1. Introduction

This document describes the hazards associated with the standard Hall A and Hall C liquid hydrogen targets at the Jefferson Laboratory.

2. Description of System

The cryogenic target installation consists of the hydrogen and deuterium storage tanks, located behind the counting house (outside the building), a gas panel, located in the hall, the actual target, and piping which connect the tanks with the gas panel and the target. The gas panel is used for pump/purge operations and filling the targets. Flow diagrams for the systems are included as an appendix. These systems are constructed entirely of metal. Metal gasketed fittings (Conflat, VCR, or equivalent) are used where demountable joints are required.

The actual target consists of a thin-walled aluminum cell mounted on an aluminum block with entrance and exit flanges for the target fluid. The fluid is circulated through the cell and a heat exchanger by a vaneaxial fan, which is located inside the heat exchanger. The fan motor is submerged in the target fluid. The fluid passes over a heater, which is used to regulate the temperature of the fluid. The complete assembly of target cells, the heat exchanger and the piping that connects them is referred to as a "target loop" (figure 1).

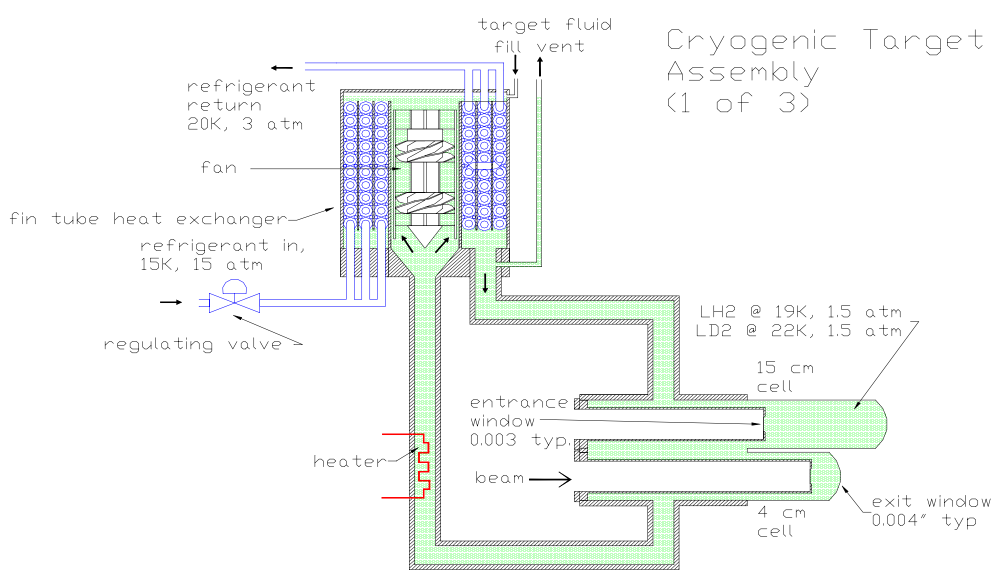

Figure 1. Schematic representation of a typical target loop.

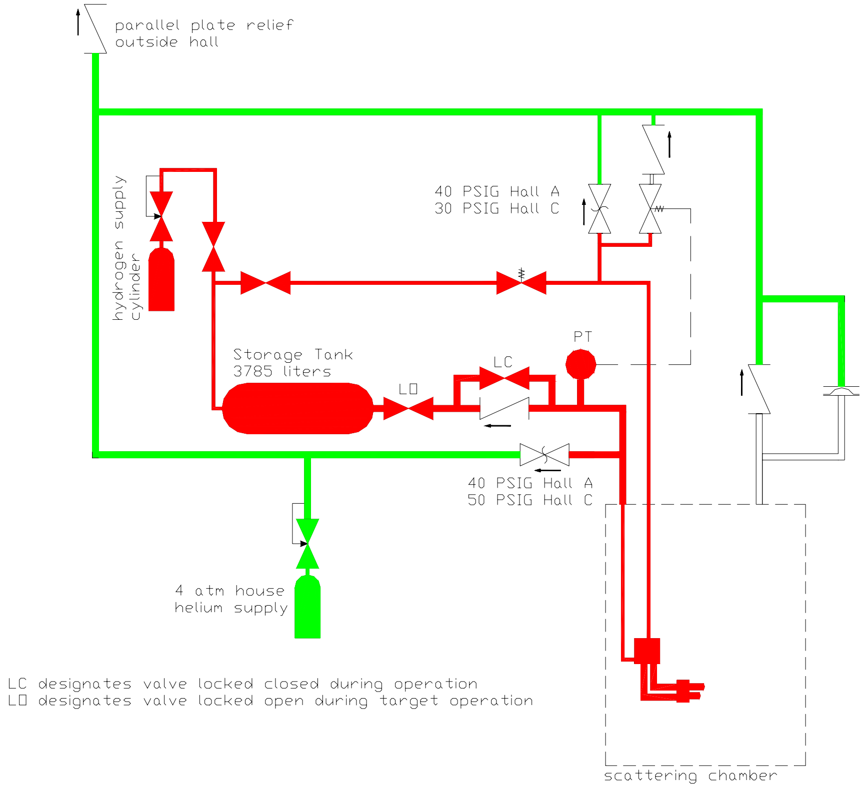

Figure 2. Simplified target flow diagram. Only one of three target loops is shown.

Our target systems contain three target loops. In normal operation, one target loop will contain hydrogen and one will contain deuterium. A third target loop, filled with low-pressure helium gas, serves as a spare. The heat exchangers are normally cooled by 15K helium gas from the End Station Refrigerator for hydrogen target operation. The target has also been operated with 4K helium liquid refrigerant. Each target loop is connected to an external gas handling system by a fill and a vent line. In the hydrogen and deuterium gas handling systems, the target return line is connected to a gas storage tank via a check valve to provide a simple, passive pressure relief. Relief valves which vent outside the hall provide a secondary relief path. A simplified flow diagram for a single hydrogen or deuterium loop is shown in Figure 2. The target loops are mounted inside the scattering chamber, with the target cells in a vertical array. The scattering chamber is fitted with large, thin aluminum windows for the spectrometers. The required target cell is positioned in the beam by an external lifting mechanism. In Hall C the cryogenic target is also able to rotate out of the beam to allow the introduction of a separate solid target assembly. The positioning devices are interlocked to prevent a foul between the two.

Several different types of target cells have been used. The most common has been a dual long (15 cm) and short (4cm) cell arrangement. These target cells are cylindrical with 0.007" thick walls and 0.003" thick entrance and 0.004" thick exit windows. The outer wall of the cell is 2.6" in diameter and is formed from an aluminum beverage can by etching the end of the can to the required thickness. The entrance window is formed by soldering an aluminum foil (annealed 5052) to the end of an aluminum tube. The entire assembly of cells, entrance windows and the cell block is soft-soldered together by first copper plating the surfaces to be soldered. This arrangement of entrance window and cell provides a target volume which is well forward of obstructions (such as piping for the target fluid), allowing the spectrometers to view the targets even when set at large angles. These thin-walled cells typically have burst pressures of approximately 80 psi, however, the observed burst pressures vary widely due to variations in the chemically etched exit windows.

Other cells which have been used include 1.6" diameter cylinders with spherical ends machined from 7075 aluminum and having 0.005" thick exit windows and walls (burst pressures over 400 psi). Upright cylinders (beam enters and exits through cylindrical wall) have also been used. These cells have 0.005" thick walls and typically burst at 270 psi when fabricated from 6061 alloy and 400 psi when fabricated from 7075 alloy.

2. Hazard Analysis

These are relatively small, simple systems and we have eight years of experience in their operation. A formal hazard and operability analysis has not been prepared. Possible failure modes are summarized in Table 1. The presence of a significant quantity of flammable gas is the major hazard associated with this system. The formation of a hydrogen/air mixture is to be avoided. When the target is in use, the bulk of the hydrogen/deuterium inventory is condensed in a thin-walled cell located inside a vacuum chamber that is fitted with thin windows. This clearly represents the greatest hazard for the uncontrolled release of hydrogen. The sudden loss of vacuum in the chamber, possibly caused by the failure of a window, would cause the hydrogen to boil rapidly and burst the cell if an adequate relief path for the target cells is not present. The failure of one cell, for any reason, would cause the sudden loss of isolation vacuum for the other cell. If one or more cells were to fail then expanding gas could cause the scattering chamber windows to rupture if an adequate relief path for the scattering chamber is not provided. If any gas other than helium were to contaminate the hydrogen or deuterium gas systems then these contaminants would freeze out in the target piping and could block the relief path. The possibility that frozen deuterium would block the relief path if temperature regulation of the loop fails has long been a concern. (The 15K refrigerant inlet temperature is normally above the freezing point of hydrogen). The target fluid temperature is set by a heater which is controlled by an IOC (single board VME computer). A second heater power supply, which can be controlled manually from the counting house, can be used to operate the heater if the IOC fails and must be rebooted. (The fluid temperatures can be observed on a TV monitor in the counting house if the IOC is unavailable). A target operator is required to be on shift at all times when the target contains liquid. With targets in operation in Hall C since 1996 and in Hall A since 1997, no events in which the target fluid froze have been observed.

Table 1 Cryogenic Target Failure Modes

Event	**Possible Consequences**	**Mitigating Measures**
Scattering chamber window failure due to excessive load or puncture.	cell rupture on loss of isolation vacuum	windows tested to failure windows tested for failure on puncture adequate relief path for target cells provided
Breach of scattering chamber window and cells by tool or object.	hydrogen/air mixture in the scattering chamber	window covers visual warning of target status limit access to pivot
Damage hose during a target move if hose becomes entangled with fixed object.	hydrogen/air mixture in hall solid air condensed in target target cell burst on warm-up	metal braid jackets on all flammable gas hoses check lifter operation after reinstallation
Cell failure due to excessive internal pressure.	chamber window rupture	adequate relief for chamber adequate pressure testing of cells
Cell failure if relief path blocked by frozen contamination or target fluid.	chamber window rupture	adequate relief for chamber maintain system above 1 atm at all times manual back-up heater controls
Breach of gas panel piping due to material handling accident or human error.	hydrogen/air mixture in hall solid air condensed in target target cell burst on warm-up	piping protected and labeled
Breach of tank or piping due to vehicle accident, material handling accident or human error.	hydrogen release	concrete barriers proper postings

Since these targets have been in use, three events have occurred in which significant quantities of hydrogen have been released from the targets. These are summarized in Table 2.

ODH hazards are mitigated by the enormous volume of the halls (40 x 10^6 liters for Hall A and 26 x 10^6 liters for hall C) in comparison with the volume of gas present in these systems.

In the past, the scattering chamber pressure relief was provided by a 4" parallel plate relief valve. Any event in which a cell ruptured caused hydrogen to be vented into the hall. When the targets are reinstalled in 2004, the scattering chamber relief valves will vent outside the hall through a 2" line maintained under a helium gas atmosphere. With this improvement, a flammable mixture of helium and air could only be formed in the hall if both a vacuum window and a cell fail simultaneously. The new relief line will include ports to purge all parts of the line with helium in the event that hydrogen is released into the line. The vent line will be fitted with a pressure switch which will alert the target operator if a positive pressure is not maintained in the vent line.

Table 2 Past Cryogenic Target Failures

Event	Cause	Corrective Measures
Destruction of cells	lifter malfunction	lifter converted to single axis drive, mechanical stops installed, electrical over-travel protection installed
Burst hydrogen cell	contamination blocked gas lines	low pressure alarm installed check valves changed to eliminate leaks automatic valves removed from computer control helium buffered vent line to be installed
Window and cell failure	Beam exit window failed. Cell burst due to crossed fill and vent hoses.	thin beam exit window eliminated hoses modified to prevent interchange additional relief valves installed

3. Flammable Gas

A. Flammable Gas Installation Classification

For the purpose of evaluating the flammable gas hazard in the hall the quantity of gas that would reduce the storage tank pressure to one atmosphere is considered. No additional gas will flow into the hall once the storage tank pressure reaches one atmosphere.

Hall A: The 1000 gallon storage tanks are initially pressurized to 48 psia at 25° C.
[(48psia-14.7psia)/14.7 psia/atm] x 3785 liters x (273K/300K) = 7800 STP liters
7800 STP liters/22.4 liters/mole x 2g/mole = 697 grams hydrogen

Hall C: The 1000 gallon storage tanks is pressurized to 40 psia at 25°C.
[(40psia-14.7psia)/14.7 psia/atm] x 3785 liters x (273K/300K) = 5928 STP liters
5928 STP liters/22.4 liters/mole x 2g/mole = 529 grams Hydrogen

If the hydrogen and deuterium loops are simultaneously in use then the total hydrogen equivalent is 15,600 STP liters in Hall A and 11,800 STP liters in Hall C.

One B size cylinder of hydrogen (2000 liters) and one B size cylinder of deuterium (3000 liters) are located behind the gas panel. These are only valved in to the panel during the initial pump/purge operation and briefly at the end of a cool-down if additional gas is needed. They are not valved in to the system during normal operation and they are therefore not included in the target system inventory.

NFPA article 45 *Fire Protection for Laboratories Using Chemicals* defines a Class D (Minimal Fire Hazard) Laboratory Unit as one having less than 4 liters of a liquefied flammable gas per $9.3m^2$ of laboratory area. This standard applies to laboratories using liquefied flammable gasses. Our systems contain less than 0.1 liter of liquefied flammable gas per $9.8\ m^2$ of floor area in the hall and thus fall well within this limit.

To evaluate the hazard posed by a flammable gas installation, it is useful to distinguish between an inventory that would burn in a local flash fire and an inventory which could cause an explosion if ignited. Burning in an unconfined space, a hydrogen combustion wave requires 10.4m to reach significant overpressure[1]. A spherical volume 10.4m in diameter with a 4% hydrogen concentration would contain 23,000 liters of hydrogen. Both of our systems contain less than 23,000 liters of hydrogen. The volume of the halls (40×10^6 liters for Hall A and 26×10^6 for Hall C) would make them an unconfined area. In view of these considerations, we will take the following approach to classifying the flammable gas installations:

- These systems are sufficiently small that the release of the entire inventory in an unconfined area would, at worst, result in a local flash fire. Measures used at large commercial or NASA installation, such as using only listed electrical devices within 15 feet of the system, are not justified here. Every reasonable effort will be made to avoid the formation of a hydrogen/air mixture in the system, to vent hydrogen gas in a safe manner when necessary and to minimize sources of ignition in and around the systemlogout.

- The scattering chamber will serve as a secondary containment volume for the hydrogen gas in the event of a target cell rupture. Only in the event that the scattering chamber vacuum windows and the cells rupture simultaneously would hydrogen be released into the hall.

While the quantity of hydrogen in our target systems would be expected to burn in a local flash fire in an unconfined space, it should be recognized that a hydrogen/air mixture in a confined space such as the scattering chamber is an explosion hazard. To place the flammable gas hazard associated with the cryogenic targets in perspective we consider liquid propane. Cylinders containing as much as 33 pounds of liquid propane are in use on this site to power fork trucks and lifts. With an equivalency factor[2] of 0.35 this corresponds to 5.25 kg of hydrogen; almost four times the total inventory of the Hall A target.

<u>B. Specific Hazard Mitigation Measures:</u>

1. All hydrogen storage tanks are ASME coded vessels, are equipped with appropriate safety relief valves, are protected from damage by vehicles, and are appropriately marked.
2. The hydrogen gas handling systems are fabricated from stainless steel tubing and fittings. Joints are made by welding or by flanges or fittings employing metal gaskets.

All valves, gauges and regulators are appropriate for hydrogen service. All pipes or tubes which may contain hydrogen (including vent lines) are clearly marked and the appropriate signage is positioned at gas storage and handling locations.

3. Detailed operating procedures are in place to insure that air is removed from the system before hydrogen is introduced and to insure that hydrogen is removed from the system before it is opened or disconnected.
4. Valves which could close the primary relief path between the target cell containing liquid hydrogen and the gas storage tank are equipped with locking handles and are locked open at the time the tank is valved into the system as per the operating instructions.
5. All piping is securely mounted and is protected from damage with the exception of the metal hoses which span the last 20 feet before the target to allow for target motion.
6. The outdoor portion of these installations are located at least 15 feet from the nearest building and 25 feet from the nearest inlet to ventilating or air-conditioning equipment. Points at which hydrogen is vented will be located at least twelve feet above the ground, 25 feet from the nearest building and 50 feet from the nearest inlet to ventilating or air-conditioning equipment.
7. Target cells are fabricated entirely from metal. Glued joints are not used. Target cells are pressure tested to at least 1.5 times the maximum pressure that they would be expected to experience in a catastrophic loss of isolation vacuum incident.
8. Thin windows on the scattering chamber are metal. Windows identical to those installed are punctured under vacuum to demonstrate that they do not fail catastrophically if punctured. Windows identical to those installed have been pressure tested to greater than 1.5 times their normal operating pressure differential.
9. When the target contains liquid hydrogen, window covers are installed over the scattering chamber windows before the hall is taken to restricted access or before any work is done on the pivot in controlled access.
10. Valves on both the upstream and downstream side of the scattering chamber close automatically if the vacuum in the chamber rises above the 10^{-5} Torr range.
11. Flammable materials and oxidizing gases are not stored within twenty feet of the system.
12. Electrical devices which communicate with the internal volume of the hydrogen gas system or the scattering chamber will be listed for use in Class 1, Group B, Division 2 locations whenever possible. The mechanical vacuum pumps on the gas handling systems and the scattering chambers are rated for Class 1, Group B, Division 2 service. The ion gauges and turbo pumps used on the scattering chambers are not listed, however, these devices shut down or are isolated by valves automatically if high pressure exists in the scattering chamber.
13. Visual warning at the pivot of the presence of liquid hydrogen will be provided whenever liquid hydrogen is present in the target.
14. The primary relief path of the hydrogen system will be through a check valve into a storage tank. It will be demonstrated that this relief path is adequately sized to prevent rupture of the cells in the event of the sudden loss of isolation vacuum in the scattering chamber.

15. All secondary relief devices or venting valves for the hydrogen systems will vent into a relief line in which a helium atmosphere is maintained. This relief line will vent outside of the hall.
16. The scattering chambers will be protected from overpressure by a check valve (1 psi) in parallel with a burst disk (3 psi) which vent outside of the hall. The relief line must be sized to accommodate the flow that would result if both target loops were to rupture. A scattering chamber fitted with vacuum-formed thin windows has been tested to an internal pressure 1.5 times the maximum pressure that would be expected in the scattering chamber if both target cells were to rupture simultaneously.
17. To prevent contamination, the operating procedures for the system specify that the hydrogen target loops and gas systems are to be maintained above atmospheric pressure at all times once the supply tanks have been valved into the system. Audible alarms in the hall and in the counting house warn of low pressure in the hydrogen systems.
18. The hydrogen gas system is helium leak tested after installation and after any repairs which involve cutting and welding piping for hydrogen gas. The operating procedures call for a rate of rise test to be performed on the hydrogen gas system and target loop as part of the system start-up.
19. Hydrogen gas detectors are installed above the gas panel and above the target. These detectors will give a low alarm if a hydrogen concentration greater than 20% of the LEL is detected and a high alarm if a hydrogen concentration greater than 40% of the LEL is detected. The emergency procedures will specify what actions are to be taken in the event of a hydrogen gas detector alarm.
20. The target control devices will be powered by a UPS. Hard wired switches in the counting house allow the target to be shut down (JT valves closed and high power heaters shut of) in the event of a controls or network outage.
21. A trained target operator is on shift, either in the counting house or in the hall, at all times when the target contains liquid.

4. Relief Path Evaluation - Loss of Isolation Vacuum

The calculation consists of two parts; determining the heat flux into the target fluid on loss of isolation vacuum and evaluating the pressure drops which result. A model developed at Bates[3] is frequently used to estimate the heat flux into the target fluid if the isolation vacuum were lost. This model combines the rate of convection through gas surrounding the target (which is assumed not to condense), the rate of conduction through the walls of the target and the rate of convection through film-boiling hydrogen to arrive at an overall heat transfer rate. This model, which is dependent on the characteristic dimensions of the loop, typically predicts heat fluxes of 8 kW/m^2 to $15kW/m^2$.

If the vacuum surrounding the target is broken by nitrogen then the nitrogen would be expected to condense on the target. Cooling nitrogen gas at 1 atmosphere from 300K to 78K requires approximately 223J/g while condensing the nitrogen would require an additional 200 J/g. Condensation of the nitrogen will tend to hold the exterior surface of the target cell at approximately 77K. Heat transfer to liquid hydrogen in the film boiling regime is described by the Breen and Westwater correlation[4].

$$h\left(\frac{\sigma}{g\,\Delta\rho_f}\right)^{\frac{1}{8}}\left(\frac{\mu_f\ \Delta T}{k_f^3\ \rho_f\ \Delta\rho_f\ g\,\lambda'}\right)^{\frac{1}{4}} = 0.37 + 0.28\left(\frac{\sigma}{g\,D^2\Delta\rho_f}\right)^{\frac{1}{2}}$$

where:

$\lambda' = [\lambda + 0.34C_{p,f}\ \Delta T]^2/\lambda$
λ = heat of evaporation
h = coefficient of heat transfer
g = acceleration of gravity
k = thermal conductivity
μ = viscosity
$\Delta T = T_w - T_l$
σ = surface tension of the liquid
$\Delta\rho_f = \rho_l - \rho_f$
ρ = density
D = diameter
C_p = specific heat

Quantities with subscript w are evaluated at the wall temperature, l at the liquid temperature and f at the film temperature, which is taken to be the mean of the wall and liquid temperatures. We assume that the wall temperature is fixed at 77K by condensation of nitrogen and that the liquid is boiling at 21.7K at a pressure of 1.5 atmospheres. The characteristic dimension of the system is taken to be the diameter of a beverage can cell; D = 2.6" = 0.066m. The relevant quantities are[5]:

T_w = 77K
T_l = 21.7K
$\mu_f = 2.414 \times 10^{-6}$ Pa s (49K, 1.5 atm)
$\rho_l = 69.08$ kg/m^3 (21.7 K, 1.5 atm)
$\Delta\rho_f = 68.3$ kg/m^3
$\sigma = 1.691 \times 10^{-3}$ N/m (21.7K, 1.5 atm)
ΔT = 77K - 21.7K = 55.3K
$T_f = ½ (T_w + T_l)$ = 49K
k_f = 0.03688 W/mK (49K, 1.5 atm)
$\rho_f = 0.7622$ kg/m^3 (49K, 1.5 atm)
$C_{p,f} = 1.909 \times 10^4$ J/kg K (49K, 1.5 atm)
$\lambda = 4.376 \times 10^5$ J/kg

$\lambda' = [4.376 \times 10^5$ J/kg + 0.34(1.909 x 104 J/kg K)(55.3 K)$]^2/4.376 \times 10^5$ J/kg
$= 1.45 \times 10^6$ J/kg

$$h\left(\frac{1.691x10^{-3}\ \frac{N}{m}}{(9.8\ \frac{m}{s^2})(\ 68.3\frac{kg}{m^3})}\right)^{\frac{1}{8}}\left(\frac{(\ 2.414\times 10^{-6}\ \frac{Ns}{m^2})(\ 55.3K)}{(0.03688\frac{W}{mK})^3\ (0.7622\ \frac{kg}{m^3})(68.3\ \frac{kg}{m^3})\ (9.8\ \frac{m}{s^2})(1.45\times 10^6)\ \frac{J}{kg}\ \lambda'}\right)^{\frac{1}{4}}$$

$$= 0.37 + 0.28\left(\frac{1.691x10^{-3}\ \frac{N}{m}}{(9.8\ \frac{m}{s^2})\ (0.066m)^2\,(68.3\frac{kg}{m^3})}\right)^{\frac{1}{2}}$$

h $(1.54 \times 10^{-3}$ m^{2}K/W) = 0.37 + 0.28(0.0241)

h = 244 W/m^{2}K $h\Delta T$ = (244 W/m^{2}K)(55.3K) = 13500 W/m^2

This is comparable to the heat flux predicted by the Bates calculation. The thermal conductivity of the walls of the cell and loop will have a small effect on the heat flux. For example, the cylindrical wall of the heat exchanger is 0.125" thick stainless steel which has a thermal conductivity of 8W/mK at 80K[6]. This gives a conductance per unit area of

$$(8\ \mathrm{W/mK})/(0.0032\mathrm{m}) = 2500\ \mathrm{W/m^2K}$$

This is much larger than the heat transfer coefficient for film boiling hydrogen. Most of the walls of the loop, cellblock and cells are thinner than 0.125" and aluminum has a higher thermal conductivity than stainless steel. The thermal resistance of the metal walls will be neglected. For uninsulated surfaces, a heat flux of 13500 W/m^2 will be assumed.

