Whitey B-62TS4
MV1A	Nupro SS-DLTW6
MV1B	Nupro SS-DLTW6
MV1C	Nupro SS-DLTW6
MV1D	Nupro SS-DLTW6
MV2	Whitey B-65TS16
MV3	Whitey B-65TS16
MV4	Whitey B-65TS16
MV5A	Matheson 4073
MV5B	Matheson 4073
MV6	Whitey B-62TS4
MV7	Whitey B-65TS16
MV8	Whitey B-65TS16
MV9	Whitey B-65TS16
MV10	Whitey B-65TS16
MV11	Whitey B-65TS16
PV12	Whitey B-62TS4-31-NC
MV12	Whitey B-65TS16
SV13	ASCO 8263G2
MV13	Whitey B-65TS16
MV14	Whitey B-62TS4
MV15	Whitey B-62TS4
MV16	Whitey B-62TS4
MV17	Whitey B-62TS4
MV18	Whitey B-65TS16
MV19	Whitey B-65TS16
MV20	Whitey B-65TS16
MV21	Whitey B-65TS16
PV21	Whitey B-65TS16-35-NC
MV22	Whitey B-62TS4
MV23	Whitey B-65TS16
MV24	Nupro SS-DLTW6
MV25	Nupro B-2P4T2
MV26	Apollo 800WOG
MV27	Apollo 800WOG
MV28	Apollo 800WOG
MV29	Whitey B-63TS8
MV30	Whitey B-62TS4
PV1	Whitey B-62TS4-31-NC
RV1	Circle Seal 559B-8MP-25
RV13A	Circle Seal 559B-4MP-25
RV13B	Circle Seal 559B-8MP-30
CV13	Circle Seal 249B-4PP
CV2	Circle Seal 259B-6PP
RV15	Circle Seal 559B-4MP-25
CV12	Circle Seal 249B-4PP
RDA	Continental Grafsert type G, 1″ 40 psi
RDB	Continental Grafsert type G, 1″ 40 psi

P8B	Omega PX142-015D 5V
P9B	Omega PX143-05BD 5V
R1	Concoa 432-2000-00
P1	US Gauge 200 psig
R6	Matheson 3122
P6	Matheson 63-3107
R30	Matheson 3122-350
P30	Matheson 63-3107
R14	
P14	US Gauge 60 psig
TWV	Whitey SS-65XTF16
VP1	Welch 1397
TC for VP1	Duniway DST-06M
VP2	Welch 1397
TC for VP2	Duniway DST-06M
VP3	Welch 1397
TC for VP3	Duniway DST-06M
VP4	Welch 1397
TC for VP4	Duniway DST-06M
VP5	Welch 1397
TC for VP5	Duniway DST-06M
Turbopump	Osaka TG1300BW
Target pump motor	Grainger 3N471
TC3	Duniway DST-06M
TC4	Duniway DST-06M
TC7	Duniway DST-06M
IG1	Duniway I-NUDE-BAC
P2A	Matheson 63-3109
P3A	Matheson 63-3109
P4A	Matheson 63-3109
P5A	Matheson 63-3109
P7	US Gauge Vac-30 psig
P8A	Weksler BC14-P
P9A	Dwyer 4080 80 in. H_2O
P10	Matheson 63-3109
GV1	Norcal GVP-8002-ISO
RV4	Circle Seal 259B-8PP
RV5	SLAC
CV3	Circle Seal 259B-4PP
CV6	Circle Seal 259B-2PP
PSU	Asco RE20A21
PSL	Omega PSW-804
R11	Fairchild 20613E
P4B	Omega PX242-060G 5V
P5B	Omega PX142-030G 5
P3B	Omega 142PC-30G
P2B	Omega PX142-030G 5
P11	Omega PX303-3KG5V
P12	Omega PX303-3KG5V