Laboratory Environment Safety and Health Committee
Cryogenic Safety Subcommittee

MINUTES OF MEETING 04-03

April 8, 2004

Final

Committee Members Present	**Committee Members Absent**
R. Alforque	**P. Mortazavi**
W. Glenn	**K. C. Wu**
S. Kane	
P. Kroon	
E. Lessard (Chairperson)	
M. Rehak	
A. Sidi Yekhlef	
R. Travis* (Secretary)	
R. Gill	
(* non-voting)	

Visitors
M. Lowry
A. Sandorfi

Agenda:

1. **LEGS Inbeam Cryostat Commissioning Requirements**

Minutes of Meeting: Appended on pages 2 through 4.

__Signature on File_______________ ______________________________

E. Lessard	**Date**	**J. Tarpinian**	**Date**
LESHC Chairperson		**ESH&Q ALD**	

DM2120.

Chairperson E. Lessard called the third meeting in 2004 of the Laboratory Environmental Safety and Health Committee (LESHC) to order on April 8, 2004 at 2:31 p.m.

1. **LEGS Inbeam Cryostat Commissioning Requirements:** LESHC 03-05[1] summarizes the August 2003 Cryogenic Safety Subcommittee review of the LEGS Inbeam Cryostat (Reference 1). Those minutes document nine action items that are required to be addressed prior to the start of the LEGS commissioning process (Actions 1.2.1.1 through 1.2.1.9). (Three additional action items 1.2.2.1 through 1.2.2.3) are required as prerequisites to the operations phase.)

1.1. In preparation for LEGS commissioning activities, the Physics Department transmitted responses[1] to the Commissioning action items via emails dated 3/16, 3/31 and 4/5/04. The nine commissioning actions and the associated status of each are provided below:

1.1.1. LESHC 03-05 action item 1.2.1.1 states: "Ensure that all personnel that are involved in the commissioning process (including the Quantum Design representative) take the BNL "Cryogen Safety", "Oxygen Deficiency Hazard" and "Static Magnet Field" training courses at http://training.bnl.gov/."
The Committee reviewed the Physics Department Response[1] and finds it acceptable.

1.1.2. LESHC 03-05 action item 1.2.1.2 requires Physics to: "Review the SBMS Subject Area "Oxygen Deficiency Hazards (ODH), System Classification and Controls" https://sbms.bnl.gov/standard/16/1600t011.htm, and perform the ODH calculations, both with and without the exhaust fans. Implement the appropriate control measures. Submit the calculations and the proposed control measures to the LESHC Cryogenic Subcommittee for review."
Prior to this meeting, the Committee reviewed the ODH calculation (with fans). The Committee questions were satisfactorily addressed for this case. The focus of discussion at the meeting was the need for ODH calculations to address fan "failure to start" and "failure to restart after one cycle". (The latter calculation should assume a lower dewar heat transfer rate to maximize the available LHe inventory when the fan fails to restart.) - **Complete**[2].
There was also significant discussion concerning the design of the ODH mitigation system (i.e., the need for latching of the fans), the location of the manual start switch for the fan, and the ODH Alarm Response Procedure (ARP). The LESHC Chairman committed to generate a memo requesting that the Light Source evaluate their ODH mitigation system design, the ARP and to determine if the O2 sensor readout and the fan controls are located suitably to minimize the risk to the emergency responders.

---

[1] These Minutes and the documents referenced herein are posted at: http://www.rhichome.bnl.gov/AGS/Accel/SND/laboratory_environemnt,_safety_and_health_committee.htm.)

[2] This action was completed prior to the issuance of these minutes.

1.1.3. LESHC 03-05 action item 1.2.1.3 states: "Perform a quench test to assure that the magnet vessel will not fail. Provide the results of this test to the Committee." The Committee reviewed the Physics Department Response[1]. Two attempts were made at the factory, but both failed to quench the magnet. The BNL power supply is stronger and Physics committed to try an in-situ quench test (during commissioning), with the understanding that the device will not be put at risk for damage. The Physics Department will provide the results of this test to the Committee.

1.1.4. LESHC 03-05 action item 1.2.1.4 states: "Perform a calculation to compare the oxygen diffusion rate with the flow rate out of the LN2 vent. Provide this information to the Committee."
The Committee reviewed the Physics Department Response[1] and finds it acceptable.

1.1.5. LESHC 03-05 action item 1.2.1.5 states: "Provide a written certification to the Committee that the electrical components of the in beam cryostat conform to Underwriter's Laboratory (UL) standards."
The Committee reviewed the Physics Department Response[1] and finds it acceptable.

1.1.6. LESHC 03-05 action item 1.2.1.6 states: "Review BNL ESH Standards 1.4.1, "Pressurized Systems for Experimental Use" and 1.4.2, "Glass and Plastic Window Design for Pressure Vessels" and demonstrate compliance to the Committee."
The Committee reviewed the Physics Department Response[1] and finds it acceptable.

1.1.7. LESHC 03-05 action item 1.2.1.7 states: "Provide design details (including drawings) of the helium 3 still and the liquid helium pressure vessels for Committee review."
The Committee reviewed the Physics Department Response[1] and finds it acceptable.

1.1.8. LESHC 03-05 action item 1.2.1.8 states: "Provide a transfer procedure(s) for: refilling the LHe cryostat from the 500 liter transfer cryostat and the replenishment of the LN2 automatic refill system."
The Committee reviewed the Physics Department Response[1] and finds it acceptable.

1.1.9. LESHC 03-05 action item 1.2.1.9 states: "Address Committee comments on the "Operating Procedures for the BNL In-beam Cryostat". Provide the revised procedures for Committee review."
The summary response and a new manual (procedure)[1] was transmitted via the 4/5/04 email and sufficient time was not available for a detailed review prior to this meeting. The Committee noted that several hardware changes have been made that could impact the procedure. Committee member Steve Kane agreed to do a detailed review of this new information.

1.2. The following motions were crafted and approved by the Committee:

1.2.1. Motion No. 1 - Prior to performing LEGS In-Beam Cryostat commissioning activities, the Physics Department must:

1.2.1.1. Perform additional ODH calculations to address fan "failure to start" and "failure to restart after one cycle". (The latter calculation should assume a lower dewar heat transfer rate to maximize the available LHe inventory when the fan fails to restart.) Submit the calculations and any proposed control measures to the LESHC Cryogenic Subcommittee for review – **Complete**[2].

1.2.1.2. Implement any recommended changes to the operating procedures, (resulting from the Committee review, 1.1.9 above.) Provide procedural revisions and inform the Committee of any hardware modifications.

1.2.2. Motion No. 2 – At the end of the commissioning process, but prior to the start of the LEGS In-Beam Cryostat operations, the Physics Department must:

1.2.2.1. Implement LESHC 03-05 Conditions 1.2.2.2 and 1.2.2.3, as appropriate for LEGS In-beam Cryostat operation. Kindly inform the LESHC Chairman and Secretary of the status of these issues prior to the start of operations.

1.2.2.2. Perform the in-situ quench test. (See 1.1.3 above.) Please transmit the results at the conclusion of the test.

2. The Meeting was adjourned at 3:45 p.m.

Building 911B
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-4250
Fax 631 344-5954
lessard@bnl.gov

Managed by Brookhaven Science Associates
for the U.S. Department of Energy

Date: *April 26, 2004*

To: *W. R. Casey*

From: *E. Lessard, Chair, BNL Environment, Safety and Health Committee*

Subject: *LESHC 04-03, LEGS Inbeam Cryostat Commissioning Requirements – Request for LS ODH Review*

The BNL ES&H Committee reviewed the commissioning requirements for the Laser Electron Gamma Source (LEGS) in our meeting of April 8, 2004. LEGS is located in Light Source Target Room 1-168 and Cryolab Room 1-169. One commissioning action required the Physics Department to review the SBMS Oxygen Deficiency Hazards (ODH) Subject Area and submit the calculations and the proposed control measures to the LESHC Cryogenic Subcommittee for review. During the course of our April 8 ODH review, there was significant Committee discussion concerning the design of the ODH mitigation system. Although we understand the LEGS ODH system design is similar to other such systems at the Light Source, it varies from ODH mitigation systems at other onsite facilities as follows:

- The emergency fans can cycle on and off, rather than being latched on by the initial ODH signal.
- The location of the manual start switch for the fan requires entry into the affected area (Room 1-168). A more preferable location would be in the hall, outside the LEGS rooms.
- The ODH sensor readout is located in the Cryolab (Room 1-169) and is viewable at a distance through the door. A more preferable readout location would be in the hallway adjacent to a set of relocated fan controls.

There was also some discussion about the requirements and procedures for entry into these rooms after an ODH alarm, particularly for personnel rescue. The meeting attendees were not conversant with the LS ODH response procedures and could not resolve these questions.

Please evaluate the current LEGS ODH mitigation system design, in conjunction with the related Alarm Response Procedure(s) to determine if system hardware and/or procedure revisions are warranted. Kindly provide a response at your earliest convenience for Committee review.

Copy to:

LESHC Members
M. Beckman
S. Dierker
J. Ellerkamp
N. Gmür
M. Lowry
A. Sandorfi
J. Tarpinian
G. VanDerlaske

Analysis of the LEGS Oxygen Deficiency Hazard Protection System

A.M. Sandorfi
(March 15, 2004)

Executive Summary

This document presents an analysis of the Oxygen Deficiency Hazards (ODH) associated with the LEGS facility at the National Synchrotron Light Source, Bldg. 725. This is an update to the June 23, 1999 ODH document and incorporates the analysis requirements as defined in the SBMS subject area: *Oxygen Deficiency Hazards (ODH), System Classification and Controls*.

Sources of potential hazards are discussed and *Fatality Rates* are calculated for three rooms in Bldg. 725, the LEGS *Cryolab* (1-169), the LEGS *target room* (1-168) and the NSLS *mechanical equipment room number 7* (MER#7). The regions in these rooms with the highest possible hazard are considered and the calculations for the five worst cases are described in detail. With the adoption of one administrative control, namely to restrict the volume of liquid helium (LHe) in a cryogenic supply dewar to less than 250 liters when in the LEGS target room (1-168), rooms 1-169 and 1-168 classify as ODH-0, and MER#7 retains its classification as ODH-0. The results are summarized as follows:

Location	Net Fatality Rate (hr^{-1})	Classification
Cryolab / 1-169	9.1×10^{-9}	**ODH-0**
Target room / 1-168	6.9×10^{-9} *	**ODH-0**
MER #7	0	**ODH-0**

* LHe in supply dewars limited to less than 250 liquid liters.

Contents ***page***

Location and potential ODH sources

A system of cryogenic devices is in the process of being installed at the Laser-Electron-Gamma-Source (LEGS) in the NSLS, Building 725, for use with a new frozen spin deuterium-hydride (HD) target. These are listed below, with the indicated liquid Helium (LHe) and liquid Nitrogen (LN_2) cryogen capacities. Also listed are the rooms in which these devices will be used, the two possibilities being Rm. 1-168 (the LEGS *Target room*) or Rm. 1-169 (the LEGS *Cryolab*) – see attached drawing.

			LHe capacity	LN_2 capacity	Location
(1)	*Storage* dewar/SD	(Janis-III),	50 liters,	25 liters,	Rm. 168,169;
(2a)	*Transfer* Cryostat/TC	(Orsay),	1 liters,	5 liters,	Rm. 168,169;
(2b)	*Transfer* Cryostat/TC	(Jülich),	1 liters,	5 liters,	Rm. 168,169;
(3a)	*In-beam* Cryostat/IBC	(Orsay),	9 liters,	0 liters,	Rm. 168;
(3b)	*In-beam* Cryostat/IBC	(Quantum),	45 liters,	5 liters,	Rm. 168;
(4)	*Production* Dewar/PD	(Janis-II),	20 liters,	20 liters,	Rm. 168,169;
(5)	*Dilution Fridge*/DF	(Oxford-1000),	96 liters,	50 liters,	Rm. 169;
(6)	*Beth* magnet		10 liters,	0 liters,	Rm. 168.

Commercial liquid helium dewars supplied by BOC Gas (250 liters or 500 liters) are used to fill the various reservoirs in these devices:

		LHe capacity	LN_2 capacity	Location
(7)	*BOC* supply dewars	500 liters	0 liters	Rm. 168,169

A commercial 500 liter receiver dewar is used to collect liquid from a helium liquifier in room 169; a 50 liter LN_2 trap is also used with the liquifier system:

		LHe capacity	LN_2 capacity	Location
(8)	*Helium liquifier* (CTI-1410),	500 liters,	50 liters,	Rm. 169;

Three additional sources of Helium gas are associated with the Helium liquifier. The Helium capacities and locations are as follows:

		He gas capacity	Location
(9)	*He gas recovery bag*	500 cu ft (gas),	Rm. 168;
(10)	*He Recovery compressor*	334 cu ft (gas) @ 2200 psi (exterior tube trailer)	Rm. 168;
(11)	*He compressors and tank*	42 cu ft (gas) @ 220 psi	MER#7.

The volume of the rooms in which these devices are used is,

(A) LEGS *Target room*, Rm. 168 of Bldg. 725: 27000 cu. ft.;
(This does not include the LEGS *counting* rooms or *Control* room – see drawing).

(B) LEGS *Cryolab*, Rm. 169 of Bldg. 725: 6600 cu. ft;

(C) Mechanical Equipment Room #7 of Bldg. 725: 7100 cu. ft.

Room layouts and standard ventilation

The LEGS *Target Room* (Rm. 168) has a staggered ceiling with a 20 ft. height over the main experimental area and 15 ft. in the area adjacent to the *Counting rooms*. Over the *Counting rooms* there is an A/C-equipment mezzanine. A 2′ x 4′ automatic louvered damper is located in the side wall joining the 15′ and 20′ ceilings at a height of about 18′. The LEGS A/C system generates a flow of at least 400 cu. ft./min. (cfm) through this damper when it is set at minimum opening (and 4000 cfm at maximum).

The LEGS *Cryolab* (Rm. 169) has a 16 ft. ceiling, a volume of 6600 cu ft and a minimum air flow of 230 cfm from the NSLS air conditioning system. A mezzanine is located against the south-west wall and houses a helium liquifier engine and vacuum pumps.

The LEGS *Counting room* and adjacent **Counting room addition** are supplied with a minimum of 400 cfm of air, and the ***Control room*** with 300 cfm of air, both from the LEGS air conditioning system. Cryostats are not used in these rooms and the rooms are not in the path of Helium flow. (When the door between the *Counting rooms* and the *Cryolab* is open the greater air supply to the *Counting rooms* ensures a net flow into the *Cryolab*.)

Mechanical Equipment Room number 7 (MER#7) in building 725 houses two gas compressors and an expansion tank associated with the LEGS helium liquifier system (in addition to other NSLS equipment). This room has 7100 cu ft of air volume. The existing air system supplies up to 1380 cfm and exhausts up to 1580 cfm, with 200 cfm taken from the NSLS floor. (The room is designed to have a slight negative pressure.)

O_2 Sensors and Emergency Ventilation

An O_2 sensor is installed in the *Cryolab* near the ceiling above the Mezzanine on the South-West wall of Rm. 169. This device is connected to NSLS Emergency Power and its calibration is checked every 6 months by NSLS Operations staff.

An O_2 sensor is in service in MER#7. It is also connected to NSLS Emergency Power and its calibration is checked every 6 months.

A *Panel Ventura exhaust fan* (EF-1), *Industrial Air* model 033, with a rated flow capacity of 8300 cfm, is mounted near the ceiling in the wall panel between Rm. 169 and Rm. 168. This exhausts gas from the *Cryolab* into the *Target room* (above the Counting Room Addition) and is activated whenever the *Cryolab* O_2 sensor registers an O_2 level less than 19.5%. A 2nd identical 8300 cfm *Ventura* exhaust fan (EF-2) unit is mounted on the roof behind the 2′ x 4′ damper. Whenever the *Cryolab* O_2 sensor registers a low level this damper opens and the 2nd *Ventura* fan is also powered on. We have the option of installing an interlock on the door accessing the A/C-equipment mezzanine in 1-168 which can power the EF-2 unit (but not EF-1) if the door is open or the interlock is not satisfied, indicating potential occupancy of the A/C mezzanine. (This option is discussed in *case 3* below.)

The air flow produced by these exhaust fans has been directly measured by Plant Engineering with an accuracy of about 5% using digital Anemometers:

- with both EF-1 and EF-2 powered, the fresh air flow into room 1-169 is 8050 cfm;
- with EF-2 only powered on, the flow out of the roof vent above Rm. 168 was measured at 4110 cfm, (consistent with the limitations of the roof damper).

Upon activation of the *Ventura* fans make-up air is provided:
(a) from the NSLS Experimental floor (bldg. 725) via 60″ x 30″ louvers which are installed above the door to Rm. 169;
(b) from the NSLS Experimental floor (bldg. 725) via a 12″ x 36″ opening in Rm. 168 at the level of the monorail crane above the point where the beam-line enters the *Target room* (see drawing);
(c) from the LEGS air supply through a 2′ x 2′ cable trench from the floor of the *Target room* and through open floor panels that are used to route cables to electronics racks. The air flow will be through the grating on the top of the Counting Room Addition.

The Ventura fan units have a manual control, as well as an automatic setting under the control of the O_2 sensor. A super-conducting magnet quench is detectable before significant amounts of Helium begin to evolve. Upon detecting a quench, the standard procedure is to immediately switch the fans on and evacuate both the *Target room* (168) and the *Cryolab* (169) for at least 5 minutes, even if the O_2 sensor has not yet registered an oxygen depleted atmosphere. (All LEGS personnel, including staff, students and collaborators, are trained in these procedures. This has been incorporated into the basic *Beam Line Safety Awareness Training* for the X5 - LEGS beam line.)

While the *Cryolab* O_2 sensor is connected to NSLS Emergency Power, the two Ventura fan units are not (due to insufficient capacity in Bldg. 725). In the case of a power interruption, LEGS or NSLS-Target-Watch staff will begin procedures to place magnets in their *safe states*. However, if either a quench is detected or the *Cryolab* O_2 sensor alarms to indicate an O_2 concentration below 19.5%, all personnel are instructed to evacuate rooms 168 and 169 and may not return until power has been restored to the Ventura fan units, which will run until any ODH has been eliminated (as indicated by the audio O_2 horn alarm).

When the O_2 sensor in *MER#7* detects an oxygen level below 19.5% dampers opens and the exhaust and supply fans are switched to high speed (to 1580 cfm and 1380 cfm, respectively). This exchanges the air in the room in about 5 minutes.

Oxygen Deficiency Hazards

The greatest potential Oxygen Deficiency Hazard (ODH) is associated with the evaporation of a large quantity of liquid Helium due to the loss of insulating vacuum in a cryostat. (Liquid nitrogen evolves gas at a comparatively slow rate even from a poorly insulated container.) When the temperature of a LHe vessel is suddenly raised above 4K, a He vapor layer forms between the LHe and the walls of its container. The rate of He gas evolution depends on the heat transfer across this layer between the surface of the LHe and the vessel, and this depends on the construction of the cryostat. The heat transfer resulting from the sudden venting of dewars was studied at CERN to evaluate the safety systems of the SPS accelerator. Three different classes of dewars were identified:
(a) multi-wrap (~200) super-insulated commercial dewars with gas-cooled shields;
(b) dewars LN_2 shields and some modest (~10 wraps) super-insulation;
(c) dewars with LN_2 shields, but no super-insulation.
All dewars at BNL are equipped with relief valves which in the event of an accident vent He gas through lines > 20 mm ∅. In the CERN study, the relief valves were removed and typically 100 liquid liters were allowed to directly vent out the top of dewars through 30 mm – 50 mm ∅ tubes as air rushed into the insulating vacuum. Their measured heat transfers are listed in Table 1.

Table 1. Heat transfers across the surface of LHe following the venting of three different types of cryostats. Measurements taken from W. Lehmann and G. Zahn, "*Safety aspects for LHe cryostats and LHe transport containers*", Proc. 7th Int. Cryogenic Engineering Conf., London (1978) 569.

Cryostat shielding	*max* $\dot{Q}$ (W/cm^2)
(a) commercial transport: multi-wrap (~200) super-insulation with gas-cooled shields	2.0
(b) LN_2 shield; some super-insulation (~10 wraps)	0.6
(c) LN_2 shields; no super-insulation	3.8

In these tests, the heat transfer rose quickly (in ~ 7 to 12 sec) to a maximum and then, for configurations (a) and (c), dropped significantly due to the decrease in temperature from evaporation and the increasing insulation of the growing solid-air layer. For dewar configuration (b), the heat transfer decreased only slightly after reaching the peak value in Table 1. Here we tabulate the measured *peak* heat-transfer values. In the following calculations we include an additional safety margin by assuming the above peak heat transfer values persist throughout the boil-down. Dewar configuration (b) clearly has a significantly lower heat transfer. Some of our LN_2-shielded dewars are similar to the class-(b) cryostat used in the CERN study, but not identical. In those cases we take the conservative approach of designating them class-(c).

Using the above heat transfer values, the boil-down time and the He gas evolution rate can be calculated. We first outline the steps in the calculation and then illustrate the results with examples.

Calculation of the He gas evolution rate

In the event of a sudden loss of the insulating vacuum, solid air will freeze on the outside of the LHe volume at 61 K. The LHe boils as energy is transferred across the $\Delta T = 61-4\ K = 57\ K$ interface. The heat capacity of LHe at 4K is,

$$C_V = 2.6\ \mathrm{J/g°K}\ ,$$

and the density of LHe at 4K is,

$$\rho = 124{,}000\ \mathrm{g/m^3}\ .$$

A temperature difference of ΔT across the walls of the LHe vessel of volume V generates a potential energy of $Q = C_V\ \Delta T\ \rho\ V$, so that when the LHe level drops by dz, the LHe volume drops by dV and the energy released is,

$$dQ = C_V\ \Delta T\ \rho\ dV \quad \text{(Joules)}. \qquad (1)$$

From Table 1, the heat transfer resulting from the venting of the insulation vacuum is,

$$\dot{Q} \quad \text{in W/cm}^2 \ \text{ or } 10^4\ \text{W/m}^2\ , \qquad (2)$$

and the boil-down time associated with this change is,

$$dt_{BD} = dQ/(\dot{Q}A) \quad \text{(sec)}, \qquad (3)$$

where A is the surface area of the $\Delta T = 57$ K interface. The instantaneous liquid-loss rate is then dV/dt_{BD} (in m^3/s). One liter of LHe expands to 27 cu ft of gas at STP, so that the instantaneous rate of He gas evolution (R) is,

$$\textit{He evolution rate}, R \text{ (in } cfm) = (27000 \times 60) \times \frac{dV\,(m^3)}{dt_{BD}\,(s)}. \qquad (4)$$

As the LHe level drops, the remaining volume of liquid and the corresponding area in contact with the warm dewar walls also drop, and so R drops. The calculations start with the maximum capacity of LHe and follow the changes until all the LHe has been boiled.

Evaluation of O_2 concentration and the associated Fatality Factor

We consider the release of He gas at a rate R (cfm) in a room of volume V_{rm} (cu ft) with fresh air intake S (cfm) and exhaust E (cfm) = $R+S$. The O_2 concentration as a function of time, $C(t)$, follows the differential equation,

$$V_{rm}\frac{dC(t)}{dt} = C_f \cdot S - (R+S)\cdot C(t)\,, \qquad (5)$$

where C_f is the O_2 concentration in fresh air, $C_f = 0.21$. For a time interval sufficiently short that S and R can be considered constant over the interval, the solution to this equation is,

$$C(t) = C_f \cdot \frac{S}{R+S} + \left(C_0 - C_f \cdot \frac{S}{R+S}\right)\cdot e^{-(R+S)t\,/\,V_{rm}}\,, \qquad \text{for } t \le t_{BD}\,, \qquad (6)$$

where C_0 is the O_2 concentration at the beginning of the time interval. The release continues until the boil-down of the cryostat is complete, at $t = t_{BD}$, and the O_2 concentration reaches the value C_{BD} . At times longer than t_{BD} the concentration follows the same differential equation in (5), but with $R = 0$, $E = S$ and boundary conditions $C(t_{BD}) = C_{BD}$ and $C(\infty) = C_f = 0.21$. The solution with these boundary conditions is,

$$C(t) = C_f + (C_{BD} - C_f)\cdot e^{-S(t-t_{BD})\,/\,V_{rm}}, \quad \text{for } t > t_{BD}\,. \qquad (7)$$

The partial pressure of O_2 with this concentration, in mm Hg, is $P_{O2} = 760 \bullet C(t)$ and the associated *Fatality Factor* (F) is taken from the minimum in $C(t)$,

$$F = 10^{\,(67-760\cdot C^{min})\,/\,10}\,, \qquad (8)$$

and for $760 \bullet C^{min} < 67$ mm Hg, F is set to 1.0 ; by convention, if $C^{min} > 0.18$ then F is set to 0.0 .

With these relations, the time profile of the O_2 concentration and its minimum value can be calculated, and from this the Fatality Factor can be deduced.

Table 2. Equipment failure rates from the loss of insulating vacuum in LEGS cryostats, and from the rupture of the He Recovery Compressor or its piping.

Cryostat/Equipment	Equipment Failure Rate, **P** (hr^{-1})
SD, IBCs, PD, DF, Beth	1×10^{-6}
TCs	1×10^{-2}
Commercial supply dewars	1×10^{-6}
Recovery Compressor rupture	3×10^{-7}
He gas piping	1×10^{-9}

Equipment failure rates and the resulting Fatality Rate

The estimate for the failure rate of dewars is taken from the FermiLab report by B. Soyars, "*FermiLab Equipment Failure Rate Estimates, Appendix Table B-I*", dated Jan. 26, 2000. This report lists a failure rate of P=1 x 10^{-6} per hour for a leak or rupture in a helium dewar. We use this value for all LEGS cryostats except the two Transfer cryostats. The integrity of the insulating vacuum for the latter depends on several welded bellows that are compressed and extended when these devices are used. Experience has shown that the TC failure rate due to leaks in a bellows is on the order of 10^{-2} per hour. These rates are summarized in Table 2. The 4th row lists the Fermi Lab estimate for the rupture of the He recovery Compressor located in the LEGS target room, 1-168. The last row gives the failure rate for the associated piping.

The net fatality rate is the product of the fatality factor and the equipment failure rate,

$$\textbf{Fatality Rate} = PF\ . \tag{9}$$

We illustrate these calculations using cases which result in the largest releases of helium.

Case 1: Fatality Rate Calculation for the loss of insulating vacuum in a Commercial 500 l dewar in the LEGS Cryolab (Rm. 1-169)

The LEGS *Cryolab* (Rm. 169) has a 16 ft. ceiling, a volume of 6600 cu ft and a minimum air flow of 230 cfm from the NSLS air conditioning system. The largest possible Fatality Rate will occur on the equipment mezzanine located against the south-west wall of the room. Thus, for the purposes of these calculations we take the relevant volume as the upper half of the room volume, or V_{rm} = *3300 cu ft*. The liquid helium vessel in a 500 liter commercial transport dewar is approximately a 39" ∅ sphere with volume V = 0.50 m^3 and surface area A = 3.05 m^2. This is a class-(a) cryostat, for which we take the heat transfer of eqn. (2) as 2.0×10^4 W/m^2 from Table 1. The rate of He gas evolution (R) following the sudden loss of insulating vacuum at time $t = 0$ in such a commercial dewar located in Rm. 169 is shown in figure 1 by the blue curve. The resulting C(O_2) oxygen concentration follows the red curve. In these calculations the liquid level is reduced in 0.01 m decrements which results in a series of time intervals determined by eqn. (3). The main features of the calculation are as follows:

- Using the standard room ventilation into this space of S=*230 cfm*, the concentration of O_2 follows eqn. (6) and drops to 19.5% in about 0.05 min or 3 sec.
- The Ventura fans then turn on, giving an exhaust E = *8050 cfm* which draws in fresh air at the rate $S = E - R$ *cfm*. The O_2 concentration again follows eqn. (6), reaching a minimum of 0.119 after 0.95 min. as the fresh air draw finally catches up to the initial He release. The concentration then rises as the LHe volume and the area in contact with the hot dewar walls continues to decrease.

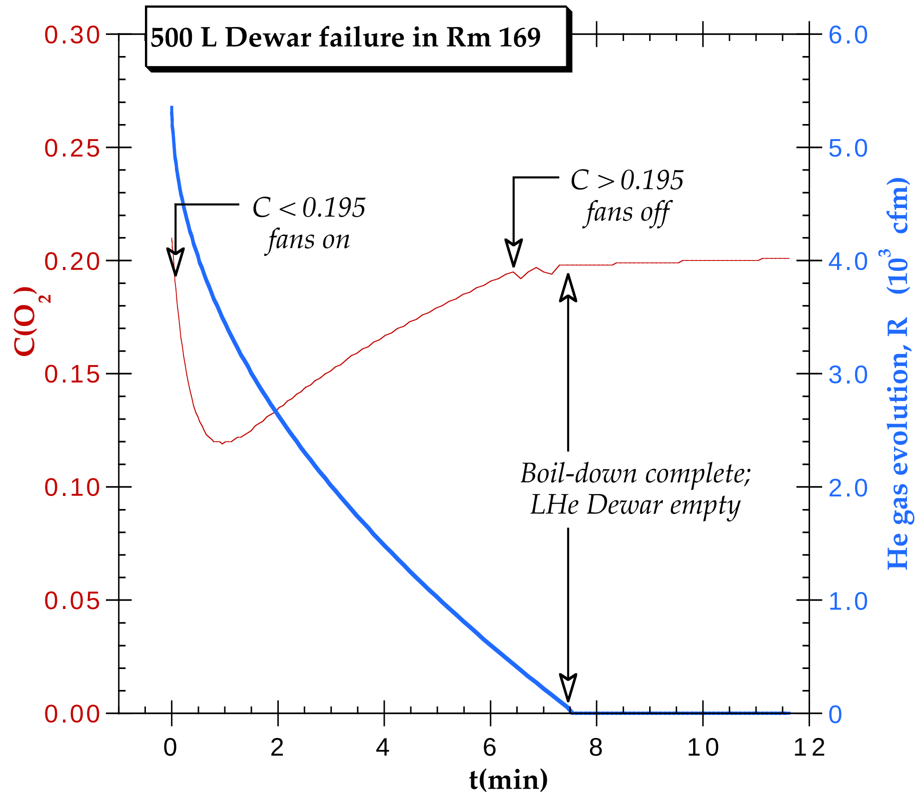


Figure 1. The time evolution of the O_2 concentration on the mezzanine of room 1-169 following a sudden loss of insulating vacuum in a commercial 500 liter dewar.

- After 6.43 min the concentration rises above 19.5% and the Ventura fans initially shut off. The O_2 concentration continues to follow eqn. (6), with the $S = 230\ cfm$ air supplied by the NSLS AC system. However, since the He gas evolution rate (R) is still significantly larger than this NSLS fresh air supply, the concentration momentarily drops and the Ventura fans go through two more cycles before the dewar runs completely dry.
- After $t_{BD} = 7.45\ min$, or 447 sec, the dewar is empty. This agrees favorably with the boil-down times observed by Lehmann and Zahn of about 1 sec per liquid liter for commercial supply dewars. The O_2 concentration at boil-down is $C_{BD} = 0.198$. The concentration then rises according to eqn. (7) with fresh air supplied by the NSLS AC system at $S = 230\ cfm$.

In calculating the Fatality rate, we take the minimum in the oxygen concentration of 0.119.

- This results in a partial pressure of O_2 , P_{O2}=760•C_{min} = 90.4 mm Hg.
- From eqn. (8), the resulting Fatality Factor is $F = 4.5 \times 10^{-3}$.
- Using the failure rate of P=1 x 10^{-6} hr^{-1} from Table 2 for a leak in a commercial helium dewar, the net *Fatality Rate* from eqn. (9) is ***PF* = 4.5 x 10^{-9} per hour**.

Case 2: Fatality Rate Calculation for the loss of insulating vacuum in the LEGS Dilution Refrigerator in the LEGS Cryolab (Rm. 1-169)

We next consider the sudden loss of insulating vacuum in the LEGS Dilution Refrigerator located in Rm. 169 and its impact for personnel on the equipment mezzanine. For this calculation we again consider only the upper half of the room 1-169 volume V_{rm} = 3300 cu ft.

The DF LHe bath volume is V = 0.096 m^3 and the surface area surrounded by insulating vacuum is A = 2.260 m^2. This is a class-(c) cryostat , for which we take the heat transfer of eqn. (2) as 3.8×10^4 W/m^2 from Table 1. The rate of He gas evolution (R) following the sudden loss of the DF insulating vacuum at time $t = 0$ is shown as the blue curve in figure 2. The resulting C(O_2) oxygen concentration follows the red curve of figure 2. The main features of the calculation are as follows:

- Using the standard room ventilation into this space of *S=230 cfm*, the concentration of O_2 follows eqn. (6) and drops to 19.5% in about 0.04 min.
- At this point the Ventura fans turn on providing an exhaust *E = 8050 cfm*, which draws in fresh air at the rate *S = E - R cfm*. The O_2 concentration then follows eqn. (6) and reaches a minimum of 0.142 after 0.39 min. The concentration then rises as the LHe volume and the area in contact with the hot walls of the LHe bath decrease.
- After t_{BD} = *0.82 min* the DF is empty and the O_2 concentration is C_{BD} = *0.154*. The concentration then rises according to eqn. (7) as the Ventura fans continue to draw fresh air into the room at the rate *S = 8050 cfm*.
- After 1.41 min the concentration rises above 19.5% and the Ventura fans shut off. The O_2 concentration then continues to rise at a rate determined by eqn. (7), with C_{BD} replaced by *0.195* and t_{BD} replaced by *1.41 min* (the time-zero conditions for this final interval), due to the *S = 230 cfm* fresh air supplied by the NSLS AC system.

For the calculation of the Fatality rate, we take the minimum in the oxygen concentration of C_{min} = 0.142 .

- This results in a partial pressure of O_2 , P_{O2}=760•C_{min} = 107.9 mm Hg.