The loops and heat exchangers are insulated with 25 layers of superinsulation. The effective thermal conductivity of this blanket at 1 atmosphere pressure is expected to be[7] approximately 0.02 W/mK (similar to the thermal conductivity of air) for a 7mm thick blanket. It will be assumed that all surfaces of the heat exchanger and loop piping are covered with 0.007m thickness of insulation having k = 0.02W/mK and that the outer surface of the insulation is at 300K. This gives an effective heat transfer coefficient for insulated surfaces of:

$$h_{eff} = [1/(244\ \mathrm{W/m^2K}) + 0.007\mathrm{m}/(0.02\mathrm{W/\ mK})]^{-1} = 2.82\ \mathrm{W/m^2K} \quad \text{heat exchanger/loop}$$

The heat flux for insulated surfaces is (280K)(2.82 W/m^{2}K) = 790 W/m^2 .
The internal areas of the various target cells which have been used in these targets are summarized below:

<u>Hall C: - original "beverage can" cell</u>

Long cell 6.47cm diameter x 16.9cm long	344 cm^2
Cell exit window 6.47cm diameter	33 cm^2
Short cell 6.47cm diameter x 11.3 cm long	230 cm^2
Cell exit window 6.47cm diameter	33 cm^2
Entrance tube 4.0cm diameter x 10.2cm long	128 cm^2
Entrance window 4.0cm diameter	13 cm^2
Entrance tube 4.0cm diameter x 15.5cm long	195 cm^2
Entrance window 4.0cm diameter	13 cm^2
Cell Block 6.43 cm diameter x 7.30 cm long 3.46 cm diameter x 1.2cm long	321 cm^2
Loop 3.81cm diameter x 100cm long (insulated)	1197 cm^2
Heat exchanger 18.4cm diameter x 21.8 cm long (insulated)	1792 cm^2

Total 1310 cm^2 uninsulated
2989 cm^2 insulated loop/heat exchanger

Hall A: - original "beverage can" cell

Long cell 6.47cm diameter x 16.9cm long		344 cm^2
Cell exit window 6.47cm diameter		33 cm^2
Short cell 6.47cm diameter x 11.3 cm long		230 cm^2
Cell exit window 6.47cm diameter		33 cm^2
Entrance tube 4.0cm diameter x 22.9cm long		300 cm^2
Entrance window 4.0cm diameter		13 cm^2
Entrance tube 4.0cm diameter x 28.4cm long		369 cm^2
Entrance window 4.0cm diameter		13 cm^2
Cell Block 6.43 cm diameter x 20.3 cm long x 2 3.46 cm diameter x 5cm long x 2		930 cm^2
Loop 3.81cm diameter x 221cm long (insulated)	2645 cm^2	
Heat exchanger 18.4cm diameter x 21.8 cm long (insulated)	1792 cm^2	

Total 2265 cm^2 uninsulated
4437 cm^2 insulated loop/heat exchanger

Hall C short cylinder

cell 4.45 cm diameter x 3.28 cm tall		45.8 cm^2
block (internal) 27.0cm x 6.3 cm x 3.53 cm		521 cm^2
Loop 3.81cm diameter x 100cm long (insulated)	1197 cm^2	
Heat exchanger 18.4cm diameter x 21.8 cm long (insulated)	1792 cm^2	

Total 567 cm^2 uninsulated
2989 cm^2 insulated loop/heat exchanger

Hall C: - machined cell (helicoflex gasket)

Long cell 4.85cm diameter x 14.4cm long		220 cm^2
Cell exit window 2.43 cm hemisphere		30 cm^2
Short cell 4.85cm diameter x 8.95 cm long		136 cm^2
Cell exit window 2.43 cm hemisphere		30 cm^2
Entrance tube 2.54cm diameter x 9.26cm long		74 cm^2
Entrance window 2.54cm diameter		5 cm^2
Entrance tube 2.54cm diameter x 14.8cm long		118 cm^2
Entrance window 2.54cm diameter		5 cm^2
Cell Block 6.43 cm diameter x 20.3 cm long x 2 3.46 cm diameter x 5cm long x 2		147 cm^2
Loop 3.81cm diameter x 100cm long (insulated)	1197 cm^2	
Heat exchanger 18.4cm diameter x 21.8 cm long (insulated)	1792 cm^2	

Total 765 cm^2 uninsulated
2989 cm^2 insulated loop/heat exchanger

Hall A; - 20cm cell

Cell 18.31 between centers, 0.978cm radius, 3.58cm high	153 cm^2
Cell Block 3.49cm diameter x 68cm long	
exclude cell area 0.978 radius x 18.31 between centers	668 cm^2
Loop 3.81cm diameter x 221cm long (insulated)	2645 cm^2
Heat exchanger 18.4cm diameter x 21.8 cm long (insulated)	1792 cm^2

Total 821 cm^2 uninsulated
4437 cm^2 insulated

The predicted heat loads and mass evolution rates are:

Hall C original cell
$(13500 W/m^2)(0.131 m^2) + (790\ W/m^2)(0.2989\ m^2) = 2005W$;
2005W/437.6 J/g = 4.58 g/s

Hall A original cell
$(13500 W/m^2)(0.2265 m^2) + (790\ W/m^2)(0.4437 m^2) = 3408W$;
3408W/437.6J/g = 7.79 g/s

Hall C machined cell
$(13500 W/m^2)(0.0765 m^2) + (790\ W/m^2)(0.2989\ m^2) = 1269W$;
1269W/437.6 J/g = 2.90 g/s

Hall A 20cm cell
$(13500 W/m^2)(0.0821 m^2) + (790\ W/m^2)(0.4437 m^2) = 1459W$;
1459W/437.6J/g = 3.33 g/s

Hall C short cylinder
$(13500 W/m^2)(0.0567 m^2) + (790\ W/m^2)(0.2989\ m^2) = 1002W$;
1002W/437.6 J/g = 2.29 g/s

Relief Paths:

Hall A	Hall C
19" 3/8 od/0.035 wall tube, 1 elbow	8' 3/8"od/0.020 wall tube, 2 elbows
10' 1/2"od/0.035" wall tube, 4 elbows	
20' 1" id metal hose	20' 1" id hose
50' 1" tube, 3 elbows	45' 1" tube, 4 elbows
switch panel: 5x 90° bend, diaphragm valve	ball valve
check valve, Circle Seal 259B6PP	check valve, Circle Seal 269B6PP
9' 1" id metal hose	
90' 2" pipe, 7 elbows	150' 2" pipe, 13 elbows
5' 1"id hose	9' 1"id hose
ball valve	ball valve

To calculate the pressure drops along the relief path, it is necessary to make some assumptions about the temperature of the gas at each point in the path. The most conservative assumption would be to assume that the gas is at 300K over the entire path. However, this is clearly unrealistic. At the point where vapor exits the loop, for example, it will be at the boiling point of the liquid. In the cryogenic targets, the first section of the relief path is a stainless steel tube which connects to the target loop at the base of the heat exchanger and exits the vacuum chamber at the top of the service can. This tube has a relatively small mass and would be expected to cool rapidly as a mixture of gas and vapor is initially expelled from the target. The tube is uninsulated over most of its length. It will be assumed that condensation of nitrogen holds the tube at 77K. Hydrogen vapor entering the tube at 22K would exchange heat with the walls at a rate given by[8]:

$$h = 0.023 N_{RE}^{0.8} N_{PR}^{0.4} (k/D)$$

In Hall A, the tube is 0.5"OD/0.035 wall over most of its length while in Hall C it is 0.35" OD/0.035" wall over its entire length. For hydrogen vapor at 24.6K and 3.0 atm, $\rho = 3.715$ kg/m^3, $\mu = 1.366 \times 10^{-6}$ Pa-s, k = 0.02122 W/mK and $N_{PR} = 1.087$.

Hall A

$$v = \frac{0.0039 \text{ kg/s}}{(3.715 \text{ kg/m}^3)(9.37 x 10^{-5} \text{ m}^2)}$$

v = 11.2m/s

$$N_{RE} = \frac{(3.715 \text{ kg/m}^3)(11.2 \text{ m/s})(1.09 \times 10^{-2} \text{ m})}{1.366 \times 10^{-6} \text{ Pa - s}}$$

$N_{RE} = 3.3 \times 10^5$

$$h = \frac{0.023(3.3 \times 10^5)^{0.8}(1.087)^{0.4}(0.02122 \text{W/mK})}{1.09 \times 10^{-2} \text{ m}}$$

h = 1200 W/m^{2}K

Hall C

$$v = \frac{0.0024 \text{ kg/s}}{(3.715 \text{ kg/m}^3)(4.714 x 10^{-5} \text{ m}^2)}$$

v = 13.7 m/s

$$N_{RE} = \frac{(3.715 \text{ kg/m}^3)(13.7 \text{ m/s})(7.75 \times 10^{-3} \text{ m})}{1.366 \times 10^{-6} \text{ Pa - s}}$$

$N_{RE} = 2.9 \times 10^5$

$$h = \frac{0.023(2.9 \times 10^5)^{0.8}(1.087)^{0.4}(0.02122 \text{W/mK})}{7.75 \times 10^{-3} \text{ m}}$$

h = 1530 W/m^{2}K

For a volume element of length l in a tube of length L and radius r, the heat transferred to the gas at temperature T from the walls at temperature T_w causes the temperature of the gas to increase:

$$C_p \pi r^2 \rho l \, dT = h(2\pi r l)(T_w - T)dt$$

If gas enters the tube at temperature T_0 flowing at velocity v then at length L the temperature will be given by:

$$\ln\left(\frac{T_w - T}{T_w - T_0}\right) = \frac{-2h}{C_p \rho r}\frac{L}{v}$$

The heat capacity of hydrogen vapor is approximately 16000J/kgK over a wide range of temperatures. Taking the wall temperature to be 77K and the initial temperature to be 24K we obtain:

$$\ln\left(\frac{77K - T}{77K - 24K}\right) = \frac{-2(1200 W/m^2 K)}{(1.6x10^4 J/kgK)(3.715 kg/m^3)(6.35 \times 10^{-3} m)}\frac{3.0m}{9.77m/s} \qquad \text{Hall A}$$

T=70K

$$\ln\left(\frac{T - 24K}{77K - 24K}\right) = \frac{-2(1530 W/m^2 K)}{(1.6x10^4 J/kgK)(3.715 kg/m^3)(3.87 \times 10^{-3} m)}\frac{2.4m}{11.4m/s} \qquad \text{Hall C}$$

T=74K

It will be assumed that the hydrogen vapor is at 77K over the entire length of metal tube inside the target chamber and at 300K in the external hoses and piping. The formulas used to calculate the pressure drops are:

$$v = \dot{m}/\rho A$$

$$N_{RE} = \rho v D/\mu$$

$$\Delta P = (4f)\tfrac{1}{2}\rho v^2 (L/D) \text{ for hose, tube and pipe and}$$

$$\Delta P = \tfrac{1}{2}\rho v^2 (K) \text{ for fittings}$$

The target systems normally operate at a pressure of 1.5 atmospheres. If the isolation vacuum is lost then the maximum pressure in the cells would occur when the pressure in the storage tank approaches the storage value of 50 psia (3.4 atm) for Hall A or 40 psia (2.72 atm) for Hall C. The pressure drops along the relief path will be estimated assuming that the system is at the storage tank pressure. The gas properties used to calculate the pressure drops are:

Hall A:
internal tubing/fittings T = 77K, P = 3.4 atm, ρ = 1.091 kg/m^3, μ = 3.453 x 10^{-6} Pa-s
external tubing/fittings T = 300K, P = 3.4 atm, ρ = 0.2779 kg/m^3, μ = 8.961 x 10^{-6} Pa-s

Hall C:
internal tubing/fittings T = 77K, P = 2.72 atm, ρ = 0.8719 kg/m^3, μ = 3.448 x 10^{-6} Pa-s
external tubing/fittings T = 300K, P = 2.72 atm, ρ = 0.2224 kg/m^3, μ = 8.960 x 10^{-6} Pa-s

Hall A Original Cell 7.79 g/s

Element	**v m/s**	**N_{RE}**	**4f or K**	**ΔP psi**
3/8" tube	75.73	1.9×10^5	0.016	1.80
3/8" elbow	75.73		0.9	1.63
½" tube	38.10	1.3×10^5	0.016	2.05
½" elbows	38.10		0.9	1.24
1" hose	27.66	2.2×10^4	0.072	2.07
1" tube	36.54	2.5×10^4	0.024	1.77
1" elbows	6.47		0.9	0.87
diaphragm valve	30 SCFM			0.07
check valve	30 SCFM			1.5
2" pipe	6.47	1.1×10^4	0.027	0.05
2" elbows	6.47		0.9	0.02
Total:				13.1

Hall C Original Cell 4.58 g/s

Element	**v m/s**	**N_{RE}**	**4f or K**	**ΔP psi**
3/8" tube	51.80	1.14×10^5	0.016	3.94
3/8" elbow	51.80		0.9	2.82
1" hose	18.91	1.34×10^4	0.072	0.67
1" tube	24.99	1.54×10^4	0.024	0.69
1" elbows	24.99		0.9	0.33
diaphragm valve	20 SCFM			0.05
check valve	20 SCFM			1.3
2" pipe	4.43	6.49×10^3	0.027	0.03
2" elbows	4.43		0.9	0.02
Total:				9.86

In Hall A, the relief valves at the target service can are set for 55psia, however, the pressure drop across the internal tubing and fittings would still exist and the pressure in the cells would reach 55psia+6.7 psia = 61.7 psia. In Hall C the 55 psig rupture disk will not break and the peak pressure will be the maximum storage tank pressure added to the pressure drops along the relief path.

The peak pressures in the cells are:

Hall A : 61.7 psia Hall C: 49.9 psia

The assembled cell blocks have been pressurized to at least 70 psig in a vacuum chamber (85 psid) before they are installed. The test pressure is more than 1.5 times the maximum anticipated absolute pressure that is expected in the cells for the Hall C target. For Hall A target cells of the original design this test pressure must be increased to 1.5(61.7) = 93psid. The original "beverage can" cells are a worst case in terms of mass flow due to their large area. The pressure drops for all of the cells are summarized below.

Flow and Pressure Drop on Loss of Vacuum - Uninsulated cells and cell blocks

Cell Type	Mass Flow	Pressure Drop	Peak Pressure
Hall A "beverage can"	7.79 g/s	13.1 psi	61.7 psia
Hall C "beverage can"	4.58 g/s	9.86 psi	49.9 psia
Hall C machined cell	2.90 g/s	4.72 psi	44.7 psia
Hall A 20cm cell	3.30 g/s	3.57 psi	53.6 psia
Hall C short 4 cm cylinder	2.29 g/s	3.43 psi	43.4 psia

The flow rates and pressure drops are modest for the newer cell designs due to their smaller areas. The situation for the conventional "beverage can" cells could be improved by insulating the cell block. The cell block can be covered with a 25 layer MLI blanket along with the loops and heat exchanger. Newer types of insulation based on aerogel[9] and composits[10] would offer similar performance with thinner layers and may be easier to apply to the complex shape of the cell block. A 3mm thick layer of "Cryocoat Ultralight" from Composite Technology Development was tested in a catastrophic loss of insulating vacuum experiments on a superfluid helium dewar[11] and was shown to reduce the heat flux by a factor of seven in comparison with an untreated surface. The manufacturer quotes a thermal conductivity of 0.02 W/mK for this material at 1 atmosphere pressure.

If the cell block only is covered with 0.002m thickness of insulation having k = 0.02W/mK and that the outer surface of the insulation is assumed to be at 300K then the effective heat transfer coefficient for insulated surfaces is:

$h_{eff} = [1/(244\ W/m^2K) + 0.002m/(0.02W\ mK)]^{-1} = 9.61\ W/m^2K$ cell/block

The heat flux heat is $(280K)(9.61\ W/m^2K) = 2690\ W/m^2$ for the surface of the cell block.

Hall A original cell with block insulated
$(13500W/m^2)(0.1335m^2) + ((2690\ W/m^2)(0.093m^2) + (790\ W/m^2)(0.4437m^2) = 2403W$;
$2403W/437.6J/g = 5.49\ g/s$

This would reduce the pressure drop to 7 psi and the peak pressure in the cell to 57psia in a loss of isolation vacuum incident. In this case, the present test pressure of 85 psid would be adequate.

5. Relief Path Evaluation - Scattering Chamber

We assume that the contents of both the hydrogen and deuterium cells are deposited on the base of the scattering chamber and undergo film boiling with a surface that remains at 300K. The liquid inventories are: (we calculate the volume of hydrogen and double the volume to account for the deuterium loop)

Hall A: The 1000 gallon storage tank is pressurized to 48 psia at 25°C. This pressure falls to approximately 22 psia when the target is condensed. The volume contained in one loop corresponds to:

[(48psia-22 psia)/14.7 psia/atm] x 3785 liters x (273K/300K) = 6092 STP liters
6092 STP liters/22.4 liters/mole x 2g/mole = 544 grams hydrogen
544 g/(0.0723g/cm^3) = 7.52 liquid liters condensed volume

Hall C: The 1000 gallon storage tans is pressurized to 40 psia at 25°C. This pressure falls to approximately 22 psia when the target is condensed. The volume contained in one loop corresponds to:

[(40psia-22 psia)/14.7 psia/atm] x 3785 liters x (273K/300K) = 4217 STP liters
4217 STP liters/22.4 liters/mole x 2g/mole = 376 grams Hydrogen
376 g/(0.0723g/cm^3) = 5.21 liquid liters

If the volume of the scattering chamber is more than 52 times the total liquid inventory then the liquid can boil to form cold vapor without the pressure in the scattering chamber exceeding 1 atmosphere. The venting process will then be relatively slow as the cold vapor warms up.

Hall A	Hall C
40" diameter x 93" tall	49" diameter x 52" tall
volume: 1900 liters	volume 1600 liters
target liquid volume: 15.0 liters	target liquid volume: 10.4 liters

In both cases we are well above the required volume ratio of 52. For the purposes of this calculation the hydrogen and deuterium combined will be treated as two hydrogen liquid inventories. The relief valve will open once the vapor has warmed sufficiently to bring the scattering chamber to 1 atmosphere:

Hall A	Hall C
1088g H^2/1900liters at 1 atm	752g H_2/1600liters at 1 atm
$\rho = 6.168 \times 10^{-4}$ g/cm^3; T = 40.45K	$\rho = 4.70 \times 10^{-4}$; T = 52.65K

It will be assumed that the walls of the chamber remain at 300K. the rate at which heat is delivered to the hydrogen vapor may be calculated using the correlations[8]:

$$N_{UL} = 0.68 + \frac{0.670 N_{RA}^{1/4}}{\left[1 + \left(\frac{0.492}{N_{PR}}\right)^{9/16}\right]^{4/9}} \qquad \text{vertical surface}$$

$$N_{UL} = 0.54 N_{RA}^{1/4} \qquad \text{base}$$

$$N_{UL} = 0.27 N_{RA}^{1/4} \qquad \text{lid}$$

$$\text{where}: N_{RA} = N_{GR} N_{PR}$$

$$N_{GR} = \frac{g\beta(T_S - T)D^3}{\mu^2} \text{ and } \beta = 1/T \text{ for an ideal gas.}$$

D is the characteristic dimension; the height for the vertical surface and the diameter for the base and lid.

For T = 40.45K and P=1 atm
μ =2.046 x 10^{-6} Pa-s, N_{PR} = 1.196
k = 0.03122 W/mK, C_P = 18.20 J/gK

D = 2.63m, β = 1/40K = 0.0247 K^{-1}

N_{GR} = 2.16 x 10^{14}

N_{RA} = 2.58 x 10^{14}

vertical surface:
N_{UL} = 2175
h = (k/D)N_{UL} = 28.77 W/m^2K
area a = π(1.016m)(2.36m) = 7.53 m^2
ha = 217 W/K

base:
1.016m diameter
N_{UL} = 2164
h = (k/D)N_{UL} = 66.4 W/m^2K
area a = $\pi(1.016m/2)^2$ = 0.81 m^2
ha = 53.8 W/K

lid:
1.016m diameter
N_{UL} = 1082
h = (k/D)N_{UL} = 33.3 W/m^2K
ha = 26.9 W/K

For T=52.62K and P=1 atm
μ =2.556 x 10^{-6} Pa-s, N_{PR} = 1.235
k = 0.0390 W/mK, C_P = 18.85 J/gK

D = 1.32m, β = 1/53K = 0.019 K^{-1}

N_{GR} = 1.62 x 10^{13}

N_{RA} = 2.00 x 10^{13}

N_{UL} = 1152
h = (k/D)N_{UL} = 34.04 W/m^2K
a = π(1.24m)(1.32m) = 5.14 m^2
ha = 175 W/K

1.244m diameter
N_{UL} = 642
h = (k/D)N_{UL} = 20.2 W/m^2K
a = $\pi(1.24m/2)^2$ = 1.21 m^2
ha = 24.4 W/K

1.244m diameter
N_{UL} = 19.0
h = (k/D)N_{UL} = 20.2 W/m^2K
ha = 21.7 W/K

The total power transfer to the gas is:

(217 W/K+53.8 W/K + 26.9 W/K)(260K)
=77,300W

(175 W/K + 24.4W/K +21.7 W/K)(248K)
= 54,800W

The gas warms at a rate:

$$\frac{77{,}300\text{W}}{(18.2\ \text{J/gK})(1088\text{g})} = 3.90\text{K/s}$$

$$\frac{54{,}800\text{W}}{(18.85\text{J/gK})(752\text{g})} = 3.87\ \text{K/s}$$

For an ideal gas $\frac{1}{V}\frac{dV}{dt} = \frac{1}{T}\frac{dT}{dt}$

$$\frac{dV}{dt} = \frac{1900\ell}{40\text{K}}(3.90\text{K/s}) = 185\ \ell/\text{s}$$

$$\frac{1600\ell}{52\text{K}}(3.87\text{K/s}) = 119\ \ell/\text{s}$$

Assuming that the gas is warm (300K) and at 1 atm over most of the 2" vent pipe (D = 5.08cm) we have:

ρ = 0.088184 kg/m3, μ = 8.958 x 10-6 Pa-s for hydrogen at 300K and 1atm

v = 91.3 m/s

v = 58.7 m/s

$$N_{RE} = \frac{(0.088184\ \text{kg/m}^3)(91.3\ \text{m/s})(5.08 \times 10^{-2}\ \text{m})}{8.958 \times 10^{-6}\ \text{Pa - s}} \qquad N_{RE} = \frac{(0.08818\text{kg/m}^3)(58.7\ \text{m/s})(5.08 \times 10^{-2}\ \text{m})}{8.958 \times 10^{-6}\ \text{Pa - s}}$$

$N_{RE} = 4.5 \times 10^4$

$N_{RE} = 2.9 \times 10^4$

For smooth pipe a friction coefficient of 0.03 would be appropriate. The relief paths are:

Hall A	Hall C
155' 2" pipe (L/D = 930)	140' 2" pipe
	9' 2" ID hose
7x 2" elbows	7 x 90° elbows
259B16PP check valve	259B16PP check valve
parallel plate relief	parallel plate relief

The nine feet of 2" hose is equivalent to three times that length of pipe, so the two relief paths will be practically identical.

$\Delta P = (0.03)\frac{1}{2}(0.08818\text{kg/m}^3)(91.3/\text{s})^2(930) = 10254$ Pa (1.5 PSI) 2" pipe
$\Delta P = 7 \times \frac{1}{2}\ (0.08818\text{kg/m}^3)(91.3\text{m/s})^2(0.9) = 2315$ Pa (0.3 PSI) elbows

The 2" check valves are quoted as having a C_v of 51. The pressure drop across this valve will be:

$$\Delta P = \frac{T\,S}{63.5\,P}\left(\frac{\dot{V}}{C_v}\right)^2 = \frac{(300\text{K})(0.0659)}{(15\text{psi})(63.5)}\left(\frac{185\ell/\text{s}}{51}\right)^2 = 0.27\text{psi}\ \ (\text{Hall A})$$

In this formula, S is the specific gravity relative to air, P is in psi, T is the temperature in K and the flow is in liters/s. The parallel plate relief valve will be set for 2 psi or less. The total pressure in the scattering chamber will be approximately 4 psig, which should be contained by the windows. The three psi rupture disk would not be expected to break as it sees only the pressure drop across the check valve.

6. Scattering Chamber and Scattering Chamber Windows

The scattering chambers are located near the center of each hall. They are not surrounded by shielding or any other type of enclosure. The large volume of the halls makes the hall an unconfined space for the volume of hydrogen in our system. The beam entrance and exit flanges are attached to the scattering chamber using metal gaskets. Joints between sections of the chamber and between spectrometer windows and the chamber are sealed by rubber O-rings. The chambers are pumped by a single 1000 l/s turbomolecular pump (Hall C) or by a two parallel 900l/s pumps (Hall A). A valve immediately in front of the chamber isolates the beam line from the chamber if the vacuum in the chamber rises above 5 x 10^{-5} Torr.

Concerns have been raised that small air leaks into the scattering chamber could go unnoticed and lead to the build-up of significant quantities of solid nitrogen and oxygen over time. Our experience indicates that this is not the case. Even when the targets are cold, the scattering chamber vacuum (as indicated by a cold cathode ionization gauge) is sensitive to small air leaks from the outside. Most cold surfaces of the target are covered with superinsulation, which reduces their effectiveness as a cryopump. When the targets have been operated under conditions of poor vacuum (mid to high 10^{-6} Torr range) a thin (~0.1mm) layer of frost was observed on uninsulated surfaces of the cellblock. This layer did not appear to grow over a period of weeks. The quantity of air frozen out on cold surfaces under these conditions was not significant. Since the targets are not operated if the scattering chamber pressure is above 5 x 10^{-5} Torr, small air leaks from the outside are not expected to lead to significant accumulations of frozen air inside the chamber and are therefore not a significant hazard.

Solid oxygen at 27K to 30K has a vapor pressure in the 10^{-7} Torr to 10^{-6} Torr range[12]. On the 18K - 22K surfaces of the target, a layer of solid oxygen several millimeters thick would be required to bring the surface of the oxygen to this temperature under the heat load of thermal radiation. One might expect solid oxygen to deposit on a cold surface until the vapor pressure on the warmest surface of that deposit matches the partial pressure of oxygen in the vacuum chamber. No such deposits are observed in our system. The concept of vapor pressure is meaningful only when the vapor and the solid or liquid are in equilibrium at the same temperature. The mean free path of oxygen molecules at 300K and 5 x 10^{-6} Torr is 10 meters[13]. Molecules collide with the 300K inner walls of the scattering chamber much more frequently than with each other. The surface area of the chamber walls exceeds the area of exposed cold surfaces by a factor of 20 to 60. The cold surfaces of the target are surrounded by warm vapor and not by cold vapor. This would explain why significant deposits are not observed in our system.

The thin windows on the scattering chambers are a significant hazard. The windows are exposed when the target is in use. Procedures call for window covers to be installed as the first step when the hall is taken to restricted access or to controlled access when work around the scattering chamber is anticipated. In Hall A the two windows are identical, while in Hall C the HMS and SOS windows differ. The thin beam exit window formerly used in Hall C was removed when an evacuated downstream beam line was installed.

When the chambers are evacuated these windows take a concave shape and vertical ridges form. For the Hall C HMS window these ridges have a spacing of 2.3". The Hall A window is very similar. For the SOS window the ridge spacing is typically 2", however, the ridge pattern is less regular.

Window	Thickness/Material	Dimensions
Hall A	0.016" thick 5052 H34 Aluminum	7" high, 170° on 43" OD chamber
Hall C SOS	0.008" thick 5052 H39 Aluminum	4" high, 165° on 55" diameter
Hall C HMS	0.016" thick 5052 H34 Aluminum	8" high, 80° on 53.5" OD chamber

The stress in a membrane of dimensions a x b (a being the long dimension) clamped at the edges is[14,15]

$$\sigma = n[E(pa/t)^2]^{1/3}$$

where E is the modulus of elasticity, p is the pressure, t is the thickness and the coefficient n depends on a/b. The modulus of elasticity for this alloy is 1.02×10^7 psi. With the scattering chamber evacuated the stresses on the windows are:

Hall A: $\sigma = 0.272[1.02 \times 10^7 \text{psi}(14.7 \text{ psi } 7''/0.016'')^2]^{1/3} = 20{,}400$ psi

Hall C HMS $\sigma = 0.272[1.02 \times 10^7 \text{psi}(14.7 \text{ psi } 8''/0.016'')^2]^{1/3} = 22{,}300$ psi

Hall C SOS $\sigma = 0.336[1.02 \times 10^7 \text{psi}(14.7 \text{ psi } 4''/0.008'')^2]^{1/3} = 27{,}500$ psi

The ultimate tensile strength for 5052H34 aluminum is 38,000psi[16]. The ultimate tensile strength for the H39 alloy is not readily available but for the H38 temper it is 42,000 psi. According to this estimate the larger windows are operating at roughly 60% of the ultimate tensile strength of the material while the smaller window operates at roughly 66% of the tensile strength of the material. However, treating this complex shape as a simple rectangular membrane will only yield a rough estimate of the actual stress. A more accurate result may be obtained by treating each segment of the window as a cylinder having a radius of curvature corresponding to the measured deflection of the segment. The measured deflections give a radius of curvature of 10.0" for the Hall C SOS window and 26.2" for the Hall C SOS window. The predicted stresses are:

$\sigma = Pr/t$ = 24,000 psi Hall C HMS
= 18,000 psi Hall C SOS

Tests in which these windows were punctured with the scattering chamber under vacuum demonstrated that the windows would not fail catastrophically if punctured. Hydrostatic tests of the Hall C windows yielded burst pressures of 35 psid for the HMS window and 40 psid for the SOS window. Two windows were burst for each test. With the scattering chamber under vacuum these windows are subjected to 14.7 psid and therefore operate

with a safety factor of greater than two. Treating the window sections as segments of a cylinder rather than a membrane more accurately predicts the burst pressures.
With vacuum-formed thin windows installed, the Hall C scattering chamber was pressurized to 6 psig. This is 1.5 times the maximum pressure that would be expected in the scattering chamber if both cells were to rupture.

7. Target Electrical Installation

Electrical devices in and around a hydrogen system are potential sources of ignition. However, few of the devices used in research laboratories are listed for use in a Class I, Division 2 locations (locations in which a flammable gas mixture could form as a result of equipment failure). Furthermore, "bag and purge" methods are clearly not practical for devices such as vacuum gauge heads. These difficulties are recognized in NFPA article 45 *Fire Protection for Laboratories Using Chemicals,* which states that "Laboratory work areas…shall be considered as unclassified electrically". Our approach has been to use hydrogen safe devices whenever they are available. Devices which could act as an ignition source are shut-off or isolated if high pressure is detected in the scattering chamber. The volumes that we consider potentially hazardous are the internal volume of the hydrogen system, the internal volume of the scattering chamber and the internal volume of the vent line. Two methods of detecting high pressure in the scattering chamber are used: a Granville-Phillips Convectron gauge with a set point of 5 Torr or a hydrogen-safe pressure switch set near its minimum actuation pressure (10 Torr).

Devices connected to the hydrogen system:

Pressure Transducers: The Sensotec type TJE and FMA pressure transducers as well as the NOSHOK type 625 pressure transducers are designated intrinsically safe by Factory Mutual. The Omega PX750 differential pressure transducers are Factory Mutual listed for Class I, Divisions 1 and 2, Group B (hydrogen).

Temperature Sensors: The diodes and resistors used as temperature sensors are energized by low-level voltage or current sources to prevent self-heating effects from interfering with the temperature measurement at low temperatures. They are not potential ignition sources.

High Power Heaters: The high power heaters are fabricated from 0.051" diameter Nichrome wire wound on a G-10 support (Hall C) or by heater wire sandwiched in Kapton film (Hall A). They are powered by 40V/25A (Hall C) or 150V/7A (Hall A) power supplies. These heaters are normally operated in a PID control loop by the target IOC. The PID loop would reduce the heater power to zero in an event such as loss of isolation vacuum. If the IOC is in a hung state or is rebooting, the PID control is inactive and the power level is constant. In some cases the heater may be powered by an auxiliary power supply manually controlled from the counting house. (This would occur when the IOC hangs while the beam is on and the power setting is low. If the beam goes off then higher power may be needed to prevent the loop temperature from dropping too far.) The high power heater is a potential source of ignition. This is particularly true if it is not

under PID control. All high power heater power supplies (main and auxiliary) are shut off if high pressure is detected in the scattering chamber.
Fans: Presently, the fans which circulate target fluid are three phase induction motors powered by variable frequency power supplies (PDL Electronics Microdrive Elite ME-6.5). The fans themselves do not contain brushes and are not sources of ignition. While the voltages across the motor coils are tens of volts, the voltages from the coils to ground can be considerably higher. It is possible for an electrical discharge to occur around the motor terminals at low pressures. However, at pressures low enough for a discharge to develop, combustion is not possible. The fans and power supplies are not an ignition source.

Thermocouple vacuum gauge Thermocouple vacuum gauges operate with the thermocouple at 250°C (DV-4) to 300°C (DV-6) when the thermocouple is in high vacuum[17]. The autoiginition temperature for a hydrogen air mixture at one atmosphere is stated to be 500°C in NFPA 50A. NASA[18] reports that ignition of a hydrogen-air mixture at reduced pressure can occur due to prolonged contact with objects at temperatures as low as 317°C. The DV-6 gauge tube can only approach this temperature under conditions of high vacuum. The thermocouple gauge tubes should not be potential ignition sources.

Mechanical vacuum pump: Hydrogen safe pumps (Class I, Division 2, Group B) are used on the gas panels.

Devices connected to the scattering chamber:

Mechanical vacuum pump: Hydrogen safe pumps (Class I, Division 2, Group B) are used on the scattering chambers.

Turbomolecular pump: Turbomolecular pumps do not employ brushes and are not likely to be an ignition source. However, they are not rated for hydrogen service. Gate valves close to isolate the turbopumps if high pressure is detected in the scattering chamber.

Cold cathode vacuum gauge: The cold cathode vacuum gauge would normally cease to discharge at pressures above 10^{-2} Torr. It is possible that contamination would allow the gauge to arc or discharge at higher pressures. The cold cathode gauges will be powered off if high pressure is detected in the scattering chamber.

Thermocouple vacuum gauge (Hall C) As noted above, the thermocouple gauge tubes should not be potential ignition sources.

Convectron gauge: The Convectron gauge element operates at 105°C and is not a potential ignition source[19].

Barksdale vacuum switch: The Barksdale DX1-A3SS is UL listed for hazardous locations, Class I, Group B (hydrogen).

Devices connected to the vent line:

Pressure Switch: The Dwyer 1950 differential pressure switch is UL and Factory Mutual listed for Class I, group B hazardous locations.

8. Control System

The target control system is based on a single board VME computer located in the hall. VME carrier boards provide this computer with A/D, D/A, digital IO and serial communications capabilities. This VME computer monitors the target temperatures, the gas system pressures, the high power heater voltage and current, the fan speed, the JT valve positions, the target position and the scattering chamber pressure. It controls the high power heater power supplies, the JT valve positions, the fan controllers, target motion and the fill solenoid valves. The operator has access to these functions through a GUI, which may be run on a computer in the counting house or the hall and communicates with the VME computer over the network. An alarm handler, running alongside the GUI, provides an audible alert if any system pressures or temperatures deviate from preset boundaries. In normal operation, the JT valve position (refrigerant flow) is fixed and the high power heater operates under PID control from the VME computer to regulate the loop temperature. The VME computer and critical devices such as the pressure and temperature monitors and the JT valve controllers operate from a UPS. The VME computer status is monitored by the alarm handler. Occasionally this computer locks-up and must be rebooted. This may be done from the counting house.

We do not rely on the VME control system to perform critical safety functions. An auxiliary high power heater power supply, controlled manually from the counting house, may be used to maintain the loop temperature if the VME computer is not operating. Separate hard-wired alarms alert the operator of loss of scattering chamber vacuum or low pressure in the hydrogen or deuterium systems. The hydrogen sensors are hard-wired to a control/alarm unit located in the counting house. Switches in the counting house allow the operator to close the JT valves and shut off the high power heater supplies should the need arise.

9. Recommendations for Future Installations

In the present design the vent line is connected to the target loop at the base of the heat exchanger and is partially filled with liquid during normal operation. In a loss of vacuum event, liquid hydrogen would be expelled into warm sections of tubing. Flash boiling of the liquid could result in high and unpredictable back pressures in the target loop. Ideally this line would be connected at the top of the target loop piping. Also, ideally this line would be insulated and heat-sunk to the refrigerant return line in a carefully engineered and well documented way.

NASA prohibits the use of soft solder joints in their hydrogen systems and reports that soft solder joints are subject to hydrogen embrittlement[18]. NFPA article 50A *Gaseous Hydrogen Systems at Consumer Sites* specifies that all brazing materials used in hydrogen gas systems shall have a melting point greater than 538° C. Our experience has been that soft solder joints are not reliable. In future installations, efforts should be made to avoid the use of soft solder joints on hydrogen cells

10. Modifications to Existing Installations

Any modifications to the target system that would contravene any of the measures listed in section 3B or which significantly alter any of the numbers used in any of the engineering calculations contained in this document must be approved by the Physics Division. This includes modifications such as introducing new thin windows, significantly altering the volume of the scattering chamber or the gas inventory, or altering the dimensions of the vacuum windows. Minor modifications (such as changing cell dimensions) must be evaluated by the target group.

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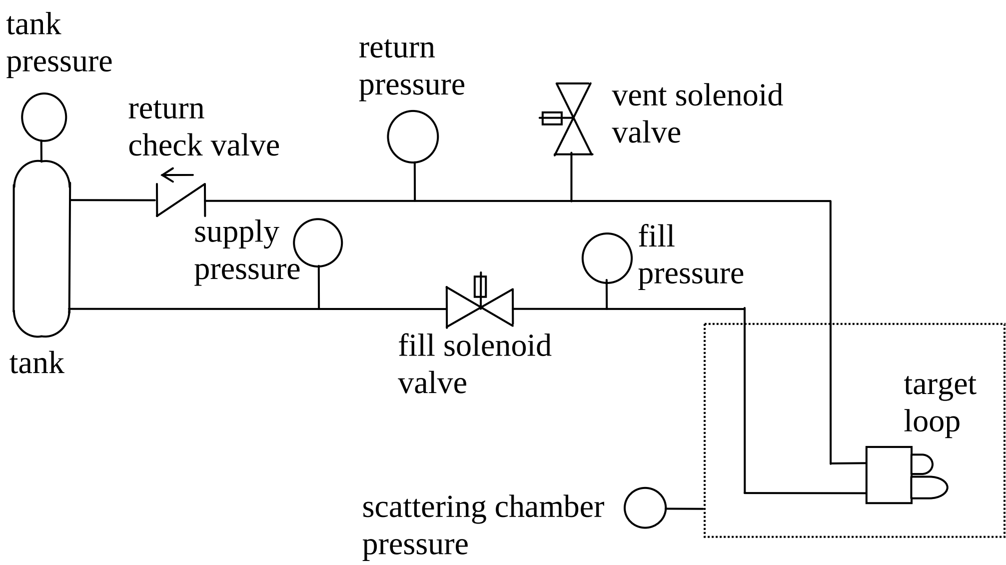
Appendix I - Procedures for Off-Normal Events

System Schematic and Component Designations

Target Gas System Schematic



Designations used in flow sheets and controls

	tank pressure	supply pressure	fill pressure	return pressure	fill solenoid valve	vent solenoid valve	scattering chamber pressure
Hall A Hydrogen	PT133	PT127	PT128	PT131	CSV33	CSV28	VPI149
Hall A Deuterium	PT142	PT136	PT137	PT140	CSV56	CSV57	
Hall C Hydrogen	PT9145	PT9009	PT9013	PT9023	SV9012	SV9014	PI9056
Hall C Deuterium	PT9145	PT9079	PT9083	PT9093	SV9082	SV9084	

The low pressure alarm operates from the return side pressure transducer and the vent solenoid operates from the fill side pressure transducer.

Procedures for Off Normal Events

If any of these events occur when an expert is not present (generally the case when the target is in operation) the first action should be to call the on-call expert.

I. Low Loop Pressure Alarm;

A. <u>During cool-down</u> - low loop pressure alarms are common and indicate that the gas is being condensed so rapidly as to produce a pressure drop between the storage tank and the loop. Close the appropriate JT valve to keep the loop pressure above one atmosphere at all times.

B. <u>During normal operation</u> - the low pressure alarm could be caused by:

- The loop temperature had gone above normal, expelling gas through the check valve and into the tank. The temperature has now fallen and the pressure has dropped.
- The loop temperature is now much too low.
- The cell has ruptured.
- The system is loosing gas, either due to a slow leak or a breach of the system.
- The pressure transducer is defective.

1. <u>Loop temperatures normal:</u> Check the pressures at the fill, return, supply and tank. If the tank and supply pressures are high while the fill and return pressures are low then the system has lost pressure either through an over temperature event, a slow leak or a sudden breech of the system. Open the fill solenoid valve to recharge the system. This should cause the loop temperature to rise as gas is condensed. While gas is condensing, check the pressure and temperature charts for evidence of recent temperature or pressure excursions. A significant pressure difference between the fill and return sides indicates possible blockage of the loop by frozen air. If opening the fill solenoid causes the tank pressure to drop while the system pressure fails to increase then a breach of the system is indicated.

2. <u>Loop temperature low:</u> Use the TV monitor to check the loop temperatures if the control system is down. If the temperature of the loop is low then close the appropriate JT valve and check the operation of the high power heater for that loop The high power heater should be in PID control with a reasonable (typically 400W to 600W) maximum power setting. If the controls are inoperative then it should be possible to use the auxiliary high-power heater supply to bring the loop temperature back up. If the control system is inoperative and it is not possible to bring the loop temperature back up using the auxiliary high power heater supply then it will be necessary to use the manual shut-down switch to close the JT valves. This will close the JT valves for all loops. Shut off all auxiliary and main high-power heater supplies immediately after closing the JT valves.
3. <u>Loop temperature high</u>; If gas is condensing (fill valve open) then a low pressure condition may be created if gas condenses too rapidly. If the temperatures of all operating loops have gone high, the scattering chamber vacuum reads high and valves to the beam line and beam dump have closed then it is possible that a cell has failed.

II. Low Vent Line Pressure Alarm

The hydrogen vent line is filled with helium gas and is maintained slightly above ambient pressure to prevent contamination. If a low vent line pressure alarm occurs during target operation, verify that the 4 atmosphere house helium supply is turned on (contact the cryogenics group). Inspect the vent line and the parallel-plate relief valve at the termination of the vent line. Check the reading of the pressure gauge on the vent line. If necessary, increase the helium regulator setting to increase helium flow into the vent line. If it is not possible to maintain a positive pressure in the vent line then initiate the target warm-up procedure.

III. Vent Solenoid Open Alarm

If the vent valve were to open and remain open it would reduce the system pressure to 1 atmosphere and make contamination of the system possible.

A. During start-up: Adding gas to the storage tank or overfilling the system during a pump/purge operation may cause the vent solenoid to open. It should close when the system pressure falls below the set point. It may be necessary to readjust the set point if gas is added to the system.
B. During normal operation: If all temperatures and pressures (other than the fill pressure) appear normal then a defective fill-side pressure sensor is likely. Unplug the transducer to close the vent solenoid. If the system temperatures and pressures are high then a loss of isolation vacuum may have occurred. See part IV.

IV. Hydrogen Sensor Alarm

All previous hydrogen sensor alarms have been caused by defective sensors, defective amplifier cards or gases other than hydrogen. The alarms failed to detect the release of large quantities of hydrogen following previous target cell failures, which is not unexpected because hydrogen disperses rapidly in air. The loss of any significant quantity of hydrogen from the gas system should be evident by the loss of pressure in the system.

A. Target not installed: If a hydrogen sensor alarm occurs when the target is not in use (gas tanks are valved off outside the hall) verify that the gas tanks are valved off. Visually inspect the area around the sensor. The sensor may then be disabled and must be replaced before the hydrogen system is returned to service.

B. Target installed: If a hydrogen sensor alarms while the target is in use (tank valves open), warn anyone present in the hall to stay clear of the area (pivot or gas panel). Check the system pressures. Unless a pump/purge operation is underway, they will be at the storage pressure (48 psia for Hall A, 40 psia for Hall C) if the target is warm, or approximately 22 psia if the target is condensed. If a pump/purge is underway, pump out any hydrogen in the system, backfill with helium perform a leak test.

1. If loss of inventory is not indicated (system pressures normal), inspect the system for damaged hoses or piping. Use a portable hydrogen sensor to approach and probe the area. Inspect the sensor wiring. Replace the sensor.
2. If a sudden and significant loss of inventory is indicated see V, Breach of Hydrogen System. It is unlikely that any event short of a sudden and significant loss of hydrogen inventory would trigger a real hydrogen sensor alarm.

V. Loss of Isolation Vacuum

Loss of isolation vacuum is indicated by a low alarm on the scattering chamber pressure (a readback of less than 10^{-10} Torr indicates that the gauge has tripped off), an alarm from the scattering chamber vacuum switch, closure of the scattering chamber entrance and exit valves and the generation of an FSD, and the sudden warm-up of the target. Loss of isolation vacuum may be caused by a leak from the refrigerant system, a leak from the hydrogen system or a leak from the exterior of the scattering chamber. If the loss of isolation vacuum is due to a hydrogen leak then the hydrogen must be pumped into the hydrogen vent using a hydrogen safe pump.

1. Close the fill solenoid valves if they are open. Immediately close the JT valves and initiate the target warm-up procedure. Shut off the fans. Check pressures in the gas systems to determine whether or not a cell has ruptured. The fill side and return side pressures will fall if there is a significant leak to the scattering chamber. The storage tank pressure will not increase as the target warms-up. Valve off the tanks once the targets have evaporated.

2. The gate valve which isolates the turbopumps will close if the pressure in the chamber exceeds 5 Torr. (The Hall A vacuum system has this provision and the Hall C system will be modified to make it identical). Shut off the turbopumps and the ion gauges. Open the bypass valve and attempt to evacuate the chamber using the mechanical pump.

3. If a poor vacuum exists in the scattering chamber then the gas panel may be used to evacuate each target cell and backfill it with helium gas. This will both remove hydrogen from the system and test for the source of the leak. If the scattering chamber is at high pressure then avoid evacuating and crushing the target cells. If the chamber can not be pumped down before the system is opened then a helium gas purge from the gas panel must be used to flush hydrogen from the target cells and piping..

4. If a significant quantity of hydrogen has been deposited in the hydrogen vent line then that branch of the line should be purged with helium. Close the helium supply valve to the vent line and set the regulator for 10 psig. Open the valve and allow the purge to run for 5 minutes. (This provides one gas change for the entire line). On completion reset the regulator for the vent line operating pressure.