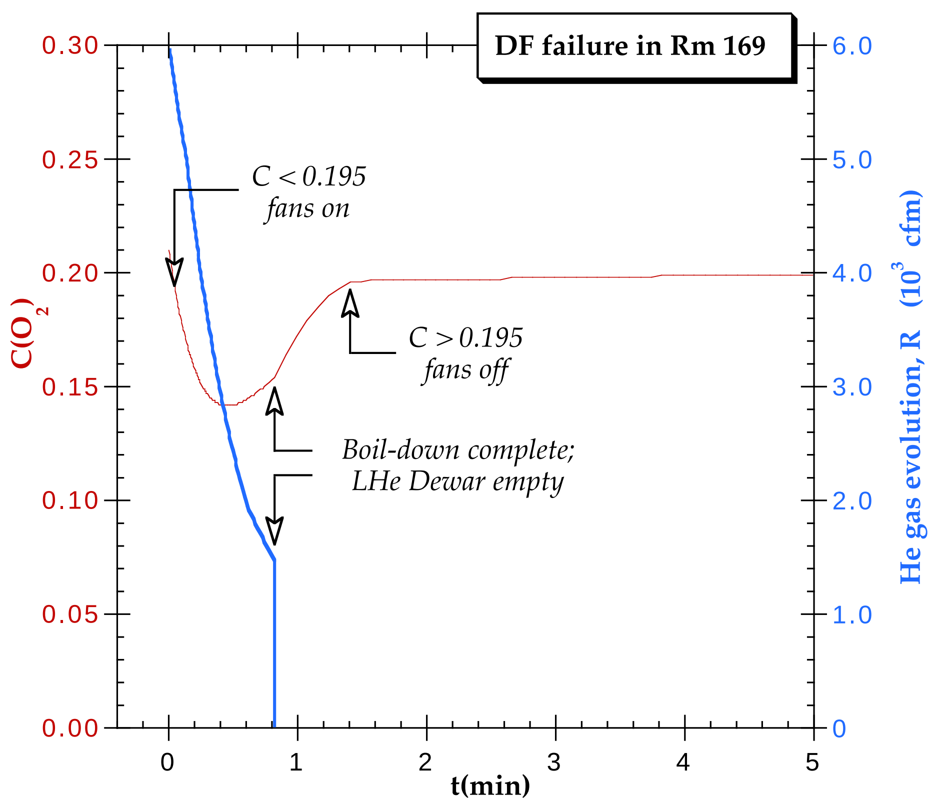


Figure 2. The time evolution of the O_2 concentration on the mezzanine of room 1-169 following a sudden loss of insulating vacuum in the LEGS Dilution Refrigerator.

- From eqn. (8), the resulting Fatality Factor is $F = 8.1 \times 10^{-5}$.
- Using the equipment failure rate of P=1×10^{-6} hr^{-1} from Table 2 for a leak in a helium dewar, the net *Fatality Rate* is ***PF* = 8.1 x 10^{-11} per hour**.

The above calculations have been repeated for each of the cryostats in use at LEGS. The results for the LEGS Cryolab (Rm 169) are summarized in Table 3 below. The net total fatality factor for the equipment mezzanine of room 1-169 (the *Cryolab*) is 9.1×10^{-9}. This is clearly dominated by the 500 L commercial supply dewars.

For personnel on the floor level area of the Cryolab, the relevant volume is the full room volume of V_{rm} = 6600 cu ft. Repeating the calculations for the failure of a 500 L commercial dewar then results in a minimum O_2 concentration of C^{min} = 0.133 which yields a fatality rate of 3.9×10^{-10} hr^{-1}, or an order of magnitude smaller than for the mezzanine area (rows 7 or 8 of Table 3). Similar reductions are encountered for the other failure cases of Table 3.

We recall the assumptions that make the above calculations quite conservative:

- The heat transfer rates in Table 1 are taken as the maximum values reported by Lehmann and Zahn and ignore the very significant reductions in heat transfer which they observed after the maximum is reached;
- Although the thermal shielding in several LEGS cryostats places them somewhere between classes (b) and (c) of Table 1, in such cases we assign them to the higher heat transfer class (c) category.

Table 3. LEGS cryostats that could be used simultaneously in room 1-169, together with their LHe capacity (V), the surface area (A) surrounded by insulating vacuum, the heat transfer rate from Table 1 following a loss of insulating vacuum, the calculated minimum in the O_2 concentration on the mezzanine in the upper half of 1-169 and the fatality factor (F) from eqn. (8). Using the equipment failure rates from Table 2 for each cryostat, the last column gives the net fatality rate **PF**.

Cryostat	*V* (m^3)	*A* (m^2)	$\dot{Q}$ (W/m^2)	$C(O_2)^{min}$	*fatality factor* **F**	*fatality rate* **PF** (hr^{-1})
(1) *SD*	0.050	0.777	3.8×10^4	0.178	1.5×10^{-7}	1.5×10^{-13}
(2a) *TC-Orsay*	0.001	0.142	3.8×10^4	0.208	0	0
(2b) *TC-Jülich*	0.001	0.142	3.8×10^4	0.208	0	0
(3a) *IBC-Orsay*	0.009	0.114	3.8×10^4	–	–	–
(3b) *IBC-Q*	0.045	0.570	3.8×10^4	–	–	–
(4) *PD*	0.020	0.412	3.8×10^4	0.194	0	0
(5) *DF*	0.098	1.782	3.8×10^4	0.142	8.1×10^{-5}	8.1×10^{-11}
(6) *ßeth magnet*	0.010	1.820	3.8×10^4	–	–	–
(7) *500 L BOC dewars*	0.500	3.040	2.0×10^4	0.119	4.5×10^{-3}	4.5×10^{-9}
(8) *Liquifier CTI receiver*	0.500	3.040	2.0×10^4	0.119	4.5×10^{-3}	4.5×10^{-9}
(9) *He gas recovery bag*	14.16	–	–	–	–	–
(10) *Recovery Compressor*	9.46	–	–	–	–	–
(10b) *Compressor piping*	9.46	–	–	–	–	–
Total:						**9.1×10^{-9}**

• We use the absolute minimum in the O_2 concentration to calculate the Fatality Factor, even though this minimum may only last a few seconds.

In conclusion, the Fatality Rate for room 1-169 is more than an order of magnitude less than 10^{-7} hr^{-1}, which determines its classification as **ODH class-0**.

Case 3: Fatality Rate Calculation for the Rm 1-168 A/C Mezzanine from a loss of insulating vacuum in Commercial dewars located on the floor of the LEGS target room (1-168)

We next consider the sudden loss of insulating vacuum in a commercial supply dewar located in the LEGS target room (1-168). Its impact will be greatest for personnel on the A/C equipment mezzanine. The A/C mezzanine is a *low-occupancy* region within the LEGS target room located above the counting and control rooms. The floor of this mezzanine is about 9′ above the target room floor. Two thirds of this area is located in the part of rm. 1-168 with a 15′ ceiling and so the mezzanine ceiling height in this region is about 6′. The rest of the mezzanine extends into the 20′ ceiling section of the building. (See attached layout.) Bounded on two sides by walls, this mezzanine has a volume of approximately 3040 cu ft, half of which is filled with equipment and air-conditioning ducts. Thus the air space in this mezzanine region is approximately V_{rm} = 1520 cu ft.

He gas rises at approximately 1 ft/s and so will quickly mix with air in the *upper half* of room 1-168. While there could be some small fraction of He gas at lower levels of the room due to turbulence, here we assume the worse case of all evolved gas limited to the upper half of the target room. The A/C mezzanine region is not in the direct path of any He gas that could evolve from a dewar or cryostat, and A/C ducts located around the perimeter of this area direct air flow away from the mezzanine. Nonetheless, in the following calculations we assume that air/gas in the mezzanine completely mixes with air/gas in the upper half of the target room. The full volume of room 1-168 is approximately 27000 cu ft, and so we take the rate of He gas evolving into the mezzanine region from the upper half of the target room as,

$$R_{mezz} = R \times (1520/13500) \qquad (10a)$$

where R is the He evolution rate from eqn. (4). The LEGS A/C system generates a fresh air flow of 400 cfm which is dumped into the upper half of room 1-168, and we assume a similar fraction enters the mezzanine area,

$$S_{mezz} = S_{A/C} \times (1520/13500) = 45 \text{ cfm.} \qquad (10b)$$

As mentioned in the introductory sections, we have the option of installing an interlock on the door accessing the A/C-equipment mezzanine in 1-168 which can power the EF-2 Ventura Fan if the access door is open or the interlock is not satisfied, indicating potential occupancy of the A/C mezzanine. The EF-2 fan exhausts gas through the damper located 18′ above the target room floor and draws air out of the upper half of the room at 4110 cfm. The exhaust from the mezzanine is then,

$$E_{mezz} = E_{EF\text{-}2} \times (1520/13500) = 463 \text{ cfm,} \qquad (10c)$$

and the fresh air entering the mezzanine becomes $S_{mezz} = E_{mezz} - R_{mezz}$.

Using the relations of eqn. (10) we can assess the potential hazard for personnel on the A/C mezzanine in the event of the sudden loss of insulating vacuum of a commercial dewar located on the target room floor. Two sizes of commercial LHe dewars are in use at LEGS,

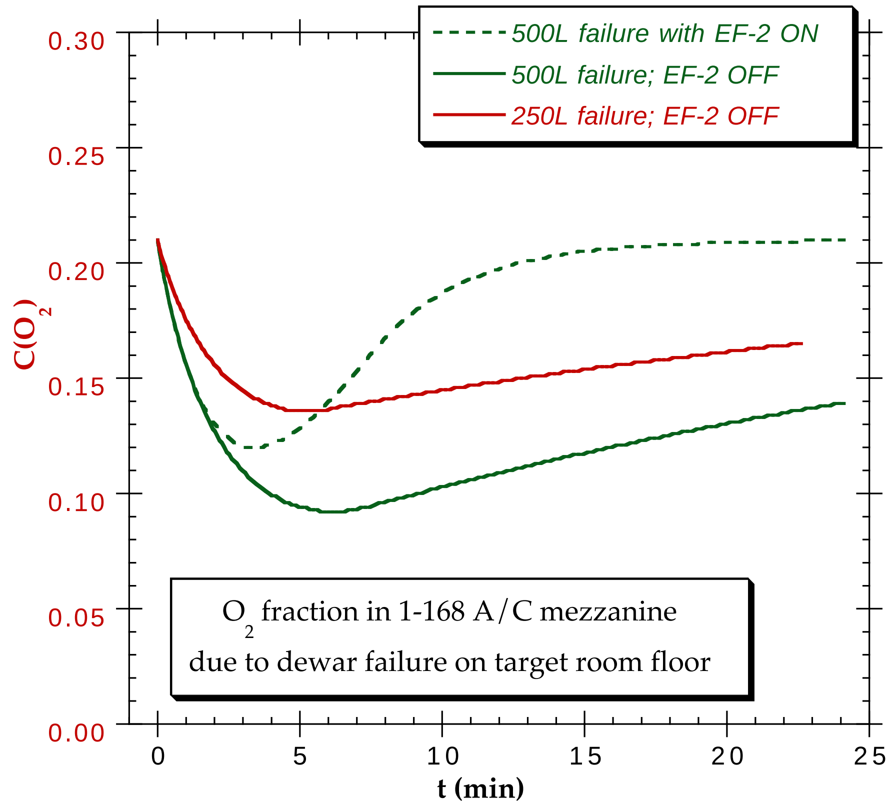


Figure 3. The time evolution of the O_2 concentration in the A/C mezzanine region of room 1-168 following the sudden loss of insulating vacuum in commercial dewars.

250 liters and 500 liters. The time evolution of the O_2 concentration in the mezzanine region following the loss of insulating vacuum in such dewars is shown in figure 3. In the case of the failure of a 250 L dewar (solid red curve), the concentration reaches a minimum of 0.136 . The associated Fatality Factor from eqn. (8) is 1.2×10^{-4} and combining this with dewar failure rate from Table 2 gives a net Fatality Rate of 1.2×10^{-10} hr^{-1}. This is consistent with an ODH class-0 designation for the LEGS target room. However, the minimum concentration reached when a commercial 500 L dewar fails (solid green curve) is 0.092 and the associated Fatality Factor is 0.5. Combining this with the anticipated dewar failure rate from Table 2 gives a net Fatality Rate of 0.5×10^{-6} hr^{-1}, which would require an ODH class-1 designation. This can be mitigated by interlocking the A/C mezzanine access door so that the EF-2 Ventura fan is powered on whenever there is potential occupancy (green dashed curve in figure 3). The minimum in $C(O_2)$ under these conditions is then 0.120 . The Fatality Factor for this concentration is 3.8×10^{-3} and combining this with the dewar failure rate from Table 2 gives a Fatality Rate of 3.8×10^{-9}, which is consistent with ODH class-0.

At present we have initiated administrative controls to limit the size of commercial dewars used in 1-168 to 250 L. Should the use of 500 L dewars become desirable, the above interlock for the A/C mezzanine door will be necessary to maintain an ODH class-0 designation for the LEGS target room.

These calculations have been repeated for each of the dewars and cryostats that could be used in room 1-168 and the results are summarized in Table 4. It is possible that as many as three 250 L supply dewars may be simultaneously located in the target room. So, for purposes of totaling the net Fatality Rate, entry (7) is repeated three times.

A 500 cu ft rubber bag is mounted on the back wall of the target room at a height of about 10 ft. and is used as a buffer volume for a He gas compressor. This bag is equipped with a 0.5 psi relief value. Nonetheless, we can imagine the scenario of a large tear somehow developing in the bag. Such a rupture could release the maximum contents of the bag in about a minute, so that R = 500 cfm for 1 min . This bag is located on the side of the target room opposite the A/C mezzanine and the emerging He would be fully mixed by the time it reached the mezzanine region. Thus R_{mezz} is given by eqn. (10a) above. Using the fresh air flow without the EF-2 Ventura fan from eqn. (10b), the O_2 concentration can be tracked with eqn. (6). The minimum is listed as the 9th entry in Table 4. While it is difficult to estimate the failure rate for the bag, since the minimum concentration is above 0.18, the Fatality factor is set to zero and there is no contribution to the net Fatality Rate.

Case 4: Fatality Rate Calculation for the Rm 1-168 A/C Mezzanine from the rupture of the He recovery compressor located on the floor of the LEGS target room (1-168)

A helium liquifier and gas recovery system is installed at LEGS. The liquifier engines are located on the mezzanine of the Cryolab, 1-169. Two compressors which feed gas to the liquifier engines are located in MER#7. A He gas Recovery compressor is mounted on the floor next to the west wall of the target room. This recovery compressor stores gas by pumping it into a 38-unit Tube-Trailer which is parked next to the North side of the building. The compressor is connected to the Tube-Trailer via a 500 ft stainless steel line (0.5″ O.D.; 0.4″ I.D.) which runs across the outside of the NSLS roof. The Tube-Trailer has a volume of 334 cu ft and can store gas at up to 2200 psi.

The greatest potential ODH hazard associated with the LEGS liquifier and recovery system is the possible rupture of the Recovery compressor which could lead to the venting of the contents of the storage Tube-Trailer into the target room. The failure rate for this compressor is listed in the last row of Table 2. The evolving gas would immediately rise into the upper half of the target room so that the greatest potential hazard occurs for personnel in the A/C equipment mezzanine of 1-169. We compute now the minimum O_2 concentration resulting from such a failure scenario.

We assume the rupture is sufficiently extensive to eliminate any impedance to the gas flow from the 0.5″ stainless line connected to the Tube-Trailer. The He mass flow emerging from this D = 0.4″ I.D. × L = 500 ft tube is determined by the following relations,

$$C_{Reynolds} = \frac{\Delta P \cdot \overline{P}}{L}\left(\frac{1}{RT}\frac{D^3}{\mu^2}\right) , \tag{11a}$$

$$M_{flow}^2 = \frac{40}{f'} \cdot C_{Reynolds} \cdot \left(\mu^2 D^2\right) , \tag{11b}$$

$$R = \frac{M_{flow}}{\rho_{He}} \cdot 60 \quad (cfm) . \tag{11c}$$

Here, ΔP is the pressure drop in lbs/ft^2 across the stainless line, which is just the pressure (P_{gas}) in the Tube-Trailer, and $\bar{P}$ is the average pressure in the line ($P_{gas}/2$). $R = 1545$ (*lb-ft/lb-°$\mathfrak{R}$*) is the gas constant and T is the mean temperature of the gas, measured in $\mathfrak{R}$ankine, which we take as 50+460 as a winter-summer average. The absolute viscosity of He gas, μ, is 1.32×10^{-5} *lb/ft-s* and the density of He gas is $\rho_{He} = 0.01114$ *lb/ft*^{3}. The friction factor, f', which appears in eqn. (11b) is a function of the $C_{Reynolds}$ parameter and we assume a relation corresponding to flow through smooth-walled pipes (W. Eshbach and M. Souders, *Handbook of Engineering Fundamentals*, Wiley, NY, 1975).

Assuming the maximum pressure in the Tube-Trailer at the start of the release, $P_{gas} = 2200 \times 12^2 = 316800$ *lb/ft*^{2}, $C_{Reynolds} = 2.9 \times 10^7$ (which corresponds to a Reynolds' index of 3×10^5) and this determines $f' = 0.020$. The gas release rate at the start of the discharge is then $R = 579$ cfm. The Recovery compressor is located on the side of the target room opposite the A/C mezzanine and the emerging He would be fully mixed by the time it reached the mezzanine region. Thus R_{mezz} is given by eqn. (10a) above. Using the fresh air flow without the EF-2 Ventura fan from eqn. (10b), the O_2 concentration is given by eqn. (6) for a time interval sufficiently short that R can be considered a constant. At the end of that interval, the *STP*-equivalent gas volume in the Tube-Trailer, V_{gas}, has been reduced to $(V_{gas} - R \bullet dt)/V_{gas}$ and, since the volume and temperature of the Tube-Trailer are constant, the pressure in the Tube-

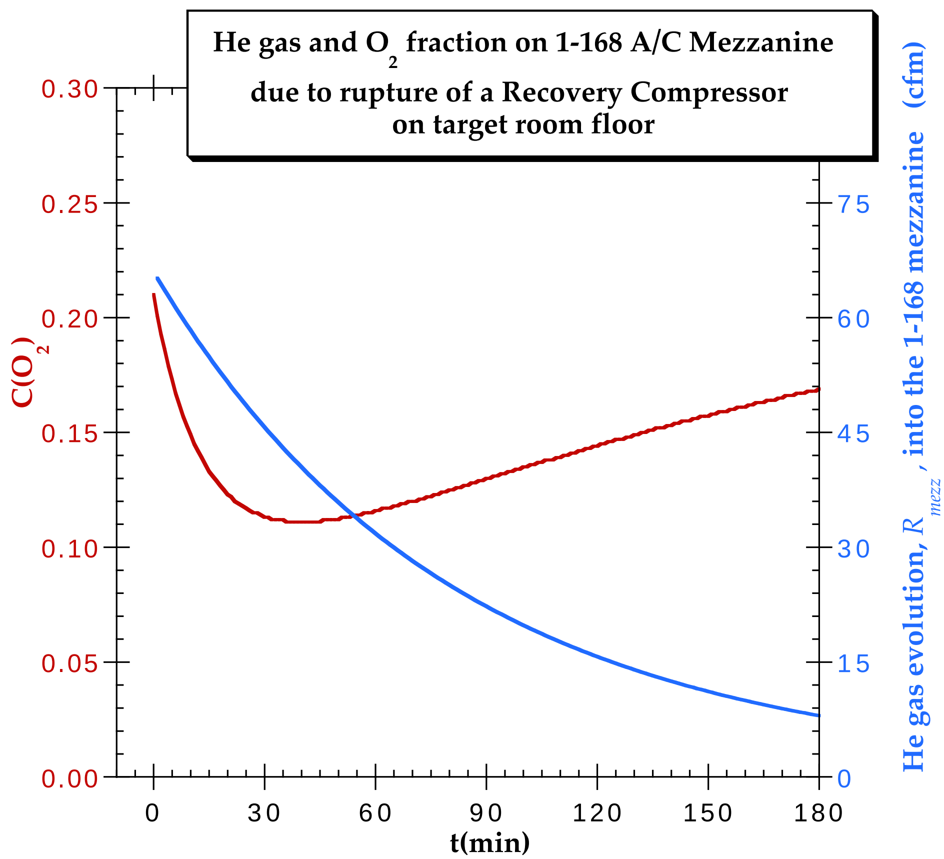


Figure 4. He gas released into the mezzanine region of 1-168 (in blue with scale on the right) together with the resulting O_2 concentration (in red with scale on the left) following the rupture of the LEGS Recovery compressor on the target room floor and the resulting discharge of the contents of the He gas Tube-Trailer into the target room.

Trailer (P_{gas}) is reduced by the same factor. The calculation proceeds in time increments *dt* until the Tube-Trailer is completely blown down to atmospheric pressure, which takes about 9.4 hr. The He gas released into the A/C mezzanine and the resulting O_2 concentration are plotted in figure 4.

A minimum O_2 concentration of 0.111 is reached after 36 min. From eqn. (8) the associated Fatality Factor is 1.8×10^{-2} and combining this with the expected failure rate of 3×10^{-7} hr^{-1} from Table 2 gives the expected Fatality Rate of 5.5×10^{-9} hr^{-1}. These values are listed below as the 10th entry in Table 4. (The *volume* in this entry is that of the Tube-Trailer.)

Finally we consider the rupture of the 0.5" stainless steel line which passes through the A/C mezzanine. Without the EF-2 fan, this would lead to a very low O_2 concentration and a Fatality Factor of 1. However, the expected failure rate from Table 2 is 1×10^{-9} hr^{-1} so that the net Fatality Rate estimate is still only 1×10^{-9} hr^{-1}. This is included in the last row of Table 4.

The total Fatality Rate for the A/C mezzanine of room 1-168 is thus 6.9×10^{-9} hr^{-1} which determines its classification as **ODH class-0**. Because of the high ceiling in this room, and the fact that He gas rises at about 1 *ft/s*, Fatality Rates for the floor area of the target room can only be significantly smaller. Thus the entire LEGS target room is classified as **ODH class-0**.

Table 4. LEGS cryostats that could be used simultaneously in room 1-168, together with their LHe capacity (V), the surface area (A) surrounded by insulating vacuum, the heat transfer rate from Table 1 following a loss of insulating vacuum, the calculated minimum in the O_2 concentration in the A/C mezzanine region of 1-168 and the fatality factor (F) from eqn. (8). Three 250 L dewars could be used simultaneously and are hence entered three times. A He gas recover bag is included here as the ninth vessel. A He gas recovery compressor, connected to a Tube Trailer outside the building, is included as the tenth entry, along with its associated piping. The EF-2 Ventura fan is assumed to be *off* in these simulations. Using the equipment failure rates from Table 2 for each device, the last column gives the net fatality rate **PF**.

Cryostat	*V* (m^3)	*A* (m^2)	$\dot{Q}$ (W/m^2)	$C(O_2)^{min}$	*fatality factor* **F**	*fatality rate* **PF** (hr^{-1})
(1) *SD*	0.050	0.777	3.8×10^4	0.191	0	0
(2a) *TC-Orsay*	0.001	0.142	3.8×10^4	0.210	0	0
(2b) *TC-Jülich*	0.001	0.142	3.8×10^4	0.210	0	0
(3a) *IBC-Orsay*	0.009	0.114	3.8×10^4	0.205	0	0
(3b) *IBC-Q*	0.045	0.570	3.8×10^4	0.193	0	0
(4) *PD*	0.020	0.412	3.8×10^4	0.202	0	0
(5) *DF*	0.098	1.782	3.8×10^4	–	–	–
(6) *ßeth magnet*	0.010	1.820	3.8×10^4	0.204	0	0
(7) *250 L BOC dewars*	0.500	3.040	2.0×10^4	0.136	1.2×10^{-4}	1.2×10^{-10}
(7) *250 L BOC dewars*	0.500	3.040	2.0×10^4	0.136	1.2×10^{-4}	1.2×10^{-10}
(7) *250 L BOC dewars*	0.500	3.040	2.0×10^4	0.136	1.2×10^{-4}	1.2×10^{-10}
(8) *Liquifier CTI receiver*	0.500	3.040	2.0×10^4	–	–	–
(9) *He gas recovery bag*	14.16	–	–	0.202	0	0
(10) *Recovery Compressor*	9.46	–	–	0.111	1.8×10^{-2}	5.5×10^{-9}
(10b) *Compressor piping*	9.46	–	–	0.016	1	1.0×10^{-9}
Total:						6.9×10^{-9}

Case 5: Fatality Rate Calculation for MER#7 from the rupture of the He buffer tank

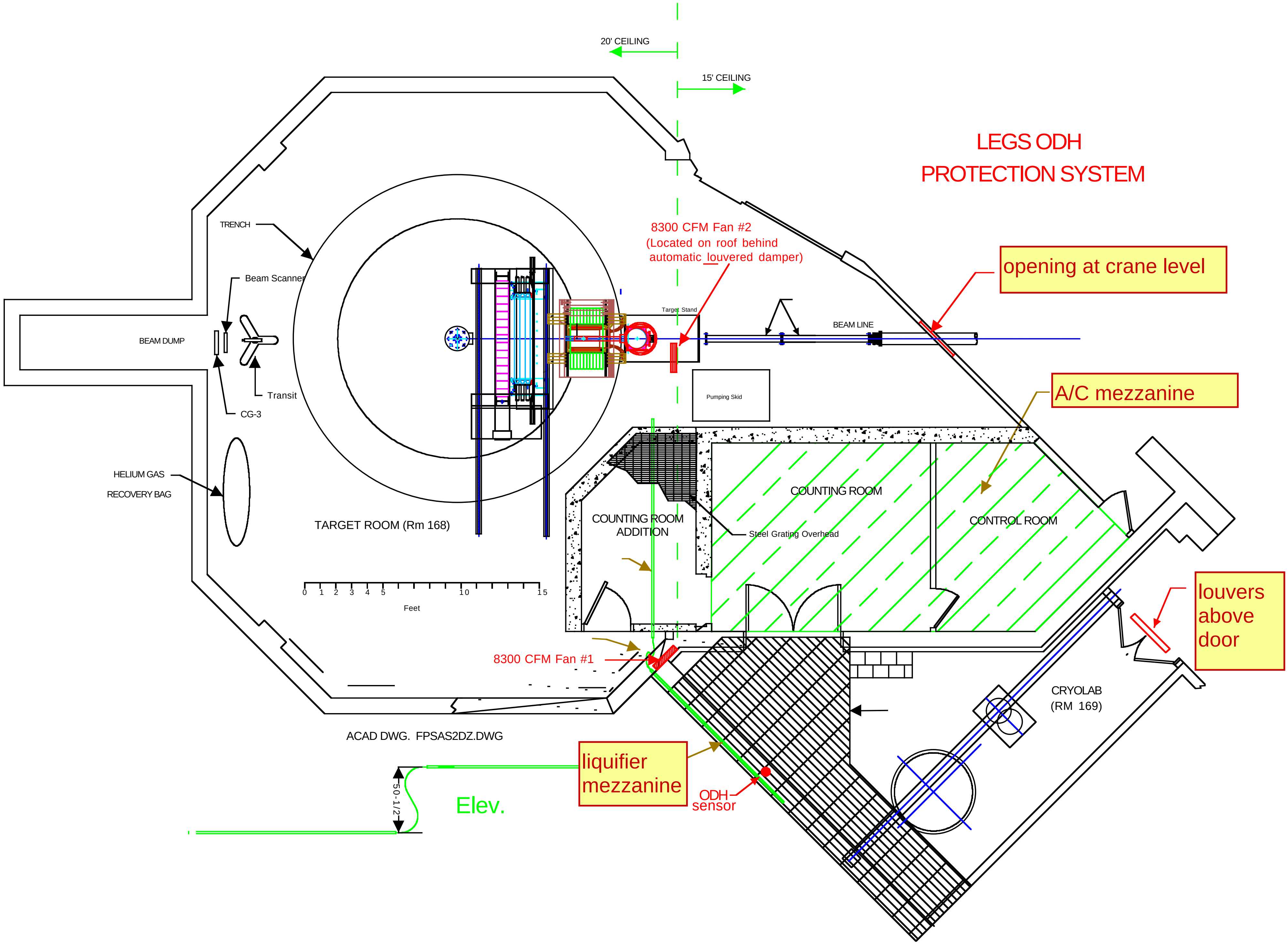
The components of the LEGS liquifier system that are installed in MER#7 consist of two compressors (for clean He gas) with 1 psi in and 220 psi out, and an overflow buffer tank to take up the gas from the compressors when the system is shut off. The tank holds up to 42 cu ft at 220 psi. In a worst case scenario, if the tank was completely full and ruptured, the Helium would expand to 660 cu ft. If we assume this happens over the course of one minute, then R = 660 cfm. Clean air is supplied to this room at the rate S = 1380 cfm and the O_2 concentration follows eqn (6). It reaches a minimum of 0.193 at the end of the 1 min release. The fatality Factor associated with this concentration is 0, and so this cannot alter the classification of this room as **ODH class-0**.

Confined Space Hazards and controls

Rm. 169 contains two floor pits, one round 5′ ID x 8′ deep for the *Dilution refrigerator*, and another rectangular 2′4″ x 3′4″ x 3′ deep for the *Storage dewar*. Access into either pit will be rare and, to protect the integrity of their super-conducting magnets, will be possible only when their cryogenic devices are not operating and have been rolled to the side against one wall of the pit. A fan positioned on the floor will direct airflow down into the 8′ deep pit when access is required. Such access is coordinated with NSLS Operation Coordinators. The 3′ deep is waist height and does not pose a significant hazard.

Transport of Commercial LHe Storage Dewars along the NSLS corridor to the LEGS area

LHe supply dewars for LEGS are delivered to the North-West rollup door of Bldg. 725 and brought down the outer access corridor of the X-ray ring experimental floor to the LEGS area. The failure rates listed in Table 2 are appropriate to equipment in use in a location for some extended number of hours, while the transport of dewars down the NSLS corridor last only minutes. The guidance given in the *SBMS* area under *ODH Calculation and Control Measures* (https://sbms.bnl.gov/standard/16/1601d011.htm) states, "**No assessment is required for areas temporarily used during transport of cryogenic dewars or compressed gases.**" Thus, no separate evaluation has been made for this case.


LEGS ODH
PROTECTION SYSTEM
20' CEILING
15' CEILING
8300 CFM Fan #2
(Located on roof behind
automatic louvered damper)
opening at crane level
TRENCH
Beam Scanner
BEAM DUMP
Transit
CG-3
Target Stand
BEAM LINE
Pumping Skid
A/C mezzanine
HELIUM GAS
RECOVERY BAG
TARGET ROOM (Rm 168)
COUNTING ROOM
ADDITION
COUNTING ROOM
CONTROL ROOM
Steel Grating Overhead
0 1 2 3 4 5 10 15
Feet
louvers
above
door
8300 CFM Fan #1
CRYOLAB
(RM 169)
ACAD DWG. FPSAS2DZ.DWG
liquifier
mezzanine
ODH
sensor
5'0-1/2"
Elev.

Appendix: Consequences of Exhaust Fan Failure

Periodic checks of the O_2 sensors at the NSLS are conducted by NSLS operations. Their testing schedule is as follows:

- weekly check of O_2 sensor readings;
- monthly check of O_2 alarm level, accompanied by verification that fans turn on at concentrations below 0.195 and that alarm sounds in NSLS control room;
- quarterly calibration of O_2 sensors;
- yearly replacement of O_2 sensor.

Nonetheless, here we consider scenarios in which the O_2 sensor and Ventura exhaust fan circuit fails during a release of LHe.

A. Failure of the emergency fans to respond to a LHe dewar/cryostat failure

The O_2 sensor in the LEGS Cryolab (1-169) is a *SafetyNet-100* manufactured by GasTech Inc. An *Alarm relay* on this detector is held open by power and closes when the O_2 concentration drops below 19.5%. There is a series connection from this *Alarm relay* to a relay in the NSLS control room (normally open) which is in turn connected to a contactor in the starter for the fan motor. The estimated failure rates for these devices are listed below in Table A1 and are taken from Table B-I of *FermiLab Equipment Failure Rate Estimates*, Jan 26, 2000, and from Table B-II of *U.S. NRC Equipment Failure Rate Estimates*, both available from the SBMS ODH subject area as document 1604e011.pdf .

Table A1. Failure rates for components of the series circuit that controls the operation of the LEGS emergency ODH fans EF-1 and EF-2.

Equipment – condition	Failure Rate
Relay – failure to close without power	3×10^{-7} / hr
Relay – failure to energize	1×10^{-4} / demand
Fan motor – failure to start	3×10^{-4} / demand
Fan motor – failure to run	1×10^{-5} / hr
Power failure	1×10^{-4} / hr

The demand frequency for this circuit is very much less than once per hour, so that the minimum failure rate of this chain can be taken conservatively as the sum of the entries in Table A1, or 5×10^{-4} /hr^{-1}. The combined failure probability for any of the cryostats in the LEGS CryoLab (room 1-169) AND the chain of the LEGS ODH O_2 sensor and emergency fan circuit is the product of the cryostat failure rate ($1 \times 10^{-6}/hr^{-1}$) for those entries in Table 3 containing more than 9 liter = 0.009 m^3 of LHe (the minimum needed to reduce the O_2 concentration to 0.195 and trigger the fan circuit) and 5×10^{-4}. There are five such dewars listed in Table 3, so that the total failure probability for this scenario is $(5 \times 10^{-6}) \times (5 \times 10^{-4}) = 1 \times 10^{-9}/hr^{-1}$. Thus, even in a case where the O_2 concentration were so low as to result in a fatality factor of unity, the combined Fatality Rate (***PF***) would still be significantly less than 1×10^{-7} hr^{-1}. Therefore, even in the scenario of a failure of the O_2 sensor and fan circuit during a dewar failure, the room classification remains ***ODH-0***.