VII. Breach of Hydrogen System

Damage to hydrogen piping or hoses may result in the release of hydrogen into the hall.

A. If targets are not condensed: Clear the area. Valve off the tanks to stop the flow of gas. Run the smoke removal fan to aid the dispersal of hydrogen.

B. If targets are condensed: Clear the area. Valve off the tank of the affected system only. Close the JT valves and shut off all fans and heaters. Do not attempt to speed up evaporation of the liquid by using fans or heaters. (The side of the system which has been breached may be blocked by frozen air or water, however, the secondary relief valves may allow the hydrogen to be vented through the remaining side.) Run the smoke removal fan to aid the dispersal of hydrogen.

VII. Simultaneous Vacuum Window and Target Cell Failure

If the breach of the vacuum windows is small and the chamber can be evacuated to 15 Torr or less then evacuating the chamber and backfilling with nitrogen will eliminate the flammable gas mixture.

If a large opening in one of the vacuum windows has been created:

1. Clear the area. Shut off the fans and high power heater power supplies. Do not operate the target lifter. Valve off the tanks. The D65B rotary vane pumps connected to the scattering chambers have a pumping speed of 90 m^3/hr. Allow the pump to pump on the chamber for a total of one hour. Shut the pump off and allow it to cool as needed. Increase the pumping time if the pressure at the pump inlet is reduced (two hours if the pressure is ½ atmosphere).

2. Approach the scattering chamber with a portable hydrogen sensor. Probe the area around the breach and inside the scattering chamber. Leave the area and continue to pump if readings of 2% or higher are encountered.

Hall A Cryotarget General Operation Manual

David Meekins

26th February 2004

Abstract

This document describes the general operation of the Hall A cryogenic target. It includes procedures for determining the current state of the target, pump/purge of the individual loops, pump/purge of the storage tanks, ^{3}He and ^{4}He operation and warm up and cool down of both 15K and 4K targets. It is intended for guidance of the target expert and not the typical target operator. The document contains checklists for each of these procedures.

Contents

1 Overview

This document describes the general operation of the Hall A cryogenic target. A flow schematic is shown in TJNAF drawing number A_CRYO_1001 sheets 1, 2, and 3. It is extremely important to understand the target system before performing one of the following procedures. If there are any questions regarding these procedures, consult Mike Seely Chris Keith or David Meekins. In all cases, make sure that a flow sheet is available and perform the procedure with care. It is possible that something was overlooked during the development of the procedure.

2 Target Inspection and Pre-configuration

This section describes the procedures for determining the current target configuration. It is best to consult a member of the target group (Mike Seely, Chris Keith, or Dave Meekins) prior to finalizing this procedure. These procedures should be performed prior to closing the scattering chamber and any pump/purge of the loops.

2.1 Inspection of target cells and inside of scattering chamber.

Procedure 2.1

No	Item	Time	Data
0	Obtain a list of targets with loop/cell configurations and solid targets needed for the current experiment		
1	Inside the scattering chamber verify that the targets match this list, specifically cell lengths and positions. Record the cell types and lengths for each loop.		
2	Check the alignment of these targets. Dummy target installed correctly, optics target foils in good condition, etc		
3	Inspect the target inside the chamber for impedance to motion of the system.		
4	Record the desired loop and target fluid configuration		
4a	Record Loop 1 cryogen		
4b	Record Loop 2 cryogen		
4c	Record Loop 3 cryogen		
4d	Record solid target configurations		
5	Procedure complete		

2.2 Inspection and certification of target lifting mechanism

The target lifting mechanism is a complicated device. Proper operation of the target lifting mechanism can cause serious damage to the target and personnel near it. Use caution when operating the target lifter. The following procedure describes the certification of the target lifting mechanism.

Procedure 2.2

No	Item	Time	Data
1	Look inside the scattering chamber for any possible obstructions to the target lifter.		
2	At the top of the scattering chamber inspect the area for possible obstructions to the target lifter		
3	Ensure that the cryogenic coolant lines have the proper slack.		
4	Ensure that the target gas lines have the proper slack and will not catch on protrusions		
5	Ensure that the electronic cables have enough slack and will not catch on protrusions.		
6	Inform all in the area that target motion is to be tested.		
7	Inspect the lifter mechanisms for damage. Inspect the motors and cables Inspect drive sprockets brakes and drive chains. Inspect shaft couplers Inspect lead screw and drive nuts Ensure that all brackets are tight		
8	Energize the target lifter.		
9	With ample spotters and communications run the home sequence.		
10	select random targets and position them in the beam.		
11	Ensure that the vertical over travel limits are correct		
12	select the bottom and top target to test the full range of motion.		
13	If there are no problems then the lifter is certified		
14	Procedure complete		

2.3 Inspection of cryo/gas lines.

At the top of the scattering chamber perform the following checks

Procedure 2.3

No	Item	Time	Data
1	Check loop connections: 1a) Loop 1 return connected to loop 1 return hose 1b) Loop 1 supply connected to loop 1 supply hose 1c) Loop 2 return connected to loop 2return hose 1d) Loop 2 supply connected to loop 2supply hose 1e) Loop 3 return connected to loop 3 return hose 1f) Loop 3 supply connected to loop 3 supply hose		
2	Check VPT line connections		
3	Check large electrical feed through connections		
4	Check JT valve connection and verify the operating range. This takes two people. 4a) Loop 1 JT motion 4b) Loop 2 JT motion 4c) Loop 3 JT motion 4d) Pre-cool JT motion		

5	Check for fouling of any line or cable with the vertical motion of the target.		
6	Check the connection of the warm return and vent header lines.		
7	Make sure that the relief on each loop return line is correct. This is very important to the safe operation of the target. Check the direction of each relief installation. H_2 and D_2 targets should have a relief setting of 40psig He targets should have a relief setting of 245psig 7a) Loop 1 relief setting (psig) 7b) Loop 2 relief setting (psig) 7c) Loop 3 relief setting (psig)		
8	Check that the U-tubes have been properly installed.		
9	Check the scattering chamber relief system. Ensure that MV01 is locked open.		
10	Procedure complete		

2.4 Inspection of the loop/gas panel connections.

The loop/gas panel connections are made in an almost inaccessible place, high in the air above the warm return valve for the target. Because these connections (flanges) are in an unfortunate position, it is advantageous to obtain the help of one on the Hall A technicians. They can help with an aerial platform lift so that inspection of these connections is not impossible. The purpose of the following checks is to ensure that the return and supply lines from the gas panel match the return and supply lines from the desired loop. Loop and gas panel connections should also be recorded and checked to make sure that these connections match the needs of the experiment. Most important, if He targets are being used, is which loops have the proper reliefs.

Procedure 2.4

No	Item	Time	Data
1	Make sure that loop supply and return lines are connected to the same gas panel return and supply lines. Make sure that return is connected to return.		
2	Record Loop 1 return connection Record Loop 1 supply connection		
3	Record Loop 2 return connection Record Loop 2 supply connection		
4	Record Loop 3 return connection Record Loop 3 supply connection		
5	Record H2 tank to panel connection		
6	Record D2 tank to panel connection		
7	Procedure complete		

2.5 Inspection of ^{3}He, H_2, and D_2 storage tank configuration.

The H_2 and D_2 storage tanks are located outside the hall behind the counting house. The ^{3}He storage tank is located on the second mezzanine in the hall.

2.5.1 Inspection of the ^{3}He storage tanks.

Inspection of the ^{3}He storage tanks is best left to target experts. The procedure follows.

Procedure 2.5.1

No	Item	Time	Data
1	If the condition of the He target is not known contact the target group Mike Seely, David Meekins or Chris Keith		
2	Ensure that MV201 and MV202 are closed and locked		
3	Read the pressure of the strage tank on PI255		
4	The pressure in the tank if ^{3}He is stored in it should be $\sim$220 psia. If this is not the case contact the target group.		
5	Procedure complete		

2.5.2 Inspection of the H_2, and D_2 storage tank configuration prior to pump and purge

Inspection of the H_2, and D_2 storage tank configuration can be performed outside the hall in back of the counting house. The Hall A storage tanks are located behind the Hall A counting room. Perform the following checks:

Procedure 2.5.2

No	Item	Time	Data
1	Make sure that the valve on the tanks are in the proper position		
2	H_2 return line valve MV39 locked closed		
3	H_2 supply line valve MV41 locked closed		
4	D_2 return line valve MV68 locked closed		
5	D_2 supply line valve MV70 locked closed		
6	Visually inspect hoses, lines and relief valves. If there is damage contact the target group and stop the procedure.		
7	Procedure complete		

2.5.3 Inspection of the H_2, and D_2 storage tank configuration prior to target fill.

Inspection of the H_2, and D_2 storage tank configuration can be performed outside the hall in back of the counting house. The Hall A storage tanks are located behind the Hall A counting room. Perform the following checks:

Procedure 2.5.3

No	Item	Time	Data
1	Make sure that the valves on the tanks are in the proper position		
2	H_2 return line valve MV39 locked open		
3	H_2 supply line valveMV41 locked open		
4	D_2 return line valve MV68 locked open		
5	D_2 supply line valve MV70 locked open		
6	Inspect hoses, lines and relief valves. If there is damage contact the target group and **DO NOT** fill the target		
7	Procedure complete		

2.6 Swap-over valve configuration for H_2 and D_2 target operation

There is a swap-over valve lineup that allows the H_2 panel to be switched with the He panel, and a second series of valves that allows the He pump/purge and D_2 panels to be swapped. This is intended to add flexibility during a run by eliminating the need for a complete target warmup and physical swapping of hoses. It is assumed that the target will be operated under normal conditions. Thus, the loop/panel connections can be correctly determined by following Procedure 2.4. These valves are located behind the main gas panels. Two of these valves are located above the beam line in a difficult position to access. Use caution when accessing these valves.

Procedure 2.6

No	Item	Time	Data
1	Configure loop/panels for normal operations 1a) Open MV158___ Connects D_2 return line 1b) Open MV162___ Connects D_2 supply line 1c) Open MV159___ Connects He supply line 1d) Open MV155___ Connects He return line 1e) Open MV172___ Connects H_2 return line 1f) Open MV173___ Connects H_2 supply line		
2	Ensure that the swap-over valves are closed. 2a) Close MV156___ and MV 157___ 2b) Close MV160___ and MV161___ 2c) Close MV174___		

3 Pump and purge procedures

Note: Before performing any pump/purge procedure be sure that the pressure in the scattering chamber is below 1×10^{-4} **Torr.** Damage to the target cells may result if the proper vacuum does not exist in the scattering chamber. Pump and purge of the H_2 and D_2 storage tanks may be performed without vacuum in the scattering chamber but caution must be exercised.

3.1 4 atm House He supply pump and purge.

Check to make sure that the 4 atm supply in Hall A has been turned on. This can be done by checking the regulator at the back of the gas panels. Sometimes work is performed on this system and the cryogenics group will close the supply valve for the 4 atm He. Perform this procedure if unsure of the status of the 4 atm supply line going to the gas panel. Check to make sure that there are no extra lines plumbed into this system. Targets such as the polarized ^{3}He target require this 4 atm gas supply to be plumbed to the pivot.

Procedure3.1

No	Item	Time	Data
0	Make sure all valves on the gas panels are closed.		
1	It is safer to perform this procedure with the scattering Chamber under vacuum if it is possible wait until this is so.		
1	Turn on the gas panel mechanical vacuum pump MP1___		
2	Ensure that the valve on the back of the panel supplying He to the pivot is closed. Also ensure that the supply valve located before the regulator is closed.		
3	Close MV163. Open: MV79___ MV75___ MV74___ CPV73. Wait for the pressure on PI145 to read less then 20 μm of mercury (μmHg). ___		
4	Close CPV73___ MV79___. Open MV163. Open CPV 73 to slightly more than 1 atm. Check the pressure on PI101. Close MV163___ .		
5	Open MV79___ . Wait for the pressure on PI145 to read less then 20 μmHg. Close MV79___		
6	Open MV163___. PI101 $\sim$ 1atm. Close MV163___.		
7	Repeat step 5		
8	Repeat step 6		
9	Repeat step 5		
10	Repeat step 6		
11	Leave $\gtrsim$ 1 atm of He on this line.		
12	Close all valves and turn off MP1.		
13	Procedure complete.		

3.2 Standby loop pump and purge with ^{4}He

Procedures 2.1, 2.3, 2.4, 2.5.2, and 2.6 must be performed prior to this procedure. One of the most crucial steps in the following procedure is to make sure that there is vacuum in the scattering chamber. This will prevent crushing the target cells.

Procedure 3.2

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read less than 10^{-5} Torr. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	Ensure that all valves on the gas panels are closed.		
2	Turn on vacuum pump MP1		
3	Behind the pump and purge panel, open MV163___ Set the pressure on PV173 > 1 atm.		
4	Record the pressures on the D_2 and H_2 loops. PI138____, 139____, PI129____, PI130____ There should be at least 1 atm on each of these gauges.		
5	Open manual valves MV79___ MV78___ and MV76___.		
6	Wait for the pressure on PI145 to read less then 20 μmHg		
	(Note that this gauge is mounted to the pump.)		
7	Examine the pressures on the gauges recorded in step 4 If these pressures are still the same continue to step 8. If they are now different then when recorded there is a problem. Close MV79___ and MV78___. Open MV74 and allow the pressure on PI147 to reach > 1 atm. Close MV74. Contact the target group and **STOP**		
8	Downstairs in the electronics rack, plug the fan controller for the He loop in and start the fan running at ~20 Hz. Wait for the pressure on PI145 to read less then 20 μmHg. Close MV79___.		
9	Open MV74___. Wait until the pressure on PI147 ~ 1atm. Close MV74___.		
10	Open MV79___ Wait for the pressure on PI145 to read less then 20 μmHg. Close MV79___		
11	Repeat step 9		
12	Repeat step 10		
13	Repeat step 9		
14	Repeat step 10		
15	Repeat step 9		
16	The pressure on PI147 should be ~1 atm.		
17	Close all valves on the panels and shut off MP1.		
18	Turn off and unplug the fan controller for this loop.		
19	Procedure complete.		

3.3 Hydrogen panel/loop pump and purge with ^{4}He

In principle, the hydrogen and deuterium loops can be pumped and purged simultaneously with ^{4}He. However, a more cautious approach is to do each separately. This allows a further check of the gas line connections to make sure that the return and supply are at least connected to the same loop and swap-over valves have been properly configured. Procedures 2.1, 2.3, 2.4, 2.5.2, and 2.6 must be performed prior to this procedure.

One of the most crucial steps in the following procedure is to make sure that there is vacuum in the scattering chamber. This will prevent crushing the target cells.

Procedure 3.3

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read below 10^{-5} Torr. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	Ensure that all valves on the gas panels are closed.		
2	Make sure that the H_2 tank isolation valves MV39___ an MV41___ are closed. This should have been done in Procedure 2.5.2.		
3	Turn on vacuum pump MP1		
4	Behind the pump and purge panel, open MV163___ Set the pressure on PV173 $>$ 1 atm.		
5	Note the pressures on PI135, PI138, and PI147 Examine the pressures on PI129 and PI131. PI31 indicates the pressure on the return line. PI29 indicates the pressure on the fill line. Open MV34___ If the pressures on PI131 and PI129 are falling and the pressures on PI135, PI138, and PI147 are not then proceed to step 6. If not close MV34___ and open SV27___ SV33___ MV25___ MV77___ and MV74___. Allow the pressure on PI130 to reach 1 atm and close all the valves and turn off MP1. Contact the target group and **STOP**.		
6	Open MV79___ Open MV77___ MV19___ MV25___ Open MV21___ MV22___ MV23___ and MV24___ Open solenoid valves CSV27___ and CSV33___. The local control switch can be found on the He pump/purge panel This pumps the hydrogen loop through both the fill and return lines. Wait for the pressure on PI145 to read less then 20 μmHg (Note that this gauge is mounted to the pump.) Cycle CSV27 and CSV33 several times to minimize the presence of trapped gas. Leave both valves open. Open MV20___ and MV36___. This pumps out the fill and return lines connected to the tank.		
7	Downstairs in the electronics rack, plug the fan controller for the hydrogen loop in and start the fan running at $\sim$20 Hz. Wait for the pressure on PI145 to read less then 20 μmHg. Turn off MP1 and record rate of rise. Turn MP1 back on. Close MV79___ and MV34___.		
8	Open MV74___. Wait until the pressure on PI126 $\sim$ 1atm. Close MV74___.		
9	Open MV79___ and MV34___. Wait for the pressure on PI145 to read less then 20 μmHg. Cycle solenoid valves CSV27 and CSV33 several times.		

	Close MV79___ and MV34___.		
10	Repeat step 8		
11	Repeat step 9		
12	Repeat step 8		
13	Repeat step 9		
14	Repeat step 8		
15	The pressure gauges on the H_2 panel should read ~ 1 atm.		
16	Close all valves on the panels and shut off MP1		
17	Turn off and unplug the fan controller for this loop		
18	Procedure complete		

3.4 Deuterium panel/loop pump and purge with ^{4}He

In principle, the hydrogen and deuterium loops can be pumped and purged simultaneously. However, a more cautious approach is to do each separately. The following procedures describe the more cautious approach.

Procedure 3.4

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read in the 10^{-6} Torr or less range. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	Ensure that all valves on the gas panels are closed.		
2	Make sure that the D_2 tank isolation valves MV68 and MV70 are closed. This should have been done in Procedure 2.5.2.		
3	Turn on vacuum pump MP1		
4	Behind the pump and purge panel, open MV163___ Set the pressure on PV173 $>$ 1 atm.		
5	Note the pressures on PI131, PI129, and PI147 Examine the pressures on PI139 and PI138. PI139 indicates the pressure on the return line. PI138 indicates the pressure on the fill line. Open MV63___ this pumps the loop through the return line. Examine the pressures on PI138 and PI139 If both pressures are falling and the pressures on PI126, PI129, and PI147 are constant then proceed to step 6. If not close MV63___ and open SV62___ SV56___ MV54___ MV75___ and MV74___. Allow the pressure on PI139 to reach 1 atm and close all the valves and turn off MP1. Contact the target group and **STOP**.		
6	Open MV79___ Open MV75___ MV48___ MV54___ Open MV50___ MV51___ MV52___ and MV53___ Open solenoid valves CSV62___ and CSV56___. The local control switch can be found on the He pump/purge panel		

	This pumps the deuterium loop through both the fill and return lines. Wait for the pressure on PI145 to read less then 20 μmHg (Note that this gauge is mounted to the pump.) Cycle CSV62 and CSV56 several times to minimize the presence of trapped gas. Leave both valves open. Open MV49___ and MV65___. This pumps out the fill and return lines connected to the tank.		
7	Downstairs in the electronics rack, plug the fan controller for the D_2 loop in and start the fan running at ~20 Hz. Wait for the pressure on PI145 to read less then 20 μmHg. Turn off MP1 and record rate of rise. Trun MP1 back on. Close MV79___ and MV63___.		
8	Open MV74___. Wait until the pressure on PI1135 ~ 1atm. Close MV74___.		
9	Open MV79___ and MV63___. Wait for the pressure on PI145 to read less then 20 μmHg. Cycle solenoid valves CSV62___ and CSV56___ several times. Close MV79___ and MV63___.		
10	Repeat step 8		
11	Repeat step 9		
12	Repeat step 8		
13	Repeat step 9		
14	Repeat step 8		
15	The pressure gauges on the D_2 panel should read ~ 1 atm.		
16	Close all valves on the panels and shut off MP1		
17	Turn off and unplug the fan controller for this loop.		
18	Procedure complete		

3.5 H_2 bottle swap and pump/purge

During the course of normal target operation (e.g. during a target fill), it may be necessary change the H_2 bottle. At the start of the H_2 panel pump and purge procedure with H_2, it will also be necessary for the line that connects the H_2 supply bottle to the gas panel to be pumped/purged. If the bottle was not changed and has adequate pressure the user should start at step 1 in the following procedure. Although it is not necessary, it is safer to have vacuum in the scattering chamber.

Procedure 3.5

No	Item	Time	Data
0	Ensure that the regulator CPV17 on top of the H_2 bottle is closed. Ensure that the manual valve MV164 on top of the H_2 bottle is closed. Remove the regulator from the bottle. Swap old bottle with new bottle. Connect the regulator to the new bottle and Snoop the connection.		

1	Ensure that the following manual valves are closed: MV63___, MV34___, MV79___, MV80___, MV81___, and MV18___.		
2	Make sure that MV164 located on top of the H_2 bottle is closed.		
3	Close regulator CPV17 attached to the H_2 bottle.		
4	Start vacuum pump MP1		
5	Open MV80___. Wait until the pressure on PI145 falls below 20 μmHg. Close MV80___		
6	Open MV164___. Set CPV17 to $>$ 1atm. Close MV164___		
7	Repeat step 5		
8	Open MV164___. Wait until the pressure on the line is $>$ 1 atm		
9	Repeat step 5		
10	Repeat step 8		
11	Repeat step 5		
12	Repeat step 8		
13	The pressure in the line should now be $>$ 1 atm.		
14	Close all valves and turn off MP1.		
15	Procedure complete		

3.6 D_2 bottle swap and pump/purge

During the course of normal target operation (e.g. during a target fill), it may be necessary change the D_2 bottle. At the start of the D_2 panel pump and purge procedure with D_2, it will also be necessary for the line that connects the D_2 supply bottle to the gas panel to be pumped/purged. If the bottle was not changed and has adequate pressure the user should start at step 1 in the following procedure.

Procedure3.6

No	Item	Time	Data
0	Ensure that the regulator CPV46 on top of the D_2 bottle is closed. Ensure that the manual valve MV165 on top of the D_2 bottle is closed. Remove the regulator from the bottle. Swap old bottle with new bottle. Connect the regulator to the new bottle and Snoop the connection.		
1	Ensure that the following manual valves are closed: MV63___, MV34___, MV79___, MV80___, MV81___, and MV47___.		
2	Make sure that MV165 located on top of the D_2 bottle is closed.		
3	Close regulator CPV46 attached to the D_2 bottle.		
4	Start vacuum pump MP1		
5	Open MV81___. Wait until the pressure on PI145 falls below 20 μmHg. Close MV81___		
6	Open MV165___. Set CPV46 to $>$ 1atm. Close MV165___		
7	Repeat step 5		

8	Open MV165___. Wait until the pressure on the line is > 1 atm		
9	Repeat step 5		
10	Repeat step 8		
11	Repeat step 5		
12	Repeat step 8		
13	The pressure in the line should now be > 1 atm.		
14	Close all valves and turn off MP1.		
15	Procedure complete		

3.7 H_2 panel pump/purge with H_2

The following procedure needs to be performed prior to normal H_2target operations. At the start of the procedure one should make sure that the line connecting the supply bottle has bee pumped and purged with H_2 as described in Procedure 3.5. Note that this procedure will not leave the valves in the proper lineup for target operation.

Procedure3.7

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read in the 10^{-6} Torr or less range. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	If the lines to the target have been changed then ensure that Procedure 3.3 has been performed. Ensure that procedure 3.5 has been performed.		
2	Ensure that all valves on the H_2 gas panel are closed. Ensure that the following valves are closed: MV77___ and MV78___ MV19___ and MV25___ and MV48___ and MV54___		
3	Make sure that the H_2 tank isolation valves MV39___ and MV41___ are closed. This should have been done in Procedure 2.5.2. Switch the hydrogen status indicator form "Empty" to "In Use"		
4	Turn on vacuum pump MP1		
5	Open the following valves: MV79___, MV19___, MV25___, MV34___ MV21___, MV22___, MV23___, MV24___ SV27___, SV33___. Open valves MV36___ and MV20___. These valves are connected to the H_2 supply tank.		
6	Downstairs in the electronics rack, plug the fan controller for the hydrogen loop in and start the fan running at ∼20 Hz.		