B. Failure of the emergency fans to cycle back on following an initial activation triggered by the loss of insulating vacuum in a 500 l LHe dewar

Case 1 of this report considered the loss of insulating vacuum in a 500 l LHe supply dewar located in the LEGS cryolab, room 1-169. As shown in Figure 1, near the end of the boil-down cycle the O_2 concentration on the mezzanine oscillates around 0.195 and the fans cycle on and off. We consider here the scenario in which the fans turn on once only and fail the second time the concentration drops below 0.195. (This is actually covered by the previous section but we carry through the explicit calculation here.) Since in case 1 there is essentially no LHe left, a failure of the fans to turn on a second time would have no effect. To study the maximum effect of such a scenario we reduce the heat transfer of eqn. (2) to the minimum value of Table 1, (corresponding to a dewar with a LN_2 shield),

$$\dot{Q} = 0.6 \quad \mathrm{W/cm^2} \quad .$$

The resulting $C(O_2)$ time evolution is shown in Figure A1 below. The minimum in $C(O_2)$ is now 0.111 and, from eqn (8), this corresponds to a *Fatality Factor* of 1.8×10^{-2}.

The combined failure probability for such a LHe dewar AND any component of the LEGS ODH O_2 sensor and emergency fan circuit is the product of dewar failure rate (1×10^{-6} hr^{-1}) with one of the entries in Table A1, and this is always less than 3×10^{-10} hr^{-1}. Combining this with a *Fatality Factor* of 1.8×10^{-2} gives a net *Fatality rate* of ***PF*** $< 5.5 \times 10^{-12}$ hr^{-1}. Thus, the room classification remains ***ODH-0***.

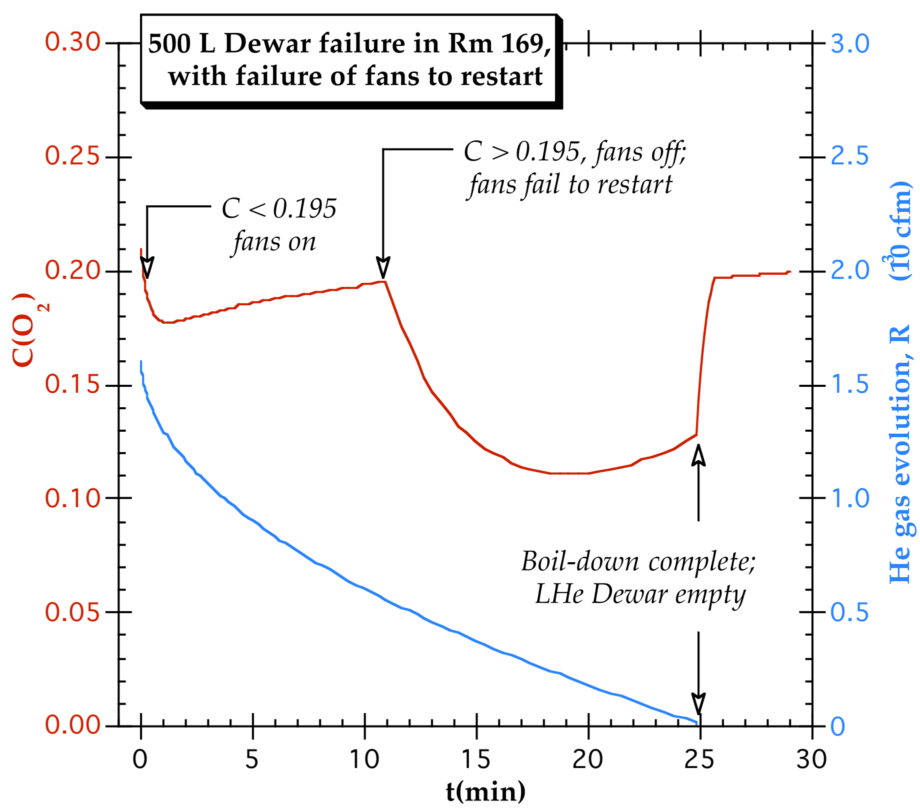


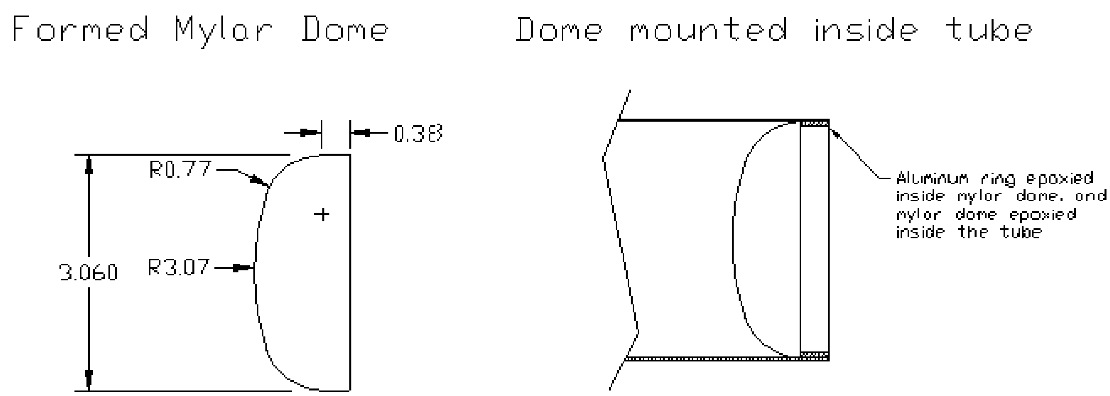
Figure A1. Time evolution of the O_2 concentration on the mezzanine of room 1-169 following the loss of insulating vacuum in a 500 liter LHe dewar with sufficient thermal shielding to limit the heat transfer to 0.6 W/cm^2. Here the emergency fans initially turn on, but are assumed to fail the second time $C(O_2)$ drops below 0.195 .

10.1.1.4 IBC Mylar Vacuum Window

10.1.1.4.1 Description of the mylar window

The window is a heat formed mylar dome which is epoxied into the end of an aluminum tube with an aluminum retainer ring on the inside, as shown below. The dome has a cylindrical section 0.38" long, followed by a curved section of radius 0.77", capped by a section of a sphere with radius 3.07". The three sections meet tangentially; that is, with no corners.

A description of the forming of the window is given in Appendix 10.1.1.4.2A and a description of the gluing procedure is given in Appendix 10.1.1.4.2B.



10.1.1.4.2 Compliance with Occupational Health and Safety Guide Interim 1.4.2; see the web site at https://sbms.bnl.gov/ld/ld08/ld08d141.pdf

Using the Guide numbering scheme, the relevant sections are:

IV.B. Radiation Damage:

1.4.2 Figure 7 shows no degradation in mylar properties for doses less than $3x10^{14}$ particles per cm^2. Radiation length of mylar is 28.7 cm so the window itself is $4.4x10^{-4}$ radiation lengths. The target and its shell are just under $2x10^{-2}$ radiation lengths. The beam is 10^7 gamma's per second, spread over 5 cm^2. Radiation is dominated by pair production, so there are two charged particles per interaction. Overall, this is $8x10^4$ particles per cm^2 per sec. A dose of 3 $x10^{14}$ particles per cm^2 takes $3.75x10^9$ sec or 120 years.

IV.B.1.a. The window has passed the deflection test; see Appendix 10.1.1.4.2C.

IV.B.1.c. The window was visually inspected during the deflection test of Appendix 10.1.1.4.2C. No scratches, pockmarks or wrinkles were present on the window.

IV.B.1.d. The window material, mylar, is compatible with the vessel contents, vacuum.

V.A This window is deemed to be Held-But-Not-Fixed.

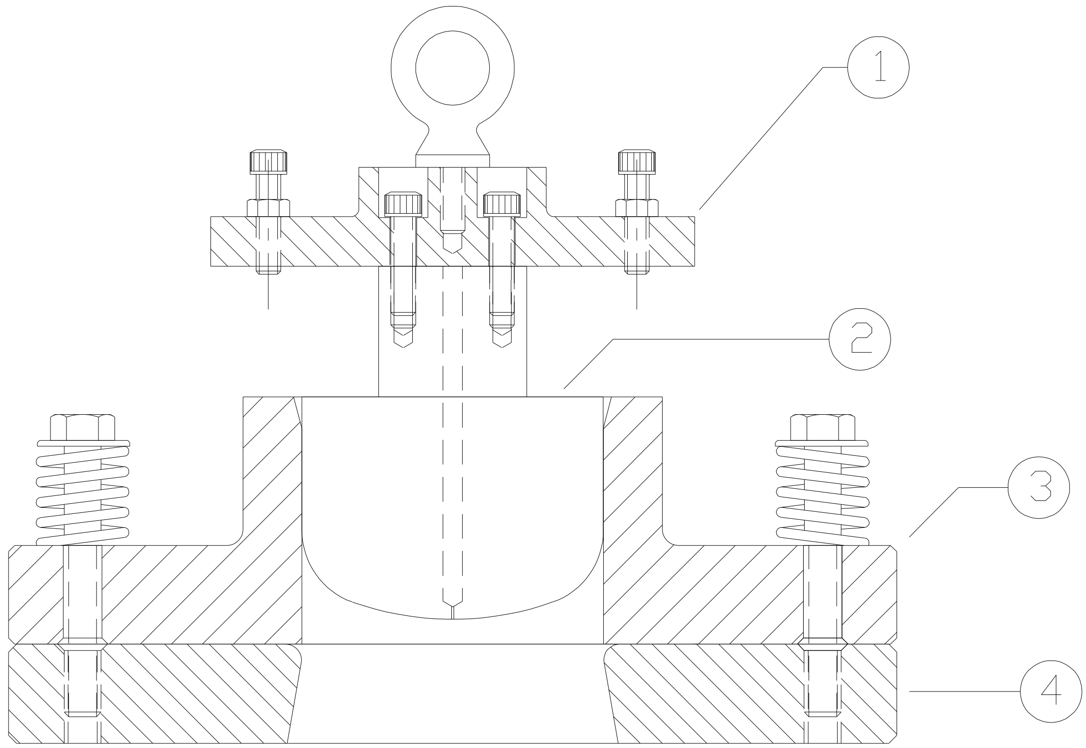
V.B.2.d. The mylar is held in the aluminum tube with epoxy and there is the concern that this may give rise to stress concentrations in the mylar due to irregularities in the epoxy edge. The product description pages for DP-460 do not show measured overlap shear values for aluminum and mylar. The shear stress for an aluminum overlap joint is 5700 psi and for a plastic like ABS it is 575 psi. Therefore, it is assumed that the shear stress between aluminum and mylar is below the mylar maximum design stress of 9500 psi.

V.C.1.c The window is deemed to to be in a frame with an infinite radius of curvature, leaving the frame with theta angle zero.

V.C.8. The maximum tensile stress in the window is calculated to be 4938 psi; see Appendix 10.1.1.4.2D.

Appendix 10.1.1.4.2A: Formation of the mylar dome

The dome is formed from a 0.005" thick mylar disc in the brass die illustrated



below.

The mylar disc is clamped between the pieces numbered 3 and 4. This assembly is heated to 180C and then a room temperature punch (2) is installed into the assembly and driven down to a stop determined by the stop screws in item 1. Mylar in contact with the room temperature punch does not stretch and the material which forms the dome is drawn from that part of the mylar disc clamped between items 3 and 4. The springs under the screws holding items 3 and 4 together provide the correct tension to allow the mylar to slide between items 3 and 4. The setting of this tension is a matter of trial and error.

Appendix 10.1.1.4.2B: Installation of the dome in the IBC snout

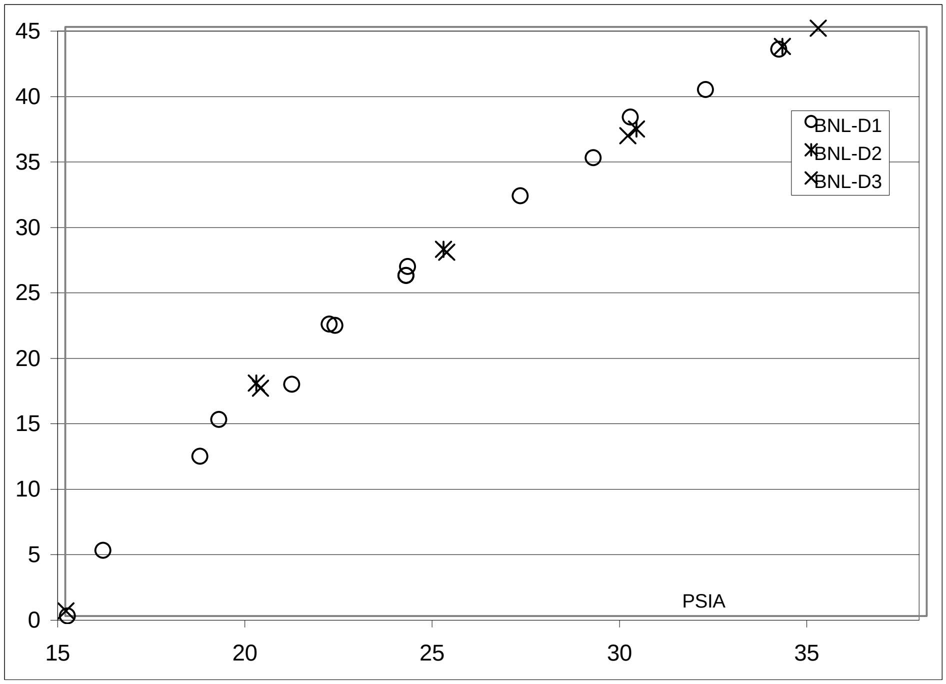
The mylar dome is epoxied into the end of the aluminum tube which forms the vacuum wall for the IBC snout, with an aluminum ring serving as a retainer on the inner diameter of the cylindrical section of the dome. The inside of the aluminum tube and the outside of the aluminum ring were roughened with Scotch Brite and both sides of the cylindrical section of the mylar dome were lightly roughened with Scotch Brite. All four surfaces were lightly coated with a 24 hour curing epoxy (3M Scotch-Weld Epoxy Adhesive DP-460) and the three pieces assembled and left to cure with the tube vertical (dome concave down). The aluminum pieces were machined to leave a nominal 0.005" epoxy gap.

Appendix 10.1.1.4.2C: Window deflection tests and visual inspection were carried out at BNL on March 29, 2004 and witnessed by Jim Durnam. He is sending separately a document memo. A graph of the results is included below.

29 March 2004 - Test for safety committee using calibrated gauge

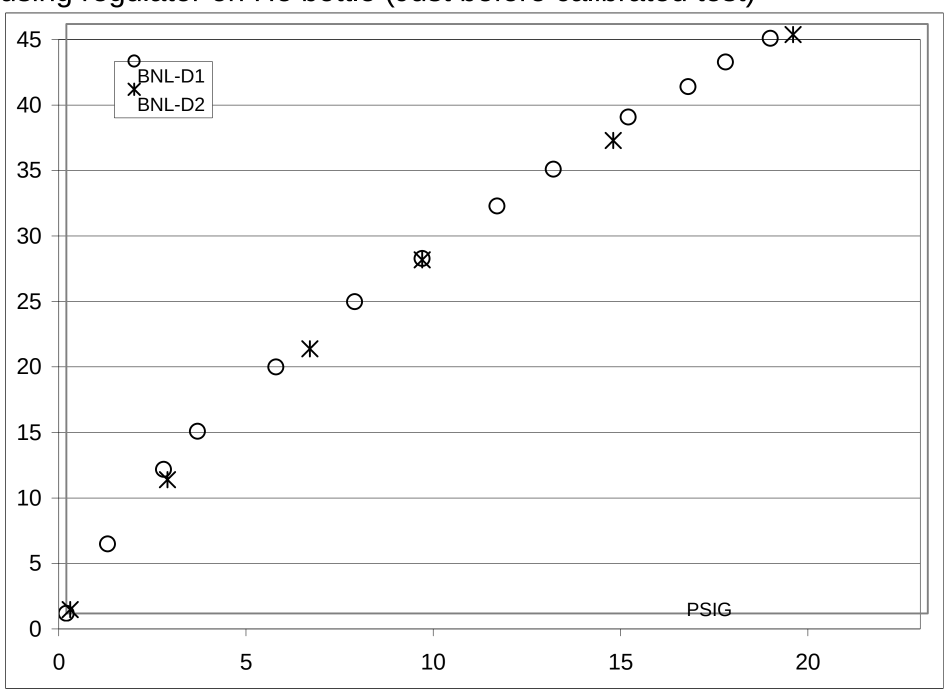
Note that this effectively calibrates the regulator gauge used in the previous test.

Psig	BNL-D1	BNL-D2	BNL-D3
15.06	0		
16.01	5		
18.6	12.2		
19.1	15		
21.05	17.7		
22.05	22.3		
22.2	22.2		
24.1	26		
24.1	26		
24.14	26.7		
27.15	32.1		
29.1	35		
30.09	38.1		
32.1	40.2		
34.05	43.3		
35.18	45.1		
36.1	46.7		
37.13	48.1		
20.1		17.8	
25.1		28	
30.25		37.2	
34.15		43.5	
36.12		46.3	
37.07		48	
15.02			0.4
20.21			17.4
25.18			27.8
30.02			36.7
35.1			44.9
36.03			46.3
37.09			48.1



29 March 2004 - Test using regulator on He bottle (Just before calibrated test)

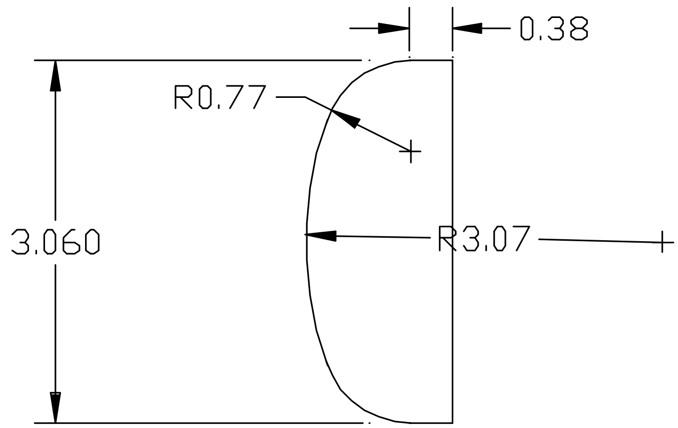
Psig	BNL-D1	BNL-D2
0	0	
0.1		0.3
1.1	5.3	
2.6	11	
2.7		10.2
3.5	13.9	
5.6	18.8	
6.5		20.2
7.7	23.8	
9.5	27.1	
9.5		27
11.5	31.1	
13	33.9	
14.6		36.1
15	37.9	
16.6	40.2	
17.6	42.1	
18.8	43.9	
19.4		44.2



Appendix 10.1.1.4.2D - Mylar window stress

Dennis Healey

March 25, 2004



The dimensions of the mylar window are shown above. The window was formed in three shapes. The outermost section is a cylindrical piece 3.06" dia x 0.38" long. The next section has radius 0.77" and the final inner section is a portion of a sphere of radius 3.07". The three sections join tangentially. The window was formed from 0.005" thick mylar. After forming, the mylar thickness was 0.0043" thick at the center of the large dome and 0.0039" thick in the cylindrical piece. (The actual window glued to the cryostat was not measured. These thicknesses were the mean values for the two spare windows.)

mylar thickness in the cylinder $t_C := 0.0039 \cdot in$

mylar thickness in the dome $t_D := 0.0043 \cdot in$

atmospheric pressure $P := 14.7 \cdot psi$

1. Stress in the cylindrical section

cylinder diameter $d := 3.06 \cdot in$

longitudinal force on cylinder $F_c := \pi \cdot \frac{d^2}{4} \cdot P$

stress in cylinder wall $S_c := \frac{F_c}{\pi \cdot d \cdot t_C}$

$S_c = 2.883 \times 10^3 psi$

2. Stress in the large central radius

This section is a portion of a sphere. The stress in a sphere of radius R and thickness t due to an internal pressure P is

$$S = \frac{R \cdot P}{2 \cdot t}$$

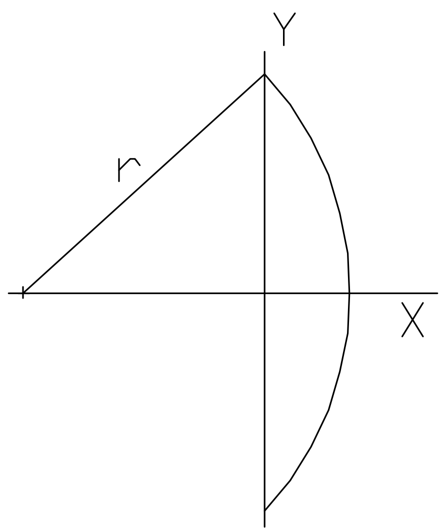
The spherical section of the dome is illustrated below. For the unstressed dome, the Y intercept is

$$y := 1.53 \cdot in$$

The radius of the sphere is $r := 3.07 \cdot in$

This gives the X intercept as $x := r - \sqrt{r^2 - y^2}$

$$x = 0.408\, in$$



Measurements of the deflection of the dome under atmospheric pressure showed that the end of the dome moved about 0.03". Assuming that most of this motion was due to deformation of the large sperical portion of the dome, and that the perifery of this section does not move much, then the X intercept changes to

$$x_{15} := x + 0.03 \cdot in$$

Then the new radius of curvature of the large shperical section of the dome is

$$R := \frac{x_{15}^2 + y^2}{2 \cdot x_{15}}$$

$$R = 2.889\,in$$

so the stress is

$$S := \frac{R \cdot P}{2 \cdot t_D}$$

$$S = 4.938 \times 10^3\,psi$$

3. Stress in the small radius section between the cylinder section and the large radius section

The stress in this section varies continuously and monotonically in this section from the cylindrical boundary (where the stress is a minimum of 2883 psi) to the large radius boundary (where the stress reaches the maximum of 4938 psi)

4. Bursting pressure

One of the visually less than perfect windows (it had some wrinkles around the cylindrical section) was glued into a test frame and increasing pressure was applied to the concave side of the window until it burst at 100 psi differential. The burst appeared to initiate near the center, in the large radius section, where the stress is supposed to be largest.

No meaurement was made of the deflection of the test dome as it neared bursting. Suppose that the deformation was linear. Then one supposes that the deformation of the dome due to 100 psi would be

$$\delta := 0.03 \cdot in \cdot \frac{100 \cdot psi}{15 \cdot psi}$$

Then the X intercept of the dome, as illustrated in section 2 above, would be

$$x_{100} := x + \delta$$

and the radius of curvature of the deformed spherical section would be

$$R := \frac{x_{100}^2 + y^2}{2 \cdot x_{100}}$$

$$R = 2.228\,in$$

at the pressure $P := 100 \cdot psi$

This gives the stress in the spherical section of the dome at the bursting pressure as

$$S := \frac{R \cdot P}{2 \cdot t_D}$$

$$S = 2.591 \times 10^4 psi$$

This measurement gives an ultimate tensile stress

$$UTS := \frac{S \cdot 100 \cdot psi}{P}$$

$$UTS = 2.591 \times 10^4 psi$$

This is in good agreement with the tensile strength (25000 psi @ 70 F) listed for mylar in Table II (Typical Properties of Plastics) of Section 1.4.2 of the Occupational Health and Safety Guide Interim.

Response to LESHC 03-05 Item 1.2.1.9

Address committee comments on the "Operating Procedures for the BNL LEGS InBeam Cryostat" . Provide the revised procedures for Committee review.

The numbering used below is the same numbering used in LESHC Minutes of Meeting 03-05, Appendix 4. The comments are shown in italics.

1) *There is no procedure for plugging. It is absolutely foreseeable that one or more of the filters will get plugged. Procedures should be developed for safely clearing this obstruction.*
   Procedures have been added in the new manual. Step 3.2.4 describes changing the external liquid nitrogen trap. Step 7.1 describes a mitigation strategy should the internal filters plug. This allows saving the polarized target before warming the cryostat to clear the plug.
2) *There is an entire redundant system in the HE-3/HE-4 mixing system, but there are no procedures for their use. If their use is envisioned, which I must presume because of the additional expense, there should be procedures to address their use.*
   In the new manual, procedure 7.2 has been added to allow changing in mid-run and comments prior to 3.1.8.5 have been added to allow startup and operation on any combination.
3) *In the P&ID for the system, there is no relief valve between valves CVLN2/CV23/LN2 Main Dewar. If this line is to be cold, and I believe it is because it is the LN2 transfer line, then a relief valve needs to be incorporated unless the LN2 bath is vented to the atmosphere.*
   A relief valve has been installed between CVLN2 and the LN2 Main Dewar. A manual fill is now used for the gas cleaners so CV23 has been eliminated.
4) *Valve Status Table*
   a) *Valves VP25 and VP26 are repeated.*
      Now VP25 andVP26 appear only once.
   b) *Valve VHB is not included in the list. Its state needs to be addressed in the procedures. (I assume it is closed for pumping but it is open before step 2.5).*
      Valve VHB is now in the State Table and its use is covered in step 3.3.7 and 3.10.1.
   c) *Valve CV9 was not closed during step 2, but the state table shows it as closed prior to step 3.*
      CV5 and CV9 are powered in parallel with M151a and b, respectively. They close when their pump is turned on. They are in the table for completeness.
   d) *Valve CVCF changes from OPEN to AUTO between step 6 and 7, but the procedures for step 6 do not make this change.*
      Making CVCF operate in AUTO was an error. It always is under manual control in the new State Table.

e)Valves CV1K, CV2K, V1K, V2K, and V1KT are not closed during step 8, therefore their state is not listed correctly in the state table. AFTER step 9 they are closed.

CV1K and CV2K are now closed in step 3.9.6. V1K and V2K are closed in step 3.9.7. V1KT has been eliminated.

5) *Step 1.4 is not clear to me. I believe it means to state, "Purge the helium-4 reservoir by evacuating the helium ...". This step also needs to be definitive, by stating the evacuation and refill procedure is done through the transfer line port. The valve nomenclature needs to be included in this step.*

This procedure has been re-written in the new manual section 3.1.7.1 to address these problems.

6) *Step 1.6 – is it okay to deadhead this pump? If not, a valve needs to be opened to prevent this. Also in step 1.6 – sixth sentence – I believe it means to state: "Close CV2K ..." vice "Close V2K ..."*

This procedure has been simplified as 3.1.7.3 in the current manual. The vacuum pumps VP1 and VP2 experience no problem from having their inputs blanked off. The cryostat is warm so, although the thermally actuated valves CV1K and CV2K are in the logical closed state (their heaters are off), they are in fact open. Closing the pumpout valves V1K and V2K allows the 1K and 2K pots to be filled with helium gas from the helium bath.

7) *Step 1.7.1 – first sentence should read - ""Attach the service pump to VT2 and turn i***t** *on."*

8) *Step 1.7.2 – can device BR7 take a 5 psi differential?*

The comments in 7) and 8) were about instructions concerning the cool down tube, but since this tube is no longer used, these two comments no longer apply.

9) *Step 1.8.3 – second sentence – should be "... turn of***f** *the turbo pump ..."*

This section has been extensively rewritten as 3.1.8. The typo was eliminated in the process.

10) *Step 4.1 – Last sentence indicates something is done automatically. What is the procedure if it is not done automatically?*

Due to piping changes in the cryostat, this whole section of the instructions has been eliminated.

11) *Steps 5.2 and 5.3 need to provide a pressure. "A predetermined value" is not acceptable.*

Steps 5.2 and 5.3 have been replaced by section 3.5.2 in the new instructions, where it indicates that <u>all</u> the gas in the Working Mixture tank is condensed into the refrigerator.

12) *Step 5.3 – is it intended that V20 also be closed when V17 is closed at the end of the step?*

V20 was supposed to stay open to provide a dump volume for the gas returning from the refrigerator. In the new instuctions, V30 stays open for this function.

13) *Step 8.2.1 – CV18 only goes to a pressure indicator. Is this correct? Is there a reason this pressure is not indicated for all operations?*

This comment implies a problem with the copy of the piping schematic reviewed. In fact, CV18 goes to the storage tanks. A dotted line showed that it was controlled by pressure indicator PI4. In the current schematic, it is forced open by pressure switch PS18.

14) *Step 8.2.3 - "designated storage value" is not acceptable. A pressure or pressure range needs to be specified.*

    In the new instructions the gas is all gathered back to the Working Gas storage tank, rather than being shared to separate tanks at some unspecified "designated storage value" pressures. See 3.9.2.3.

Response to LESHC 03-05 Item 1.2.1.1

Ensure that all personnel that are involved in the commisioning process (including the Quantum Design representative) take the BNL “Crogen Safety”, “Oxygen Defiency Hazard” and “Static Magnet Field” training courses at http://training.bnl.gov/ .

The three courses are already required for LEGS personnel and everyone is up to date. The three Quantum Technology representatives have completed the courses as well.

Response to LESHC 03-05 Item 1.2.1.2

Review the SBMS Subject area “Oxygen Deficiency Hazards (ODH), System Classification and Controls” https://sbms.bnl.gov/standard/16/1600t011.htm and perform the ODH calculations, both with and without the exhaust fans. Implement the appropriate control measures. Submit the calculations and proposed control measures to the LESHC Cryogenic Subcommittee for review.

The calculations and proposed measures were submitted on March 16, 2004. Signs prohibiting the use of LHe storage dewars greater than 250 liters have been posted.

Response to LESHC 03-05 Item 1.2.1.3

Perform a quench test to assure that the magnet vessel will not fail. Provide the results to the Committee.

Two attempts were made at the factory to accomplish this. In the first try, a fault in the magnet power supply design limited its voltage so only 93 Amps instead of the full field value of 100 Amps could be applied. Efforts to quench the magnet at this value failed. In the second attempt, the cooling of the shield outside the magnet vessel was reduced in an effort to save on LHe usage. As a result, the magnet vessel had too high a heat load to maintain LHe in it despite being directly coupled to the LHe reservoir, not to the 2K pot as in the version presented to the Committee. The magnet was run in vapor and quenched at 67 Amps, half the stored energy of full current. No problems in vessel integrity or in refrigerator operation occurred. The shield is back to its original configuration and the power supply has been upgraded but the cryostat is now on site. Given the successful test at 67 Amps, we seek permission to proceed with commissioning and attempt to quench the magnet at full current here.

Response to LESHC 03-05 Item 1.2.1.4

Perform a calculation to compare the oxygen diffusion rate with the flow rate out of the LN2 vent. Provide this information to the Committee.

The vent of the LN2 reservoir is a 0.5 inch ID, 10 inch long tube. The Chemical Rubber handbook gives the diffusion constant of O2 in air at 0 C as 0.178 sq cm/sec. Assuming the value for pure N2 is similar, the temperature is nearly the same and the concentration is zero in the reservoir implies a diffusion rate of 0.00701 cm/sec. The steady state LN2 blow off is approximately 35 liters per day of liquid (an additional 15 liters per day is used during transfer) or 260 cc/sec of gas. The 1.27 sq cm crosssection gives a flow rate of 205 cm/sec or 29250 times larger.

Response to LESHC 03-05 Item 1.2.1.5

Provide a written certification to the Committee that the electrical components of the inbeam cryostat conform to Underwriter's Laboratories (UL) standards.

The certificate is attached.

Response to LESHC 03-05 Item 1.2.1.6

Review BNL ESH Standards 1.4.1, “Pressurized Systems for Experimental Use” and 1.4.2, “Glass and Plastic Window Design for Pressure Vessels” and demonstrate compliance to the Committee.

A separate document is attached.

Response to LESHC 03-05 Item 1.2.1.7

Provide design details (including drawings) of the helium 3 still and the liquid helium pressure vessels for Committee review.

Two Autocad drawings illustrating the construction of the liquid helium reservoir, the 1K pot, the 2K pot and the Still were emailed to Steve Kane, designated committee recipient, on Thursday, August 21, 2003 by Quantum Technology. Accompanying them were an Excel file showing pressure ratings of tubes used in the He-3 loop and a written summary of the pressure ratings on the 1K pot, 2K pot, and still.

Response to LESHC 03-05 Item 1.2.1.8

Provide a transfer procedure(s) for refilling the LHe cryostat from the 500 liter transfer cryostat and the replenishment of the LN2 automatic refill system.

The procedure for refilling the LHe cryostat is 3.2.2 in the new version of the manual. The replenishment of the LN2 system is covered in 3.2.1 and 3.2.3. The new manual is attached.

Response to LESHC 03-05 Item 1.2.1.9

Address committee comments on the "Operating Procedures for the BNL LEGS InBeam Cryostat" . Provide the revised procedures for Committee review.

The new manual and a written reponse to the comments are attached.

Lessard, Edward T

From: Sandorfi, Andrew
Sent: Thursday, April 15, 2004 4:08 PM
To: Kane, Steven F; Lessard, Edward T; Travis, Richard J
Cc: Lowry, Michael; Wei, Xiangdong; Calvin Winter, President; Dennis Healey
Subject: FW: LEGS Quantum Cryostat Pressure Relief Valves/ Tests

Table Relief Valves 4.pdf (50 ...

This memo has already addressed the question raised by Steve Kane regarding point 3.1.2 . It is possible he did not receive a copy earlier. A. Sandorfi
------ Forwarded Message
From: "Ellerkamp, John J" <ellerkamp@bnl.gov>
Date: Tue, 06 Apr 2004 08:09:51 -0400
To: "Lessard, Edward T" <lessard@bnl.gov>, "Travis, Richard J" <travis@bnl.gov>
Cc: "Sandorfi, Andrew" <sandorfi@bnl.gov>, "Hoey, Steven A" <hoey@bnl.gov>
Subject: LEGS Quantum Cryostat Pressure Relief Valves/ Tests
On April 2, I verified that the factory puchased valves were as per spec according to the maufacturer's markings, rated pressures on valves and the enclosed table and locations per gas flow schematic drawing 2004\P153\Block_48.dwg. I witnessed the successful testing of the highlighted adjustable relef valves as well. Jack
<<LEGS relief Valve Table>>
------ End of Forwarded Message

Table 1 Relief Valves.

Table of Relief Valves		
Revised Apr 5/04		
Name of Relief Valve	Valve Setting	Location of the Relief Valve
S13	5 psig*	On valve above turbo-pumps
S14	1 psig*	Alcatel pump M151a exhaust
S15	1 psig*	Alcatel pump M151b exhaust
S10	5 psig*	After adsorber, on back of pump stand panel
S11	10 psig*	On gas cleaner
S11a	30 psig*	On gas cleaner
S12	10 psig*	On gas cleaner
S12a	30 psig*	On gas cleaner
S9	<0.1 psig	On cryostat
S7	15 psig	On He-3 return line, on back of flow panel (on side of cryostat)
SBY	15 psig	Bypass return relief, on back of flow panel (on side of cryostat)
S6	5 psig*	1K pot pump line, on top of cryostat
S16	5 psig*	2K pot pump line, on top of cryostat
S3b	1 psig*	Helium reservoir (at totalizer inlet), to maintain reservoir pressure
S3	4 psig	Helium recovery line, high capacity, on top of cryostat
SLN_2	10 psig*	LN_2 delivery line to cryostat, beside solenoid valve
SLN_2a	1 psig*	Cryostat LN_2 reservoir exhaust line
LN_2-supply	5 psig*	LN_2 supply line

* - Purchased valve, sat factory, NOT adjustable

Adjustable valve

Quantum

Quantum Technology Corp.

3650 Wesbrook Mall
Vancouver, BC V6S 2L2 CANADA
Tel: 604-222-5539   Fax: 604-677-5826
quantum@quantum-technology.com
http://www.quantum-technology.com

Attn:
LEGS Group
Brookhaven National Laboratory

2004 March 30

RE: Model Q02-P153 In Beam Cryostat, Control System and Pump Control

- - QUALITY CONTROL CERTIFICATE - -

This is to certify that the above equipment conforms to Underwriters Laboratories (UL) standards.

The equipment has labels to that effect.

Yours Sincerely,

Quantum Technology Corp.
per C. Winter Pres.

Quantum

Quantum Technology Corp.

LASER ELECTRON GAMMA SOURCE:

IN-BEAM CRYOSTAT MANUAL

MODEL Q02-P153

Quantum Technology Corporation USA

PMB 183, 250 H Street
Blaine, WA 9823 USA

T (888) 271-9466
F (888) 711-5222

Email: quantum@quantum-technology.com
Web: http://www.quantum-technology.com

Quantum Technology Corporation

BC Research & Innovation Complex
3650 Wesbrook Mall
Vancouver BC V6S 2L2 CANADA

T (604) 222-5539 (General Office)
T (604) 224-4331 ext 580
F (604) 677-5826

Email: quantum@quantum-technology.com
Web: http://www.quantum-technology.com

APPROVAL

Quantum Technology Corp.

Title: **LASER ELECTRON GAMMA SOURCE: IN-BEAM CRYOSTAT MANUAL**

Name: Dr. Calvin Winter

Name: Dr. Dennis Healey

Name: Dr. Terry Templeton

Date Approved:

SHIPPING LIST

	Item	Description	Qty	Box
1.	Main system	Cryostat, consists of the dilution refrigerator, iris, snout, and vacuum chamber: as drawing number	1	B
		Tip trolley, include Lock arms and all screws	1	G
2.	Pump stand/ flow control valve unit	Varian DS202 Mechanical Pump/ for 1K pot line S/N 204489	1	A
		Varian DS202 Mechanical Pump/ for 2K pot line S/N 207608	1	A
		Varian TV1001 Turbo Pump, S/N 201823	1	G
		Varian 1000HT Turbo Pump Controller, S/N 222662	1	G
		Alcatel 2063H Mecanical Pump, S/N 399727	1	C
		Edwards speed valve	2	F
		Edwards Active Pirani Gauge	1	G
		Omega Pressure Transducer	2	G
		VRC Gate Valve	1	F
		LN_2 Trap	1	G
3.	Gas Cylinders	He.4 Dump/ 108L Cylinder	1	D
		He.3+4 Dump/ 108L Cylinder	1	D
		He.3 Dump/ 216L Cylinder	1	D
		He.3 Dump/ 21.6L Cylinder	1	D
4.	Tubing	ISO160 Flex Hose (He3 return line)	1	F
		ISO160 Angle (on the gate valve)	1	F
		KF40 Flex Hose (TP to Valve Control)	1	F
		KF25 Flex Hose (1K pot line)	1	F
		KF25 Flex Hose (2K pot line)	1	F
		KF16 Flex Hose (He dumps, LN2 trap)	1	F
		KF25 Flex Hose (to alcatel)	1	F
		KF40 Flex Hose (to alcatel)	1	F
		Clamps, centerings, Cross and Tees	many	F
		LHe Transfer line	1	G
5.	Control unit + connecting cable	Main Control Rack	1	E
		Connecting Cables for control	1	G
		Connecting Cables for magnet power supply	1	G

6.	Literature	Instruction manual	1	G
7.	Spare Parts	Top Flange O-ring (AS568A-469)	2	G
		Bottom Flange O-ring (AS568A-385)	2	G
		Side Flange O-ring (AS568A-382)	4	G
		Iris Flange O-ring (AS568A-376)	2	G
		Snout Flange O-ring (AS568A-368)	2	G
		Screws Nuts + Washers for The Top Flange (1/2"-13 stud L3.0" + 1/2" Heavy Hex Nuts)	9 sets	G
		Screws Nuts + Washers for The Bottom Flange (3/8"-16 Flat Head L2.0" + 3/8" Heavy Hex Nuts)	9 sets	G
		Screws Nuts + Washers for The Bottom Side Flanges(3/8"-16 stud L2.5" + 3/8" Heavy Hex Nuts)	20 sets	G
		Screws + Washers for Turbo Pump on the stand/ M6 – L50mm	6	G
		CFF34 Gasket	4	G
8.	Tools	Tool box	1	G
9.	Returning BNL equipment	Magnetometer, Hall Probe	1	G
10.				
11.				

Package:
A= H64” × W36” × D35.5”(inside dimension) CRATE FOR Pump Stand, On 4’ × 4’ Skid (Box 1 of 8)
B= H79” × W21” × D72”(inside dimension) CRATE FOR CRYOSTAT, On 6’ × 4’ Skid (Box 2 of 8)
C= H24” × W46” × D13” CRATE (Use Original Crate) for Alcatel Pump, On 4’ × 4’ Skid (Box 3 of 8)
D= H58” × W48” × D48” CRATE for gas cylinders, On 4’ × 4’ Skid (Box 4 of 8)
E= On 4’ × 4’ Skid + covering panels for Control Rack (Box 6 of 8)
F= On 4’ × 4’ Skid/ Cardboard Box for 6” tube, other tubing, clamps, etc (Box 7 of 8)
G= On 4’ × 4’ Skid/ Tip trolley, spare parts, etc (Box 8 of 8)

Summary

The LEGS group operates a spin polarized solid HD target in conjunction with a unique polarized photon sourc

e. Three key cryostats are used: One is with a high magnetic field for target polarization which requires a few weeks. Up to three targets are polarized at the same time. They are mounted vertically on a copper support in a ~20 milliKelvin dilution refrigerator for this purpose.

A portable transfer cryostat (TC) is used to remove a target from the polarizing cryostat and to carry it to the in beam cryostat. The in beam cryostat must tilt nose down to accept the sample from the transfer cryostat. After disconnecting the in beam cryostat is tilted back so that the target is horizontal.

This manual describes the operation of the in beam cryostat. It maintains previously frozen spin polarization of the target at ~250 mK in a magnetic field of 1 Tesla. In addition, in a spin polarization calibration mode it can warm up and maintain the target at ~7K.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Design goals:

Maintain Target below 0.5K prefer below 0.2K

Maintain target polarization at all times with a magnetic field.

~1Tesla around target during experiment

~0.1T in transfer position

Field homogeneity in region of target: 10-3

Experiment duration: 2 weeks or more

Autonomy of target and magnetic field: 5 minutes without electric power (able to recover automatically from a short power failure).

Liquid helium fills: once per day. (No continuous transferring of liquid helium required.

Liquid nitrogen fills: once per day (or if more frequent an auto-fill system is required)

Compatible with existing transfer cryostat.

Axial force on LN_2 shield iris opener: 150 pounds (700 N).

Torque on solid hydrogen target when inserting: 24 foot-pounds (34 N-m) Measured value was 16 foot-pounds (190 inch-pounds) +/-10%.

Equipment protection from failure:

Quench protection for superconducting magnet

Relief valves on all cryogen spaces.

Specification of cryostat dimensions are shown on the attached drawing. Several of these dimensions are critical to compatibility of equipment.

Inlet vacuum flange: ISO63. (The transfer cryostat has ISO63K [clamp style]) The target cryostat has an ISO63 bolted flange gate valve to match.

2 SYSTEM SPECIFICATIONS

2.1 Cryostat volume:

Vacuum vessel volume: 230 liters

2.2 Volumes in the cryostat:

LHe reservoir: 45 liters

LN_2 reservoir: 5 liters

2.3 SC Magnet:

Magnetic Field: 1 Tesla @ 100A

2.4 Snout dimensions:

Target snout outside diameter: 80 mm

Target holder diameter: 35 mm

2.5 Operating parameters:

Target operating temperature: ~250 mK

Cooling power: 1 mW @ 375 mK
2 mW @ 634 mK

2.6 Cryogen consumption:

100 LHe liters per day

50 LN_2 liters per day

2.7 Materials around the target in radial direction:

Table 1 Materials around the target in radial direction.

O:\2004\MANUFACTURING\P153-LEGS\EXCEL\BNL6-r4_material near tgt.XLS 27/01/2004

Materials around the target in the radial direction

Item	Material	Radius outside mm (UPDATED 27/01/2004)	Outside Radii mm ## (AMS) (26/01/2004)	Radius outside mm	Radial space to next shield (mm)**	Material Thickness mm ## (AMS) (26/01/2004)	Thickness mm	Density gm/cm^3	Density gm/cm^3 (########)	Areal Density mg/cm^2	density x thick g/cm^3 (26/01/2004)	Radiation Length cm	Rad Length cm (26/01/2004)	Energy Loss from centre of target: Fractional Radiation Length	Energy Loss from centre of target: fractional Rad Length cm (########)	Fraction of Loss
Target	HD				2.5*	12.6	15	0.12	0.147	180	0.185	800	783	0.0019	0.0016	0.026
target cooling wires (Al 20% by weight of target)	Aluminum wire		12.6			12.6			& 0.04		0.046		986		0.0013	
Target container	mylar		13.1	15	1.5	0.5	0.08	1.4	2.14	11	0.107	19	162	0.0004	0.0003	0.006
NMR Former	Kel-F		15.5	16.5	0	1	1	1.4	2.14	140	0.214	19	162	0.0053	0.0006	0.073
Magnet former, inner	Aluminum	26	27.3	26	0	1	0.75	2.7	2.7	203	0.270	9	8.9	0.0083	0.0112	0.115
Holding coil	Cu, NbTi***	27.21	29.7	26	0	1.778	0.4445	9	# 8.2	314	1.968	1.4	1.59	0.0318	0.1118	0.437
Magnet former, outer	Aluminum	30.5	30.5	28.5	2.5	1	0.75	2.7	2.7	203	0.270	9	8.9	0.0083	0.0112	0.115
20 K shield	Aluminum	33.9	34	31.5	1	0.66	0.2	2.7	2.7	54	0.178	9	8.9	0.0022	0.0074	0.031
77 K shield	Aluminum	35.9	35.9	33.5	3	1	0.2	2.7	2.7	54	0.270	9	8.9	0.0022	0.0112	0.031
30 layers SI	mylar					0.19	0.2	1.4	1.4	28	0.027	19	28.7	0.0011	0.0007	0.015
Vacuum shell	Aluminum	40.1	40	39		1	1	2.7	2.7	270	0.270	9	8.9	0.0111	0.0112	0.153
Totals								TOTALS:		1456				0.0726	0.1687	
													sum if yellow H16-H20 used		0.0748	

* Note: Radial space from the target to the magnet former is measured from the outside of the refrigerator housing

** These radial spaces are construction clearances. They may not match thickness and radii around target because several shields are machined thinner in the target section.

*** Radiation length of copper was used. The ratio of Copper to superconductor is Cu:Sc = 1.34:1 (by volume?). Composition of NbTi is approx. 46.5 - 50% weight percent Ti.

as taken from BNL 45-P.dwg

& effective Al density taken as 0.037 to give 20% Al by mass

density of 4x0.6 mm wire = 8.96*(1.34/2.34) + [(4.54+9.92)/2]*(1/2.34) = 8.2

2.8 Pump Specifications:

2.8.1 2K Pot Varian DS 202

VARIAN DS 202 - ROTARY VANE TWO STAGE PUMP

Model L580PR

No 204490-2002

Pumping speed: 6CFM @ 60 Hz (2.832 l/s)

Ultimate Total Pressure: 2 x 10-3 Torr

Weight: 55 lbs

Inlet and exhaust port size: NW25KF

100-120 V, 60 Hz, 1720 RPM, 0.55 kW, power factor>0.8, 8.8 A

2.8.2 1K Pot Varian DS 202

VARIAN DS 202 - ROTARY VANE TWO STAGE PUMP

Model L580PR

No 105962-2001

Pumping speed: 6CFM @ 60 Hz (2.832 l/s)

Ultimate Total Pressure: 2 x 10-3 Torr

Weight: 55 lbs

Inlet and exhaust port size: NW25KF

100-120 V, 60 Hz, 1720 RPM, 0.55 kW, power factor>0.8, 8.8 A

2.8.3 Varian Turbo Pump

He_3 VARIAN TURBO PUMP – WATER COOLED

Model 9698931

No 201823

Input 650 Hz

N2: 790 l/s, He 820 l/s, H2: 860 l/s

2.8.4 Alcatel 2063H

He_3 HERMETIC PUMP – WATER COOLED

No 399727

208, 60 Hz, 750 RPM, 3.00 HP, 0.87 PF, 9.90 A

60 Hz, 42.4 CFM, 20 l/s

3 OPERATING INSTRUCTIONS

These instructions are referenced to Table 3 Cryostat Device State Tables,

Figure 6 Gas Flow Schematic and Table 2 Relief Valves.

Table 2 Relief Valves.

Table of Relief Valves		
Revised Mar 15/04		
Name of Relief Valve	Valve Setting	Location of the Relief Valve
S13	5 psig*	On valve above turbo-pumps
S14	1 psig*	Alcatel pump M151a exhaust
S15	1 psig*	Alcatel pump M151b exhaust
S10	5 psig*	After adsorber, on back of pump stand panel
S11	10 psig*	On gas cleaner
S12	10 psig*	On gas cleaner
S11a	30 psig*	On pump stand at gas cleaner inlet
S12a	30 psig*	On pump stand at gas cleaner inlet
S9	<0.1 psig#	On cryostat
S7	15 psig*	On He-3 return line, on back of flow panel (on side of cryostat)
SBY	15 psig#	Bypass return relief, on back of flow panel (on side of cryostat)
S6	5 psig*	1K pot pump line, on top of cryostat
S16	5 psig*	2K pot pump line, on top of cryostat
S3b	1 psig*	Helium reservoir (at totalizer inlet), to maintain reservoir pressure
S3	4 psig#	Helium recovery line, high capacity, on top of cryostat
SLN_2	10 psig*	LN_2 delivery line to cryostat, beside solenoid valve
SLN_2a	1 psig*	Cryostat LN_2 reservoir exhaust line

* - Purchased valve, sat factory, NOT adjustable
# - Adjustable valve

Table 3 Cryostat Device State Table.

	BNL In-Beam Cryostat Device State Table											Revised 25 Mar/04	
Status at the beginning of the Steps in the Operating Procedures					Step 3.1	Step 3.3	Step 3.4	Step 3.5	Step 3.6	Step 3.7	Step 3.8	Step 3.9	Step 3.10
						Preparations Complete	LN2 & LHe Reservoirs Full	Magnet Cold	Refrigerator Operating	Target Loaded	7K done	Target Removed	
Name	Physical Location	Control	Description	Function	Initial Conditions	Ready to Fill Reservoirs	Ready to Cool Pots and Precool Reservoirs	Ready to Operate Refrigerator	Ready to Load Target	Ready for 7K Operation	Ready to Remove Target	Ready to Warm Cryostat	Ready for Final Shutdown
BR3	Cryo. Panel	manual	flow meter	1st 4He counter-flow hEX	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR4	Cryo. Panel	manual	flow meter	current lead	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR5	Cryo. Panel	manual	flow meter	current lead	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR6	Cryo. Panel	manual	flow meter	20K shield & Iris Opener vent	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR7	Cryo. Panel	manual	flow meter	Magnet can gas vent	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
CV18	Pump panel	manual/PLC	solenoid	valve to dumps for MIX	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
CV1K	inside IBC	PLC	thermal CV	needle valve for 1K pot	CLOSED	CLOSED	OPEN	AUTO	AUTO	AUTO	AUTO	AUTO	CLOSED
CV2K	inside IBC	PLC	thermal CV	needle valve for 2K pot	CLOSED	CLOSED	OPEN	AUTO	AUTO	AUTO	AUTO	AUTO	CLOSED
CV5	Alcatel M151a	PLC	solenoid	equalize pressure on power loss	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
CV9	Alcatel M151b	PLC	solenoid	equalize pressure on power loss	OPEN	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	OPEN
CVBY	inside IBC	PLC	thermal CV	needle V bypass to cool MC	CLOSED	CLOSED	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
CVCF	inside IBC	PLC	thermal CV	needle V, Dilution Refrigerator flow impedance	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
CVLN2	LN2 supply dewar	PLC	solenoid	auto fill for IBC LN2 reservoir	CLOSED	CLOSED	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	CLOSED
M151a	Pump Stand	manual/PLC	Alcatel MP	Rotary Pump for MIX circulation	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
M151b	Pump Stand	manual/PLC	Alcatel MP	Rotary Pump for MIX circulation	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
NV17	Main Panel	manual	Needle V	Meter gas into refrigerator	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
RTBY	Cryo. Panel	manual	gas valve	seals off CVBY bypass	CLOSED	OPEN	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
Shutter	IBC beam port	manual	rotating rod	100K and 4K radiation shutters	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
TP1	Pump Stand	manual	Turbo-left	Varian Turbo for IMX circulation	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
TP1a	Pump Stand	manual	Turbo-right	Varian Turbo for IMX circulation	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
V1	Main Panel	manual	Gate valve	Isolation Valve for Turbo-left	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V1a	Main Panel	manual	Gate valve	Isolation Valve for Turbo-right	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V10	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
V11	Main Panel	manual	gas valve	LN2 trap F152 inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V12	Main Panel	manual	gas valve	LN2 trap F151 inlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V13	Main Panel	manual	gas valve	LN2 trap F152 service valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V14	Main Panel	manual	gas valve	LN2 trap F151 service valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V15	Main Panel	manual	gas valve	LN2 trap F152 outlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V16	Main Panel	manual	gas valve	LN2 trap F151 outlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V17	Main Panel	manual	gas valve	Coarse gas inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V19	He-4 dump tank	manual	gas valve	Isolate He-4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V19a	He-4 dump tank	manual	gas valve	Isolate He-4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V1K	1K pot pump	manual	gas valve	I K Pot Pump Valve	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V2	Main Panel	manual	gas valve	Gas inlet shut-off valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V20	He3/4 dump tank	manual	gas valve	Isolate He3/He4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V20a	He3/4 dump tank	manual	gas valve	Isolate He3/He4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V21	Main Panel	manual	gas valve	Evacuate He3 return line	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V23	Main Panel	manual	gas valve	Isolate TP1 (turbo-left) exhaust	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V23a	Main Panel	manual	gas valve	Isolate TP1a (turbo right) exhaust	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V24	Main Panel	manual	gas valve	Remove gas in F151 gas cleaner	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V25	Main Panel	manual	gas valve	Remove gas in F152 gas cleaner	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V26	He3 dump tank	manual	gas valve	Isolate He3 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V27	Main Panel	manual	gas valve	Adsorber inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V28	Main Panel	manual	gas valve	Adsorber inlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V2a	Main Panel	manual	gas valve	Gas inlet needle valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V2b	Pump Stand	manual	gas valve	Gas inlet port pump-out valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V2K	2K pot pump	manual	gas valve	2K Pot Pump Valve	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V30	Mixture tank	manual	gas valve	Isolate mixture tank	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V3	Main Panel	manual	gas valve	Alcatel inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V4	Main Panel	manual	gas valve	Alcatel inlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V6	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
V7	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
V8	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
VFILL	Cryostat	manual	LHe valve	Shut-off LHe fill	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
VHB	top of cryostat	manual	gas valve	vent helium reservoir to totalizer	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
VHBa	on totalizer	manual	gas valve	vent helium reservoir to atm	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
VP1	Pump Stand	manual	Varian MP	1K pot pump	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
VP2	Pump Stand	manual	Varian MP	2K pot pump	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
VP25	Cryostat	manual	gas valve	Cryostat evacuation valve	CLOSED	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
VP26	Pump Stand (on V1a)	manual	gas valve	Evacuate 6" flex line	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED

3.1 Prior To Cooldown:

This section describes the procedures that are necessary to establish the insulation vacuum in the cryostat and to purge and leak check the internal gas circuits in the cryostat. These procedures prepare the cryostat for the initial cooling.

3.1.1 Pre-cool check.

Check that all devices are correctly set as designated by the State Table, the column labelled "Step 3.1". Note that CV5 and CV9 are N.O. electric solenoid valves and are open when the associated Alcatel pump is off

3.1.2 Relief-valve check.

Check that all relief valves are unobstructed and appear to be in working order. The relief valves and their locations are listed in the Table of Relief Valves.

3.1.3 LabVIEW program startup procedure.

3.1.3.1 Locate the latest version of LEGS program which is linked to a desktop shortcut LEGS.

3.1.3.2 Double click to start LabVIEW program.

3.1.3.3 Check the settings for data file save (frequency) and recommended directory for storing data on LabVIEW tab. Decide if you want to APPEND data to the existing file or CREATE a new one.

3.1.3.4 Make sure that "Enable DAQ" switch is ON and click on white arrow to start the program (See Fig. 1), the arrow will change to black.

3.1.3.5 Pop-up windows show that you use to select the location and the name of the file.

3.1.3.6 To stop the program press "Enable DAQ" switch once and wait for the loop to finish (~1.5 s). Arrow should revert back to white form.

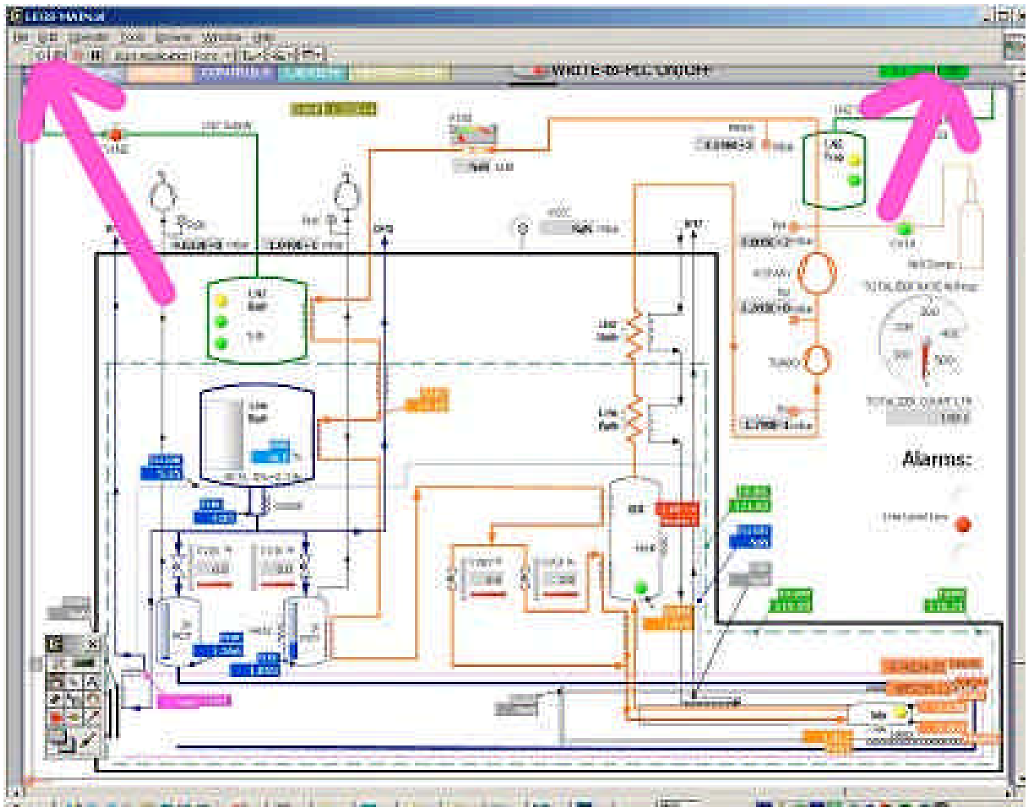


Figure 1 Start LabVIEW buttons.

CAUTION: If you use the same file name AND you selected "CREATE new file" settings you will write over the existing data file.

3.1.4 Control program check.

Check that the PLC and LabVIEW control programs are running and that all the displayed values look reasonable (i.e.: that it looks like all the pressure, temperature and level sensors are hooked up and functioning).

3.1.5 Pump-down.

Evacuate target cryostat through valve VP25 using a mechanical vacuum pump to twenty microns, monitoring the visual dial gauge (for pressures between 760 Torr and approximately 10 Torr) and the thermocouple gauge (a local controller will have to be provided for this gauge – it can be disconnected once cooling starts).

Note: The pump-out should be done slowly over about five minutes to avoid disturbing the superinsulation.

3.1.6 Leak test.

3.1.6.1 Attach a helium leak detector to the cryostat. This can be in parallel with the mechanical pump if this pump is required to maintain low pressure in the cryostat. Check the cryostat for leaks from atmosphere by spraying the joints and welds with a low flow of helium gas. Any detected air leaks with a leak rate greater than 10E-5 atm-cc/sec must be repaired. Note that helium permeates rapidly through the Mylar beam exit window so leaks detected in this region may be due to permeation.

3.1.6.2 Check that no detectable helium leak is present inside the cryostat. The leak detector should have a helium sensitivity of at least 10E-8 atm-cc/sec. The checking will occur automatically as the helium circuits are purged with helium in the following sections.

3.1.7 Purging.

3.1.7.1 Purge the helium-4 reservoir by evacuating to about 10 Torr and back filling with helium to about 3 psig. Maintain this pressure during the following operations. This evacuation and refill is done through the helium transfer line port by mechanical vacuum pump with a manifold that allows both pumping and back-filling with helium. This procedure automatically checks the helium reservoir and the magnet container for leaks.

3.1.7.2 Purge the helium-4 circuits. In sequence slightly open and leave open the flow meter valves BR3, BR4, BR5, BR6, and BR7 and ensure that flow exists. Leave the helium flowing for 5 minutes at a rate of about 1 liter/minute. Close BR3, BR4, BR5, BR6, and BR7 and leave the helium-4 reservoir pressurized at 3 psig.

3.1.7.3 Purge the 1 K and 2 K Pots. Turn on the 1 K Pot and 2 K Pot pumps (VP1 and VP2) and open their associated valves (V1K and V2K). Once the pots are pumped to a stationary pressure (in about a minute or less), then close V1K and V2K and observe the pressure rising in the pots on PI1K and PI2K as helium comes in through the valves CV1K and CV2K. Note that these valves will be open because the LN_2 reservoir is still warm. The pressure rise is slow because CV1K and CV2K are quite restrictive. Letting the pressure rise to about half an atmosphere is adequate to leak check the 1K and 2K pots. Turn off VP1 and VP2.

3.1.8 Preparing the refrigerator circuit

3.1.8.1 Prepare the LN_2 cooled gas cleaners (F151 and F152). Evacuate both traps using the service pump through valves V13 and V14 until a pressure of 30 microns is reached. Close V13 and V14.

3.1.8.2 Open RTBY. Evacuate the refrigerator with a mechanical pump via VP26 and V21 (connected together and teed to the mechanical pump via a separate service valve) to a pressure of less than 10E-1 Torr (PI1) and close the service valve once this pressure is reached, to avoid oil backstreaming into the refrigerator. Close VP26 and V21.

3.1.8.3 At this point one should leak check the two pipes connecting the pump stand to the cryostat. First connect a helium leak detector to V21 and check the line from V16 to the cryostat for air leaks (including the leg that includes RTBY). Then connect the leak detector to VP26 and check the pump line from the cryostat to V1 for air leaks. The leak detector connected to the cryostat may be borrowed for this function, and then returned to the cryostat.

3.1.8.4 Cool both gas cleaners F151 and F152. This cooling is done manually by transfering LN2 from a transport dewar into the gas cleaner dewar until the liquid level is about six inches from the top of the gas cleaner dewar. (If one is using the gas cleaner dewar supplied by Quantum Technology, then this dewar should be refilled manually every three days. If some other gas cleaner dewar is used, then the level must be monitored manually during the first use to determine the proper refill schedule.) The LN2 level is monitored by two discrete sensors and displayed on the Main LabVIEW page. If the level drops below the lower level, then an alarm condition is displayed on this page. Let in pump gas by opening V12 and V28. Leave the cleaner to cool for 20 minutes.

NOTE: In the following procedures, reference is made only to TP1 and M151b. In fact there are two turbopumps and two mechanical pumps which can be used in any one of four combinations (along with associated valves). If pumps other then TP1 and M151b are to be used, then the instruction pump and valve names must be modified accordingly. The valves associated with the four pumps are shown below:

Table 4 Valves controlling the pumps.

Turbopump TP1	**Inlet valve V1**	**Outlet valve V23**
Turbopump TP1a	Inlet valve V1a	Outlet valve V23a
Alcatel pump M151b	**Inlet valve V4**	**Outlet valve V28**
Alcatel pump M151a	Inlet valve V3	Outlet valve V27

3.1.8.5 Turn on the rotary pump M151b.

3.1.8.6 Open V23 and open V4 so now M151b is backing TP1.

3.1.8.7 After 5 minutes, open V1.

3.1.8.8 Open V16 to let helium that was in the mechanical pump into the refrigerator. One will see a momentary flow in F150 and see a pressure rise in PIMXS.

3.1.8.9 Open V30 and then slowly open NV17 to meter helium gas into the refrigerator to a pressure of 700 mBars, as read by PI4, then close NV17.

3.1.8.10 Helium is now flowing slowly through the refrigerator, metered by CVCF and CVBY in parallel. Check the function of the flow meter F150 and the pressure gauge PIMXS by closing and opening V16. Finish with V16 open.

3.1.8.11 Turn off M151b. Gas will flow into the refrigerator via CV9. As the pressure rises in the pump line, then leaks from this space into the cryostat become more easily detected.

This completes the purging, flow testing, and leak testing of all flow loops and the system is now ready for cooldown. If there is any uncertainty, go back and recheck the system. A few minutes of checking out at room temperature can save days in preventing a faulty cooldown.

3.2 Standard Procedures:

Following are the procedures to be followed for refilling thecryostat LN2 reservoir, refilling the cryostat LHe reservoir, refilling the gas cleaner LN2 reservoir, and cleaning the gas cleaner.

3.2.1 LN_2 transfer procedure for the cryostat LN_2 reservoir:

- On average the refill happens once every three hours.
- Make sure that the LN_2 tank is full before starting the tipping procedure.
- Make sure that the LN_2 tank is disconnected (manual valve closed) during tipping procedure.
- Make sure that dewar is fitted with low pressure relief valve ~5 PSI.

As long as the nitrogen transport dewar is connected to the cryostat, then refills of the cryostat liquid nitrogen reservoir are automatically controlled by the PLC, governed by the level sensors in the reservoir. The transport dewar pressure should be in the range 3-5 psig. To change the transport dewar, close its manual valve and also unplug 110 VAC cable to the solenoid valve in the cryostat liquid nitrogen line. If necessary, warm the connection to the transport dewar with a hot air gun. After replacing the transport dewar and checking that its delivery pressure is in the range 3-5 psig, open the valve on the transport dewar and reconnect the 110 VAC cable to the solenoid valve in the cryostat liquid nitrogen line.

3.2.2 LHe transfer procedure:

<u>Please Note:</u> *In the following "Supply line" means the long flexible line from the Supply dewar and "Cryostat Line" means the short rigid section which stays in the cryostat.*

3.2.2.1 Reduce the magnet current to 30 A.

3.2.2.2 Push the cryostat line down so that it is approximately six inches above being fully pushed into the port.

3.2.2.3 Close the pressure relief valve on the transport dewar.

3.2.2.4 Begin installing the supply line to the dewar, slowly so as to avoid pressure build-up in the dewar beyond about 2 psig.

3.2.2.5 At the same time, open the valve on the cryostat line slightly so some cooling gas comes out of this line. When white vapor is coming from the cryostat line, close the valve.

3.2.2.6 Some cooling gas will begin coming from the supply line as it is lowered. Wait until there is almost a plume of cold gas and then connect the two halves of the transfer line together. Wear gloves and eye protection for this procedure to avoid injuries.

3.2.2.7 Open the cryostat line valve fully.

3.2.2.8 Raise the transport dewar pressure to 4-6 psig (with an external helium gas source or with the heater on the transport dewar, if it is supplied with such).

3.2.2.9 Observe the gas totalizer (the exhaust gas meter). It will spin rapidly for the final cooling of the transfer line and then slow down as the transfer starts.

3.2.2.10 While transferring, monitor the totalizer, the transport dewar pressure, and the level meter reading. Keep the dewar pressure steady. The totalizer rate should be about 6 sec/rev during filling and the level meter should show a steady increase towards 100%. As the level meter nears 100%, a sudden increase in the totalizer rev rate will indicate that the cryostat is full.

- Totalizer rate conversion (4-6 s/rev. during fill)
  1 rev=0.05m^3 so the boil off during fill is as follows:
  0.05m^3/5seconds*1/750 Liquid L/gaseous L*60s/min*60 min/hour
  Boil off=0.048m^3/hour=48L/hour

3.2.2.11 When the cryostat is full, close the cryostat line valve and open the valve to the transport dewar relief valve.