7	Wait for the pressure on PI145 to read less then 20 μmHg. Cycle SV27 and SV33. Close MV79___ and MV34___.		
8	Open MV164 on top of the H_2 bottle. Open MV18___. Wait until the pressure on PI126 $\sim$ 1atm. CPV17 may have to be adjusted. Close MV18___.		
9	Open MV79___ and MV34___. Wait for the pressure on PI145 to read less then 20 μmHg. Cycle solenoid valves CSV27 and CSV33 several times. Close MV79___ and MV34___.		
10	Repeat step 8		
11	Repeat step 9		
12	Repeat step 8		
13	Repeat step 9		
14	Repeat step 8		
15	The pressure gauges on the H_2 panel should read $\sim$ 1 atm.		
16	Adjust CPV17 to 40 psig		
17	Open MV18 and allow the pressure on PI126 to reach 40psia. This brings the pressure closer to the normal starting pressure of the loop.		
18	Close all valves on the panels and shut off MP1		
19	Turn off and unplug the fan controller for this loop		
20	Procedure complete		

3.8 D_2 panel pump/purge with D_2

The following procedure needs to be performed prior to normal H_2target operations. At the start of the procedure one should make sure that the line connecting the supply bottle has bee pumped and purged with H_2 as described in Procedure 3.6. Note that this procedure will not leave the valves in the proper lineup for target operation.

Procedure 3.8

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read in the 10^{-6} Torr or less range. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	If the lines to the target have been changed then ensure that Procedure 3.4 has been performed.		
2	Ensure that all valves on the gas panels are closed. Ensure that the fo8llowing valves are closed: MV77___ and MV78___ MV19___ and MV25___ and MV48___ and MV54___		
3	Make sure that the D_2 tank isolation valves MV68___ and MV70___ are closed This should have been done in Procedure 2.5.2.		

	Switch the hydrogen status indicator from "Empty" to "In Use"		
4	Turn on vacuum pump MP1		
5	Open the following valves: MV79___, MV48___, MV54___ MV63___ MV50___, MV51___, MV52___, MV53___ SV56___, SV62___. Open valves MV49___ and MV65___. These valves are connected to the D_2 supply tank.		
6	Downstairs in the electronics rack, plug the fan controller for the D_2 loop in and start the fan running at $\sim$20 Hz.		
7	Wait for the pressure on PI145 to read less then 20 μmHg. Close MV79___ and MV63___.		
8	Open MV165 on top of the deuterium bottle. Open MV47___. Wait until the pressure on PI1135 $\sim$ 1atm. Close MV47___.		
9	Open MV79___ and MV63___.		
	Wait for the pressure on PI145 to read less then 20 μmHg.		
	Cycle solenoid valves CSV62___ and CSV56___ several times.		
	Close MV79___ and MV63___.		
10	Repeat step 8		
11	Repeat step 9		
12	Repeat step 8		
13	Repeat step 9		
14	Repeat step 8		
15	The pressure gauges on the D_2 panel should read $\sim$ 1 atm.		
16	Adjust CPV46 to $\sim$ 40 psig		
17	Open MV47 and allow the pressure in the deuterium loop to reach $\sim$40 psia. This is close to the normal starting pressure.		
18	Close all valves on the panels and shut off MP1		
19	Turn off and unplug the fan controller for this loop.		
20	Procedure complete		

3.9 H_2 storage tank pump/purge.

Due to the large volume of the tank ($\sim$1000 gal), this procedure is time extensive. It is best to pump on the tank overnight to clean out the system after each purge. Because of the large time needed by the process, pump and purge with ^{4}He is often not performed in favor of a simple 2 or 3 cycle pump and purge with H_2. The procedure below describes the full procedure with both pump and purge cycles (^{4}He and H_2).

Procedure 3.9

No	Item	Time	Data

0	Ensure that all valves on the gas panels are closed. Ensure that procedures 2.5.2, and 2.4 have been performed. Ensure that procedures 3.1 and 3.5 have been performed		
1	Ensure that the swap over valves are all closed. These valves are located in the back of the gas panels and above the beam line. Some of these valves are in difficult places; use caution when checking these valves. If there is no vacuum in the scattering chamber EXTREME CAUTION MUST BE EXERCISED. Do not proceed with this procedure without fully understanding the target gas system. Damage to the target could result. Ensure that the following valves are closed. MV172_ _ _, MV 173_ _ _, MV174_ _ _, MV253_ _ _, MV254_ _ _, MV78_ _ _, MV76_ _ _, MV48_ _ _, MV49_ _ _, MV54_ _ _, MV63_ _ _.		
2	Turn on MP1		
3	Open the following valves Open MV41_ _ _ and MV39_ _ _ located on the H_2 tank. Open MV79_ _ _, MV19_ _ _, and MV20_ _ _ Open MV34_ _ _ and MV36_ _ _		
4	The tank will take a considerable time to pump down.		
5	When the pressure on PI145 is less than 20 μmHg close MV34_ _ _ and MV79.		
6	Open MV163_ _ _. Set the pressure on CPV73 to $>$ 3 atm. Open MV74_ _ _.		
7	Open MV77_ _ _ and watch the pressure on PI130. When the pressure is $\sim$1 atm close MV77_ _ _		
8	Open MV34_ _ _ and MV79_ _ _. When the pressure on PI145 is less than 20 μmHg close MV34_ _ _ and MV79_ _ _		
9	Repeat step 7		
10	Repeat Step 8		
11	Repeat step 7		
12	Repeat step 8		
13	Ensure that the line connecting the H_2 bottle to the gas panel has been pumped and purged. Follow procedure 3.5 if this is not known to be the case.		
14	Open MV164_ _ _. Set CPV17 to $>$ 1 atm.		
15	Open MV18_ _ _. Allow pressure on PI130 to reach $>$ 1 atm. Close MV18_ _ _		
16	Open MV34_ _ _ and MV79_ _ _. When the pressure on PI145 is less than 20 μmHg close MV34_ _ _ and MV79_ _ _		
17	Repeat step 15		
18	Repeat step 16		
19	Repeat step 15		
20	Repeat step 16		
21	The tank is now ready to fill.		
22	Open MV18_ _ _. Allow pressure on PI130 to reach 48 psia. Close MV18_ _ _.		
23	Close all valves on the gas panels. Stop MP1.		
24	Close and lock MV39_ _ _ and MV41_ _ _ on the H2 storage tank.		
25	Procedure complete		

3.10 D_2 storage tank pump/purge.

Due to the large volume of the tank (∼1000 gal), this procedure is time extensive. It is best to pump on the tank overnight to clean out the system after each purge. Because of the large time needed by the process, pump and purge with ^{4}He is often not performed in favor of a simple 2 or 3 cycle pump and purge with D_2. The procedure below describes the full procedure with both pump and purge cycles (^{4}He and D_2).

Procedure 3.10

No	Item	Time	Data
0	Ensure that all valves on the gas panels are closed. Ensure that procedures 2.5.2, and 2.4 have been performed.		
1	Ensure that the swap over valves are all closed. These valves are located in the back of the gas panels and above the beam line. Some of these valves are in difficult places; use caution when checking these valves. If there is no vacuum in the scattering chamber EXTREME CAUTION MUST BE EXERCISED. Do not proceed with this procedure without fully understanding the target system. Damage to the target could result. Ensure that the following valves are closed. MV19___, MV25___, MV34___, MV78___, MV76___ MV80___, MV81___, MV156___, MV157___, MV158___ MV160___, MV161___, MV162___		
2	Turn on MP1		
3	Open the following valves Open MV68___ and MV70___ located on the H_2 tank. Open MV79___, MV48___, and MV49___ Open MV63___ and MV65___.		
4	The tank will take a considerable time to pump down.		
5	When the pressure on PI145 is less than 20 μmHg close MV63___ and MV79___.		
6	Open MV163___. Set the pressure on CPV73 to > 3 atm. Open MV74___.		
7	Open MV75___ and watch the pressure on PI139. When the pressure is ∼1 atm close MV75___		
8	Open MV63___ and MV79___. When the pressure on PI145 is less than 20 μmHg close MV63___ and MV79___		
9	Repeat step 7		
10	Repeat Step 8		
11	Repeat step 7		
12	Repeat step 8		
13	Ensure that the line connecting the D_2 bottle to the gas panel has been pumped and purged. Follow procedure 3.6 if this is not known to be the case.		
14	Open MV165___. Set CPV46 to > 1 atm.		
15	Open MV47___. Allow pressure on PI139 to reach > 1 atm. Close MV47___		
16	Open MV63___ and MV79___. When the pressure on PI145 is less than 20 μmHg close MV63___ and MV79___		
17	Repeat step 15		
18	Repeat step 16		

19	Repeat step 15		
20	Repeat step 16		
21	The tank is now ready to fill.		
22	Open MV47___. Allow pressure on PI130 to reach 48 psia. Close MV47___.		
23	Close all valves on the gas panels. Stop MP1.		
24	Close and lock MV68___ and MV70___ on the D_2 storage tank.		
25	Procedure complete		

4 15K Target Operation

Operation of the 15K target should only be performed by experts. If both hydrogen and deuterium are needed both targets can be cooled down concurrently. The loops that are not to be filled are standby loops and need to be filled with ^{4}He at a pressure of > 1 atm to prevent loss of the cells in the event of vacuum loss in the scattering chamber.

4.1 Configuration of standby loop

The standby loop or loops must be filled with ^{4}He to ensure a positive pressure on the cell at all times. The loops are left on the regulator with the 4 atm house helium supply. The following procedure sets up the operation conditions.

Procedure 4.1

No	Item	Time	Data
0	Ensure that the following procedures have been performed. Procedure 2.4 Procedure 2.5.2 Procedure 2.6 Procedure 3.2 Procedures 3.4 and 3.3		
1	Set the pressure on CPV73 to slightly more than 1 atm (17 - 20 psia)		
2	Open MV74___ Open MV76___		
3 4	If the Hydrogen loop is to be on standby open MV77___, MV25___ and CSV27___. If the deuterium loop is to be on standby open MV75___, MV54___ and CSV56___.		
5	Ensure that the pressures in all loops are as expected.		
6	Procedure complete.		

4.2 15K Hydrogen and Deuterium Target Cool Down

Cooling down the hydrogen and deuterium targets can be performed simultaneously. Prior to cooling down the loops the electronics should be checked and certified. Further, the target control GUI should be tested and running before starting the procedure. Cooling down the target presents a considerable load to the ESR. Patience and caution should be exercised because of the possible effects to other halls. Inform the other halls when the procedure is to be started. It will also be necessary to obtain a copy of the latest cool down procedure. This can be obtained from the MCC operations page on the web or at https://polweb/halla/index.html where a list of documents is displayed. The following is the procedure to cool down the target.

Procedure 4.2

No	Item	Time	Data

0	Ensure that the following procedures have been completed. Procedure 2.1 Procedure 2.3 Procedure 2.4 Procedure2.5.2 Procedure 3.1 Procedure 3.2 Procedure 3.3 Procedure 3.4 Procedure 3.7 Procedure 3.8 Procedure 4.1 Procedure 2.2		
0.1	If the hydrogen loop is to be filled open the following valves. Lock open MV41___ and MV39___ located on the H_2 storage tank. Ensure that MV36 is closed. Open MV20___, and CSV27___ A path through the filters must be selected Open either MV21___ and MV23___ OR MV22___ and MV24___.		
0.2	If the deuterium loop is to be filled open the following valves. Lock open MV68___ and MV70___. Ensure that MV65 is closed. Open MV49___ and CSV56___. A path through the filters must be selected. Open either MV50___ and MV52___ OR MV51___ and MV53___.		
1	Plug in all fan controllers controls will not work properly without all three on. Ensure that the auxiliary high power heater supplies are turned off Energize the high power heater supplies for each loop. that is to be filled. Setup survey scopes and measure target position. Check scattering chamber vacuum. If vacuum is not in 10^{-6} torr range stop the procedure and contact the group. Now is a good time to reboot the IOC. Check to make sure that the reboot goes properly		
2	Start the GUI in a convenient location. Ensure that the high power heater PIDs are enabled for the loops to be filled. Ensure that the GUI is configured correctly.		
3	Ensure that the warm return valve is fully open and that the ball valve near the automax is locked open.		
4	Call MCC and ask to start the 15K target cool down procedure.		
5	Obtain the latest version of the target cool down procedure for the MCC.		
6	It will take the MCC $\sim$1 hour to allow opening of the target JT valves.		
7	Monitor the ESR and loop pressures and temperatures to ensure that all is as expected.		
8	When instructed by MCC open JT valves on loops to be cooled down.		
9	Open the Pre-cool JT valve. This provides an additional warm return path for the coolant.		
10	In $\sim$2 hours the return temperatures will be around 35K. Inform MCC that it is time close the warm return and open the path to cold return.		
11	When instructed close warm return valve and continue filling the target.		
12	Ensure that the high power heater PIDs are working properly.		
13	Check for proper operation of the loops		

	Read survey scopes and remove them from hall.		
14	Start GUI in counting house and hand over operation to target operator.		
15	Procedure complete.		

4.3 15K Hydrogen and Deuterium Target Warm Up

Warming up the hydrogen and deuterium targets is performed simultaneously. Inform the other halls when the procedure is to be started. It will also be necessary to obtain a copy of the latest cool down/warm up procedure. This can be obtained from the MCC operations page or on the web or at https://polweb/halla/index.html where a list of documents is displayed. The following is the procedure to cool down the target.

Procedure 4.3

No	Item	Time	Data
0	Ensure that access to the hall is available.		
1	Call MCC and request the warm up of the Hall A 15K target.		
2	Close the JT valves slowly when instructed to do so . Open the warm return valve when instructed to do so. Allow target to vent into storage tanks. As this is happening: Turn off High power heater supplies in both the counting house and the Hall Turn off the fan controlers and unplug all of them. Wait for the target to warm up to room temp before continuing.		
3	Turn off the temperature controlers Valve off the storage tanks Close and lock MV39___ and MV41___ Close and lock MV68___ and MV70___		
4	Perform Procedure 3.3		
5	Perform Procedure 3.4		
6	Switch the hydrogen status indicators to "In Use" to "Empty"		
7	Turn off MP1 and close all valves.		
8	Procedure complete.		

5 ^{4}He Target Configuration and Operation

This section describes the pump/purge fill and operation of the ^{4}He target in the loop 1 tuna can cell in Hall A. While the ^{4}He cell is not restricted to loop 1, it is assumed to be the case. There are no procedural changes if this is not the case except that the user must be aware of the loop configuration when checking initial conditions. The initial state of the target gas panels (both the ^{3}He and the H_2 D_2 panels) is assumed to be such that all valves are closed. ***The ^{3}He target gas which is both rare and valuable is assumed to be contained in the ^{3}He cylinder. If this is not known to be the case, consult Mike Seely, Dave Meekins, or Chris Keith before continuing in any way. For proper operation of the ^{4}He target, ensure that the relief and vent line are connected as described later in the document.*** This provides relief for the target cell and insures that the cell will not be over pressured. The ^{4}He target does not have a recovery system (i.e. a tank similar to the H_2 and D_2 targets). In the event that the target vents, a new fill must be performed. A procedure for this is described later in this section. For a flow schematic, refer to drawing A_CRYO_1001 sheets 1, 2, and 3.

5.1 Pre-starting conditions (not for running target)

The following procedure is designed to ensure that the target is in the proper configuration for setting up ^{4}He operations. To properly configure the target for ^{4}He running several other procedures must be followed. Many of these steps are redundant to steps in previous procedures but at left here for completeness. It never hurts to double check.

Procedure 5.1

No	Item	Time	Data
1	Ensure that the isolation valves on the H_2 and D_2 tanks are closed These valves are located outside behind the Hall A counting house. They should be locked closed.		
1a	Make sure that all valves on the H_2, D_2, and He pump/purge are closed.		
2	Ensure that the ^{3}He target gas is contained in the ^{3}He cylinder. If you are unsure of the state of this gas **STOP NOW**.		
3	Connect the flex line after MV206 to the hall vent header.		
4	Open MV206. This provides all relief for the He target cell during the course of a vent.		
5	Ensure that the following valves are closed: MV201___, MV202___ MV214___, MV220___, MV225___, MV233___, MV231___, MV234___, MV228___, MV244___, MV249___, These valves are located on the He panel to the right of the main gas panel (with white background).		
6	Ensure that the cross over valves located in back of the main gas panel are all closed: MV156___, MV157___, MV160___, MV161___ Ensure that MV155___ and MV159___ are closed. These valves isolate the main gas panel from the He cell.		
7	Open the following valves: MV158___, MV162___, MV172___ and MV173___. These valves connect the H_2 and D_2 panels to Loop 3 and Loop 2 respectively for the standard configuration.		
8	Open MV250___ and MV251___. Close MV253___ and MV254___. This connects the He panel to the loop 1 tuna can cell, for the standard configuration.		

9	Check the scattering chamber pressure on VPI149. If the pressure does not read in the 10^{-6} torr range do not continue and consult Ed Folts and the Target Group.		

5.2 H_2 and D_2 panel/loop configuration

The H_2 and D_2 panel and loops must be configured properly so that the cells in these two loops do not see a subatmospheric pressure. This is a safety measure that protects the cells in the event of vacuum loss in the scattering chamber. Perform the following procedure.

Procedure 5.2

No	Item	Time	Data
1	Perform the pump and purge of the H_2 panel with ^4He as described in Procedure 3.3.		
2	Perform the pump and purge of the D_2 panel with ^4He as described in Procedure 3.4.		
3	Make sure that the the H_2 and D_2 cells have a pressure $>$ 15 psia.		
4	Both loops are left with a supply of He from the house supply on slightly above 1 atm. This ensures that the loops have a positive pressure at all times in case there is a loss of vacuum in the scattering chamber. For now leave the valves on all panels closed.		

5.3 He panel pump/purge and fill.

The He panel to the right of the pump and purge panel is used for both ^{3}He and ^{4}He running. Again at the start of the pump and purge procedure, all valves should be closed on the panel except MV206 which connects the vent line from the cell to the vent header.

Procedure 5.3

No	Item	Time	Data
0	Check again that the relief line is connected to the vent header and that MV206 is locked open ___		
1	Open all the gauge isolation valves: MV229___ MV227___ MV248___		
2	Open MV228___. This opens the He panel to the pump MP1 on the main panel.		
3	Make sure that MV243 on top of the He supply bottle is closed___. (This is located downstairs in the gas bottle rack)		
4	Open PRV242___ MV241___ MV230 Wait for the pressure on PI145 to read less then 20 μmHg. Close MV228___ Close PRV242 Open MV243___. Open PRV242 to $\sim$ 1 atm. ___ Check PI262, the pressure should be $\sim$ 1 atm. ___. Close MV243___.		
5	Open MV228___ Wait for the pressure on PI145 to read less then 20 μmHg. Close MV228		
6	Open MV243___. PI262 $\sim$ 1atm. Close MV241___.		
7	Repeat steps 5 and 6 three times.		
8	The He cell is now ready to be pumped and purged. Open MV228___ MV236___ EV245___ and EV212___ Cycle EV245 several times to relieve trapped gas. Wait for the pressure on PI145 to read less then 20 μmHg. Close MV228___		
9	Open MV 241___ . PI262 $\sim$ 1atm. Close MV241___.		
10	Open MV228___ . Cycle EV245 several times to relieve trapped gas. Wait for the pressure on PI145 to read less then 20 μmHg. Close MV228___		
11	Repeat step 9		
	Repeat step 10		
	Repeat step 9		
	Repeat step 10		
12	Close and lock MV230___ and MV236___		
13	Set PRV242 to proper operating pressure. Close all valves on the He panel.		
14	Procedure complete		

5.4 Replacing He supply bottle

After a target vent or during a fill, it may be necessary to replace the He supply bottle. Make sure that the replacement bottle is of high purity ^{4}He. Contact Mike Seely, Dave Meekins or Chris Keith if in doubt or in need of a supply. The following procedure describes the installation of a new He supply bottle.

Procedure 5.4

No	Item	Time	Data
1	Turn on the gas panel mechanical vacuum pump MP1___		
2	Close MV251___ and EV245. Verify that MV236 is closed This isolates the He Cell from the He bottle and panel vacuum pump. Note the pressure on PI268___		
3	Close MV243___ this is located at the top of the He supply bottle. Open MV229___ Slowly open MV228___ Slowly open MV230___ to relieve bottle line Close MV228 when the presssure on PI222 is slightly higer than 1 atm.		
4	Close MV241___ Disconnect He bottle and connect full one. Back the regulator PRV242 off closed.		
5	Open MV243 and leak check the connection with snoop. Set PRV242 to slightly higher than 1 atm. Close MV243___ Open MV241___		
6	Open MV228___ Wait for the pressure on PI145 to read less then 20 μmHg. Close MV228___		
7	Open MV243___ and allow the pressure in the He line to reach 1 atm. Close MV243___		
8	Repeat step 6		
9	Repeat step 7		
10	Repeat step 6		
11	Repeat step 7		
12	Close MV230___ and lock		
13	Close MV229___ and turn off MP1		
14	Open MV251___ and EV245___		
15	The target is ready to resume filling or start to fill.		

5.5 ^{4}He target cool down.

The following procedure must be completed to properly cool down the ^{4}He target. In this procedure, the target is cooled first with a roughly constant pressure of ~1 atm. After the target is at operating temperature and on cold return, it is filled.

Procedure 5.5

No	Item	Time	Data

0	Prior to starting this procedure procedures 5.1, 5.3,5.2 must be completed.		
1	Make sure that there is ∼1 atm of pressure on CPV73___. Ensure that MV163___ and MV74___ are open. Open MV77___, MV75___, MV25___, CSV27___, MV54___, and CSV56___. Ensure that MV158___, MV162___, MV172___, and MV173___ are open.		
2	Ensure that MV156___, MV157___. MV160___, MV161___, MV174___, MV253___, and MV254___ are closed.		
3	If the valves in steps 1 and 2 are not in the proper state stop the procedure and contact the target group immediately.		
4 5	Set PRV242___ (regulator on top of the ^{4}He bottle) to slightly more than 1 atm. This will keep the loop at a positive pressure during cool down. Open MV241___, MV 251___, EV245___, MV250___.		
6	Ensure that the following valves are closed. MV231___, MV230___, MV244___, MV249___, MV252___, MV248___, MV 229___, MV237___, MV236___ MV227___, MV220___, MV222___, MV 224___, MV 225___, MV 234___, MV232___, MV272___, MV 275___ MV202___, MV201___, MV204___, MV205___, MV 214___, MV219___, MV270___, MV271___, EV215___		
7	Ensure that MV206__ is open. This is the relief for the target.		
8	Call MCC and inform them that you need to start the cool down of the 4K target in Hall A. It will take some time for them to set this up. Now is a good time to double check valve settings and electronics. Make sure that the fan controllers are plugged in (all three must be on) Ensure that the high power heater supplies are energized. Make sure that the warm return valve is fully open.		
8	Start the target control GUI and monitor the incoming ESR and target pressure and temperature.		
9	MCC will provide notification to open the target JT and begin cool down. This procedure takes some time. Ensure that the fan in the He loop is spinning. Ensure that the high power heater PID is enabled.		
10	Slightly open the He loop JT and open the Pre-cool JT.		
11	When the target is cold ∼6.5 K Inform MCC that it is time to switch to cold return. When this is done it is time to start filling the target.		
12	Open the pressure regulator PRV242 to a higher setting. Be careful to monitor the loop temperature and the ESR return temperature. During this procedure, it will be necessary to perform procedure 5.4 when the supply bottle empties. When the target is at the proper pressure close MV241___.		
13	Hand over operation of the target to the target operator.		
14	Procedure complete		

6 ^3He Target Configuration and Operation

This section describes the pump/purge fill and operation of the ^{3}He target in the loop 1 tuna can cell in Hall A. While the ^{3}He cell is not restricted to loop 1, it is assumed to be the case. There are no procedural changes if this is not the case except that the user must be aware of the loop configuration when checking initial conditions. The initial state of the target gas panels (both the ^{3}He and the H_2 D_2 panels) is assumed to be such that all valves are closed. ***The ^{3}He target gas which is both rare and valuable is assumed to be contained in the ^{3}He cylinder. If this is not known to be the case, consult Mike Seely, Dave Meekins, or Chris Keith before continuing in any way.***

6.1 Pre-starting conditions (not for running target)

The following procedure is designed to ensure that the target is in the proper configuration for setting up ^{3}He operations. To properly configure the target for ^{3}He running several other procedures must be followed. Many of these steps are redundant to steps in previous procedures but at left here for completeness. It never hurts to double check.