3.2.2.12 Remove the supply line from the transport dewar and close the transport dewar ball valve.

3.2.2.13 Disconnect the supply line from the cryostat line.

3.2.2.14 Raise the cryostat line to about 15 inches above the cryostat entry port fitting (do not pull it out of the cryostat).

3.2.2.15 Raise the magnet current back to its initial operating point.

Check the transport dewar pressure. It should be back down to about 1 psig and gas should be venting slowly from the low pressure relief valve.

3.2.3 Refill of the LN_2 gas cleaner dewar.

Refill is done manually by transferring LN_2 from a transport dewar into the gas cleaner dewar until the liquid level is about six inches from the top of the gas cleaner dewar. (If one is using the gas cleaner dewar supplied by Quantum Technology, then this dewar should be refilled manually every three days. If some other gas cleaner dewar is used, then the level must be monitored manually during the first use to determine the proper refill schedule.) The LN_2 level is monitored by two discrete sensors and displayed on the Main LabVIEW page. If the level drops below the lower level, then an alarm condition is displayed on this page.

3.2.4 Cleaning the Gas Cleaners.

There are two parallel gas cleaners (called LN_2 trap in Figure 6 Gas Flow Schematic) in the gas handling system. These are meant to remove contaminants (principally air and light oil vapors) from the helium gas stream before it is sent back to the refrigerator. Only one is used at a time, the second one being kept as clean and ready for use when the first must be cleaned. For the following it is presumed that the LN_2 Trap F151 is being used and LN_2 Trap F152 is on standby (this follows the convention above, see paragraph 3.1.8.4). If the situation is reversed, then change the valve names according to Table 5 Valves controlling the cold traps.

Table 5 Valves controlling the cold traps.

Trap F151	Inlet Valve V12	Outlet Valve V16	Evacuation Valve V24
Trap F152	Inlet Valve V11	Outlet Valve V15	Evacuation Valve V25

To clean trap F151

3.2.4.1 Open V15. Wait one minute and then open V11.

3.2.4.2 Close V12 and then close V16. This procedure will have changed the gas flow from F151 to F152.

3.2.4.3 Slowly open V24. This is done slowly so as not to introduce a large pressure rise on the outlet of the turbopump. There is no instantaneous pressure readout at this point so it is best to be guided by the turbopump power and try to open V24 at such a slow rate that the turbopump power does not rise more than 10% above its value before V24 was opened.

3.2.4.4 Once V24 is fully open, wait one minute and then close V24. This procedure will have removed almost all the helium from the trap.

3.2.4.5 It will be instructive to learn how much air has been collected in the gas cleaner. Do this by attaching a small volume pressure gauge (range –30” to 30 psi) to V14 and then opening V14. (The small volume applies to both the gauge and the short length of small diameter tubing connecting it to V14.) The pressure gauge will drop from a reading of zero to –30”. Next remove the gas cleaner from the LN_2 dewar and allow it to warm to room temperature. As it warms, air will be evolved from the charcoal and the pressure shown will rise. At 30 psi, the relief valve S11 will open to limit the pressure rise. A pressure rise to less than 0 psi on the gauge is ok (it indicates that not much air has collected in the cleaner and there is little danger that any air has passed the cleaner and gone on to the refrigerator). A pressure rise to above 5 psi indicates that the gas cleaner should have been changed earlier.

3.2.4.6 Close V14 and remove the pressure gauge.

3.2.4.7 Attach a mechanical vacuum to V14 and evacuate F151 for 5 minutes. Then close V14.

3.2.4.8 Remove the mechanical pump from V14 and place the gas cleaner back into the LN_2 dewar to cool. Leave it cooling for 30 minutes before passing any helium through it (ie: before changing back from the other cleaner).

3.3 Cooldown Procedure:

This section describes the procedures used to cool and fill the LN_2 and LHe reservoirs. It also describes starting the flow through the refrigerator and through the 1K and 2K pots to start cooling these elements.

3.3.1 Disconnect the leak detector.

Close the vacuum pumping port VP25, leaving the leak detector and mechanical pump connected for later use. VP25 can be re-opened momentarily to check for helium accumulation in the cryostat, which may occur during cooling and filling. Continue to observe the cryostat pressure with the thermocouple gauge.

3.3.2 Start turbo pumps.

Turn on the mechanical circulation pump (M151b). After one minute, turn on the turbopump TP1. Set the CVCF and CVBY temperature setpoints to 200K so these valves will stay open during cooling, and so allow helium to flow through the refrigerator during the cooling procedure. Maintain PI4 at about 700 mBar using NV17 to admit gas as required.

3.3.3 Initial cooling.

Fill the cryostat LN_2 reservoir using the autofill system. The source dewar for the LN_2 should have a pressure of about 3-5 psi. It takes about ninety minutes for the LN_2 reservoir to cool sufficiently for the autofill system to function properly. During this period, liquid spills from the reservoir vent before the top level sensor is covered. Each time liquid spills, the flow control solenoid must be disconnected, and then reconnected when vapor stops flowing from the vent. This phase requires manual monitoring. Eventually the auto system will take over. Wait two hours to allow the 80K shield to begin cooling. Charcoal mounted on the 80K shield will begin to cryopump as it cools. As the pressure reading on the thermocouple gauge falls to less than two microns, the cold cathode gauge (VGCC) can be turned on. When it comes on scale due to the cryopumping of the charcoal, the thermocouple gauge controller can be disconnected.

3.3.4 Precool.

Start cooling the helium reservoir by pouring in about ten liters of liquid nitrogen (by hand to get a fairly accurate measurement). This should boil away completely in cooling the reservoir. After this, liquid nitrogen may be added 3-4 liters at a time to cool the shield. The magnet is connected to the reservoir by a 6 mm ID copper pipe and some liquid nitrogen may run down this pipe into the magnet bath. This will only cause a problem if liquid nitrogen begins to collect in the magnet bath, so the temperature of the magnet bath must be monitored to insure that it does not fall below 100K (monitor using the magnet temperature sensor TI202). If the magnet bath approaches 100K, then the remaining liquid nitrogen in the helium reservoir should be removed by siphoning.

3.3.5 LN_2 removal.

Liquid nitrogen cooling of the helium bath and shield will take about 3-4 hours. When the shield has cooled to less than 150K (as measured by TI1201 at the bottom of the helium shield), remove the remaining LN_2 from the helium bath (by siphon).

3.3.5.1 Siphoning the liquid nitrogen from the helium bath will leave some liquid remaining in a 1.5” dia by 4” long SS pipe, which extends down from the bottom of the helium bath. There is a 5/16” OD copper tube connecting the bottom of the SS pipe to the magnet bath (this tube carries the current leads and supplies helium to the magnet). The copper pipe has a heater and a temperature sensor (TI4K) mounted at its center. Now one can get rid of the remnant liquid nitrogen by turning on the heater at full power and leaving it on until TI4K rises above 80K (this will take about ten minutes). Then turn the heater off. Check that TI4K and TI202 stay above 80K to ensure that liquid nitrogen is gone from the reservoir and the magnet bath.

3.3.5.2 Check that there is no nitrogen in the lines feeding the 1K and 2K pots. First open CV1K and CV2K by setting their temperature set points to 200K and waiting until the temperature readbacks are above 180K. Then pressurize the helium bath to 5 psig and monitor flow from the 1K and 2K pots for five minutes (monitor the flow through a port made by temporarily disconnecting the mechanical pressure gauge just above the 1K and 2K pot pumps).

3.3.5.3 Check that there is no nitrogen in the other helium lines by pressurizing the helium bath to 3 psig and opening BR3 (for the counterflow heat exchanger), BR6 (for the 20K shield and Iris Opener heat exchangers), and BR7 (for the magnet bath helium flow) and observing gas flow for five minutes. Then close BR3, BR6, and BR7.

3.3.6 Start a helium transfer in the cold gas flow mode.

3.3.6.1 The helium transfer line is in two parts. Install the lance with the shut-off valve (VFILL) to the liquid helium bath, right to the bottom of the bath. Check that VFILL is closed. Connect the other half of the transfer line to the valve section and install the other end very slowly into the helium transport dewar. The speed of this insertion is governed by the rate of boil-off that one is willing to accept from the helium transport dewar.

3.3.6.2 Do not transfer any liquid at this stage. It is preferable to use a slow flow of cold gas directed right to the bottom of the reservoir for a long time - about 6 hours - to cool the cryostat. Putting in more liquid can waste a huge amount of liquid helium and will not appreciably shorten the cooldown time (which is limited by thermal diffusion time constants).

3.3.6.3 This slow cold gas transfer mode is effected by throttling the exit helium flows and connecting a very small overpressure to the helium supply vessel.

3.3.6.4 To do this set the valves BR4 and BR5 to ½ turn open and BR3, BR6 and BR7 each to 1 turn open. Pressurize the helium source vessel to 3psig (0.2 bar). The desired total flow rate during this phase is 3 liquid liters per hour (40 gas liters per minute). Adjust BR3, BR4, BR5, BR6, and BR7 to achieve this rate, monitoring the gas totalizer.

3.3.6.5 Turn on the 1K and 2K pot pumps. Open V1K and V2K to start helium gas flow through the 1K and 2K pots. Reduce the flow through the 5 valves above to maintain a flow rate of 3 liquid liters/hr. This will start cooling the 1 K Pot and the 2 K Pot.

3.3.7 Start the LHe fill start.

Once the helium-4 reservoir is below 40K (as measured by TI1200 on the top plate of the helium shield) for 1 hour it is possible to fill the reservoir with liquid. This is done by fully opening all flow control valves BR3, BR4, BR5, BR6 and BR7. Open Ball Valve VHB to allow a large gas flow. Monitor the liquid helium level gauge. The desired transfer rate is 1 liquid liter per minute. Initially this will cause a gas flow rate of 750 gas liters/minute, but as liquid begins to accumulate in the reservoir, this rate will drop. About 40 minutes is required for the transfer. Adjust the liquid supply dewar pressure as necessary to achieve this. Again monitor the flow rate using the gas totalizer.
If liquid fails to accumulate after 15 minutes close the ball valve VHB and continue with cold gas flow cooling for 1 hour. Then open VHB and repeat the liquid transfer procedure.

3.3.8 Finish the LHe transfer.

Once the liquid helium reservoir is full as shown on the superconducting liquid helium level gauge LM2, then close VFILL and vent the LHe supply cryostat. Remove the flex section of the transfer line from; the source dewar and disconnect it from the section remaining in the cryostat. Raise that portion of the transfer line which is in the helium bath by 15 inches but do not take it out of the top of the helium bath.

3.4 After The Liquid Helium Reservoir Is Full:

This section describes cooling the 1K and 2K pots to their operating points, and cooling the mixing chamber to about 10K

3.4.1 1 K Pot operation.

As the 1 K Pot starts to fill with liquid helium the flow through the needle valve CV1K will become excessive (PI1K too high). Switch CV1K to automatic control. The automatic control (PLC) uses the level sensor to monitor the 1 K Pot cooldown and closes the valve CV1K gradually to prevent excessive flow.

3.4.2 2 K Pot operation.

Similarly, the 2 K Pot flow control valve (CV2K) should be switched to automatic when it starts to fill.   Note that the magnet is cooled by a heat exchanger between CV2K and the 2K pot, and that cooling and filling the 2K pot will automatically cool the magnet bath to the same temperature. Since the magnet bath is directly connected to the helium reservoir at about 1 psig by an open pipe, this means that the magnet bath will automatically fill with helium at the 2K pot temperature.

3.4.3 Flow rate monitoring.

Monitor the flow rate and the cooling of the mixing chamber. As the flow rate rises slowly close CVBY by reducing its temperature set-point to keep the flow rate below 1.5 liters/min. When the mixing chamber reaches 5K, then close RTBY, leaving the flow through CVCF only. It may be necessary to adjust CVCF to keep the flow rate below 1.5 liters/min. After ten minutes close CVBY.

3.5 Cooling The Refrigerator To The Operating Temperature:

This section describes filling the refrigerator with its operating mixture of He-3 and He-4 from the storage reservoirs in the pump stand, and bringing the refrigerator to its operating temperature.

3.5.1 2K operating conditions.

By this point, the liquid nitrogen and liquid helium reservoirs have been filled, the magnet bath has been cooled to about 2 K, and the mixing chamber has been cooled to about 2 K. Helium gas is slowly circulating through the refrigerator through CVCF.

3.5.2 NV17 control.

Slowly open NV17 to meter the working mixture into the system, maintaining a condensing pressure of less than 700 mBar (PI4). When NV17 is fully open, then open V17. After five minutes close V17 and NV17.

3.5.3 Tuning.

Once the fluid has been condensed to the mixing chamber and the still, tune the refrigerator for the desired low temperature. The parameters to use are the still heater power and the setting of the flow restriction valve above the counterflow heat exchanger (CVCF). After each change allow the refrigerator to come to equilibrium (approx. 30 minutes). The refrigerator may also be sensitive to the amount of He_3 condensed in the system, and this may be varied by adding or removing gas in the circulation stream, using the He_3 tank as the source or dump for the gas.

3.6 Loading The Target Into The Cryostat:

This section describes the procedures to be followed to load a target into the IBC and return the refrigerator to its operating temperature.

3.6.1 Roll the IBC back to the tipping location.

3.6.2 Preparing the refrigerator.

The target is loaded into the refrigerator at about 2 K and this may cause a bump in the turbopump inlet pressure. Hence before loading, one should select Low Speed on the turbopump controller (allow 30 minutes for the turbopump to slow) and the still power should be reduced to zero.

3.6.3 Check the level in the cryostat LHe reservoir

One will have to determine if there is enough helium (~25% full, ~11 liters LHe) in the reservoir to last for the time required to load the target. If not, then a helium refill transfer should be done. Note that when the cryostat is tipped, there will be a step change in the helium level read-out. This is because the helium level sensor is located on the high side (when the cryostat is tipped) of the helium reservoir.

3.6.4 Refill the cryostat LN_2 reservoir

It is prudent to do a manual fill of the cryostat liquid nitrogen reservoir before tipping and starting the target load (if only to avoid the shock of an automatic fill starting when engaged in the loading procedure). Do this fill by:

3.6.4.1 Disconnect the electrical connector to the LN_2 fill solenoid

3.6.4.2 Connect this connector to a 110 VAC source. This will start an LN_2 flow into the LN_2 phase separator.

3.6.4.3 Monitor the LabVIEW Main Page. When the LN_2 Bath top (of 3) lights turns green, disconnect the extension cord to stop the LN_2 flow. (Alternatively, since the LabVIEW Main Page has a refresh time of about 1 minute, one may see liquid spraying from the LN_2 reservoir vent before the top light shows green. This is an adequate signal to stop the fill.)

3.6.4.4 This fill will last about 3 hours before another fill is required.

3.6.5 Energize the magnet.

On the LabVIEW Magnet page set the magnet current setpoint to 100 A. Wait for the magnet to be fully charged.

3.6.6 Tip the cryostat to 25 degrees snout down.

3.6.6.1 Release the hold down screws on the two zero degree posts and release the clamp on the tilting handwheel.

3.6.6.2 Slowly turn the handwheel, lowering the snout until one reaches the 25 degree stop posts. Install the holding screws into these posts. During the lowering procedure, monitor the target parameters (principally turbo inlet pressure and helium reservoir exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level.

3.6.7 Procedure for target installation

3.6.7.1 Connect the transfer cryostat to the in-beam cryostat

3.6.7.2 Evacuate the connection space between the two cryostats to less than 10^{-4} Torr

3.6.7.3 Open the two transfer vacuum valves

3.6.7.4 Open the in-beam cryostat shutter

3.6.7.5 Insert the target holder and screw it to the refrigerator

3.6.7.6 Remove the target transfer mechanism

3.6.7.7 Close the two transfer vacuum valves

3.6.7.8 Close the in-beam cryostat shutter

3.6.7.9 Disconnect the transfer cryostat from the in-beam cryostat

3.6.8 Tip the cryostat back to zero degrees

3.6.8.1 Release the hold down screws on the two 25 degree posts and release the clamp on the tilting handwheel.

3.6.8.2 Slowly turn the handwheel, raising the snout until one reaches the zero degree stop posts. Install the holding screws into these posts. During the raising procedure, monitor the target parameters (principally turbo inlet pressure and helium reservoir exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level

3.6.9 Cooling the refrigerator back down

3.6.9.1 As the turbopump inlet pressure allows, bring the turbo back to full speed.

3.6.9.2 Raise the still power back to its value before the transfer.

3.6.9.3 Tune the refrigerator as in section 4.5.

3.7 7K Test Instructions:

This section describes the 7K mode operation. This mode is unique to this refrigerator and is to allow a gentle warming of the target to a controlled temperature, **WITHOUT OVERSHOOTING THE TEMPERATURE**. An overshoot (for example to 9K) would cause the hydrogen to sublime and spoil the vacuum and the target would be lost.

In Dilution Refrigerator (DR) mode of operation the target temperature is very stable because of the large thermal heat capacity of the liquid helium in the mixing chamber. In the "7K" mode that helium is boiled off and there is little heat capacity left. At constant heat there will be a huge change in the slope of the temperature graph. While the helium is liquid the temperature will remain constant. When the liquid is all gone the temperature will rise suddenly and rapidly. **PROCEED WITH EXTREME CAUTION!!!**

3.7.1 Theory of operation

The 1K pot valve is set to a fixed manual constant value to provide a constant amount of cooling. The CVBY valve is opened to bypass the heat exchanger and provide the cooling directly to the mixing chamber. One automatic control loop controls the temperature of the 1K pot. After the liquid has all boiled out of the 1K pot then its temperature rises above 4K enabling a software interlock so that a second control loop can be activated. This second loop controls the temperature of the mixing chamber by slowly ramping it up to the desired set point. (The 4K interlock [PLC address v3700] is to prevent heating the mix while liquid He-3/4 is still condensing in the heat exchanger on the 1K pot because injecting slugs of liquid rather than a continuous flow of cold gas will cause severe temperature swings).

It is also possible to make this happen by setting the controls manually, but this is not recommended because of the overshoot hazard.

NOTE: in either case this involves removing a substantial quantity of liquid from the DR and returning it to the dump tanks.

3.7.2 Before starting:

Get ready for about 1-1/2 hours of concentration (refreshments? ...)

3.7.3 Procedure for Helium removal from 1K pot.

3.7.3.1 Turn both Turbo Pumps ON and set to Low Speed (LS).

Set the turbopump(s) to low speed mode, just to protect them because this procedure vents a lot of gas.

3.7.3.2 Remove manually He-3 to working mixture storage tank.

- Open CV18 valve to let gas back to storage tank.
- Close the gas cleaner outlet valve.
- Heat the still and mix to 2-3 K, keep Pi1 below 0.1 Torr.
- Close CV18 and slowly open the gas cleaner valve to let some gas circulate again.

3.7.3.3 Ensure that valve on working mixture storage dump tank is open (it is normally always open when operating), also open the manual bypass valve (RTBY) on cryostat.

3.7.3.4 Set CV1K to manual mode with a temperature set point of 160K (valve at 152K). This sets the required cooling flow of He-4.

3.7.3.5 Set CVBY valve to manual mode with a temperature set point of 182 (valve at 172K). This sets the required flow of He-3/He-4 mixture.

3.7.3.6 Turn on 1K pot heater mode QPHASE=8 with 1K set temperature of 4K HET1K on AUTO.

3.7.3.7 Wait and monitor while the 1K pot slowly empties of liquid He-4.

Watch closely as the level approaches zero (0 = 2-3%). Be prepared to turn off the 1K pot heater in the event of a rapid temperature rise. During the boiloff of helium the 1K pot heater may be about 14% duty cycle. Once the helium is gone the heat must reduce to about 1%.

Emptying the 1K pot Helium bath takes about 1 hour starting at 10% full. Half of that time the level reading is zero (below the level sensor), but do not be fooled! As long as there is large heat input and a cool temperature there is still liquid boiling.

It is recommended to manually limit the heat level of the 1K pot by switching the 1K pot heat mode off and then on again once the 1K pot level is below 10% and to repeatedly switch if off and on every 5 minutes until the pot is empty. This is done by switching from QPHASE=8 to QPHASE=5. The purpose is to reduce the applied heat in anticipation of a rapid temperature rise. The automatic algorithm only slowly increases the heat 1.5% per step, so by switching it off then on it goes up slowly.

NOTE: In one test of boiling off the 1K pot the temperature rose from 3.8K to 10K in a single data point!!! This was at 20% heater power on the 1K pot – clearly too much. (Fortunately the mixing chamber remained cold, because it still has liquid in it).

Table 6 "1K Pot" Heater Setpoints (in %).

SET POINT	TYPICAL HEAT INPUT	
3.0 K	6 %	
3.5 K	11 %	
4.0 K	14 %	
4.5 K	16 %	More would be too much heat

Do not exceed 20% heat to avoid overshoot.

3.7.3.8 Once the 1K pot temperature has stabilized around 4K then increase its set point to 4.5K and wait 5 minutes for stabilization.

3.7.4 Procedure for steady MIX chamber warmup to 7 K.

3.7.4.1 Wait for Ti1K temperature to stabilize.

3.7.4.2 Set cryostat heaters MIX and HSTILL both to AUTO mode. Then turn on the 7K mode with a set point of 3.5K.

After temperature (Ti101) has stabilized gradually increase the set point until the desired temperature is reached. In the event of any difficulty turn the 7K mode off and leave it off for 5 minutes, then on again and the ramp up will automatically recommence slowly. Do not turn off then immediately back on – it may cause an overshoot.

3.7.4.3 Once everything is stabilized, it is possible to improve the temperature stability by switching the 1K pot heater to manual. As an initial setting use a little less heat than the automatic mode. ~ 1% duty cycle.

3.7.5 Return to cold operation.

3.7.5.1 Switch off the 7K heat mode. (This turns off the MIX and STILL heaters)

3.7.5.2 Switch back to normal operation QPHASE=5. (This turns off the 1K pot heater).

3.7.5.3 Switch the 1K valve back to automatic (This allows it to automatically keep the 1K pot full).

3.8 Removing The Target From The In-Beam Cryostat:

This section describes the removal of the target from the IBC. Before the target retraction device (assumed to be at about 2 K) can be attached to the target, the refrigerator must be prepared for the accompanying temperature rise. Select Low Speed on the turbopump controller (allow 30 minutes for the turbopump to slow) and set the still power to zero

3.8.1 Move the in-beam cryostat to the insertion position

3.8.2 Check the level in the cryostat LHe reservoir

One will have to determine if there is enough helium in the reservoir to last for the time required to load the target; for example; if the job may take up to 3 hours, the reservoir should be at least 25% full, ~11 liters. If not, then a helium refill transfer should be done. Note that when the cryostat is tipped, there will be a step change in the helium level read-out. This is because the helium level sensor is located on the high side (when the cryostat is tipped) of the helium reservoir.

3.8.3 Refill the cryostat LN_2 reservoir

It is prudent to do a manual fill of the cryostat liquid nitrogen reservoir before tipping and starting the target load (if only to avoid the shock of an automatic fill starting when engaged in the loading procedure). Do this fill by:

3.8.3.1 Disconnect the electrical connector to the LN2 fill solenoid

3.8.3.2 Connect this connector to a 110 VAC source. This will start an LN2 flow into the LN2 phase separator.

3.8.3.3 Monitor the LabVIEW Main Page. When the LN2 Bath top (of 3) lights turns green, disconnect the extension cord to stop the LN2 flow.

3.8.3.4 This fill will last about 3 hours before another fill is required.

3.8.4 Energize the magnet.

On the LabVIEW Magnet page set the magnet current setpoint to 100 A. Wait for the magnet current to ramp up.

3.8.5 Tip the cryostat to 25 degrees snout down.

3.8.5.1 Release the hold down screws on the two zero degree posts and release the clamp on the tilting handwheel.

3.8.5.2 Slowly turn the handwheel, lowering the snout until one reaches the 25 degree stop posts. Install the holding screws into these posts. During the lowering procedure, monitor the target parameters (principally turbo inlet pressure and helium reservoir exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level.

3.8.6 Procedure for target removal

3.8.6.1 Connect the transfer cryostat to the in-beam cryostat

3.8.6.2 Evacuate the connection space between the two cryostats to less than 10E-4 Torr

3.8.6.3 Open the two transfer vacuum valves

3.8.6.4 Open the in-beam cryostat shutter

3.8.6.5 Insert the target holder and screw it to the target, loosening the target from the refrigerator

3.8.6.6 Remove the target

3.8.6.7 Close the two transfer vacuum valves

3.8.6.8 Close the in-beam cryostat shutter

3.8.6.9 Disconnect the transfer cryostat from the in-beam cryostat

3.8.7 Tip the cryostat back to zero degrees

3.8.7.1 Release the hold down screws on the two 25 degree posts and release the clamp on the tilting handwheel.

3.8.7.2 Slowly turn the handwheel, raising the snout until one reaches the zero degree stop posts. Install the holding screws into these posts. During the raising procedure, monitor the target parameters (principally turbo inlet pressure and helium reservoir exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level.

If one wishes to keep the refrigerator running, raise the turbopump speed back to full speed and return the still power back to the value used before removal of the target.

3.9 Warming The In-Beam Cryostat:

This section describes the procedures to be followed to recover the operating gas mixture from the refrigerator, turn off the magnet, turn off the pumps, set the valves, and allow the IBC to warm to room temperature.

3.9.1 Ramp down and turn off the magnet power supply

3.9.2 Recover the gas from the refrigerator

3.9.2.1 Open CV18 and close V12. After PIMXS drops substantially, open V24 slowly (don't let PI2 rise too high).

3.9.2.2 Turn on the mixing chamber heater

3.9.2.3 When the mixing chamber temperature rises above 2 K, reduce the mixing chamber heater to maintain this temperature. When the pressure at PI1 drops to zero (all gas recovered), turn off the mixing chamber heater and turn off the still heater. Close CV18 and V30.

3.9.2.4 Close V16 and V24.

3.9.2.5 Close CVCF.

3.9.3 Close V1 and V23 and turn off TP1.

3.9.4 Close V4 and V28 and turn off the rotary mechanical pump M151b

3.9.5 Turn off the automatic LN_2 filler to the cryostat LN_2 reservoir (CVLN2)

3.9.6 Close CV1K and CV2K.

3.9.7 Close V1K and V2K.

3.9.8 Turn off 1K pot and 2K pot pumps.

3.9.9 Leave cryostat to warm naturally (about 2 days) to above 273 K.

3.10 After The Cryostat Has Warmed:

This section describes the procedures required for the final shut-down of the IBC. After the cryostat has warmed to above 273 K.

3.10.1 Close all remaining valves and turn off all remaining pumps.

4 ASSEMBLY PROCEDURE

4.1.1 Preparation of the cryostat vertical insert:

4.1.1.1 Wiring complete and extending to bottom ready to solder.

4.1.1.2 Helium shield installed and insulated, NMR leads checked for shorts to ground and each other.

4.1.1.3 Nitrogen shield installed and NMR leads checked for shorts

4.1.1.4 Bypass LN_2 heat exchanger bolted on outside of LN_2 shield (near top) with thermal grease.

4.1.1.5 Iris opener LN_2 heat exchanger bolted on with thermal grease.

4.1.1.6 LN_2 snout heat exchanger fitted for close fit to braid, checked for flat, bolted to braid and soldered lightly at two holes in Cu plate. Use sanding block to confirm that the Cu plate is reasonably flat.

4.1.1.7 Attach LN_2 shield sensor (Ti 1301 - RED) to the LN_2 shield.

4.1.1.8 Tape wires for Ti 200 (VIOLET) and T1 1300 (YELLOW) to the LN_2 shield with excess

4.1.1.9 Super-insulate LN_2 shield.

4.1.1.10 Check NMR cables again.

4.1.2 Install the snout on the cryostat.

(The snout assembly must be complete with NMR cables installed and alignment finished and checked.) The heat exchanger for the magnet must be installed.

4.1.3 Install three LN_2 shield extensions.

Install three LN_2 shield extensions to the snout LN_2 shield root. For each shield use 2 x ¼” x 10-32.

4.1.4 Drop the vertical cryostat insert into the cryostat

Drop the vertical cryostat insert into the cryostat (feeding the magnet wire from the snout into the connection port). Stop the drop when there is still about one inch to go, for the next step. (Before dropping the insert in, it must be complete with all wiring done and properly anchored, shields in place, and super-insulation installed.) shields (all three) reaching up from below go outside the 80K leg reaching down from above and inside the 80K superinsulation.

4.1.5 Attach the thermal connections.

Attach the thermal connections from the vertical section LN_2 shield to the snout LN_2 shield root using five 3/4” 10-32 screws. Use lift to rotate flange after getting 1 started.

4.1.6 Remove flange.

If it has been removed, then install the cut-out in the 4K shield (this cut-out allowed access to install the screws in part 5 above). Hold this cut-out in with aluminium tape applied along the joint on the inside of the shield. Fold up the aluminium tape from the 20K shield aluminium extension tube. Add more tabs hanging down from the taped in aluminium half moon.

4.1.7 Mount the temperature sensor.

Mount the temperature sensor to the copper tab on the 20K shield (4-40 screw and nut).

4.1.8 Connect the 20K shield heat exchanger.

Connect the 20K shield heat exchanger with three 3/8” or 1/2” 10-32 screws.

4.1.9 Install the indium gasket on the snout magnet connection port.

Lower the insert further so that this joint can be bolted using (4) ½” 6-32 screws. Arrange the nuts so that there is minimum projection towards the Iris Opener.

4.1.10 Connect Ti 202 sensor directly to Magnet flange.

Use Indium gasket and ½” x 4-40 screw with washer and lock washer.

4.1.11 Make the magnet electrical connections in two lap joints.

The individual leads from the magnet are three wires twisted and soldered together. The six wires from the power supply are wrapped as a sheath around these three wires, in the same direction as the three wires are twisted. Then the whole bundle is wrapped with a bare copper wire, with a pitch of 1 mm. This results in a joint about 4”-5” long. This joint is fluxed with acid flux and soldered with aqua-sol solder, using a large iron. The flux is washed away with a wet cloth. This process is repeated for the second connection.

4.1.12 Lap joint installation.

Cover each lap joint with heat shrink tubing and install a one inch length of teflon tubing around both leads and into the tee-joint. (This teflon tubing must be of sufficiently small diameter to fit into the tube that forms the cap over the lap joints. The tube acts as a shield under the soft solder joint that will be made soon.)

4.1.13 Solder the magnet lap joint cover.

(Cool the indium joint when doing this soldering.) Leak check this connection and the indium joint.

4.1.14 Final leak check.

[OPTIONAL: leak check all of these joints now. Repeat leak test will be made with the cryostat evacuated.]

4.1.15 Connect the five gas joints to the snout.

(MC supply, top, and return, bottom, Magnet bath vent line (from side of elbow into Magnet bath), and Magnet root heat exchanger (2 lines on bottom side). Check these pipes for flow

Air flow rate: 3He cvcf + bypass=410cc/30s; @15psi air
3He cvcf only=175 (+/-10) cc / 60s; @15psi air
Magnet vent = huge @ 4psi air.

[OPTIONAL: leak check all of these joints now. Repeat leak test will be made with the cryostat evacuated.]

4.1.16 Do sensitive leak test of all internal cryostat plumbing.

Put the bottom, two sides and back (iris port) cover plates on to leak check everything inside vacuum can. During leak checking, some open gas connections on top of the dewar should be plugged and all internal plumbing should be pumped out. Backfill each section of internal plumbing to leak check.

After leak checking, the main vacuum vessel should be SLOWLY vented to atmosphere for Iris opener insertion.

4.1.17 Install the Iris Opener.

The LN_2 tabs on the 77K shield will have to be tied down with steel wire, and the vertical insert will have to be raised ~1/2" to provide clearance. The installation is done with the leading edge raised, to help get by the shields of the vertical insert.

Align the Iris opener with the inner tube of the snout by pushing Iris opener UP AND TO RIGHT before tightening the bolts. Keep trying until it is right.

Lower cryostat top plate to seal upper O-ring. Insure that the upper O-ring is clear (no superinsulation across the O-ring).

4.1.18 Connect the thermal straps.

Connect the thermal straps from the vertical insert LN_2 shield to the Iris Opener 77K shield with ¼-20 x 0.58" long hexagon head screw. Put on lower straps first on both side of the Iris opener. Put Apiezon-N grease under the thermal strap for thermal contact.

4.1.19 Connect the 4K heat exchanger.

Connect the 4K heat exchanger to the Iris Opener 4K shield with Apiezon-N thermal grease.

4.1.20 Fold down Al flaps from 4K shield to iris opener 4K Cu can.

4.1.21 Attach the Iris Opener 77K and 4K thermal sensors.

4.1.22 Make the electrical connections to the snout.

(M/C heater, 4 M/C temperature sensors, 2 of 4 NMR cables, currently using #2 and #3). Check the connections for continuity and grounding.

At this time, all sensors except Ti1201 (Bottom of 4K shield) Should be connected and functioning. Use the LabView Main Page and Controls Page to read the temperatures. Sensors T1 102, 104 and MxBNL are RuOx and do not function at RT. These resistances can be measured directly, as well as the resistances of all heaters (Table 7 Connector M pin assignment.).

It is difficult to see the pin numbers on Connector M. A sketch is shown here:

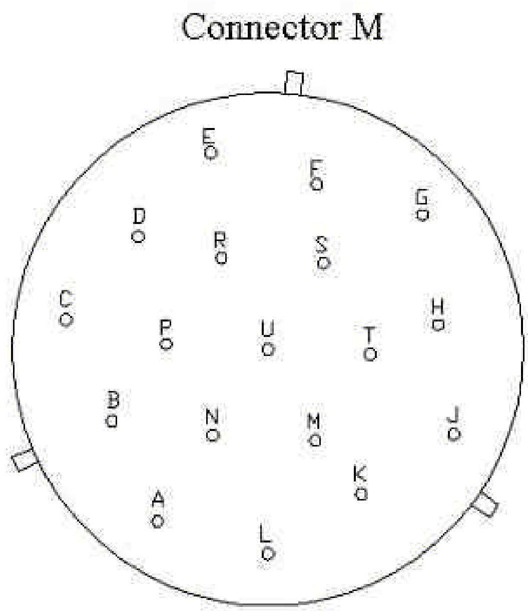


Figure 2 Connector M pin assignment.