Procedure 6.1

No	Item	Time	Data
1	Ensure that the isolation valves on the H_2 and D_2 tanks are closed These valves are located outside behind the Hall A counting house. They should be locked closed.		
1a	Make sure that all valves on the H_2, D_2, and He pump/purge are closed.		
2	Ensure that the ^{3}He target gas is contained in the ^{3}He cylinder. If you are unsure of the state of this gas **STOP NOW**.		
3	Cap the line after MV206 with a blank flange.		
4	Ensure that MV206 is closed. This will allow the ^{3}He storage tank to valved in.		
5	Ensure that the following valves are closed: MV201___, MV202___ MV214___, MV220___, MV274___, MV225___, MV233___, MV231___, MV234___, MV228___, MV244___, MV249___, These valves are located on the He panel to the right of the main gas panel (with white background).		
6	Ensure that the cross over valves located in back of the main gas panel are all closed: MV156___, MV157___, MV160___, MV161___ Ensure that MV155___ and MV159___ are closed. These valves isolate the main gas panel from the He cell.		
7	Open the following valves: MV158___, MV162___, MV172___ and MV173___. These valves connect the H_2 and D_2 panels to Loop 3 and Loop 2 respectively for the standard configuration.		
8	Open MV250___ and MV251___. This connects the He panel to the loop 1 tuna can cell, for the standard configuration.		
9	Check the scattering chamber pressure on VPI149. If the pressure does not read in the 10^{-6} torr range do not continue and consult Ed Folts and the Target Group.		

6.2 H_2 and D_2 panel/loop configuration

The H_2 and D_2 panel and loops must be configured properly so that the cells in these two loops do not see a subatmospheric pressure. This is a safety measure that protects the cells in the event of vacuum loss in the scattering chamber. Perform the following procedure.

Procedure 6.2

No	Item	Time	Data
0	Check the scattering chamber pressure. If the pressure is above 10^{-5} torr STOP THE PROCEDURE.		
1	Perform the pump and purge of the H_2 panel with ^{4}He as described in Procedure 3.3.		
2	Perform the pump and purge of the D_2 panel with ^{4}He as described in Procedure 3.4.		
3	Make sure that the the H_2 and D_2 cells have a pressure $>$ 15 psia.		
4	Both loops are left with a supply of He from the house supply on slightly above 1 atm. This ensures that the loops have a positive pressure at all times in case there is a loss of vacuum in the scattering chamber. For now leave the valves on all panels closed.		

6.3 He panel pump/purge and fill with ^3He

The He panel to the right of the pump and purge panel is used for both ^{3}He and ^{4}He running. Again at the start of the pump and purge procedure, all valves should be closed on the panel except MV206 which connects the vent line from the cell to the vent header.

Procedure 6.3

No	Item	Time	Data
0	Check again that the scattering chamber pressure is below 10^{-5} torr and that MV206 is locked closed.		
1	Open all the gauge isolation valves: MV203___, MV270___, MV219___, MV232___ MV229___ MV227___ MV248___		
2	Open the compressor isolation valves MV271___ and MV274___.		
3	Verify that the compressor vent valves MV272 and MV275 are locked closed.		
4	Turn on main vacuum pump MP1 and open MV228.		
5	Open MV237___ PRV238___ to pump out the line to the purge gas cylinder.		
6	Close MV237___ and open MV239. Set PRV238 to ~ 1 atm. ___ Close MV239___		
7	Open MV237___ Wait for the pressure on PI145 to read less then 20 μmHg. Close MV237___.		
8	Open MV239___ Close MV239___		
9	Repeat step 7		
10	Repeat step 8		
11	Repeat step 7		
12	Repeat step 8		
13	Verify that the loop 1 fan drive is disconnected.		
14	The He cell is now ready to be pumped and purged. Open MV230___ MV236___ EV245___ Cycle EV245 several times to relieve trapped gas.		
15	Open MV208___ and EV212 to pump out the return line to the tank.		
16	Open MV205___, MV214___ MV220___, MV231___, MV233___, and EV215___		
17	Open MV244___ and MV249___ to pump out P2		
18	Operate the compressor P1 and pump P2 for 30 sec		
19	Open MV225___ and MV234___ to pump out filter.		
20	Wait for the pressure on PI145 to read less then 20 μmHg. Close MV228___		
21	Open MV237___ . PI262 $\sim$ 1atm. Close MV237___.		
22	Open MV228___ . Cycle EV245 and EV215 several times to relieve trapped gas. Turn on loop 1 fan drive at 20 Hz for 30 seconds. Turn off fan and disconnect the drive. Wait for the pressure on PI145 to read less then 20 μmHg.		

	Close MV228___		
23	Open MV237___ . PI262 $\sim$ 1atm. Close MV237___.		
24	Open MV228___ and repeat step 18. Wait for the pressure on PI145 to read less then 20 μmHg. Close MV228___.		
25	Repeat step 23		
26	Repeat step 24		
27	Repeat step 23		
28	Repeat step 24		
29	Close and lock MV230___ Close and lock MV236___ Close and lock MV244___ Close and lock MV249___		
30	Ensure that EV212 is open Close EV215___ Close PRV216___ Slowly open MV202 to pressurize the system with ^3He		
31	Open and lock MV201___ This opens the relief path back to the tank. Close MV208___ Close EV212___		
32	Adjust PRV216 so that the pressure on PI258 is 125 psia This is the compressor inlet pressure.		
33	The system is now ready for cool down Procedure complete		

6.4 ^{3}He target cool down.

The following procedure describes the cool down of the 4K ^{3}He target. It is assumed that Procedure **??** has already been performed. If this is not known to be the case STOP and contact the target group immediately. Care must be taken when performing this procedure because ^{3}He is both rare and valuable. This procedure should only be performed by a target expert (Mike Seely, David Meekins, or Chris Keith.

Procedure 6.4

No	Item	Time	Data
1	Ensure that procedure **??** has been performed.		
2	Contact MCC and inform them of the need to cool down the 4K He target in Hall A. Verify that the warm return valve is open.		
3	Start the ^{3}He target loop fan at 20 Hz.		
4	Once MCC indicated it is time to start the cool down of the target. Open the pre-cool JT valve to 100%. Slowly open the He loop JT valve to ∼15%		
5	Adjust the He loop JT as needed during the cool down. Monitor the coolant return line temperature.		
6	As soon as the return line temperature is falls below 6.5K, it is necessary to switch to cold return. The MCC operator will give instructions on how when the warm return valve must be closed.		
7	When the system reaches the base operating temperature (∼4.5K) the pressure in the He loop will have fallen to ∼100 psia.		
8	Close MV 214___, MV220___, MV233___ Verify that EV212 is closed Ensure that MV205___, MV231___, MV225___ MV234___ and EV245___ are open		
9	Start compressor P1. Note that EV215 may be opened if the suction pressure falls below 115 psia		
10	The addition of warm gas will cause the target to warm up. Adjust EV215 so that the return temperature does not exceed 6.5K.		
11	When the target reaches 220 psia and 4.5K the pressure in the storage tank will be ∼25 psia Stop the compressor and close EV245___ Close EV215___ Close the pre-cool JT valve.		
12	The target is now ready for operation. Hand the controls over to a qualified operator		
13	Procedure complete		

6.5 Refill of ^{3}He target cell

If pressure is lost to the ^{3}He cell, the target must be repressurized. This will require access to the hall. Ensure that a working control system is available in the hall before starting the procedure. This procedure should only be performed by target experts. It is assumed that the target is still cold and that Procedure 6.4 has been performed.

Procedure 6.5

No	Item	Time	Data
1	Ensure that procedure 6.4 has been performed.		
2	Open EV245___ Turn on compressor P1 Once the supply pressure PT256 or PI257 falls below 115 psia open EV215		
3	Open the pre-cool JT valve to 100%		
4	When the target reaches operating pressure Close EV245___ Turn off compressor P1 Close EV215___ Close the pre-cool JT valve		
5	Procedure complete		

6.6 ^{3}He target warm up and active gas recovery

The following procedure must be performed to warm up the ^{3}He target. The procedure should only be performed by target experts. Active gas recovery starts at step 7.

Procedure 6.6

No	Item	Time	Data
1	Check all temperatures and pressures in the target		
2	Relieve the pressure on the target cell Slowly open MV214___. Open EV212___		
3	Call MCC and inform them that the 4K hall A target must be warmed up.		
4	Follow the operators instructions for closing the JT valve and opening the warm return valve.		
5	Turn off the high power heater supply Turn off the He loop fan		
6	As the target warms the pressure should approach ∼210 psia. Do not begin active gas recovery until the loop temperature is above 30K		
7	Start active gas recovery. Open MV214___ and MV 220___. Close MV205___ and MV231___ Ensure that MV202 is open.		
8	Start compressor P1. Once the system pressure falls below 115 psia Open EV 215		

9	As soon as the pressure in the system falls below 1 atm close MV201___ Open MV208___ and EV212___ use the sealed vacuum pump to recover the remaining ^{3}He. Check the pressure on PI267. If the pressure is not below 15 psia, wait. The pump is not rated for pressures above 1atm. If PI267 reads less than 1 atm Open MV249___ MV244___		
10	Start the vacuum pump P2 Slowly close EV245 while watching PI266 Do not allow the pressure on PI266 to exceed 20 psia As the system pressure falls, it should be possible to close EV245 completely.		
11	Allow pump P2 to reach its base pressure of 0 psia. Compressor P1 should reach a base pressure of $\sim$7 psia. (Use PI266 and PI257)		
12	Close MV249___ Stop P2 Close MV244___ Lock these two valves closed.		
13	Close EV 215___ and MV214___		
14	Close MV202___ Stop the compressor P1. Close MV220___, EV212___, MV208___, MV250___, MV251___, Close all valves on the ^{3}He panel.		
15	Pump and purge the He pump purge panel. This ensures that no contaminates will enter the cold cell. Open MV155___ and MV159___. Connects the pump purge panel to the He loop Perform procedure 3.2		
16	Procedure complete		

Hall C Cryotarget General Operation Manual

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Abstract

This document describes the general operation of the Hall C cryogenic target. It includes procedures for determining the current state of the target, pump/purge of the individual loops, pump/purge of the storage tanks, ^3He and ^4He operation and warm up and cool down of both 15K and 4K targets. It is intended for guidance of the target expert and not the typical target operator. The document contains checklists for each of these procedures.

Contents

1 Overview

This document describes the general operation of the Hall C cryogenic target. A flow schematic is shown in TJNAF drawing number C_CRYO_1001 sheets 1, 2, and 3. It is extremely important to understand the target system before performing one of the following procedures. If there are any questions regarding these procedures, consult Mike Seely Chris Keith or David Meekins. In all cases, make sure that a flow sheet is available and perform the procedure with care. It is possible that something was overlooked during the development of the procedure.

2 Target Inspection and Pre-configuration

This section describes the procedures for determining the current target configuration. It is best to consult a member of the target group (Mike Seely, Chris Keith, or Dave Meekins) prior to finalizing this procedure. These procedures should be performed prior to closing the scattering chamber and any pump/purge of the loops.

2.1 Inspection of target cells and inside of scattering chamber.

Procedure 2.1

No	Item	Time	Data
0	Obtain a list of targets with loop/cell configurations and solid targets needed for the current experiment		
1	Inside the scattering chamber verify that the targets match this list, specifically cell lengths and positions. Record the cell types and lengths for each loop.		
2	Check the alignment of these targets. Dummy target installed correctly, optics target foils in good condition, etc		
3	Inspect the target inside the chamber for impedance to motion of the system.		
4	Record the desired loop and target fluid configuration		
4a	Record Loop 1 cryogen		
4b	Record Loop 2 cryogen		
4c	Record Loop 3 cryogen		
4d	Record solid target configurations		
5	Procedure complete		

2.2 Inspection and certification of target lifting mechanism

The target lifting mechanism is a complicated device. Proper operation of the target lifting mechanism can cause serious damage to the target and personnel near it. Use caution when operating the target lifter. The following procedure describes the certification of the target lifting mechanism.

Procedure 2.2

No	Item	Time	Data
1	Look inside the scattering chamber for any possible obstructions to the target lifter.		
2	At the top of the scattering chamber inspect the area for possible obstructions to the target lifter		
3	Ensure that the cryogenic coolant lines have the proper slack.		
4	Ensure that the target gas lines have the proper slack and will not catch on protrusions		
5	Ensure that the electronic cables have enough slack and will not catch on protrusions.		
6	Inform all in the area that target motion is to be tested.		
7	Inspect the lifter mechanisms for damage. Inspect the motors and cables Inspect drive sprockets, brakes and drive chains. Inspect shaft couplers Inspect lead screw and drive nuts Ensure that all brackets are tight		
8	Energize the target lifter.		
9	With ample spotters and communications run the home sequence.		
10	select random targets and position them in the beam.		
11	Ensure that the vertical over travel limits are correct		
12	select the bottom and top target to test the full range of motion.		
13	If there are no problems then the lifter is certified		
14	Procedure complete		

2.3 Inspection of cryo/gas lines.

At the top of the scattering chamber perform the following checks

Procedure 2.3

No	Item	Time	Data
1	Check loop connections: 1a) Loop 1 return connected to loop 1 return hose 1b) Loop 1 supply connected to loop 1 supply hose 1c) Loop 2 return connected to loop 2return hose 1d) Loop 2 supply connected to loop 2supply hose 1e) Loop 3 return connected to loop 3 return hose 1f) Loop 3 supply connected to loop 3 supply hose		
2	Check VPT line connections		
3	Check large electrical feed through connections		
4	Check JT valve connection and verify the operating range. This takes two people. 4a) Loop 1 JT motion 4b) Loop 2 JT motion 4c) Loop 3 JT motion 4d) Pre-cool JT motion		

5	Check for fouling of any line or cable with the vertical motion of the target.		
6	Check the connection of the warm return and vent header lines.		
7	Make sure that the relief on each loop return line is correct. This is very important to the safe operation of the target. Check the direction of each relief installation. H_2 and D_2 targets should have a relief setting of 50 psig He targets should have a relief setting of 245psig 7a) Loop 1 relief setting (psig) 7b) Loop 2 relief setting (psig) 7c) Loop 3 relief setting (psig)		
8	Check that the U-tubes have been properly installed.		
9	Check the scattering chamber relief system Ensure that MV9064 on top of the rupture disk is locked open.		
10	Procedure complete		

2.4 Inspection of the loop/gas panel connections.

The loop/gas panel connections are made at the top of the target mezzanine nearest the pivot. The purpose of the following checks is to ensure that the return and supply lines from the gas panel match the return and supply lines from the desired loop. Loop and gas panel connections should also be recorded and checked to make sure that these connections match the needs of the experiment. Most important, if He targets are being used, which loops have the proper reliefs.

Procedure 2.4

No	Item	Time	Data
1	Make sure that loop supply and return lines are connected to the same gas panel return and supply lines. Make sure that return is connected to return.		
2	Record Loop 1 return connection Record Loop 1 supply connection		
3	Record Loop 2 return connection Record Loop 2 supply connection		
4	Record Loop 3 return connection Record Loop 3 supply connection		
5	Record H2 tank to panel connection		
6	Record D2 tank to panel connection		
7	Procedure complete		

2.5 Inspection of ^{3}He, H_2, and D_2 storage tank configuration.

The H_2 and D_2 storage tanks are located outside the hall behind the counting house. The ^{3}He storage tank is located on the first level of the mezzanine in the hall.

2.5.1 Inspection of the ^{3}He storage tanks.

Inspection of the ^{3}He storage tanks is best left to target experts. The procedure follows.

Procedure 2.5.1

No	Item	Time	Data
1	Check the pressure in the storage tank.		
2	If the tank is full of ^{3}He than the storage pressure should be ∼220 psia		
3	Ensure that MV9716 and MV9719 are closed		
4	If this is not found to be the case contact the target group immediately.		
5	Procedure complete		

2.5.2 Inspection of the H_2, and D_2 storage tank configuration prior to pump and purge

Inspection of the H_2, and D_2 storage tank configuration can be performed outside the hall in back of the counting house. The Hall C storage tanks are located behind the Hall C counting room. Perform the following checks:

Procedure 2.5.2

No	Item	Time	Data
1	Make sure that the valve on the tanks are in the proper position		
2	H_2 return line valve MV9130 locked closed		
3	H_2 supply line valve MV9120 locked closed		
4	D_2 return line valve MV9131 locked closed		
5	D_2 supply line valve MV9133 locked closed		
6	Visually inspect hoses, lines and relief valves. If there is damage contact the target group and stop the procedure.		
7	Procedure complete		

2.5.3 Inspection of the H_2, and D_2 storage tank configuration prior to target fill.

Inspection of the H_2, and D_2 storage tank configuration can be performed outside the hall in back of the counting house. The Hall C storage tanks are located behind the Hall C counting room. Perform the following checks:

Procedure 2.5.3

No	Item	Time	Data
1	Make sure that the valves on the tanks are in the proper position		
2	H_2 return line valve MV9130 locked open		
3	H_2 supply line valve MV9120 locked open		
4	D_2 return line valve MV9131 locked open		
5	D_2 supply line valve MV9133 locked open		
6	Inspect hoses, lines and relief valves. If there is damage contact the target group and **DO NOT** fill the target		
7	Procedure complete		

2.6 Swap-over valve configuration for H_2 and D_2 target operation

There is a swap-over valve lineup that allows the H_2 panel to be switched with the He panel, and a second series of valves that allows the He pump/purge and D_2 panels to be swapped. This is intended to add flexibility during a run by eliminating the need for a complete target warmup and physical swapping of hoses. It is assumed that the target will be operated under normal conditions. Thus, the loop/panel connections can be correctly determined by following Procedure 2.4. These valves are located behind the main gas panels. Two of these valves are located above the beam line in a difficult position to access. Use caution when accessing these valves.

Procedure 2.6

No	Item	Time	Data
1	Configure loop/panels for normal operations 1a) Open MV9729___ Connects He supply line 1b) Open MV9730___ Connects He return line 1c) Open MV9126___ Connects H_2 return line 1d) Open MV9127___ Connects H_2 supply line		
2	Ensure that the He swap-over valves are closed. 2a) Close MV9732___ and MV 9731___ 2b) Close MV9125___ and MV9124___		

3 Pump and purge procedures

Note: Before performing any pump/purge procedure be sure that the pressure in the scattering chamber is below 1×10^{-4} Torr***.*** Damage to the target cells may result if the proper vacuum does not exist in the scattering chamber. Pump and purge of the H_2 and D_2 storage tanks may be performed without vacuum in the scattering chamber but caution must be exercised.

3.1 4 atm House He supply pump and purge.

Check to make sure that the 4 atm supply in Hall C has been turned on. This can be done by checking the regulator at the back of the gas panels. Sometimes work is performed on this system and the cryogenics group will close the supply valve for the 4 atm He. Perform this procedure if unsure of the status of the 4 atm supply line going to the gas panel. Check to make sure that there are no extra lines plumbed into this system. Targets such as the polarized ^{3}He target require this 4 atm gas supply to be plumbed to the pivot.

Procedure3.1

No	Item	Time	Data
0	Make sure all valves on the gas panels are closed.		
1	It is safer to perform this procedure with the scattering Chamber under vacuum if it is possible wait until this is so.		
1	Turn on the gas panel mechanical vacuum pump MP1___		
2	Ensure that the He supply valve located on the back of the panel before the regulator is closed.		
3	Check again that all valves are closed especially MV9100, MV9080, MV9046, MV9030, MV9010, MV9040, and MV9053. Open MV9041, MV9037 and MV9035 (located in back of the panel). Wait for the pressure on PI9042 to read less then 20 μm of mercury (μmHg).		
4	Close MV9041. Set PRV9035 to $\sim$1 atm. Check the pressure on PI9051. Close MV9035___ .		
5	Open MV9041___ . Wait for the pressure on PI9042 to read less then 20 μmHg. Close MV9041___		
6	Open MV9035___. PI9051 $\sim$ 1atm. Close MV9035___.		
7	Repeat step 5		
8	Repeat step 6		
9	Repeat step 5		
10	Repeat step 6		
11	Leave $\gtrsim$ 1 atm of He on this line.		
12	Close all valves and turn off MP1.		
13	Procedure complete.		

3.2 Standby loop pump and purge with ^{4}He

Procedures 2.1, 2.3, 2.4, 2.5.2, and 2.6 must be performed prior to this procedure. One of the most crucial steps in the following procedure is to make sure that there is vacuum in the scattering chamber. This will prevent crushing the target cells.

Procedure 3.2

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read less than 10^{-5} Torr. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	Ensure that all valves on the gas panels are closed. Ensure that procedure 3.1 has been completed Ensure that the following valves are closed MV9100, MV9080, MV9046, MV9010, MV9040, MV9030, and MV9053		
2	Turn on vacuum pump MP1		
3	Behind the pump and purge panel, open MV9035___ Set the pressure on PRV9035 > 1 atm.		
4	Record the pressures on the D_2 and H_2 loops. PI9101____, PI9093____, PI9023____, PI9031____ There should be at least 1 atm on each of these gauges.		
5	Open manual valves MV9041___ MV9052___ and MV9053___.		
6	Wait for the pressure on PI9042 to read less then 20 μmHg (Note that this gauge is mounted to the pump.)		
7	Examine the pressures on the gauges recorded in step 4 If these pressures are still the same continue to step 8. If they are now different then when recorded there is a problem. Close MV9041___ Open MV9037 and allow the pressure on PI9051 to reach > 1 atm. Close MV9037. Turn off MP1 Contact the target group and **STOP**		
8	Downstairs in the electronics rack, plug the fan controller for the He loop in and start the fan running at ~20 Hz. Open SV9044___ Open SV9038___ Wait for the pressure on PI9042 to read less then 20 μmHg. Close MV9041___.		
9	Open MV9037___. Wait until the pressure on PI9051 ~ 1atm. Close MV9037___.		
10	Open MV9041___ Wait for the pressure on PI9042 to read less then 20 μmHg. Close MV9041___		
11	Repeat step 9		
12	Repeat step 10		
13	Repeat step 9		
14	Repeat step 10		
15	Repeat step 9		
16	The pressure on PI9051 should be ~1 atm.		
17	Close all valves on the panels and shut off MP1.		
18	Turn off and unplug the fan controller for this loop.		
19	Procedure complete.		

3.3 Hydrogen panel/loop pump and purge with ^{4}He

In principle, the hydrogen and deuterium loops can be pumped and purged simultaneously with ^{4}He. However, a more cautious approach is to do each separately. This allows a further check of the gas line connections to make sure that the return and supply are at least connected to the same loop and swap-over valves have been properly configured. Procedures 2.1, 2.3, 2.4, 2.5.2, and 2.6 must be performed prior to this procedure. One of the most crucial steps in the following procedure is to make sure that there is vacuum in the scattering chamber. This will prevent crushing the target cells.

Procedure 3.3

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read below 10^{-5} Torr. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	Ensure that all valves on the gas panels are closed.		
2	Make sure that the H_2 tank isolation valves MV9130___ and MV9120___ are closed. This should have been done in Procedure 2.5.2.		
3	Turn on vacuum pump MP1		
4	Behind the pump and purge panel, open MV9035___ Set the pressure on PRV9035 $>$ 1 atm.		
5	Examine the pressures on PI9101 and PI9093 Check the H_2 loop pressure on PI9023 and PI9031 Open manual valve MV9030___. This will pump the target through the return line. Examine the pressures on PI9023 and PI9031 PI9023 indicates the pressure on the return line. PI9031 indicates the pressure on the fill line. If both pressures are falling and the pressures on PI9101, and PI9093 are constant then proceed to step 6. If not close MV9030___ and open SV9012___ MV9037___, MV9052___, MV9010___ and MV9022___ Allow the pressure on PI9031 to reach 1 atm and close all the valves and turn off MP1. Contact the target group and **STOP**.		
6	Open MV9010___, MV9040___, MV9052___, MV9019___, SV9003___, SV9012___, SV9014___, MV9017___, MV9022___, MV9005___, MV9006___, MV9007___, and MV9008 This pumps the hydrogen loop through both the fill and return lines.		
7	Open MV9148___ and MV9114___. This pumps out the return line to the tank. Wait for the pressure on PI9042 to read less then 20 μmHg (Note that this gauge is mounted to the pump.) Cycle SV9012, SV9003,and SV9014 several times to minimize the presence of trapped gas. Leave both valves open.		

8	In the electronics rack, plug the fan controller for the hydrogen loop in and start the fan running at ∼20 Hz. Wait for the pressure on PI9042 to read less then 20 μmHg. Turn off MP1 and record rate of rise. Turn MP1 back on. Close MV9030___ and MV9041___.		
9	Open MV9037___. Wait until the pressure on PI9031 ∼ 1atm. Close MV9037___.		
10	Open MV9030___ and MV9041___. Wait for the pressure on PI9042 to read less then 20 μmHg. Cycle solenoid valves SV9012, SV9003, and SV9014 several times. Close MV9041___ and MV9030___.		
11	Repeat step 9		
12	Repeat step 10		
13	Repeat step 9		
14	Repeat step 10		
15	Repeat step 9		
16	The pressure gauges on the H_2 panel should read ∼ 1 atm.		
17	Close all valves on the panels and shut off MP1		
18	Turn off and unplug the fan controller for this loop		
19	Procedure complete		

3.4 Deuterium panel/loop pump and purge with ^{4}He

In principle, the hydrogen and deuterium loops can be pumped and purged simultaneously. However, a more cautious approach is to do each separately. The following procedures describe the more cautious approach.

Procedure 3.4

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read below 10^{-5} Torr. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	Ensure that all valves on the gas panels are closed.		
2	Make sure that the D_2 tank isolation valves MV9131 and MV9133 are closed. This should have been done in Procedure 2.5.2.		
3	Turn on vacuum pump MP1		
4	Behind the pump and purge panel, open MV9035___ Set the pressure on PRV9035 > 1 atm.		
5	Examine the pressures on PI9023 and PI9031. Check the loop pressure on PI9101 and PI9093 Open manual valve MV9100___. This will pump the target through the return line. Examine the pressures on PI9101 and PI9093		

	PI9093 indicates the pressure on the return line. PI9101 indicates the pressure on the fill line. If both pressures are falling and the pressures on PI9023 and PI9031 are constant then proceed to step 6. If not close MV9100___ and open SV9082___ MV9092___, MV9080___ and MV9037___ Allow the pressure on PI9093 to reach 1 atm and close all the valves and turn off MP1. Contact the target group and **STOP**.		
6	Open MV9080___, MV9046___, MV9041___, MV9105___, SV9073___, SV9082___, SV9084___, MV9087___, MV9092, MV9075___, MV9076, MV9077___, and MV9078 This pumps the deuterium loop through both the fill and return lines.		
7	Open MV9149___ and MV9108___. This pumps out the return line to the tank. Wait for the pressure on PI9042 to read less then 20 μmHg (Note that this gauge is mounted to the pump.) Cycle SV9082, SV9073,and SV9084 several times to minimize the presence of trapped gas. Leave both valves open.		
8	In the electronics rack, plug the fan controller for the hydrogen loop in and start the fan running at ~20 Hz. Wait for the pressure on PI9042 to read less then 20 μmHg. Close MV9100___ and MV9041___.		
9	Open MV9037___. Wait until the pressure on PI9093 ~ 1atm. Close MV9037___.		
10	Open MV9100___ and MV9041___. Wait for the pressure on PI9042 to read less then 20 μmHg. Cycle solenoid valves SV9082, SV9073, and SV9084 several times. Close MV9041___ and MV9100___.		
11	Repeat step 9		
12	Repeat step 10		
13	Repeat step 9		
14	Repeat step 10		
15	Repeat step 9		
16	The pressure gauges on the D_2 panel should read ~ 1 atm.		
17	Close all valves on the panels and shut off MP1		
18	Turn off and unplug the fan controller for this loop		
19	Procedure complete		

3.5 H_2 bottle swap and pump/purge

During the course of normal target operation (e.g. during a target fill), it may be necessary change the H_2 bottle. At the start of the H_2 panel pump and purge procedure with H_2, it will also be necessary for the line that connects the H_2 supply bottle to the gas panel to be pumped/purged. If the bottle was not changed and has adequate pressure the user should start at step 1 in the following procedure. Although it is not necessary, it is safer to have vacuum in the scattering chamber.

Procedure 3.5

No	Item	Time	Data
0	Ensure that the regulator PRV9001 on top of the H_2 bottle is closed. Ensure that the manual valve MV9135 on top of the H_2 bottle is closed. Remove the regulator from the bottle. Swap old bottle with new bottle. Connect the regulator to the new bottle and Snoop the connection.		
1	Ensure that the following manual valves are closed: MV9080___, MV9046___, MV9100___, MV9030___, MV9010___, MV9040___. MV9041___, MV9103___, and MV9033___		
2	Make sure that MV9135 located on top of the H_2 bottle is closed.		
3	Close regulator PRV9001 attached to the H_2 bottle.		
4	Start vacuum pump MP1		
5	Open MV9033___. Wait until the pressure on PI9042 falls below 20 μmHg. Close MV9033___		
6	Open MV9135___. Set PRV9001 to $>$ 1atm. Close MV9135___		
7	Repeat step 5		
8	Open MV9135___. Wait until the pressure on the line is $>$ 1 atm. Close MV9135___		
9	Repeat step 5		
10	Repeat step 8		
11	Repeat step 5		
12	Repeat step 8		
13	The pressure in the line should now be $>$ 1 atm.		
14	Close all valves and turn off MP1.		
15	Procedure complete		

3.6 D_2 bottle swap and pump/purge

During the course of normal target operation (e.g. during a target fill), it may be necessary change the D_2 bottle. At the start of the D_2 panel pump and purge procedure with D_2, it will also be necessary for the line that connects the D_2 supply bottle to the gas panel to be pumped/purged. If the bottle was not changed and has adequate pressure the user should start at step 1 in the following procedure.

Procedure3.6

No	Item	Time	Data
0	Ensure that the regulator CPV46 on top of the D_2 bottle is closed. Ensure that the manual valve MV165 on top of the D_2 bottle is closed. Remove the regulator from the bottle. Swap old bottle with new bottle. Connect the regulator to the new bottle and Snoop the connection.		
1	Ensure that the following manual valves are closed: MV9080___, MV9046___, MV9100___, MV9030___, MV9010___, MV9040___. MV9041___, MV9103___, and MV9033___		

2	Make sure that MV9134 located on top of the D_2 bottle is closed.		
3	Close regulator PRV9071 attached to the D_2 bottle.		
4	Start vacuum pump MP1		
5	Open MV9103___. Wait until the pressure on PI9042 falls below 20 μmHg. Close MV9103___		
6	Open MV9134___. Set PRV9071 to $>$ 1atm. Close MV9134___		
7	Repeat step 5		
8	Open MV9134___. Wait until the pressure on the line is $>$ 1 atm. Close MV9134___.		
9	Repeat step 5		
10	Repeat step 8		
11	Repeat step 5		
12	Repeat step 8		
13	The pressure in the line should now be $>$ 1 atm.		
14	Close all valves and turn off MP1.		
15	Procedure complete		

3.7 H_2 panel pump/purge with H_2

The following procedure needs to be performed prior to normal H_2target operations. At the start of the procedure one should make sure that the line connecting the supply bottle has bee pumped and purged with H_2 as described in Procedure 3.5. Note that this procedure will not leave the valves in the proper lineup for target operation.

Procedure3.7

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read below 10^{-6} Torr. If it does not **STOP THE PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		
1	If the lines to the target have been changed then ensure that Procedure 3.3 has been performed. Ensure that procedure 3.5 has been performed.		
2	Ensure that all valves on the H_2 gas panel are closed. Ensure that the following valves are closed: MV9052___, MV9010___, MV9040___ MV9080___ ,MV9046___, MV9100___, MV9030___, MV9033___, MV9103___.		
3	Make sure that the H_2 tank isolation valves MV9130___ and MV9120___ are locked closed This should have been done in Procedure 2.5.2. Switch the hydrogen status indicator from "Empty" to "In Use"		
4	Turn on vacuum pump MP1		

5	Open the following valves: MV9041___, MV9040___, MV9010___ MV9030___, MV9022___, MV9017___, SV9003___, SV9012___, SV9014___ MV9005___, MV9006___, MV9007___, MV9008___ Open valves MV9019___ MV9148___ and MV9114___ These valves connect the H_2 supply tank lines.		
6	In the electronics rack, plug the fan controller for the hydrogen loop in and start the fan running at ~20 Hz.		
7	Wait for the pressure on PI9042 to read less then 20 μmHg. Cycle the solenoid valves opened in step5. Leave these valves open. Close MV9030___ and MV9041___.		
8	Open MV9135 on top of the hydrogen bottle Open MV9004___. Wait until the pressure on PI9031 ~ 1atm. PRV9001 may have to be adjusted. Close MV9004___.		
9	Open MV9041___ and MV9030___. Wait for the pressure on PI9042 to read less then 20 μmHg. Cycle solenoid valves SV9003, SV9012, and SV9014 several times. Close MV9041___ and MV9030___.		
10	Repeat step 8		
11	Repeat step 9		
12	Repeat step 8		
13	Repeat step 9		
14	Repeat step 8		
15	The pressure gauges on the H_2 panel should read ~ 1 atm.		
16	Open PRV9001 to ~40 psig		
17	Open MV9004 and allow the pressure in the loop to reach ~40 psia. This brings the pressure in the loop closer to the starting pressure.		
18	Close all valves on the panels and shut off MP1		
19	Turn off and unplug the fan controller for this loop		
20	Procedure complete		

3.8 D_2 panel pump/purge with D_2

The following procedure needs to be performed prior to normal D_2target operations. At the start of the procedure one should make sure that the line connecting the supply bottle has bee pumped and purged with H_2 as described in Procedure 3.6. Note that this procedure will not leave the valves in the proper lineup for target operation.

Procedure 3.8

No	Item	Time	Data
0	Check the scattering chamber pressure. It must read below 10^{-5} Torr. If it does not **STOP THE** **PROCEDURE IMMEDIATELY** and call the target group. Damage to the cells could result from continuing.		

1	If the lines to the target have been changed then ensure that Procedure 3.4 has been performed. Ensure that procedure 3.6 has been performed		
2	Ensure that all valves on the D_2 gas panel are closed. Ensure that the following valves are closed: MV9052___, MV9010___, MV9040___, MV9037___ MV9080___ ,MV9046___, MV9100___, MV9053___ MV9030___, MV9033___, MV9103___.		
3	Make sure that the D_2 tank isolation valves MV9131___ and MV9133___ are locked closed. This should have been done in Procedure 2.5.2. Switch the hydrogen status in dicator from "Empty" to "In Use".		
4	Turn on vacuum pump MP1		
5	Open the following valves: MV9100___, MV9041___, MV9052___ MV9080___, MV9046___, MV9092___ MV9087___, SV9073___, SV9082___ SV9084___, MV9075___, MV9076___ MV9077___, and MV9078___. Open valves MV9105___ , MV9108___, and MV 9149___. Theses valves are connected to the D_2 supply tank.		
6	In the electronics rack, plug the fan controller for the D_2 loop in and start the fan running at $\sim$20 Hz.		
7	Wait for the pressure on PI9042 to read less then 20 μmHg. Close MV9100___ and MV9041___.		
8	Open MV9134 on top of the deuterium bottle. Open MV9037___. Wait until the pressure on PI1135 $\sim$ 1atm. Close MV9037___.		
9	Open MV9100___ and MV9041___. Wait for the pressure on PI9042 to read less then 20 μmHg. Cycle solenoid valves SV9073___, SV9082___ and SV9084___ several times. Close MV9100___ and MV9041___.		
10	Repeat step 8		
11	Repeat step 9		
12	Repeat step 8		
13	Repeat step 9		
14	Repeat step 8		
15	The pressure gauges on the D_2 panel should read $\sim$ 1 atm.		
16	Adjust PRV9071 to $\sim$40 psig		
17	Open MV 9074 and allow the pressure in the deuterium loop to reach $\sim$ 40psia. Close MV9074.		
18	Close all valves on the panels and shut off MP1		
19	Turn off and unplug the fan controller for this loop.		
20	Procedure complete		

3.9 H_2 storage tank pump/purge.

Due to the large volume of the tank (~1000 gal), this procedure is time extensive. It is best to pump on the tank overnight to clean out the system after each purge. Because of the large amount time needed by the process, pump and purge with ^{4}He is often not performed in favor of a simple 2 or 3 cycle pump and purge with H_2. The procedure below describes the full procedure with both pump and purge cycles (^{4}He and H_2). It is also time saving to perform the pump and purge with a blower placed on the middle deck of the target mezznine. The pump shoult be connected to the port after MV9201.

Procedure 3.9

No	Item	Time	Data
0	Ensure that all valves on the gas panels are closed. Ensure that procedures 2.5.2, and 2.4 have been performed. Ensure that procedures 3.1 and 3.5 have been performed. Connect a blower pump cart to the port after MV9201.		
1	Ensure that the swap over valves MV9126___ and 9127___ are closed. These valves are located on the middle deck of the target mezzanine closest to the red support structure. If there is no vacuum in the scattering chamber, EXTREME CAUTION MUST BE EXERCISED. Do not proceed with this procedure without fully understanding the system. Damage to the target could result. Ensure that the following valves are closed. MV9041___, MV9053___, MV9100___, MV9030___, MV9046___, MV9080___, MV9010___, MV9040___,		
2	Turn on MP1		
3	Open the following valves Open MV9120___ and MV9130___ located on the H_2 tank. Open MV9148___, MV9114___, and MV9019___ Open MV9040___ MV9041____, and SV9003___ Open MV9030___, MV9052___ Open MV9102 if a blower cart is being used.		
4	The tank will take a considerable time to pump down.		
5	When the pressure on PI9042 is less than 20 μmHg close MV9030___ MV9041___ and MV9201 (blower only)		
6	Open MV9037___. Set the pressure on PRV9035 to $>$ 3 atm		
7	Open MV9035 Watch the pressure on PI9051. When the pressure is ~1 atm close MV9037___		
8	Open MV9041___ and MV9030___. When the pressure on PI9042 is less than 20 μmHg close MV9030___ and MV9041___		
9	Repeat step 7		
10	Repeat Step 8		
11	Repeat step 7		
12	Repeat step 8		
13	Ensure that the line connecting the H_2 bottle to the gas panel has been pumped and purged. Follow procedure 3.5 if this is not known to be the case.		

14	Open MV9134___. Set PRV9001 to > 3 atm.		
15	Open MV9004___. Allow pressure on PI9023 to reach > 1 atm. Close MV9004___		
16	Open MV9030___, MV9041___, When the system pressure is less than 1 psia. open if using a blower MV9201___. This avoids venting hydrogen into the hall When the pressure on PI9042 is less than 20 μmHg close MV9030___ , MV9041___and MV9201___ (blower only)		
17	Repeat step 15		
18	Repeat step 16		
19	Repeat step 15		
20	Repeat step 16		
21	The tank is now ready to fill.		
22	Open MV9004___. Allow pressure on PI9023 to reach 45 psia. Close MV9004___		
23	Close all valves on the gas panels. Stop MP1.		
24	Close and lock MV9130___ and MV9120___ on the H2 storage tank.		
25	Procedure complete		

3.10 D_2 storage tank pump/purge.

Due to the large volume of the tank (~1000 gal), this procedure is time consuming. It is best to pump on the tank overnight to clean out the system after each purge. Because of the large time needed by the process, pump and purge with ^{4}He is often not performed in favor of a simple 2 or 3 cycle pump and purge with D_2. The procedure below describes the full procedure with both pump and purge cycles (^{4}He and D_2). The use of a blower cart connected to the port after MV9202 is also helpfull. There is no way to isolate the loop from the gas panel vacuum pump and storage tank on the deuterium loop. As part of this procedure, the fill and return lines are disconnected at the top level of the target mezzanine. Only experts should do this. These lines will have to be blanked off for all of the pump and purge cycles. At the end of the procedure, the lines will have to be reconnected.

Procedure 3.10

No	Item	Time	Data
0	Ensure that all valves on the gas panels are closed. Ensure that procedures 2.5.2, and 2.4 have been performed. Disconnect the fill and retrun lines from the target and blank these line off. If a blower is being used, connect it to the port near MV9202.		
1	If there is no vacuum in the scattering chamber, EXTREME CAUTION MUST BE EXERCISED. Do not proceed with this procedure without fully understanding the system. Damage to the target could result. Ensure that the following valves are closed. MV9041___, MV9053___, MV9100___, MV9030___, MV9046___, MV9080___, MV9010___, MV9040___,		

2	Turn on MP1		
3	Open the following valves Open MV9131___ and MV9133___ located on the D_2 tank. Open MV9105___, MV9108___, and MV9149___ Open MV9100___ MV9046___, and SV9073___. Open MV9202___ if using a blower.		
4	The tank will take a considerable time to pump down.		
5	When the pressure on PI9042 is less than 20 μmHg close MV9041___, MV9100___, and MV9202___ (if used)		
6	Open MV9035___. Set the pressure on PRV9035 to $>$ 3 atm.		
7	Open MV9037___ and watch the pressure on PI9053. When the pressure is $\sim$1 atm close MV9037___		
8	Open MV9100___, MV9041___, and MV9202___ (blower only) When the pressure on PI9042 is less than 20 μmHg close MV9100___, MV9041___, and MV9202 (blower only)		
9	Repeat step 7		
10	Repeat Step 8		
11	Repeat step 7		
12	Repeat step 8		
13	Ensure that the line connecting the D_2 bottle to the gas panel has been pumped and purged. Follow procedure **??** if this is not known to be the case.		
14	Open MV___. Set CPV46 to $>$ 1 atm.		
15	Open MV47___. Allow pressure on PI139 to reach $>$ 1 atm. Close MV47___		
16	Open MV63___ and MV79___. When the pressure on PI9042 is less than 20 μmHg close MV63___ and MV79___		
17	Repeat step 15		
18	Repeat step 16		
19	Repeat step 15		
20	Repeat step 16		
21	The tank is now ready to fill.		
22	Open MV47___. Allow pressure on PI130 to reach 50 psia. Close MV47___.		
23	Close all valves on the gas panels. Stop MP1.		
24	Close and lock MV68___ and MV70___ on the D_2 storage tank.		
25	Procedure complete		

4 15K Target Operation

Operation of the 15K target should only be performed by experts. If both hydrogen and deuterium are needed both targets can be cooled down concurrently. The loops that are not to be filled are standby loops and need to be filled with ^{4}He at a pressure of $>$ 1 atm to prevent loss of the cells in the event of vacuum loss in the scattering chamber.

4.1 Configuration of standby loop or loops

The standby loop or loops must be filled with ^{4}He to ensure a positive pressure on the cell at all times. The loops are left on the regulator with the 4 atm house helium supply. The following procedure sets up the operation conditions.

Procedure 4.1

No	Item	Time	Data
0	Ensure that the following procedures have been performed. Procedure 2.4 Procedure 2.5.2 Procedure 2.6 Procedure 3.2 Procedures 3.4 and 3.3		
1	Set the pressure on PRV9035 to slightly more than 1 atm (17 - 20 psia)		
2	Open MV9035___ Open MV9037___, and MV9053___		
3 4	If the deuterium loop is to be on standby open MV9052___, MV9080___ and SV9082___. If the hydrogen loop is to be on standby open MV9052___, MV9012___ and SV9012___.		
5	Ensure that the pressures in all loops are as expected.		
6	Procedure complete.		

4.2 15K Hydrogen and Deuterium Target Cool Down

Cooling down the hydrogen and deuterium targets can be performed simultaneously. Prior to cooling down the loops the electronics should be checked and certified. Further, the target control GUI should be tested and running before starting the procedure. Cooling down the target presents a considerable load to the ESR. Patience and caution should be exercised because of the possible effects to other halls. Inform the other halls when the procedure is to be started. It will also be necessary to obtain a copy of the latest cool down procedure. This can be obtained from the MCC operations page or on the web or at https://polweb/hallc/index.html where a list of documents is displayed. The following is the procedure to cool down the target.

Procedure 4.2

No	Item	Time	Data

0	Ensure that the following procedures have been completed. Procedure 2.1 Procedure 2.3 Procedure 2.4 Procedure2.5.2 Procedure 3.1 Procedure 3.2 Procedure 3.3 Procedure 3.4 Procedure 3.7 Procedure 3.8 Procedure 4.1 Procedure 2.2		
0.1	If the hydrogen loop is to be filled open the following valves. Lock open MV9120_ _ _ and MV9130_ _ _ located on the H_2 storage tank. Lock open MV9148_ _ _ Ensure that MV9114 is locked closed. Open MV9019_ _ _, and SV9012_ _ _ A path through the filters must be selected Open either MV9005_ _ _, and MV9006_ _ _ OR MV9007_ _ _, and MV9008_ _ _.		
0.2	If the deuterium loop is to be filled open the following valves. Lock open MV9131_ _ _ and MV9133_ _ _. located on the D_2 storage tank. Lock open 9149_ _ _. Ensure that MV9108 is locked closed. Open MV9105_ _ _ and SV9082_ _ _. A path through the filters must be selected. Open either MV9075_ _ _ and MV9076_ _ _ OR MV9077_ _ _, and MV9078_ _ _.		
1	Plug in all fan controllers controls will not work properly without all three on. Ensure that the auxiliary high power heater supplies are turned off Energize the high power heater supplies for each loop that will be used. Setup survey scopes and measure target position. Check scattering chamber vacuum. If vacuum is not below 10^{-5} Torr stop the procedure and contact the target group. Now is a good time to reboot the IOC. Check to make sure that the reboot goes properly		
2	Start the GUI in a convenient location. Ensure that the high power heater PIDs are enabled for the loops to be filled. Ensure that the GUI is configured correctly.		
3	Ensure that the warm return valve is fully open and that the ball valve near the automax is locked open.		
4	Call MCC and ask to start the 15K target cool down procedure.		
5	Obtain the latest version of the target cool down procedure for the MCC.		
6	It will take the MCC $\sim$1 hour to allow opening of the target JT valves.		
7	Monitor the ESR and loop pressures and temperatures to ensure that all is as expected.		
8	When instructed by MCC open JT valves on loops to be cooled down.		
9	Open the Pre-cool JT valve. This provides an additional warm return		

	path for the coolant.		
10	In ~2 hours the return temperatures will be around 35K. Inform MCC that it is time close the warm return and open the path to cold return.		
11	When instructed close warm return valve and continue filling the target.		
12	Ensure that the high power heater PIDs are working properly.		
13	Check for proper operation of the loops Read survey scopes and remove them from hall.		
14	Start GUI in counting house and hand over operation to target operator.		
15	Procedure complete.		

4.3 15K Hydrogen and Deuterium Target Warm Up

Warming up the hydrogen and deuterium targets is performed simultaneously. Inform the other halls when the procedure is to be started. It will also be necessary to obtain a copy of the latest cool down/warm up procedure. This can be obtained from the MCC operations page or on the web or at https://polweb/hallc/index.html where a list of documents is displayed. The following is the procedure to cool down the target.