Table 7 Connector M pin assignment.

Conn.	Pins	R	Object
A	AB	1062	Ti 102, I+/-
A	CD	1062	Ti 102, V+/-
A	BH	1023	Ti 104, I+/-
A	JK	1023	Ti 104, V+/-
B	JK	549	1K Pot Heater (Spare)
C	GH	2086	Ti MxBNL, I+/-
C	JK	2086	Ti MxBNL, V+/-
E	AH	366	Film Burner
E	BC	27	CH200
E	BD	546	1K Pot Heater
E	EF	480	Still Heater
E	EG	477	Mix Chamber Heater
E	JK	513	2K Pot Heater
M	MN	467	Still Heater (Spare)
M	GL	49	CV1K Actuator Heater
M	TK	47	CV2K Actuator Heater
M	JU	47	CVCF Actuator Heater
M	PH	50	CVBY Actuator Heater

4.1.23 Install the bottom of the 4K shield.

Use Apiezon-N on the bolt tabs at the top. Use (4) ½” x ¼ - 20 bolts. Use Al tape to cover the crack between top and bottom shield sections.

4.1.24 Connect the 4K shield thermal sensor.

Cover two large holes in 4K shield with Al plate and tape.

4.1.25 Install the two 4K side shield cut-outs.

Use Al tape to seal the gap. Complete the superinsulation.

4.1.26 Install the bottom of the 77K shield.

The three LN_2 shield extensions attached to the snout have to be outside the 77K can and the can has to be in between the Al posts (4K and 77K). Use Apiezon-N on (4) vertical tabs at top, bolt with (4) ½” ¼ x 20 hex head bolts.

4.1.27 Install LN_2 cooling pipe to the bottom half of 77K shield.

Use Thermal grease under Cu connection plates. Complete the superinsulation.

4.1.28 Install the bottom cover flange.

4.1.29 Install the two side access flanges.

Use long studs in 4 locations on each side plate, as marked, for tip trolley hard stops.

4.1.30 Pump cryostat down.

Do a final overall leak. First check all flanges and top plate connections at RT. Then (OPTIONAL - cool to LN_2 temperature overnight to) leak check by pumping each distinct volume in the cryostat and back-filling each with helium to 1 atm. (This includes the He-3 system and the He-4 system.) Also blow some helium into the LN_2 reservoir and out its vent line.

4.1.31 Install the cryostat to the tip trolley.

5 GENERAL SYSTEM DRAWINGS

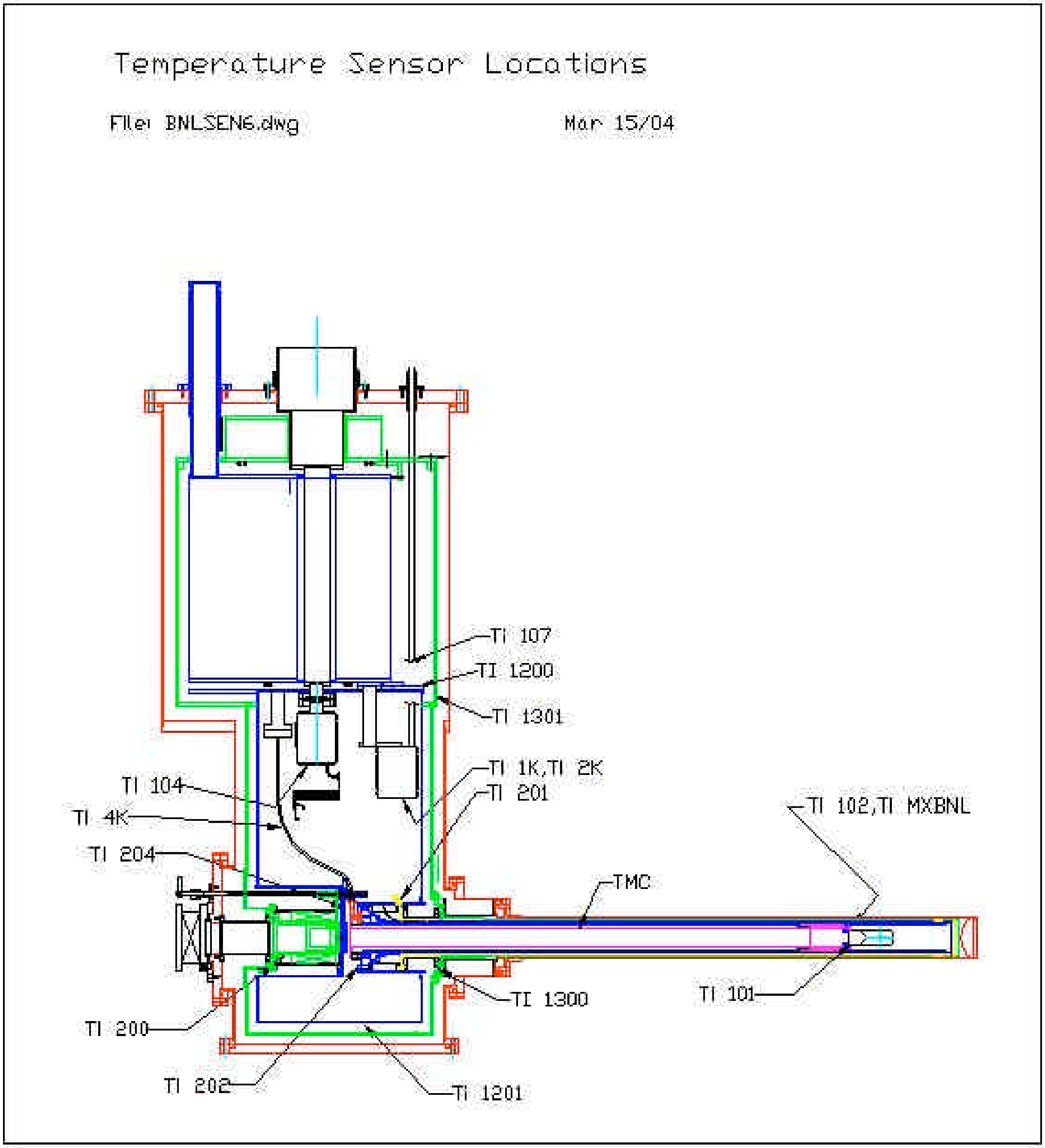


Figure 3 Physical location of temperature sensors.

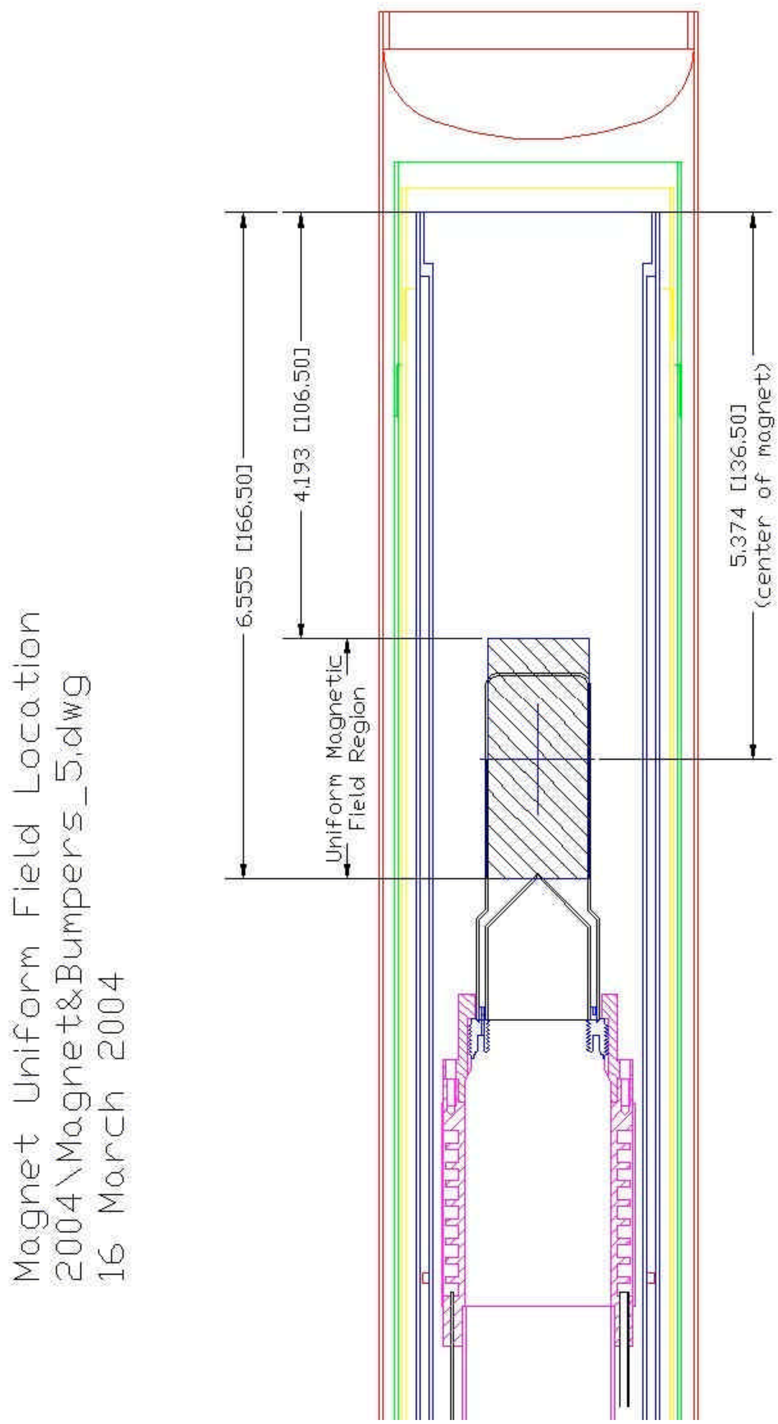


Figure 4 Magnet Uniform Field Location.

BNL45P_measured dimensions.dwg

Showing some 'as measured' dimensions to the target and magnet can

March 15/04

NOTE: The dimensions shown are not scaled to the drawing

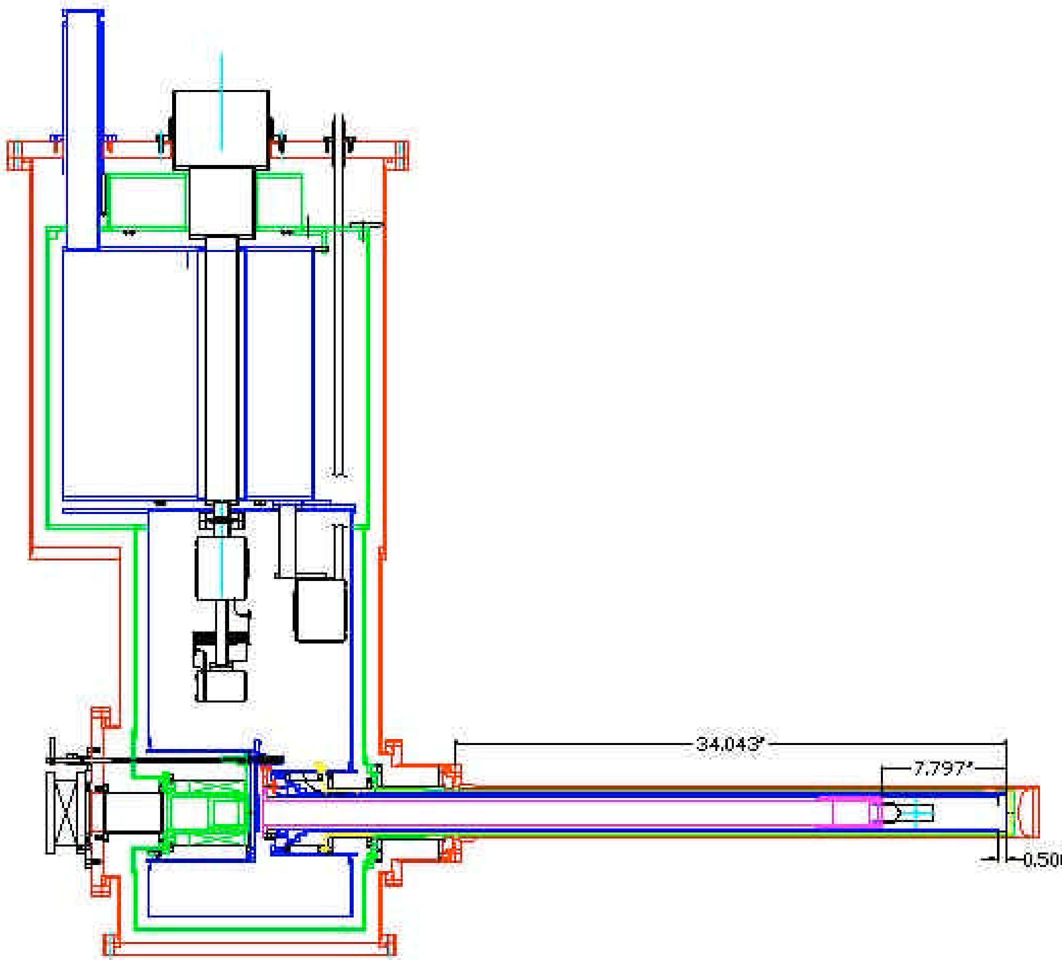


Figure 5 Target Location Measured Dimensions

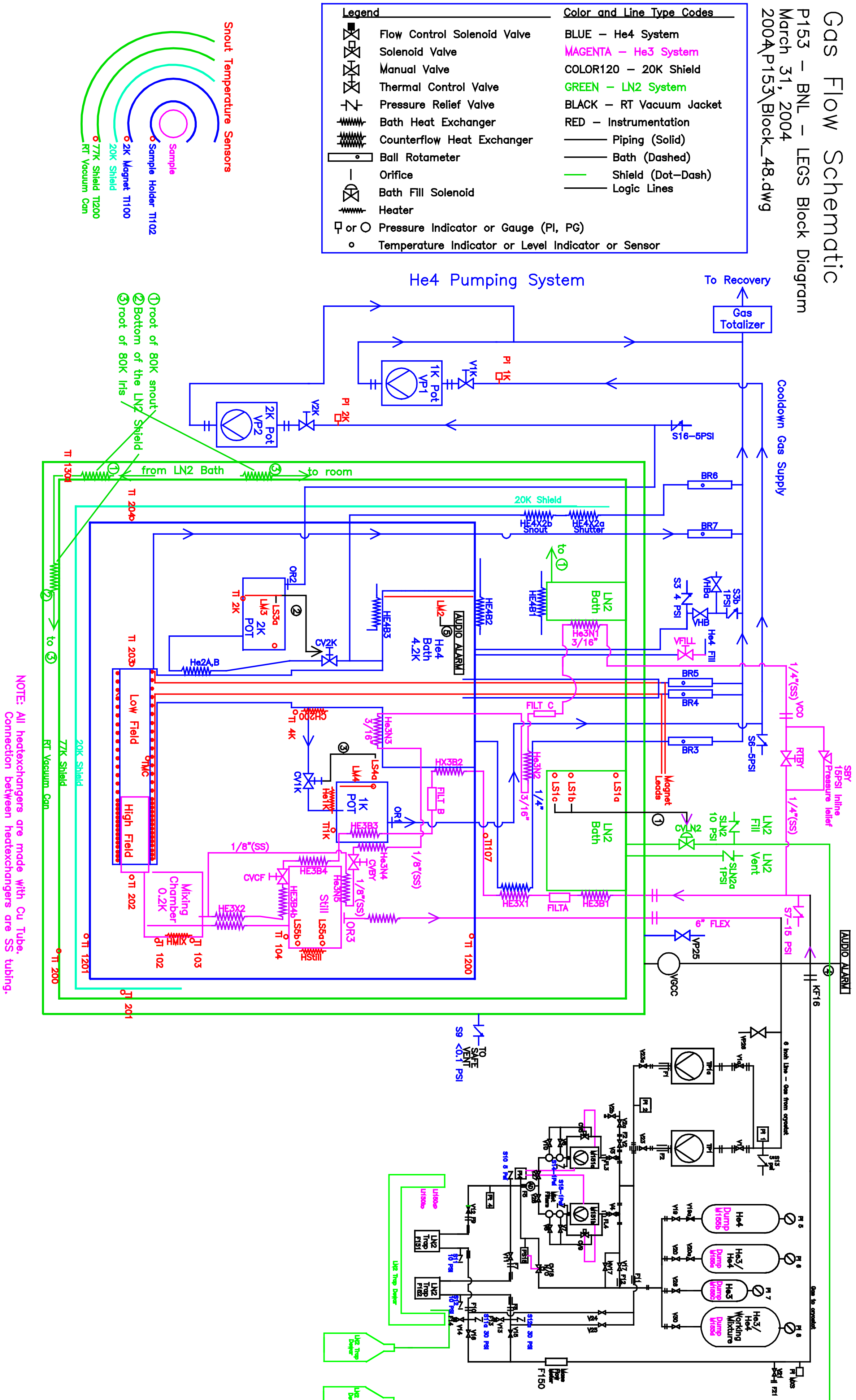


Figure 6 Gas Flow Schematic

Gas Flow Schematic

P153 — BNL — LEGS Block Diagram
March 31, 2004
2004\P153\Block_48.dwg

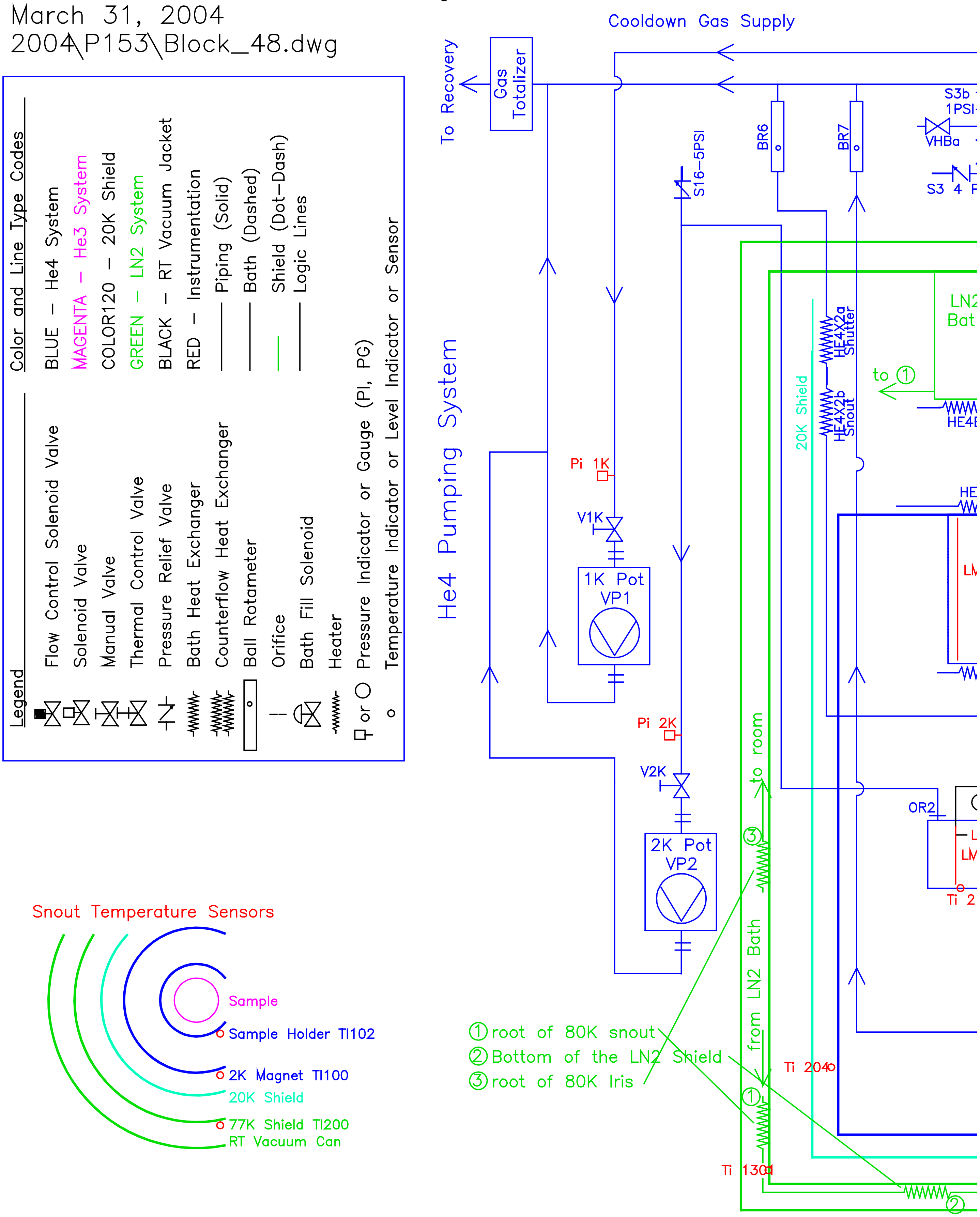


Figure 6a Gas Flow Schematic

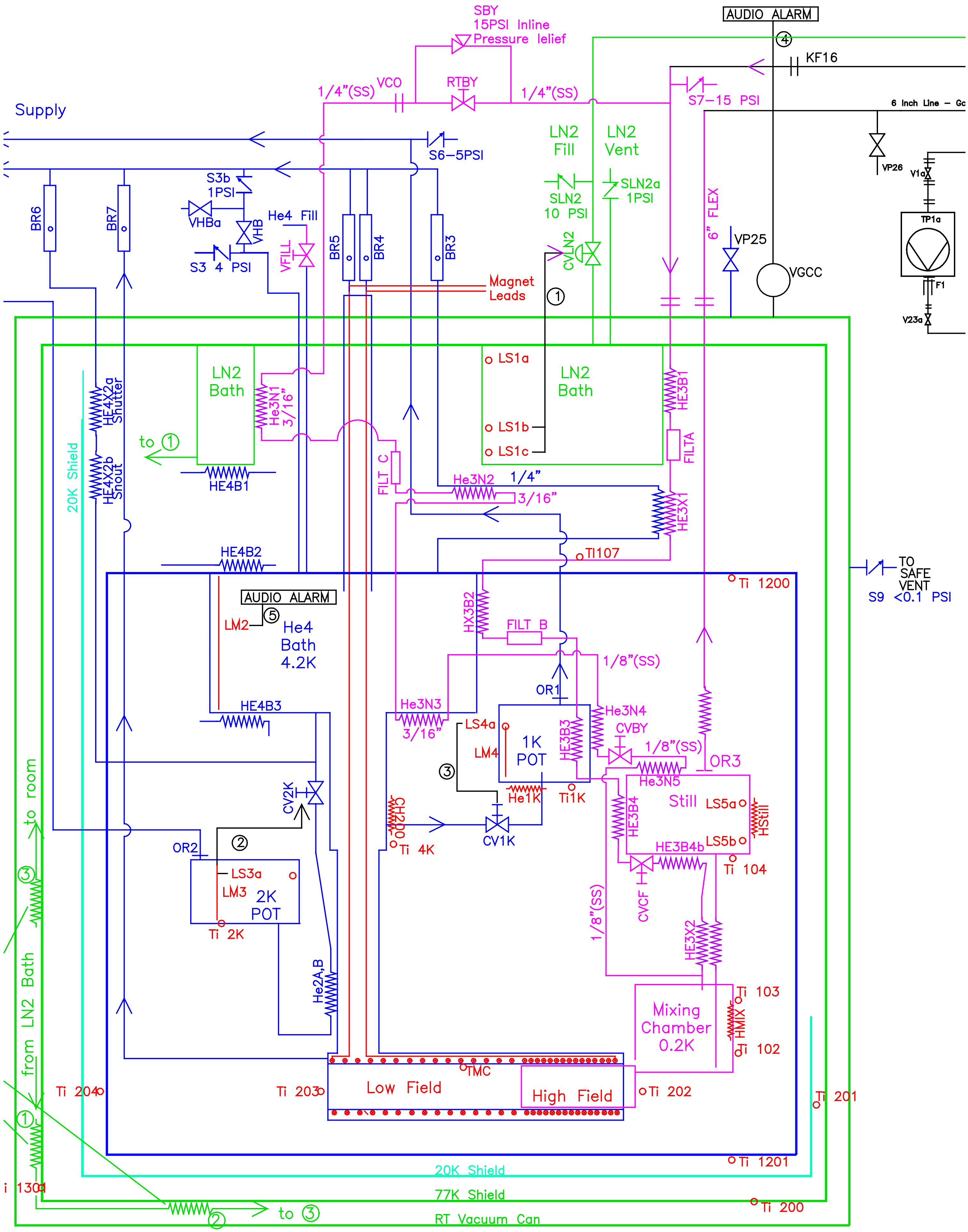
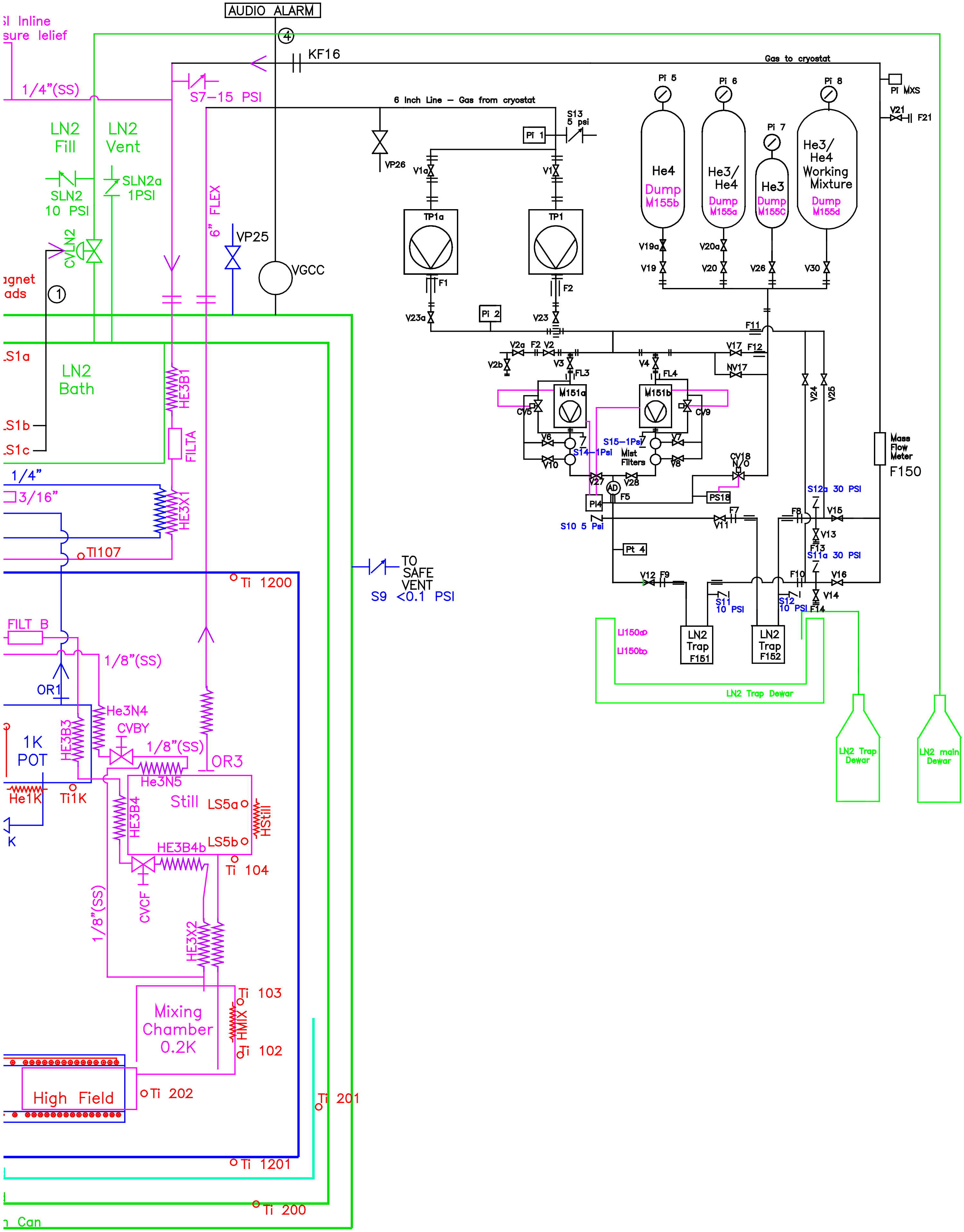


Figure 6b Gas Flow Schematic

NOTE: All heatexchangers are made with Cu Tube.
Connection between heatexchangers are SS tubing.



ngers are made with Cu Tube.
etween heatexchangers are SS tubing.

Figure 6c Gas Flow Schematic

6 PICTURES

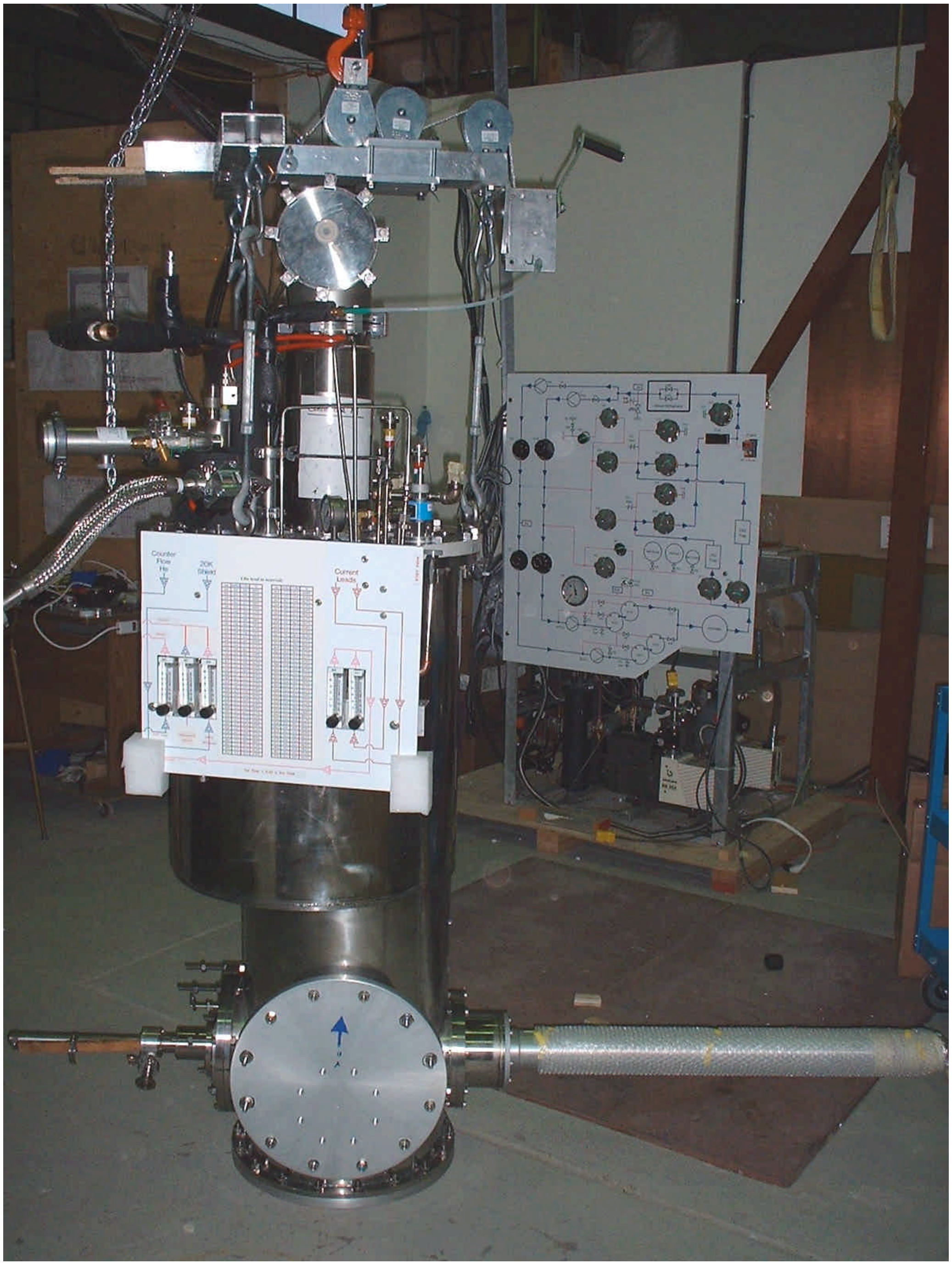


Figure 7 General view.

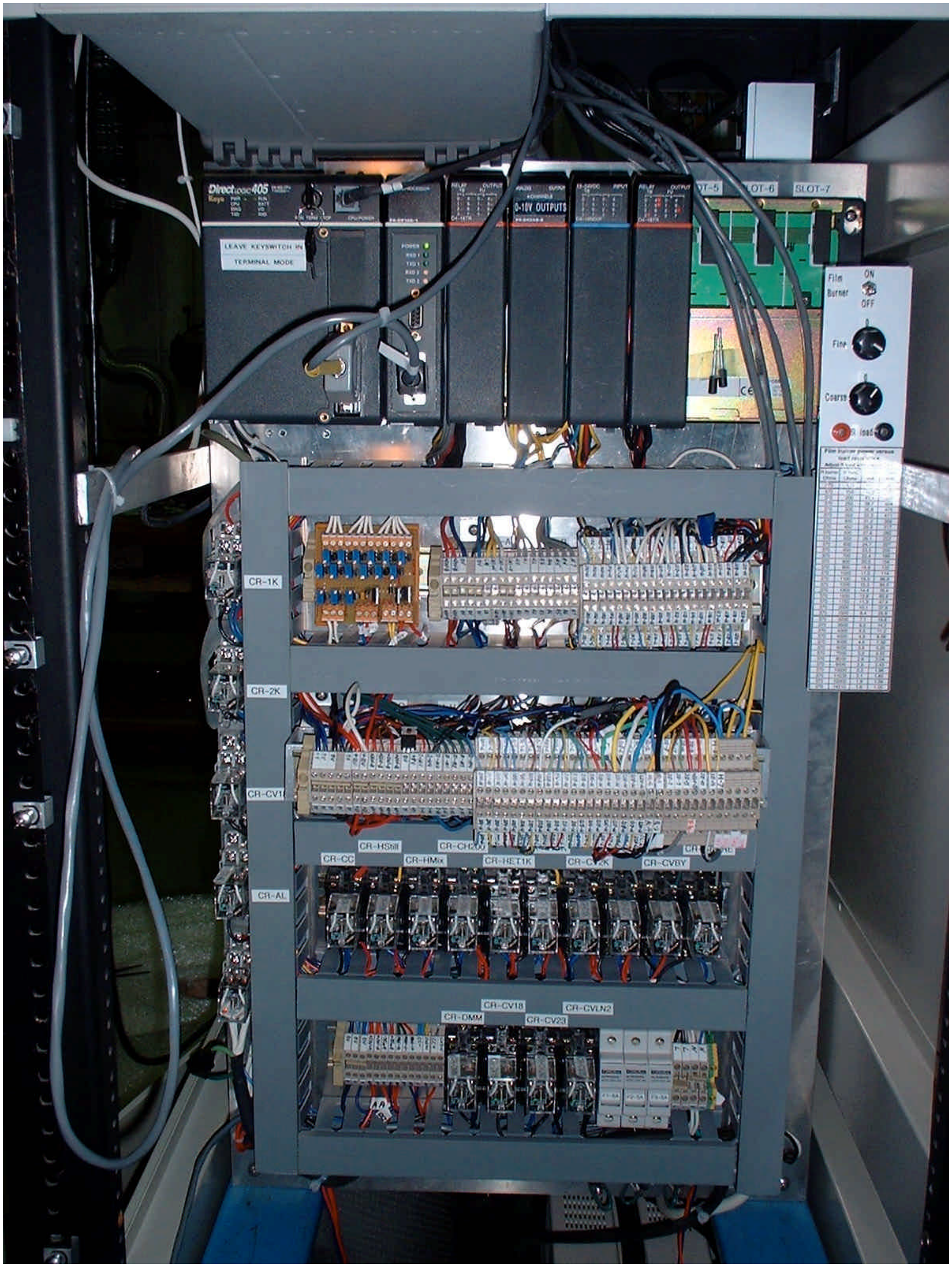


Figure 8 Electrical rack.

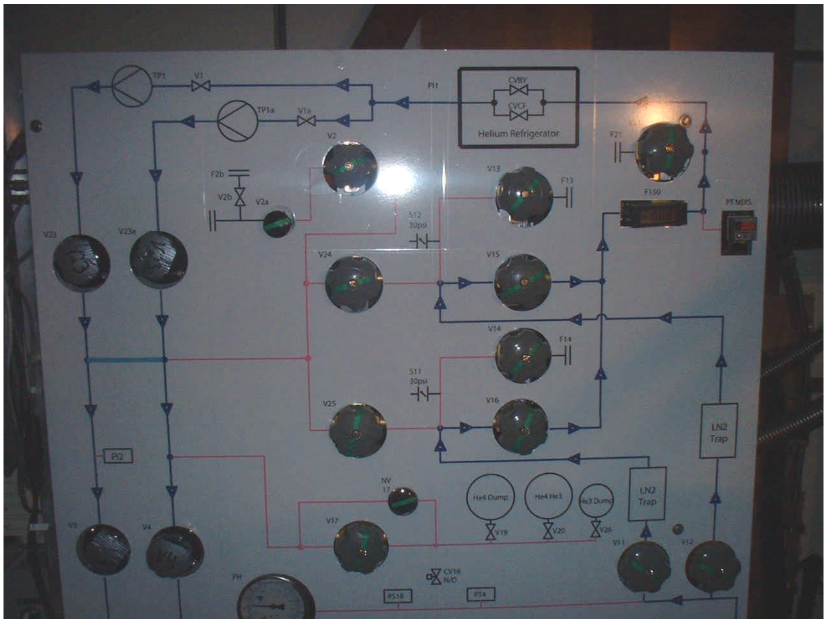


Figure 9 Gas Flow System.

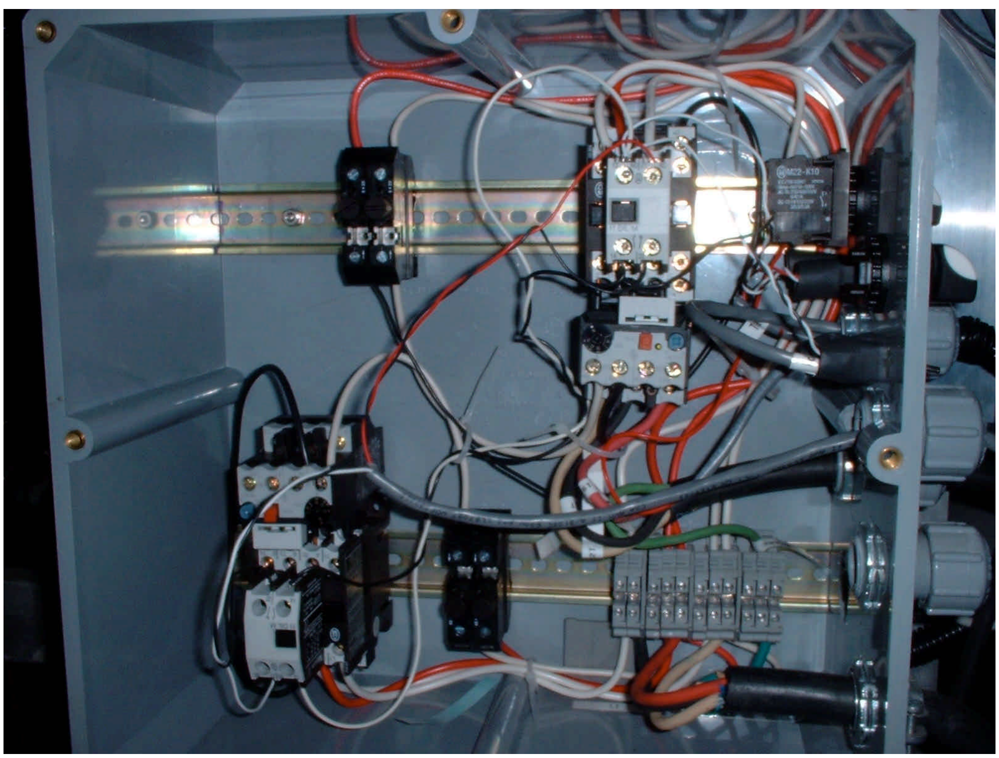


Figure 10 Pump control box.

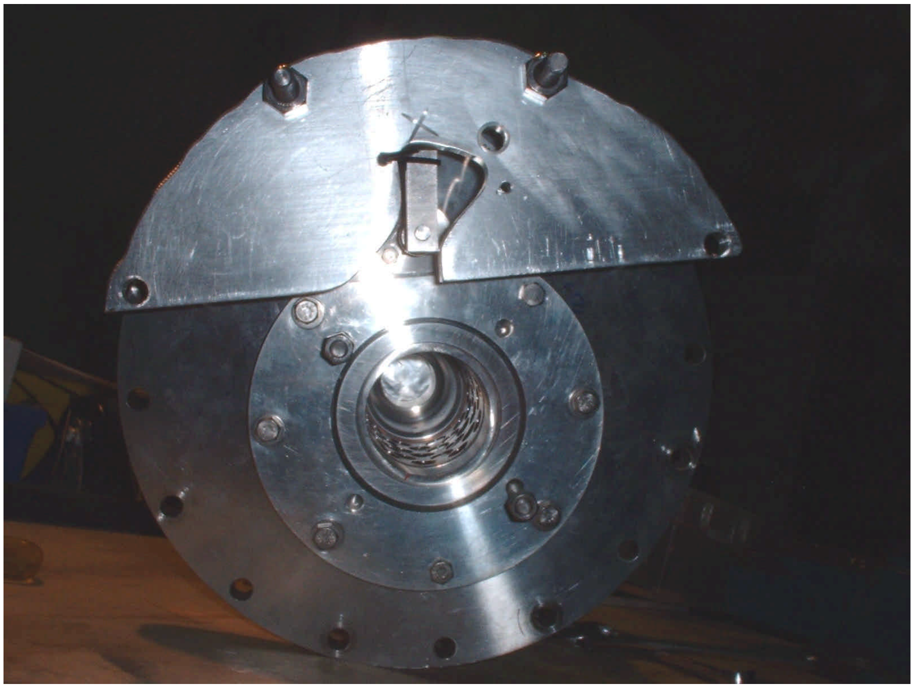


Figure 11 Shutter control lever in CLOSED position.

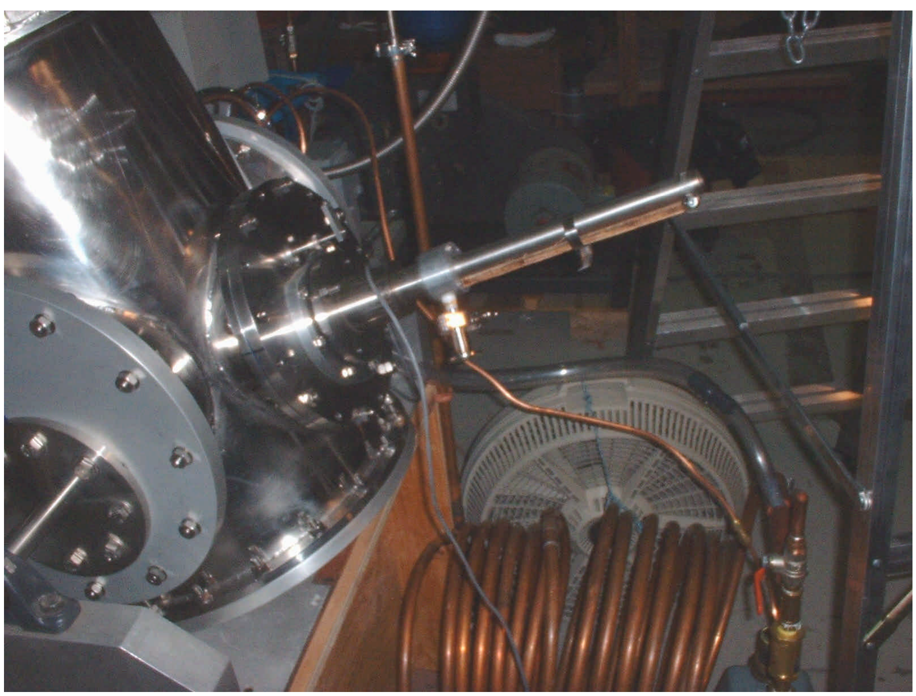


Figure 12 Cryostat in tilt position.

7 TROUBLESHOOTING

7.1 Plugging of He_3 return line.

If the refrigerator should block, causing the flow of helium-3 to stop, then the mixing chamber will begin to warm. It is almost certain that the blockage is at the level of the liquid helium reservoir. In this case one can open RTBY and CVBY and operate the refrigerator, probably somewhere between 0.7K and 1.0K for a sufficiently long period to recover the target.

Before doing this, it would be a good idea to change gas cleaners and to pump all of the gas in the helium-3 return line to the cryostat back into the pumps, so that it can have one more pass through a fresh gas cleaner before it goes into the refrigerator.

7.2 Response to a pump failure:

7.2.1 The four pumps and their associated inlet and outlet valves.

Turbopump TP1	Inlet valve V1	Outlet valve V23
Turbopump TP1a	**Inlet valve V1a**	**Outlet valve V23a**
Alcatel pump M151b	Inlet valve V4	Outlet valve V28
Alcatel pump M151a	**Inlet valve V3**	**Outlet valve V27**

Table 4 Valves controlling the pumps.

7.2.2 Abnormal pump functioning indicators.

There must be some reason that one suspects that a pump is not running properly. Perhaps the pump inlet pressure is unusually high, or a turbopump front display panel indicates off, or an Alcatel pump is to quiet or vibration free. Two things to check are the circuit breaker for the pump and the cooling water flow (if the cooling water to the Alcatel fails, then the pump will overheat and turn off on an overtemperature switch. When the Alcatel goes off, then the turbopump also turns off.).

7.2.3 General pump switching notes.

If one decides that one wants to switch to another pump (maybe to let the original one cool), then close the pump inlet and outlet valves and set the pump ON/OFF switch to OFF.

7.2.4 Switching to another Alcatel pump.

If the failed pump is an Alcatel mechanical pump and the turbopump still seems to be running (probably at full power and reduced speed, due to excessive exhaust pressure.), then open the replacement pump exhaust valve and turn the replacement pump on. Determine that the pump seems to be running (noise and/or vibration) and then open the replacement pump inlet valve SLOWLY. This valve is opened slowly while monitoring the local pressure dial gauge PI4 which measures the Alcatel pump outlet pressure. Try to keep this pressure below –10”, to avoid dumping gas back to the dump tank via CV18.

7.2.5 Switching to alternative Varian turbo-pump.

If the failed pump is a turbopump and the backing Alcatel still seems to be running, then open the replacement turbo inlet valve and then the replacement turbo outlet valve. Open the outlet valve SLOWLY, watching PI4 as in the previous paragraph. When the exhaust valve is fully open, then turn on the turbopump.

7.2.6 Pump switching order.

If both the turbopump and the Alcatel are to be replaced, then first get the Alcatel pump running and then get the turbopump running by:

7.2.6.1 Open the replacement Alcatel exhaust valve

7.2.6.2 Turn on the replacement Alcatel pump

7.2.6.3 Open the replacement Alcatel pump inlet valve

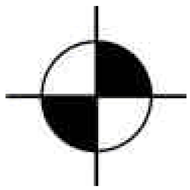
7.2.6.4 Open the replacement turbopump inlet valve

7.2.6.5 Open the replacement turbopump outlet valve SLOWLY (monitoring the local pressure gauge PI4 as in paragraph 7.2.4 above)

7.2.6.6 Once the replacement turbopump outlet valve is fully open, then turn on the replacement turbopump.

8 LABELS, CERTIFICATES

Label 4: Quantity 5 Size 2" x 2" Black letters on self adhesive white background

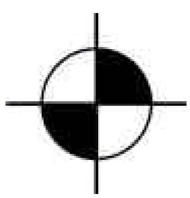


Center of Mass
Weight 920 lbs

Label 5: Quantity 3 Size: 8" x 4" White letter on blue background

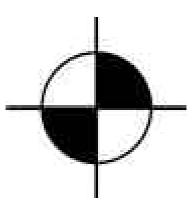
QUANTUM TECHNOLOGY CORP.
MODEL: Q02.5 - P153
IN BEAM CRYOSTAT SYSTEM
HELIUM DILUTION REFRIGERATOR

Label 6: Quantity 3 Black letters on white background size 2" x 2"



Center of Magnet
when warm
(when cold moves ~3mm)

Label 7: Quantity 3 Black letters on white background size 2" x 2"



Stop on Target Holder
when warm
(when cold moves ~3mm)

Label 8: Quantity 20 Size: 2" x 4" Blue letter on White background

Made in Canada
Quantum Technology Corp.
3650 Wesbrook Mall
Vancouver BC V6S 2L2
tel: 604-222-5539
fax: 604-677-5826
email: sales @ quantum-technology.com
www . quantum-technology . com

Label 9: Quantity 2 Size 4x4" blue letter white background

Model: Q02.5 - P153 Control System
Certified to conform to
Underwriters Laboratory (UL) standards
Made in Canada
Quantum Technology Corp.
3650 Wesbrook Mall
Vancouver BC V6S 2L2
tel: 604-222-5539
fax: 604-677-5826
email: sales @ quantum-technology.com
www . quantum-technology . com
Power: 115V 1Phase 60Hz 15A
⚠ Disconnect all supplies and UPS before servicing

Label 10: Quantity 2 Size 4x4" blue letter white background

Model: Q02.5 - P153 Pump Control
Certified to conform to
Underwriters Laboratory (UL) standards
Made in Canada
Quantum Technology Corp.
3650 Wesbrook Mall
Vancouver BC V6S 2L2
tel: 604-222-5539
fax: 604-677-5826
email: sales @ quantum-technology.com

www . quantum-technology . com
Power: 208V 3Phase 60Hz 30A
Internally protected

⚠ Disconnect all supplies and UPS before servicing.

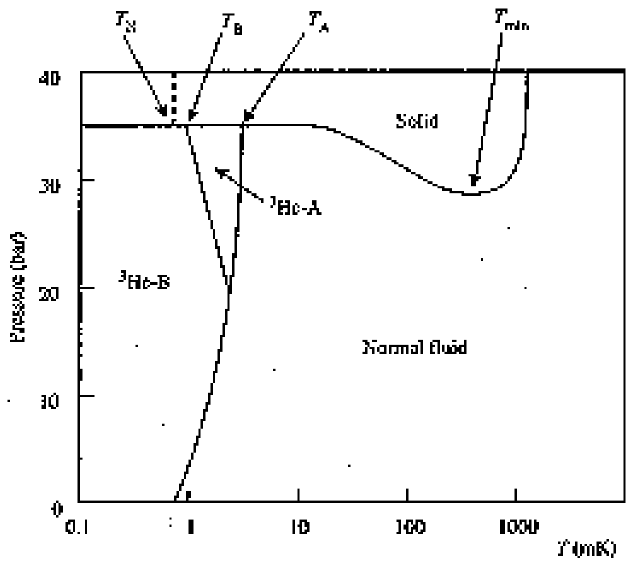
9 REFERENCES, THEORETICAL MODELS

9.1.1 Thermophysical properties of He_3.

^{3}He / ^{4}He Properties (liquid phase at boiling point)

Fluid	Boiling Point (K)	Density (kg/m^3)	Volume Ratio (Gas:Liquid)	Latent Heat of Vaporization (kJ/kg)	Heat Capacity (kJ/kg-K)	Viscosity (mN-s/m^2)	Thermal Conductivity (mW/mK)
^{3}He	3.20	8.9	600:1	8.48	4.6	0.00162	17.1
^{4}He	4.215	25	600:1	20.7	4.56	0.00357	27.0

^{3}He Phase Diagram - (from D.S. Greywall, Phys. Rev. **B33**, 7520 (1986).



4-Helium Properties

Helium Properties at 101.325 kPa

Temp. [K]	Density [kg/m^3]	PV/RT	Energy [J/g]	Enthalpy [J/g]	Entropy [J/g-K]	Cv [J/g-K]	Cp [J/g-K]	Conductivity [W/m-K]	Viscosity [microPa-s]
1	146.9	0.3321	0.0165	0.7063	0.0162	0.1023	0.1023		
2	147.5	0.1653	1.641	2.328	0.9658	5.228	5.25		
3	143.4	0.1134	4.923	5.63	2.372	2.016	2.494		
4.222	124.9	0.0925	9.208	10.02	3.575	2.552	5.255	0.0187	3.263
4.222	16.84	0.6859	24.72	30.74	8.473	3.238	9.144	9.04E-03	1.242
5	11.98	0.8145	28.21	36.67	9.767	3.159	6.77	0.0102	1.392
8	6.433	0.9478	38.76	54.51	12.58	3.111	5.581	0.0145	1.959
10	5.016	0.9724	45.3	65.5	13.81	3.115	5.429	0.0169	2.293
20	2.44	0.9995	77.06	118.6	17.5	3.121	5.251	0.0262	3.624
40	1.216	1.003	139.7	223	21.12	3.119	5.206	0.0405	5.52
100	0.4871	1.001	326.8	534.9	25.88	3.117	5.194	0.0737	9.543
200	0.2437	1.001	638.5	1054	29.48	3.116	5.193	0.118	15
300	0.1625	1	950.1	1574	31.58	3.116	5.193	0.156	19.92

10 APPENDICES

10.1 APPENDIX A: SAFETY ANALYSIS

Following are a number of unusual circumstances which may arise in the operation of the IBC, and the expected response of the IBC to these circumstances, in the absence of operator intervention.

10.1.1 LEGS Cryostat Safety Review Notes

10.1.1.1 Replacement Cryostat

This is a safety review of a replacement cryostat which is very similar to a cryostat which passed safety review and has raised no safety concerns during the three years that it has been on site at BNL.

10.1.1.2 Overview of Cryostat:

Purpose - maintain a solid spin polarized HD target (0.03 liters)

Method: Permanently evacuated (not pumped) vacuum insulated vessel with the following cooling systems:

a) Liquid nitrogen (77K) cooled shields

b) Liquid helium (4.5K) cooled shields

c) Pumped liquid helium (2K) cooled superconducting magnet (1T)

d) Pumped liquid helium (1.5K) heat exchange bath to condense helium-3 mix.

e) Still to evaporate helium-3 mix (0.8K)

f) Dilution refrigerator where helium-3 rich fluid mixed with helium-4 rich fluid (0.2K)

Helium-4 boiloff from the main helium bath and the 2K and 1K pot pumps is normally recovered to an external helium recovery system (and liquefier).

Helium-3 mix is always below atmospheric pressure, it is circulated closed-cycle by a turbopump and hermetic vacuum pump.

Control system: The system operates on a PLC on a UPS independent of computers. Operator interface to change parameters is through Labview software on an external computer.

Design Parameters:

Maximum design/Allowable working pressures:

Cryostat outer vacuum vessel (stainless steel)

Operating pressure: vacuum
Relief port: 25mm diameter vented to a 2" OD pipe for connection to a 350 cfm fan which is on emergency power.

Relief port pressure setting: 0 (gravity operated)

Volume of vacuum vessel is: 230 litres

Volume of vacuum = 230 liters - 45L LHe - 5L LN_2 = 180 liters

ASME code safe internal working pressure approx: 87psig

Liquid nitrogen vessel (stainless steel)

Operating pressure: 1 PSIG

Vented to atmosphere

Volume approximately 5 litres

ASME code safe internal working pressure approx: 92psig

Liquid helium vessel (stainless steel)

Volume approx. 45litres

Operating pressure: 1 psig

Normal Vented through recovery system

Safety relief vent to room: 2.35 sq.in. orifice set pressure < 5psig.

ASME code safe internal working pressure approx: 92psig

2K pot helium vessel (copper)

Volume approx. 1/2 liter

Relief valve: 1/2 diameter (0.4" diameter orifice)

ASME code safe internal working pressure >100 psi

1K pot helium vessel (copper)

Volume approx 1/2 liter

Relief valve: 1/4 diameter pipe (0.2" diameter orifice) set at 5 PSIG

ASME code safe internal working pressure >100psi

He-3 mix volume (copper)

Volume approx 1/3 liter (total volume of mix ~200 atm. liters)

Relief valve: 1/4 diameter pipe (0.2" diameter orifice) set at 15psig

Total volume of pumping tube = 100 liters

(so maximum pressure is 200atm.liters/100liters = 2 absolute atmospheres = 15psig)

Note in the event of a power failure the He-3 gas will bypass the hermetic pump and return to the dump tank as long as the valves are left open (normal operating mode).

10.1.1.3 Potential Hazards Identified:

- **Oxygen Deficiency Hazard (ODH):**

  This will be operated in an experimental area which has already been approved by the safety review committee for a 250 liter liquid helium transport dewar. The volume of the experimental area is 27,000 cubic feet. This experimental area is equipped with exhaust fans on emergency power.

  The volume of liquid helium stored in the cryostat is only 45 liters. After expansion to room temperature 45 liters of liquid helium x 750/28.3 = 1,200 cubic feet of helium gas, which is less than 5% of the volume of the room (could reduce 21% O_2 to 20%). This volume of helium would be safe in this room even without ventilation according to the BNL ODH rules (19.5% mininum O_2).

  The main ODH is in helium transfers and with the storage vessel. However, this has already been approved by a safety committee based on the ventilation in the room.

  The volume of liquid nitrogen stored in the cryostat is only 5 liters. After expansion to room temperature 5 liters of liquid nitrogen x 646/ 28.3 = 114 cubic feet of nitrogen gas, which is less than 1% of the volume of the room.

  Physical layout: Please see drawing DRLayout_2.dwg

  Piping and instrument drawing: Please see drawing: Block_48.dwg

- **Power failure:**

  System designed and tested to withstand power failures. In the event of a power failure, the pumps will cease operating and certain electrically driven valves may change state. The circulation pumps (typically TP1 and M151b) switch off. CV9 and CV18 open. There is an orifice in series with CV9 which will pass high pressure gas slowly from the exhaust of M51b to the turbo exhaust, causing the turbo to decelerate slowly.

The helium liquid in the refrigerator will evaporate slowly and pass back to the storage tanks via the normally open valves CV9 and CV18. If power is restored before all the liquid has evaporated, then the circulation pumps can be restarted and the refrigerator brought back into operation. If for some reason V1 has been closed so the gas can't get back to the storage tanks, then the volume of the flexible pump line (6" ID x approx 13 ' long) will allow the pressure to rise to about 1.3 bar, whereupon some gas may vent through S13.

The 1K and 2K pot pumps likewise stop, and the fill valves for these pots close slowly, with an approximate five minute time constant. The liquid trapped in these two pots evaporates slowly and escapes through relief valves to the experimental hall.

There is no pump on the insulation vacuum space of the cryostat and the vacuum will be maintained by cryopumping to the helium reservoir so long as there is liquid helium in the reservoir. Depending on the depth of helium at the time of the power failure, this should be several hours. The hold time of the IBC reservoir is expected to be in excess of 12 hours.

The polarization holding magnet power supply should be on UPS and see no loss of field until the magnet warms due to the loss of the 2K pump.

The thermally actuated valves (CV1K, CV2K, CVBY, and CVCF) are operated by heaters (the valves are opened by the differential expansion of two metals) that are located outside the cryostat. Power on causes the valves to open and when the power fails they will close slowly as the actuators cool.

Superconducting magnet is powered by a very low power supply rated at 100A and 3V.

- **Loss of service air pressure**

The IBC does not use service air.

- **Loss of cooling water**

The bearings of the turbopump are water cooled. In the event of the loss of cooling water, the bearing temperature will rise and the turbopump power supply will shut off the pump. This will leave only the mechanical pump circulating the refrigerator helium and one will see (a possibly considerable) target temperature rise.

- **Liquid nitrogen failure**

Liquid nitrogen is held in a small reservoir in the IBC to cool the outermost shield, and in another small reservoir in the pumping package to cool a flow through gas cleaner. These reservoirs are automatically refilled from a large transport dewar. If this dewar goes empty, then the small reservoirs will not refill, causing excessive heating in the IBC (due to the outer shield failure) and possible plugging of the refrigerator (if the flow through gas cleaner warms). The large transport dewar should have a pressure sensor on it to signal if it goes empty (if its head pressure falls to zero).

- **Atmospheric pressure on the IBC**

There are two areas of concern about the external atmospheric pressure on the IBC, the thin walled snout and the mylar beam exit window. The snout is an aluminium tube 80 mm OD, 1 mm wall, and about 1 m long. It’s calculated collapsing pressure is 41 PSID. The mylar beam exit window glued into the end of this tube is torospherical in shape and between 4 and 5 thousandths of an inch thick. Several windows were manufactured, one, which was good looking, was glued into the tube and another (not quite so good looking) was glued into a test jig where it was subjected to a pressure test and burst at 100 PSI differential pressure.

If the thin walled snout collapses under the atmospheric load, it will come to rest against the LN_2 cooled shield and the effect of this will be to warm this shield and increase the heat load on the refrigerator. Since there are still two more shields around the target, it is not expected that the target will warm to the subliming temperature.

- **Vacuum leaks**

A slow air leak from the outside will simply condense on the helium reservoir and will not be noticed until this reservoir is deliberately warmed at the end of the run.

A slow helium leak inside the cryostat will degrade insulation vacuum and cause an increasing heat leak to the cryogen reservoirs and to the refrigerator. Eventually the target will begin to sublime, but even if it vaporizes entirely, it will only raise the pressure inside the cryostat to about 80 Torr.

- **Catastrophic loss of insulating vacuum**

If this occurs due to a sudden dump of helium into the vacuum space, then the target will sublime rapidly, mix with helium at a very low density, and be blown out through the downstream window and/or through the IBC vent in the top plate. There should be no explosion hazard.

If the occurrence is due to a catastrophic air leak, then a similar scenario would ensue except the approximately 20 atmospheric liters of hydrogen from the target would be mixed with air, and the potential for a small combustion event would exist for a few seconds.

In either case, the pressure in the helium reservoir would rise to maybe 5 atm (all the liquid converted to a supercritical gas at about the same temperature). The stress in the stainless steel walls of the helium reservoir would rise to about 10,000 psi and the gas would vent through a 2” dia tube (about 16” long) to the experimental hall in one or two seconds. The total amount of gas involved would be about 40,000 atm-liters. The vent is about 8 feet above the floor and as long as it is directed up, there should be no personnel hazard.

- **LN_2 trap plugging:**

  He-3 will return to dump tanks. The LN_2 traps are equipped with 30psi relief valves.

- **Potential for a combustion of hydrogen:**

  The volume of the target is 30cm^3 which corresponds to 3 grams of HD.

  The total energy of combustion is similar to burning 1 tablespoon of gasoline.

Hydrogen burns with an almost invisible flame to produce water.

The net heat of combustion is 120kJ/gram for hydrogen (about 80kJ/gm for HD). The total energy released by combustion of the target would thus be 80kJ/gm x 3 gm = 240kJ.

For hydrogen the lower flammable limit is 4% in air.

The lower explosive limit is 18% in air.

It is difficult to construct a scenario, which would result in ignition of the hydrogen before it would be so diluted with air that it would not ignite.

For example, if the mylar window breaks then air rushing past the target will evaporate it to make 24 litres of HD gas mixed with 180 litres of air.

In the first instant this would be 13% hydrogen, or still a flammable mixture. Air will continue to flow slowly into the cryostat, condensing on the liquid helium cooled surfaces. This will soon dilute the mixture to below the flammable threshold. Even if there was ignition the heat would be mainly dissipated inside the cryostat resulting in an insignificant (~1K) increase in average cryostat temperature.

In another example, suppose that someone removes the blankoff port and opens the vacuum pumpout valve on the main cryostat. In this case the cryostat will fill with air from the other end, causing the target to evaporate.

In this case there will be a hydrogen rich region in the target snout end, however ignition is unlikely.

The natural concern with hydrogen is the "pop" small explosion, which can occur when an appropriate mixture of hydrogen and air is ignited. However, in our case the amount of hydrogen is so small that even if this were to occur after the cryostat vacuum vessel was filled with air and somehow be so well mixed that the entire volume could participate in the explosion, the internal pressure would only rise (instantaneously) to 84psi. This is within the design pressure of the vacuum vessel so the vacuum vessel would not break, and the hot air would be exhausted out the relief port (and possibly out the snout mylar window).

The principal hazard to personnel is the potential for hearing damage due to the loud pop. Given the small size of this target, the distance to personnel and lack of ignition sources we consider this risk of hearing damage in the event of an explosion to be very low and risk of a "pop" to be remote.

High pressure on cold gauge triggers alarm through PLC program.

Thermocouple gauge is interlocked to switch off high voltage supplies to detectors.

- **Quench protection:**

Very small superconducting magnet 100A at 0.1 H so stored energy is 500 Joules. This will cause a temperature rise of the coil from 2.K to 4K.

- **Electrical equipment:**

Industry standard equipment, Agilent digital voltmeter, power supply, pressure and temperature sensors, vacuum pumps are used. The custom superconducting magnet power (3V 100A) supply has been built using rated components to industry standard. The control rack has been built to industry standard and is fully enclosed in a grounded metal case. Quantum Technology Corp. certifies that this equipment meets North American electrical codes.

- **Static Magnetic Field**

  The 60mm diameter (2.3") solenoid field is 1T, 250mm (10") long.

  We have reviewed BNL's Static Magnetic Field Standard. We provided 5Gauss line and 600Gauss line contour plots on the physical layout drawing.

  This cryostat will require Sign # 1 - Safety Sign External field. It will also require following BNL guidelines re: medical electronic devices (e.g. cardiac pacemakers).

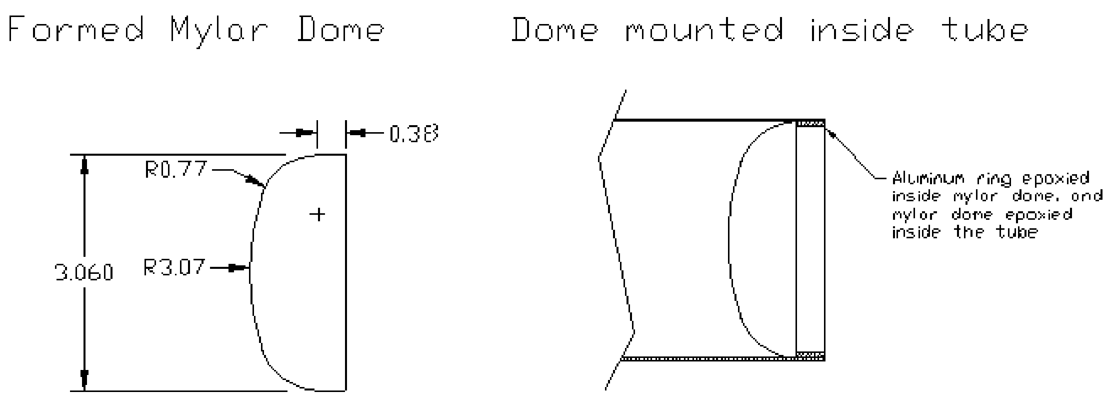
  The 600G field contour is essentially confined within the apparatus. The 5G field contour is generally within the area of cryostat and detectors. Please see contour plot.

10.1.1.4 IBC Mylar Vacuum Window

10.1.1.4.1 Description of the mylar window

The window is a heat formed mylar dome which is epoxied into the end of an aluminum tube with an aluminum retainer ring on the inside, as shown below. The dome has a cylindrical section 0.38" long, followed by a curved section of radius 0.77", capped by a section of a sphere with radius 3.07". The three sections meet tangentially; that is, with no corners.

A description of the forming of the window is given in Appendix 10.1.1.4.2A and a description of the gluing procedure is given in Appendix 10.1.1.4.2B.