Procedure 4.3

No	Item	Time	Data
0	Ensure that access to the hall is available.		
1	Call MCC and request the warm up of the Hall C 15K target.		
2	Close the JT valves slowly when instructed to do so . Open the warm return valve when instructed to do so. Allow target to vent into storage tanks. As this is happening: Turn off High power heater supplies in the electronics rack. Turn off the fan controlers and unplug all of them. Wait for the target to warm up to room temp before continuing.		
3	Turn off the temperature controlers Valve off the storage tanks Close and lock MV9130___ and MV9120___ Close and lock MV9131___ and MV9133___		
4	Perform Procedure 3.3		
5	Perform Procedure 3.4		
6	Switch the hydrogen status indicators to "In Use" to "Empty"		
7	Turn off MP1 and close all valves.		
8	Procedure complete.		

5 ^{4}He Target Configuration and Operation

This section describes the pump/purge fill and operation of the ^{4}He target in the loop 1 tuna can cell in Hall C. While the ^{4}He cell is not restricted to loop 1, it is assumed to be the case. There are no procedural changes if this is not the case except that the user must be aware of the loop configuration when checking initial conditions. The initial state of the target gas panels (both the ^{3}He, ^{4}He, H_2 and D_2 panels) is assumed to be such that all valves are closed. ***The ^{3}He target gas which is both rare and valuable is assumed to be contained in the ^{3}He cylinder. If this is not known to be the case, consult Mike Seely, Dave Meekins, or Chris Keith before continuing in any way.*** It is possible to run both the helium targets at the same time. The reliefs must be sized apropriately for helium operation. The ^{4}He target does not have a recovery system (i.e. a tank similar to the H_2 and D_2 targets). In the event that either helium target vents, a new fill must be performed. Procedures for both targets are described later in this section. For a flow schematic, refer to drawing C_CRYO_1001 sheets 1, 2, and 3.

5.1 Pre-starting conditions (not for running target)

The following procedure is designed to ensure that the target is in the proper configuration for setting up ^{4}He operations. To properly configure the target for ^{4}He running several other procedures must be followed. Many of these steps are redundant to steps in previous procedures but at left here for completeness. It never hurts to double check.

Procedure 5.1

No	Item	Time	Data
1	Ensure that the isolation valves on the H_2 and D_2 tanks are closed These valves are located outside behind the Hall C counting house. They should be locked closed. These valves are labled on the flow sheet as MV9131 MV9133, MV9130, and MV9120.		
1a	Make sure that all valves on the H_2, D_2, and He pump/purge are closed.		
2	Ensure that the ^{3}He target gas is contained in the ^{3}He starge tank. If you are unsure of the state of this gas **STOP NOW**.		
3	It is assumed that only ^{4}He will be used therefore the swapover valves must be configured properly. Open MV9125___ and MV9124___. Close MV9126___ and MV9127___. Ensure that MV9131 and MV9132 are closed.		
4	Ensure that all valves on the ^{3}He and ^{4}He panels are closed.		
5	Check to make sure that there is an adequate supply of helium for target operations. Bottles of research grade helium are required for this.		
6	Procedure complete.		

5.2 H_2 and D_2 panel/loop configuration

The H_2 and D_2 panel and loops must be configured properly so that the cells in these two loops do not see a subatmospheric pressure. This is a safety measure that protects the cells in the event of vacuum loss in the scattering chamber. Perform the following procedure.

Procedure 5.2

No	Item	Time	Data
0	Check the vacuum in the scattering chamber. Ensure that the pressure is below 10^{-5} Torr. If not **STOP THE PROCEDURE AND CONTACT THE TARGET GROUP**.		
1	Perform Procedure 3.2 Perform Procedure 3.3 Perform Procedure 3.4		
2	Configure the swapover valves (located on the middle deck) Open MV9124___ and MV9125. Close MV9126___ and MV9127.		
3	At this point the deuterium panel gauges and pump/purge panel gauge should read slightly more than 1 atm.		
4	Both loops are left with a supply of He from the house supply on slightly above 1 atm. This ensures that the loops have a positive pressure at all times in case there is a loss of vacuum in the scattering chamber.		

5.3 He panel pump/purge and fill.

The ^{4}He panel is located on the second deck of the mezzanine. accross from the ^{3}He panel. This is a relatively simple panel and allows for simultaneous ^{3}He and ^{4}He operations. this is not true in Hall A. Ensure that the house helium (4 atm supply) is connected. This should normally be the case. If the connection is not present the target group (David Meekins, Mike Seely, or Chris Keith) should be contacted.

Procedure 5.3

No	Item	Time	Data
0	Check the scattering chamber vacuum. If the pressure is not below 10^{-5} Torr **STOP THE PROCEDURE IMMEDIATELY.**		
1	Open all the gauge isolation valves: MV9150___ MV9151___ .		
2	Turn on the main vacuum pump MP1		
3	Make sure that MV9153 on top of the He supply bottle is closed___. (This is located downstairs in the gas bottle rack)		
4	Ensure that Procedure 3.1 has been performed.		
5	Ensure that MV9152 is closed Ensure that PRV9153 is closed		
6	Open MV9122___ and MV9154___. Wait for the pressure on PI9042 to read less then 20 μmHg. Close MV9122___ Open MV9153 and PRV9153 to $\sim$ 1 atm. ___ Close MV9153		
7	Open MV9122 Wait for the pressure on PI9042 to read less then 20 μmHg. Close MV9122		
8	Open MV9153 to fill line Close MV9153		
9	Repeat step 7		
10	Repeat step 8		
11	Repeat step 7		
12	Repeat step 8		
13	Open MV9122___ MV9123___ SV9102___ MV9128___. This will pump on both sides of the He loop Wait for the pressure on PI9042 to read less then 20 μmHg. Cycle MV9128 several times. Close MV 9122___ and MV9123___		
14	Open MV9152___ . PI9103 $\sim$ 1atm. Close MV9152___.		
15	Repeat step 13		
16	Repeat step 14		
17	Repeat step 13		
18	Repeat step 14		
19	Close all valves and turn off MP1		
20	Procedure complete		

5.4 Replacing He supply bottle

After a target vent or during a fill, it may be necessary to replace the He supply bottle. Make sure that the replacement bottle is of high purity ^{4}He. Contact Mike Seely, Dave Meekins or Chris Keith if in doubt or in need of a supply. The following procedure describes the installation of a new He supply bottle.

Procedure 5.4

No	Item	Time	Data
1	Turn on the gas panel mechanical vacuum pump MP1___		
2	Close MV9128___ and SV9102 This isolates the He Cell from the He bottle and panel vacuum pump		
3	Close MV9153___ this is located at the top of the old He supply bottle.		
4	Swap empty He bottle for full one. Snoop the connection after tightening the regulator. Open MV9154___		
5	Ensure that MV9153 is closed. Open MV9122___. this will pump out the line to the new He bottle. Close MV9122___ Ensure that PRV9153 is set to ∼1 atm.		
6	Open MV9153___ and allow the pressure in the line to stabilize. Close MV9153.		
7	Repeat step 5		
8	Repeat step 6		
9	Repeat step 5		
10	Repeat step 6		
11	Open SV9102___ and MV9128___		
12	Begin filling the target by increasing the pressure on PRV9153. Monitor the return temperature. Adjust PRV9153 and the He JT valve such tha the return temperature does no exceed 6.5K		
13	The target is ready to resume operations. Hand the target over to a qualified operator.		
14	Procedure complete		

5.5 ^{4}He target cool down.

The following procedure must be completed to properly cool down the ^{4}He target. In this procedure, the target is cooled first with a roughly constant pressure of ∼1 atm. After the target is at operating temperature and on cold return, it is filled.

Procedure 5.5

No	Item	Time	Data
0	Prior to starting this procedure procedures 5.1, 5.3, and 5.2 must be completed.		

1	Ensure that MV9152 is closed. Ensure that MV9123 is closed Ensure that SV9102 is closed. Ensure that MV9150___, MV9151___, MV9153___ SV9102___ and MV9128___ are open.		
2	Check the pressure on PRV9153. Ensure that it is $\sim$1 atm. Open MV9154___		
3	If the valves in steps 1 and 2 are not in the proper state stop the procedure and contact the target group immediately.		
4	Ensure that MV9124___ and MV9125___ are open. Ensure that MV9126___ and MV9127___ are closed.		
5	Call MCC and inform them that you need to start the cool down of the 4K target in Hall C. It will take some time for them to set this up. Now is a good time to double check valve settings and electronics. Make sure that the fan controllers are plugged in (all three must be on) Ensure that the high power heater supplies are energized. Make sure that the warm return valve is fully open.		
8	Start the target control GUI and monitor the incoming ESR and target pressure and temperature.		
9	MCC will provide notification to open the target JT and begin cool down. This procedure takes some time. Ensure that the fan in the He loop is spinning. Ensure that the high power heater PID is enabled.		
10	Slightly open the He loop JT and open the Pre-cool JT.		
11	Constantly monitor the return temperature. After the return temperature reaches 10K call MCC and inform them that it is time to switch to cold return. Follow their instructions when closing the warm return valve.		
11	When the target is cold $\sim$6.5 K start filling the target.		
12	Open the pressure regulator PRV9153 to a higher setting. Be careful to monitor the loop temperature and the ESR return temperature. Adjust PRV9153 and the He JT valve sutch that the return temperature is below 6.5K During this procedure, it will be necessary to perform procedure 5.4 when the supply bottle empties. When the target is at the proper pressure close MV9154___.		
13	Hand over operation of the target to the target operator.		
14	Procedure complete		

6 ^{3}He Target Configuration and Operation

This section describes the pump/purge fill and operation of the ^{3}He target in the loop 1 tuna can cell in Hall C. While the ^{3}He cell is not restricted to loop 1, it is assumed to be the case. There are no procedural changes if this is not the case except that the user must be aware of the loop configuration when checking initial conditions. The initial state of the target gas panels (both the ^{3}He and the H_2 D_2 panels) is assumed to be such that all valves are closed. ***The ^{3}He target gas which is both rare and valuable is assumed to be contained in the ^{3}He cylinder. If this is not known to be the case, consult Mike Seely, Dave Meekins, or Chris Keith before continuing in any way.***

6.1 Pre-starting conditions (not for running target)

The following procedure is designed to ensure that the target is in the proper configuration for setting up ^{4}He operations. To properly configure the target for ^{4}He running several other procedures must be followed. Many of these steps are redundant to steps in previous procedures but at left here for completeness. It never hurts to double check.

Procedure 6.1

No	Item	Time	Data
1	Ensure that the isolation valves on the H_2 and D_2 tanks are closed MV9120_ _ _, MV9130_ _ _, MV9131_ _ _, MV9133_ _ _. These valves are located outside behind the Hall C counting house. They should be locked closed.		
2	Perform Procedure 2.4 make sure all connections are correct. Failure to do so could result in the loss of ^{3}He inventory.		
3	Make sure that all valves on the H_2, D_2, and He pump/purge are closed.		
4	Ensure that the ^{3}He target gas is contained in the ^{3}He cylinder. If you are unsure of the state of this gas **STOP NOW**.		
5	Configure the swap over valve panel for ^{3}He running Close MV9729_ _ _ and MV9730_ _ _ Open MV9731_ _ _ and MV9732_ _ _		
6	If ^{4}He is to be used simultaneously, go to step 7 Otherwise the hydrogen loop will have to be configured for standby with the deuterium loop go to step 8		
7	Configure the swap over valves for ^{4}He running. Open MV9124_ _ _ and MV9125_ _ _ Close MV9126_ _ _ and MV9127_ _ _ Perform procedure 6.3		
8	Configure the swap over valves for hydrogen loop standby. Open MV9126_ _ _ and MV9127_ _ _ Close MV9124_ _ _ and MV9125_ _ _ Perform procedure 6.2		
9	Procedure complete.		

6.2 ^{3}He running only, H_2 and D_2 panel/loop configuration

The H_2 and D_2 panel and loops must be configured properly so that the cells in these two loops do not see a subatmospheric pressure. This is a safety measure that protects the cells in the event of vacuum loss in the scattering chamber. Perform the following procedure.

Procedure 6.2

No	Item	Time	Data

0	Check the scattering chamber pressure. If the pressure is above 10^{-5} torr STOP THE PROCEDURE.		
1	Perform the pump and purge of the H_2 panel with ^{4}He as described in Procedure 3.3.		
2	Perform the pump and purge of the D_2 panel with ^{4}He as described in Procedure 3.4.		
3	Make sure that the the H_2 and D_2 cells have a pressure $>$ 1 atm.		
4	Both loops are left with a supply of He from the house supply on slightly above 1 atm. This ensures that the loops have a positive pressure at all times in case there is a loss of vacuum in the scattering chamber. For now leave the valves on all panels closed.		

6.3 ^{3}He and ^{4}He running, D_2 panel/loop configuration

The H_2 and D_2 panel and loops must be configured properly so that the cells in these two loops do not see a subatmospheric pressure. This is a safety measure that protects the cells in the event of vacuum loss in the scattering chamber. Perform the following procedure.

Procedure 6.3

No	Item	Time	Data
0	Check the scattering chamber pressure. If the pressure is above 10^{-5} torr STOP THE PROCEDURE.		
2	Perform the pump and purge of the D_2 panel with ^{4}He as described in Procedure 3.4.		
3	Ensure that the pressure in the D_2 loop is $>$ 1 atm.		
4	Both loops are left with a supply of He from the house supply on slightly above 1 atm. This ensures that the loops have a positive pressure at all times in case there is a loss of vacuum in the scattering chamber. For now leave the valves on all panels closed.		

6.4 He panel pump/purge and fill with ^{3}He

In Hall C it is possible to have both ^{3}He and ^{4}He targets simultaneously. If Both targets are required, Procedure 5.3 will also need to be performed. Again at the start of the pump and purge procedure, all valves should be closed on the panel.

Procedure 6.4

No	Item	Time	Data
0	Check again that the scattering chamber pressure is below 10^{-5} Torr. If not **STOP THE PROCEDURE**. Ensure that MV9716___ and MV9719___ are closed If not **STOP THE PROCEDURE**		
1	Open all the gauge isolation valves: MV9127___, MV9733___, MV9720___, 9728___, MV9723___, MV9734___, MV9721___.		
2	Open the compressor isolation valves MV9740___ and MV9741___.		
3	Verify that the compressor vent valves MV9742 and MV9743 are locked closed.		
4	Turn on main vacuum pump MP9703 and open MV9712		
5	Open MV9711___ PRV9702___ to pump out the line to the purge gas cylinder. Close PRV9702___		
6	Close MV9712___ Set PRV9702 to ~ 1 atm. ___ (read on PI9707) Close MV9735___		
7	Open MV9712___ Wait for the pressure on PI9706 to read less then 20 μmHg. Close MV9712___.		
8	Open MV9735___ Close MV9735___		
9	Repeat step 7		
10	Repeat step 8		
11	Repeat step 7		
12	Repeat step 8		
13	Verify that the loop 1 fan drive is disconnected.		
14	The He cell is now ready to be pumped and purged. Double check the vacuum (as in step 0) Open MV9715___, MV9709___, EV9702___		
15	Open SV9703___ and MV9710___ to pump out the return line to the tank.		
16	Open the following valves: MV9701___, MV9702___, SV9701___, MV9740___ MV9741___, MV9704___, MV9705___, MV9736___ Be careful of the distintion between MV ans SV.		
17	Open MV9707___ and MV9708___ to pump out P2		
18	Operate the compressor P1 and pump P2 for 30 sec		
19	Open MV9713___ and MV9714___ to pump out filter.		
20	Wait for the pressure on PI9706 to read less then 20 μmHg. Close MV9712___		
21	Open MV9735___ . PI9707 ~ 1 atm. Close MV9707___.		

22	Open MV9712___ . Cycle EV9702, SV9703 and SV9701 several times. Turn on loop 1 fan drive at 20 Hz for 30 seconds. Turn off fan and disconnect the drive. Wait for the pressure on PI9706 to read less then 20 μmHg. Close MV9712___		
23	Open MV9735___ . PI9707 $\sim$ 1atm. Close MV9735___.		
24	Open MV9712___ and repeat step 18. Wait for the pressure on PI976 to read less then 20 μmHg. Close MV9712___.		
25	Repeat step 23		
26	Repeat step 24		
27	Repeat step 23		
28	Repeat step 24		
29	Close and lock MV9709___ Close and lock MV9715___ Close and lock MV9707___ Close and lock MV9708___		
30	Ensure that SV9703 is open Close EV9701___ Close PRV9701___ Slowly open MV9719 to pressurize the system with ^{3}He		
31	Open and lock MV9716___ This opens the relief path back to the tank. Close MV9710___ Close SV9703___		
32	Adjust PRV9701 so that the pressure on PI9701 is 125 psia This is the compressor inlet pressure.		
33	The system is now ready for cool down Procedure complete		

6.5 ^{3}He target cool down.

The following procedure describes the cool down of the 4K ^{3}He target. It is assumed that Procedure **??** has already been performed. If this is not known to be the case STOP and contact the target group immediately. Care must be taken when performing this procedure because ^{3}He is both rare and valuable. This procedure should only be performed by a target expert (Mike Seely, David Meekins, or Chris Keith).

Procedure 6.5

No	Item	Time	Data
1	Ensure that procedure **??** has been performed. Ensure that procedure 6.2 has been performed.		
2	Contact MCC and inform them of the need to cool down the 4K He target in Hall C. Verify that the warm return valve is open.		
3	Start the ^{3}He target loop fan at 20 Hz.		
4	Once MCC indicated it is time to start the cool down of the target. Open the pre-cool JT valve to 100%. Slowly open the He loop JT valve to ∼15% Start the target control GUI.		
5	Adjust the He loop JT as needed during the cool down. Monitor the coolant return line temperature.		
6	As soon as the return line temperature is falls below 6.5K, it is necessary to switch to cold return. The MCC operator will give instructions on how when the warm return valve must be closed.		
7	When the system reaches the base operating temperature (∼4.5K) the pressure in the He loop will have fallen to ∼100 psia.		
8	Close MV9705___, MV9702___, MV9704___ Verify that SV9710 and MV9710 are closed Ensure that MV9701___, MV9703___, MV9713___ MV9714___ and EV9702___ are open		
9	Start compressor P1. Note that SV9701 may be opened if the suction pressure falls below 115 psia		
10	The addition of warm gas will cause the target to warm up. Adjust EV9702 so that the return temperature does not exceed 6.5K.		
11	When the target reaches 220 psia and 4.5K the pressure in the storage tank will be ∼25 psia Stop the compressor and close EV9702___ Close SV9701___ Close the pre-cool JT valve.		
12	The target is now ready for operation. Hand the controls over to a qualified operator		
13	Procedure complete		

6.6 ^{3}He and ^{4}He targets cool down.

The following procedure describes the cool down of the 4K ^{3}He and ^{4}He targets simultaneously. It is assumed that Procedures 5.3 and **??** have already been performed. If this is not known to be the case **STOP** and contact the target group immediately. Care must be taken when performing this procedure because ^{3}He is both rare and valuable. This procedure should only be performed by a target expert (Mike Seely, David Meekins, or Chris Keith).

Procedure 6.6

No	Item	Time	Data
0	Ensure that procedure **??** has been performed. Ensure that procedure 5.3 has been performed. Ensure that procedure 6.3 has been performed.		
1	Perform steps 0 through 4 of procedure 5.5		
2	Contact MCC and inform them of the need to cool down the 4K He target in Hall C. Verify that the warm return valve is open. Start the target control GUI		
3	Start the ^{3}He target loop fan at 20 Hz.		
4	Once MCC indicated it is time to start the cool down of the target. Open the pre-cool JT valve to 100%. Slowly open the ^{3}He and ^{4}He loop JT valves to $\sim$15%		
5	Adjust the loop JTs as needed during the cool down. Monitor the coolant return line temperature.		
6	As soon as the return line temperature is falls below 6.5K, it is necessary to switch to cold return. The MCC operator will give instructions on how and when the warm return valve must be closed.		
7	When the system reaches the base operating temperature ($\sim$4.5K) the pressure in the ^{3}He loop will have fallen to $\sim$100 psia. We will fill only one target at a time and start with ^{3}He		
8	Close MV9705___, MV9702___, MV9704___ Verify that SV9710 and MV9710 are closed Ensure that MV9701___, MV9703___, MV9713___ MV9714___ and EV9702___ are open		
9	Start compressor P1. Note that SV9701 may be opened if the suction pressure falls below 115 psia		
10	The addition of warm gas will cause the target to warm up. Adjust EV9702 so that the return temperature does not exceed 6.5K.		
11	When the target reaches 220 psia and 4.5K the pressure in the storage tank will be $\sim$25 psia Stop the compressor and close EV9702___ Close SV9701___		
12	Open the pressure regulator PRV9153 to a higher setting. Be careful to monitor the loop temperature and the ESR return temperature. Adjust PRV9153 and the He JT valve sutch that the return temperature is below 6.5K During this procedure, it will be necessary to perform procedure 5.4 when the supply bottle empties. When the target is at the proper pressure close MV9154___.		

14	Close the precool JT valve. Hand the controls over to a qualified operator		
15	Procedure complete		

6.7 Refill of ^{3}He target cell

If pressure is lost to the ^{3}He cell, the target must be repressurized. This will require access to the hall. Ensure that a working control system is available in the hall before starting the procedure. This procedure should only be performed by target experts. It is assumed that the target is still cold and that Procedure 6.5 has been performed.

Procedure 6.7

No	Item	Time	Data
1	Ensure that procedure 6.5 has been performed.		
2	Open EV9702___ Turn on compressor P1 Once the supply pressure PT9701 or PI9701 falls below 115 psia open SV9701		
3	Open the pre-cool JT valve to 100%		
4	When the target reaches operating pressure Close EV9702___ Turn off compressor P1 Close EV9701___ Close the pre-cool JT valve		
5	Procedure complete		

6.8 ^{3}He target warm up and active gas recovery

The following procedure must be performed to warm up the ^{3}He target. The procedure should only be performed by target experts. Active gas recovery starts at step 7.

Procedure 6.8

No	Item	Time	Data
1	Check all temperatures and pressures in the target		
2	Relieve the pressure on the target cell Slowly open MV9702___. Open SV9703___		
3	Call MCC and inform them that the 4K Hall C target must be warmed up.		
4	Follow the operators instructions for closing the JT valve and opening the warm return valve.		

5	Turn off the high power heater supply Turn off the He loop fan		
6	As the target warms the pressure should approach ~210 psia. Do not begin active gas recovery until the loop temperature is above 30K		
7	Start active gas recovery. Open MV9702___ and MV9704___. Close MV9701___ and MV9703___ Ensure that MV9719 is open.		
8	Start compressor P1. Once the system pressure falls below 115 psia Open SV9701		
9	As soon as the pressure in the system falls below 1 atm close MV9716___ Open MV9710___ and SV9703___ use the sealed vacuum pump to recover the remaining ^{3}He. Check the pressure on PI9702. If the pressure is not below 15 psia, wait. The pump is not rated for pressures above 1atm. If PI9702 reads less than 1 atm Open MV9707___ and MV9708___		
10	Start the vacuum pump P2 Slowly close EV9702 while watching PI266 Do not allow the pressure on PI9705 to exceed 20 psia As the system pressure falls, it should be possible to close EV9702 completely.		
11	Allow pump P2 to reach its base pressure of 0 psia. Compressor P1 should reach a base pressure of ~7 psia. (Use PI9701 and PI9705)		
12	Close MV9708___ Stop P2 Close MV9707___ Lock these two valves closed.		
13	Close EV9701___ and MV9702___		
14	Close MV9719___ Stop the compressor P1. Close MV9704___, EV9703___, MV9710___, MV9732___, MV9731___, Close all valves on the ^{3}He panel.		
15	Pump and purge the He pump purge panel. This ensures that no contaminates will enter the cold cell. Open MV9729___ and MV9730___. Connects the pump purge panel to the He loop Perform procedure 3.2		
16	Procedure complete		