10.1.1.4.2 Compliance with Occupational Health and Safety Guide Interim 1.4.2; see the web site at https://sbms.bnl.gov/ld/ld08/ld08d141.pdf

Using the Guide numbering scheme, the relevant sections are:

IV.B. Radiation Damage:

1.4.2 Figure 7 shows no degradation in mylar properties for doses less than $3x10^{14}$ particles per cm^2. Radiation length of mylar is 28.7 cm so the window itself is $4.4x10^{-4}$ radiation lengths. The target and its shell are just under $2x10^{-2}$ radiation lengths. The beam is 10^7 gamma's per second, spread over 5 cm^2. Radiation is dominated by pair production, so there are two charged particles per interaction. Overall, this is $8x10^4$ particles per cm^2 per sec. A dose of 3 $x10^{14}$ particles per cm^2 takes $3.75x10^9$ sec or 120 years.

IV.B.1.a. The window has passed the deflection test; see Appendix 10.1.1.4.2C.

IV.B.1.c. The window was visually inspected during the deflection test of Appendix 10.1.1.4.2C. No scratches, pockmarks or wrinkles were present on the window.

IV.B.1.d. The window material, mylar, is compatible with the vessel contents, vacuum.

V.A This window is deemed to be Held-But-Not-Fixed.

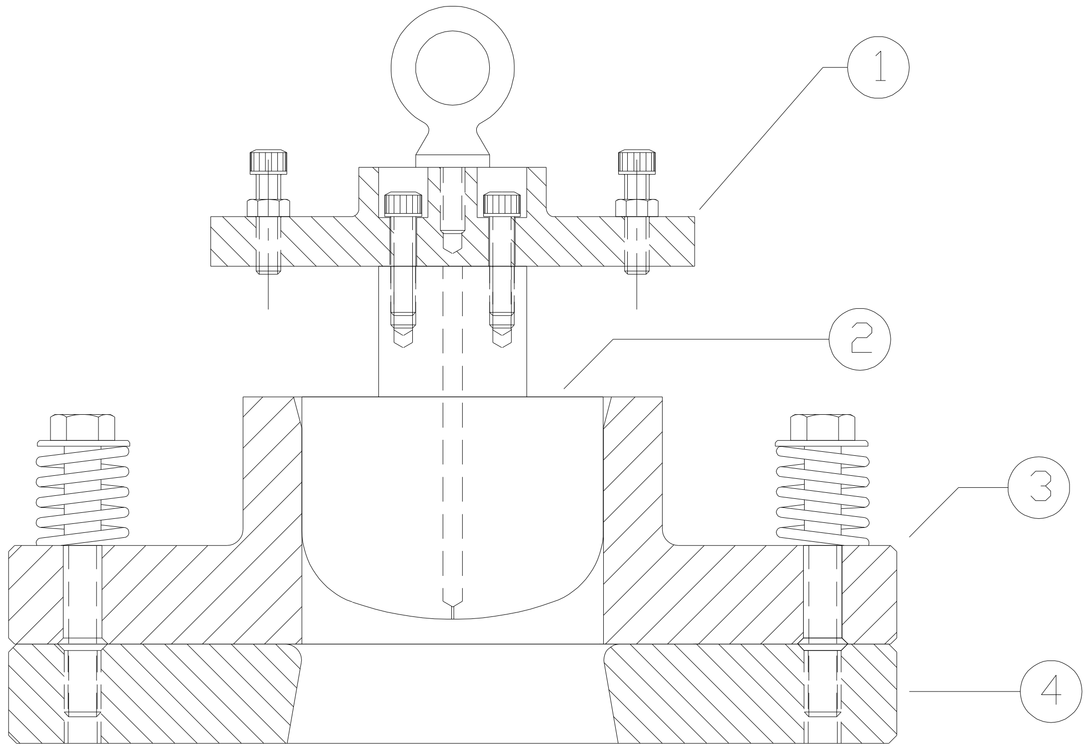
V.B.2.d. The mylar is held in the aluminum tube with epoxy and there is the concern that this may give rise to stress concentrations in the mylar due to irregularities in the epoxy edge. The product description pages for DP-460 do not show measured overlap shear values for aluminum and mylar. The shear stress for an aluminum overlap joint is 5700 psi and for a plastic like ABS it is 575 psi. Therefore, it is assumed that the shear stress between aluminum and mylar is below the mylar maximum design stress of 9500 psi.

V.C.1.c The window is deemed to to be in a frame with an infinite radius of curvature, leaving the frame with theta angle zero.

V.C.8. The maximum tensile stress in the window is calculated to be 4938 psi; see Appendix 10.1.1.4.2D.

Appendix 10.1.1.4.2A: Formation of the mylar dome

The dome is formed from a 0.005” thick mylar disc in the brass die illustrated



below.

The mylar disc is clamped between the pieces numbered 3 and 4. This assembly is heated to 180C and then a room temperature punch (2) is installed into the assembly and driven down to a stop determined by the stop screws in item 1. Mylar in contact with the room temperature punch does not stretch and the material which forms the dome is drawn from that part of the mylar disc clamped between items 3 and 4. The springs under the screws holding items 3 and 4 together provide the correct tension to allow the mylar to slide between items 3 and 4. The setting of this tension is a matter of trial and error.

Appendix 10.1.1.4.2B: Installation of the dome in the IBC snout

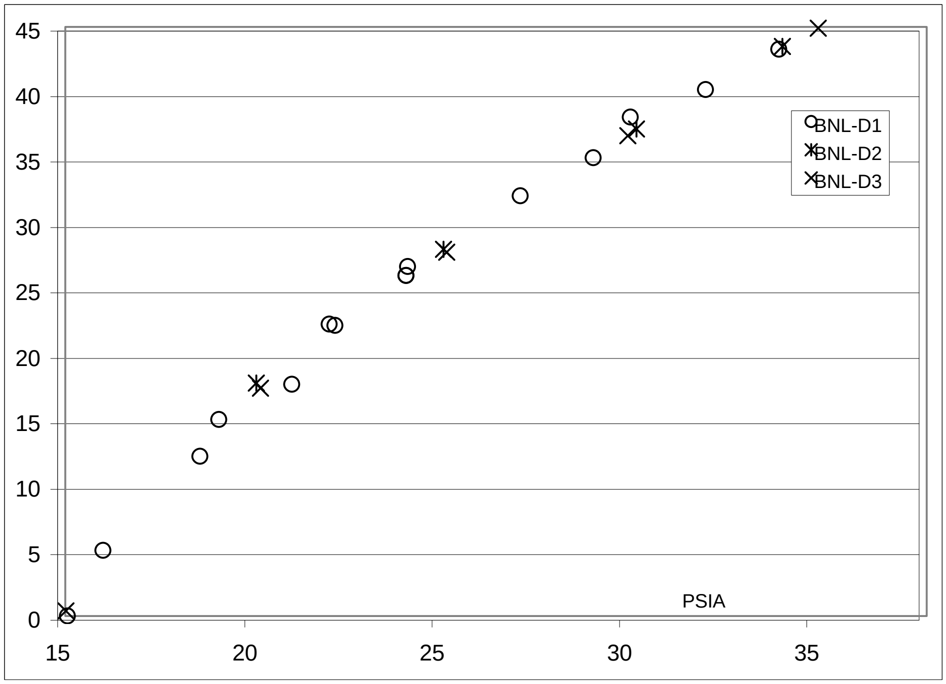
The mylar dome is epoxied into the end of the aluminum tube which forms the vacuum wall for the IBC snout, with an aluminum ring serving as a retainer on the inner diameter of the cylindrical section of the dome. The inside of the aluminum tube and the outside of the aluminum ring were roughened with Scotch Brite and both sides of the cylindrical section of the mylar dome were lightly roughened with Scotch Brite. All four surfaces were lightly coated with a 24 hour curing epoxy (3M Scotch-Weld Epoxy Adhesive DP-460) and the three pieces assembled and left to cure with the tube vertical (dome concave down). The aluminum pieces were machined to leave a nominal 0.005” epoxy gap.

Appendix 10.1.1.4.2C: Window deflection tests and visual inspection were carried out at BNL on March 29, 2004 and witnessed by Jim Durnam. He is sending separately a document memo. A graph of the results is included below.

29 March 2004 - Test for safety committee using calibrated gauge

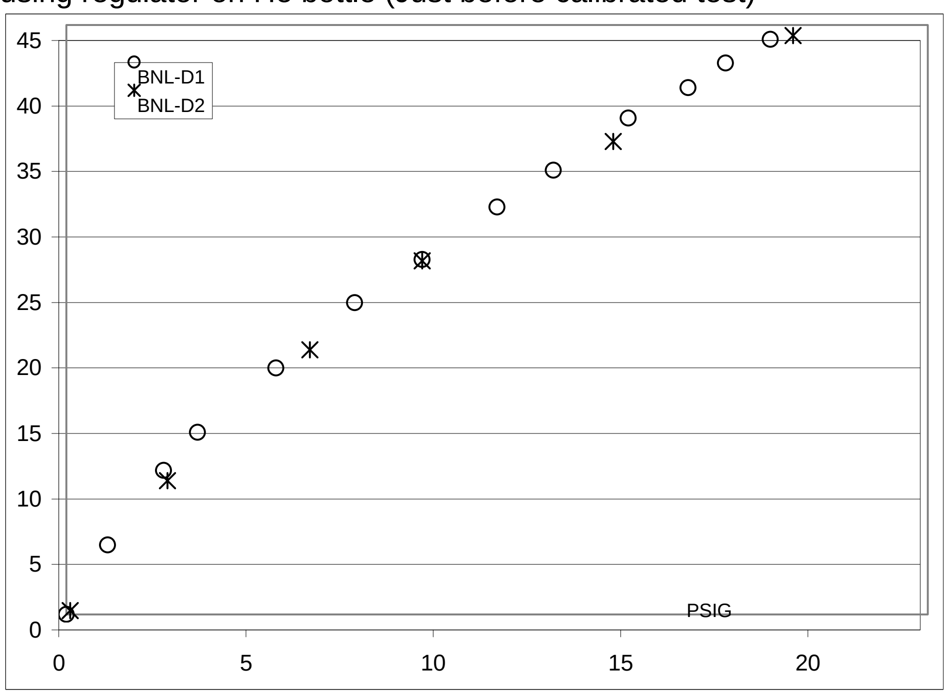
Note that this effectively calibrates the regulator gauge used in the previous test.

Psig	BNL-D1	BNL-D2	BNL-D3
15.06	0		
16.01	5		
18.6	12.2		
19.1	15		
21.05	17.7		
22.05	22.3		
22.2	22.2		
24.1	26		
24.1	26		
24.14	26.7		
27.15	32.1		
29.1	35		
30.09	38.1		
32.1	40.2		
34.05	43.3		
35.18	45.1		
36.1	46.7		
37.13	48.1		
20.1		17.8	
25.1		28	
30.25		37.2	
34.15		43.5	
36.12		46.3	
37.07		48	
15.02			0.4
20.21			17.4
25.18			27.8
30.02			36.7
35.1			44.9
36.03			46.3
37.09			48.1



29 March 2004 - Test using regulator on He bottle (Just before calibrated test)

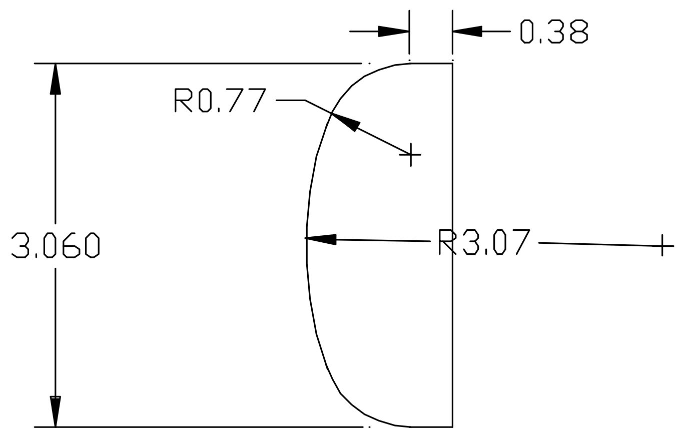
Psig	BNL-D1	BNL-D2
0	0	
0.1		0.3
1.1	5.3	
2.6	11	
2.7		10.2
3.5	13.9	
5.6	18.8	
6.5		20.2
7.7	23.8	
9.5	27.1	
9.5		27
11.5	31.1	
13	33.9	
14.6		36.1
15	37.9	
16.6	40.2	
17.6	42.1	
18.8	43.9	
19.4		44.2



Appendix 10.1.1.4.2D - Mylar window stress

Dennis Healey

March 25, 2004



The dimensions of the mylar window are shown above. The window was formed in three shapes. The outermost section is a cylindrical piece 3.06" dia x 0.38" long. The next section has radius 0.77" and the final inner section is a portion of a sphere of radius 3.07". The three sections join tangentially. The window was formed from 0.005" thick mylar. After forming, the mylar thickness was 0.0043" thick at the center of the large dome and 0.0039" thick in the cylindrical piece. (The actual window glued to the cryostat was not measured. These thicknesses were the mean values for the two spare windows.)

mylar thickness in the cylinder $t_C := 0.0039 \cdot in$

mylar thickness in the dome $t_D := 0.0043 \cdot in$

atmospheric pressure $P := 14.7 \cdot psi$

1. Stress in the cylindrical section

cylinder diameter $d := 3.06 \cdot in$

longitudinal force on cylinder $F_c := \pi \cdot \frac{d^2}{4} \cdot P$

stress in cylinder wall $S_c := \frac{F_c}{\pi \cdot d \cdot t_C}$

$S_c = 2.883 \times 10^3 psi$

2. Stress in the large central radius

This section is a portion of a sphere. The stress in a sphere of radius R and thickness t due to an internal pressure P is

$$S = \frac{R \cdot P}{2 \cdot t}$$

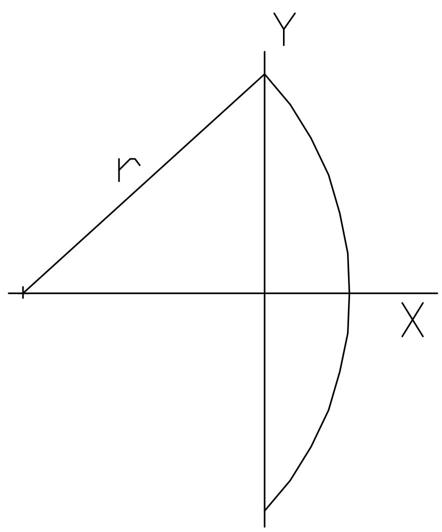
The spherical section of the dome is illustrated below. For the unstressed dome, the Y intercept is

$$y := 1.53 \cdot in$$

The radius of the sphere is $r := 3.07 \cdot in$

This gives the X intercept as $x := r - \sqrt{r^2 - y^2}$

$$x = 0.408\,in$$



Measurements of the deflection of the dome under atmospheric pressure showed that the end of the dome moved about 0.03". Assuming that most of this motion was due to deformation of the large sperical portion of the dome, and that the perifery of this section does not move much, then the X intercept changes to

$$x_{15} := x + 0.03 \cdot in$$

Then the new radius of curvature of the large shperical section of the dome is

$$R := \frac{x_{15}^2 + y^2}{2 \cdot x_{15}}$$

$$R = 2.889\,\text{in}$$

so the stress is $$S := \frac{R \cdot P}{2 \cdot t_D}$$

$$S = 4.938 \times 10^3\,\text{psi}$$

3. Stress in the small radius section between the cylinder section and the large radius section

The stress in this section varies continuously and monotonically in this section from the cylindrical boundary (where the stress is a minimum of 2883 psi) to the large radius boundary (where the stress reaches the maximum of 4938 psi)

4. Bursting pressure

One of the visually less than perfect windows (it had some wrinkles around the cylindrical section) was glued into a test frame and increasing pressure was applied to the concave side of the window until it burst at 100 psi differential. The burst appeared to initiate near the center, in the large radius section, where the stress is supposed to be largest.

No meaurement was made of the deflection of the test dome as it neared bursting. Suppose that the deformation was linear. Then one supposes that the deformation of the dome due to 100 psi would be

$$\delta := 0.03 \cdot \text{in} \cdot \frac{100 \cdot \text{psi}}{15 \cdot \text{psi}}$$

Then the X intercept of the dome, as illustrated in section 2 above, would be

$$x_{100} := x + \delta$$

and the radius of curvature of the deformed spherical section would be

$$R := \frac{x_{100}^2 + y^2}{2 \cdot x_{100}}$$

$$R = 2.228\,\text{in}$$

at the pressure $$P := 100 \cdot \text{psi}$$

This gives the stress in the spherical section of the dome at the bursting pressure as

$$S := \frac{R \cdot P}{2 \cdot t_D}$$

$$S = 2.591 \times 10^4 psi$$

This measurement gives an ultimate tensile stress

$$UTS := \frac{S \cdot 100 \cdot psi}{P}$$

$$UTS = 2.591 \times 10^4 psi$$

This is in good agreement with the tensile strength (25000 psi @ 70 F) listed for mylar in Table II (Typical Properties of Plastics) of Section 1.4.2 of the Occupational Health and Safety Guide Interim.

APPENDIX B1: MECHANICAL DRAWINGS (BINDER)

10.2 APPENDIX B2: MECHANICAL DRAWINGS (BINDER)

10.3 APPENDIX C: ELECTRICAL DRAWINGS (BINDER)

10.3.1	Instrument Rack Layout Rev.J (Rear & Front View, 14 Pin Connector Coding)	B-Sch-00-1
10.3.2	Plc Pin Connections Rev.K (Schematic Diagram, Rs-232 Cables)	B-Sch-00-2
10.3.3	120v Power Supply Rev.K (Fuses, Main Lines, Ups)	B-Sch-00-3
10.3.4	Temperature Sensors Rev.L (Ti102, Ti103, Ti104, Mxbnl)	B-Sch-01
10.3.5	Temperature Sensors Rev.L (Ti4k, Ti2k, Xxxx, Ti204)	B-Sch-02
10.3.6	Temperature Sensors Rev.L (Tmc, Ti201, Ti1200, Ti101)	B-Sch-03
10.3.7	Temperature Sensors Rev.K (Xxxx, Ti1201, Ti107, Ti202)	B-Sch-04
10.3.8	Temperature Sensors Rev.I (Ti1k, Xxxx)	B-Sch-05
10.3.9	Level Sensors Rev.I (Ls3a, Ls3b, Ls4a, Ls4b)	B-Sch-06
10.3.10	Misc Rev.I (Lm2, Sc V Taps, Ls3l, Ls4l)	B-Sch-07
10.3.11	Level Sensors Rev.J (Ls1a, Ls1b, Ls1c, Fi51, Fi52)	B-Sch-08
10.3.12	Flowmeters Rev.H (F150)	B-Sch-12
10.3.13	Pressure Transducers Rev.H (Pt4, Vgcc, Vgcv)	B-Sch-15
10.3.14	Pressure Transducers Rev.I (Pi1, Pi2, Ptimx)	B-Sch-16
10.3.15	Pressure Transducers Rev.I (Pi1k, Pi2k)	B-Sch-17

10.4 APPENDIX E: INSTRUMENTATION (BINDER)

10.5 APPENDIX G: PROGRAMMING (BINDER)

10.5.1 PLC Program Structure

10.5.2 PLC Ladder Program

10.5.3 List of Scanned Sensors

10.5.4 PLC Notes and Memory Map

10.5.5 DL450 Products

10.5.6 FACTS Basic Program: P153x41.abm

10.5.7 OPC Server

10.5.8 LabVIEW

10.5.9 SCPI Command Summary

10.6 APPENDIX H: EQUIPMENT MANUALS (BINDER)

10.6.1 AGILENT 34970A DMM MANUAL

10.6.1.1 Quick Reference Guide

10.6.1.2 Online User's Guide

10.6.1.3 Product Overview

10.6.1.4 User's Manual

10.6.2 F4-CP128-1 MANUAL (PLC)

10.6.3 EXTENDED BASIC REFERENCE MANUAL (PLC)

10.7 APPENDIX I: DL-405 MANUAL (PLC) (BINDER)

10.7.1 GETTING STARTED

10.7.2 INSTALLATION, WIRING, & SPECIFICATIONS

10.7.3 CPU SPECIFICATIONS & OPERATION

10.7.4 SYSTEM DESIGN & CONFIGURATION

10.7.5 STANDARD RLL INSTRUCTIONS

NOTE: FOR OTHER MANUALS CHECK APPENDIX E.

Building 510A
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-7236
Fax 631 344-5568
Pager 631-664-2550
kane1@bnl.gov

BROOKHAVEN NATIONAL LABORATORY

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: November 22, 2002

To: E. Lessard

From: Steven F. Kane

Subject: Partial Review of LEGS Procedures

References: (a) Quantum Technology Corp. Laser Electron Gamma Source: In-beam Cryostat Manual Model Q02-P153

I have completed a review of the first three steps, and have the following comments:

Schematic:

The Schematic is incorrect. I am advised that Orifices OR 1 and OR2 no longer exist, but are shown on the schematic. Also, There is no indication or reference to the gas recovery connection. This will need to be controlled for some of these steps, but is not.

Step 3.1 Prior to Cooldown

3.1.2 – How does one check that the relief valves are in working order? If this is an important step, then this needs some detail.

3.1.4 – What are “reasonable” values? Do you mean room temperature/1 atm pressure? This needs to be specified.

3.1.5 – The end of the last sentence talks about disconnecting something, but it is not clear if it is the pump, the gauge, or the controller. Which is it?

3.1.7.1 – How many times should the reservoir be purged? We usually advocate three times, but the procedure only indicates one. How is the helium-4 reservoir evacuated? Through what port/valve? Also, nomenclature may need adjusting; I see He4 bath and He4 dump, but I do not see He4 reservoir on the schematic.

3.1.7.2 – Where does the flow go to? To Recovery? When did we activate this?

3.1.8.1 – What service pump? Connected through what port/valve? What LN2 “cooled gas cleaners”? I see LN2 traps on the schematic.

3.1.8.3 – This is a redundant system. What about the lines to V15 and V1a?

3.1.8.4 – How does gas get in? V24/V16/V4 is closed.

3.2 - Why are these systems not diagramed and labeled?

3.2.1 – Will operators be exposed to cryogenic fluid during the solenoid connect/disconnect evolution. Seems awfully inelegant for a foreseeable situation.

3.2.2.2 – How do we know when it is approximately 6 inches above being fully pushed in? is this marked on the device?

3.2.2.7 – Is this some valve that is not on any schematic?

3.3.3 – Will operators be exposed to cryogenic fluid during the solenoid connect/disconnect evolution. Seems awfully inelegant for a foreseeable situation.

3.3.4 – Into where do we pour the liquid nitrogen? How doe we siphon the liquid nitrogen in the last sentence?

3.3.5.2 – Removing the pressure gauge seems to defeat the purpose of having leak checked everything. Potential for air to get in to the system.

3.3.6 – When was VFILL opened following 3.3.6.1? I see it was closed in 3.3.8.

3.3.6.5 – What 5 valves? Must be specific.

cc:
R. Travis
A. Sandorfi

Building 510A
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-7236
Fax 631 344-5568
Pager 631-664-2550
kane1@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: April 16, 2004

To: E. Lessard

From: Steven F. Kane

Subject: Partial Review of LEGS Procedures Second Memorandum

References: (a) Quantum Technology Corp. Laser Electron Gamma Source: In-beam Cryostat Manual Model Q02-P153

I have completed a review of the next step, Step 3.7, and have the following comments:

Step 3.7 - 7k Test Instructions

This has en extended lead-in discussion which is uncharacteristic of the other steps. It is the first time we see Dilution Refrigerator mode mentioned. If some of this is important, I suggest a principles of operations section. The second paragraph has a warning to proceed with extreme caution, right after the first paragraph states that the procedure will not overshoot the temperature. These are contradictory, and lowers ones expectation of the procedure.

3.7.1 – This is not a step.

3.7.3.1 – The turbo pumps referred to in this step ae TP1 and TP1a? References to equipment need to be consistent. How does one set the speed? This is the first time in the procedure we are setting a speed. Before we turned it on and off.

3.7.3.2 – Different format from other steps. Why? Second bullet – what is the gas cleaner? The LN2 trap? V12 is already open. What valve? Third bullet – How do we heat the still and mix? Nomenclature? Last bullet – What valve? Nomenclature?

3.7.3.3 – What valve?

3.7.3.4 & 5 – What does the parenthetical tell the operator? I'm confused by this step. What do I set, and to what do I set it? How do I set it?

3.7.3.6 – It looks like some words are missing in this sentence. I can't discern what is supposed to be done. Is it more than one operation?

3.7.3.7 – Yet another format for multiple steps within a "step." First sentence – what is supposed to be monitored? How? Third sentence (second paragraph?) How rapid is rapid? Fifth sentence – Does the operator reduce the heat to about 1% or will the system do it? Eighth sentence – Does the operator have to turn the heat mode on and off manually? Can't this be automated? Isn't there a more elegant way to do this? Ninth sentence – Is QPHASE=8 ON and QPHASE=5 OFF? We can't make the display indicate ON and OFF? Tenth sentence – Increases or decreases?

3.7.3.8 – How do we increase the set point?

3.7.4.2 – How do we turn on the 7k set point? How do we gradually increase the set point? The desired temperature is 7K, right? How do we turn the 7K mode off?

3.7.4.3 – How do we switch the 1K pot heater to manual?

3.7.5.1 – How do we switch off the 7K heat mode?

3.7.5.2 - How do we switch back to "normal" operation?

3.7.5.3 – How do we switch back to automatic?

It appears to me that this procedure may be using the LabView program to run the operation, but I can't tell from this procedure. This should be more clear. On LabView, we would use "select [icon]" or type something. Until I saw a QPHASE=8, we could be using a switch panel.

cc:
R. Travis
A. Sandorfi

Building 510A
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-7236
Fax 631 344-5568
Pager 631-664-2550
kane1@bnl.gov

Memo

Date: April 15, 2004

To: E. Lessard

From: Steven F. Kane

Subject: Partial Review of LEGS Procedures Second Memorandum

References: (a) Quantum Technology Corp. Laser Electron Gamma Source: In-beam Cryostat Manual Model Q02-P153

I have completed a review of the next two steps, Steps 3.4 and 3.5, and have the following comments:

Step 3.4 - After the Liquid Helium Reservoir is Full

When did CVLN2 get put into AUTO? It is not discrete in the procedures.

3.4.3 – How is one to monitor the flow rate? Using what sensor? At what point do you want the operator to begin closing CVBY? How low do you want the temperature set-point to go? Is there any problems if the set-point is lowered too fast/slow? How do you want the operator to adjust CVCF? Is there a secondary indication that you want the operators to use other than 10 minutes? What if 10 minutes is not enough/too much?

3.5 – Cooing The Refrigerator To The Operating Temperature

3.5.1 – This is not really a step.

3.5.2 - Is there a secondary indication that you want the operators to use other than 5 minutes? What if 5 minutes is not enough/too much?

3.5.3 – Perhaps this step should include a table to indicate to the operator the effects of each tuning parameter manipulation. Is there a preferred order to use these two parameters? Should there be a maximum increment, after which you would want the operator to wait to see what the effect will be? Perhaps give the operator a feel for how much a particular adjustment will effect the temperature so as to prevent large excursions.

cc:
R. Travis
A. Sandorfi

Building 510A
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-7236
Fax 631 344-5568
Pager 631-664-2550
kane1@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: April 19, 2004

To: E. Lessard

From: Steven F. Kane

Subject: Partial Review of LEGS Procedures Second Memorandum

References: (a) Quantum Technology Corp. Laser Electron Gamma Source: In-beam Cryostat Manual Model Q02-P153

I have completed a review of the Steps 3.8 through 3.10, and have the following comments:

Step 3.8 - Removing the Target from the In-beam Cryostat

End of lead-in paragraph – Need to note Still power for Step 3.8.7.2.

3.8.3 – This is a procedure. Is this supposed to be done or not?

3.8.3.1 – Is this the most elegant way to accomplish this task? This is a foreseeable event. Can't there be a switch or something?

3.8.3.4 – Do you need to reconnect the connector?

3.8.4 – How long to we wait for magnet current to ramp up? Is there an indication when it is ramped up?

3.8.6 – Figures? Nomenclature? This is too abstract to be useful to the intended audience.

3.8.7.2 – Need to reclamp the tilting handwheel.

Paragraph after 3.8.7.2 – Why would one wish to keep the refrigerator running? By turbo pump do you mean TP1 or TP1a? How does one turn on still power? Is that the still heater power?

3.9 – Warming the In-Beam Cryostat

3.9.1 – How much of a ramp? How?

3.9.1 – How substantially? Can't you use a level indication? How high is too high? How does one not let the pressure rise too high?

3.9.5 – How does one turn off the LN2 filler?

3.9.6 – How does one close CV1K and CV2K?

3.9.9 – Shouldn't there be some valves in the LN2 and LHe circuits be left open to let the rest of the gas escape? Will the BRx valves do this?

3.10 – After the Cryostat has Warmed

3.10.1 – What pumps? The procedure has all the pumps off before this step.

cc:
R. Travis
A. Sandorfi

Building 510A
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-7236
Fax 631 344-5568
Pager 631-664-2550
kane1@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: April 25, 2004

To: E. Lessard

From: Steven F. Kane

Subject: Review of First responses to BNL Comments on LEGS Procedures

References: (a) Quantum Technology Corp. Laser Electron Gamma Source: In-beam Cryostat Manual Model Q02-P153; Revised, undated, and unapproved
(b) Quantum Technology Corp. Responses to BNL Memorandums 1-5

I have completed a review of References (a) and (b), and I have the following comments:

New Procedure, and Reply to Memo 1 – I am still not comfortable with the totalizer and how it fits into this system. I don't know how it fits in. The procedure provides no indication that the totalizer is connected to the system, and there is no check to ensure the totalizer and its downstream connection is open, closed, or otherwise. In installing this system and doing its initial checkout, There needs to be a reference to another procedure for the installation/ connection, and there needs to be a check that the downstream system is open, closed or otherwise.

Reply to Memo 1 – There should be list of equipment necessary for the procedure. As an example, the extension cord for the LN2 solenoid valve and the "mechanical vacuum pump with thermocouple pressure gauge. Getting half way into a procedure is not the time to find out they are missing equipment.

Step 3.2.1 – Is there a potential for the operator to be exposed to cryogens as LN2 is relieved through SLN2?

3.6.4 – What are the consequences if Autofill starts while the cryostat is tipped?

3.7.2.1 – Now that I understand that speed will be used for controlling the turbo pumps, speed should be added to the state tables. Even if it is off, the proper speed should be preselected for the next time it is to be turned on.

3.7.2.7 – I am still not clear on the information trying to be conveyed in the parenthetical. Does this tell the operator that, even though the set point was set to 160, the valve temperature will indicate 152? This is not proper control logic. The normal condition is when the set point and the indication are the same. Other indications mean the system is not operating properly. This can be a cause for unstructured operator inputs which can lead to system unbalance, loss of the sample, and maybe a hazard.

3.7.3.7 – This comment addresses the entire procedure, and not just this step. The procedure needs to reference the software version of the LabVIEW program. Now that the procedure, that manual and LabVIEW have been changed, without this indication, the PLC controls can be reacting in a manner inconsistent with the obsolete procedure the operator is using. This can be a safety hazard and also lead to loss of operations. A first step should be to verify the software version with the manual.

Reply to Memo 4, Step 3.9.9 – Now that you have mentioned the concern for retained pressure in the 1k and 2k circuits, what should be done to resolve the safety issue?

3.3.3 – Next to last sentence – How is VGCC to be turned on? Last sentence – how is the thermocouple gauge controller disconnected?

3.3.5.1 – More unlisted equipment. Is this gas connection supposed to have a regulator and relief valve attached? What is the setting for the relief valve? What ½" plug? When did we remove it?

3.3.5.2 – How do we open CV1K and CV2K? LabVIEW? If so, the entire procedure has not been gone through to ensure the references to LabVIEW are complete. Next to last sentence – Does this mean that there is no nitrogen? If it is not adequate, then what is to be done?

3.3.6.1 – Is the second sentence correct? Should it read; "Install the lance <u>through</u> the shut-off…"?

3.3.6.3 – How are VP1 and VP2 to be turned on? LabVIEW or switches on the pumps? LabVIEW requires more instruction; for switches this is okay.

3.4.3 – How is flow monitored, on LabVIEW or directly?

3.5 – is something missing from the second paragraph?

3.5.2 – Is this all done on LabVIEW? Can we distinguish that?

3.6.4.2 – Add "using an extension cord." to the end of the first sentence.

3.6.6.2 – Original questions are still unanswered. What is the operator to do if the parameters change? I believe this also applies to the corresponding section in 3.8. Same goes for the response to our comments to 3.6.8.2; what does the operator do if there are impacts during tipping?

3.6.9.1 – How does the turbo pump allow or not allow? What is the indication the operator is looking for?

3.6.9.2 – Another place where the LabVIEW control is not adequately described. This step is refereeing to still heater power?

3.7.2.7 – What does the parenthetical tell us? Why is it parenthetical? Why doesn't read 160 if we set it to 160?

3.7.4.2 – Already set to 8 at step 3.7.4.2.

3.8.4.2 – Add “using an extension cord.” to the end of the first sentence.

3.8.6.2 – Need to add the step to reclamp the handwheel.

3.8.6.2 & 3.8.8.2 – What is the operator supposed to do if there are impacts? You are telling them to monitor this for a reason, right?

3.9.2.1 – how is the operator supposed to not let PI2 rise above 20 mBar?

cc:
R. Travis
A. Sandorfi

Building 510A
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-7236
Fax 631 344-5568
Pager 631-664-2550
kane1@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: April 16, 2004

To: E. Lessard

From: Steven F. Kane

Subject: Partial Review of LEGS Procedures Second Memorandum

References: (a) Quantum Technology Corp. Laser Electron Gamma Source: In-beam Cryostat Manual Model Q02-P153

I have completed a review of the next step, Step 3.6, and have the following comments:

Step 3.6 - Loading the Target into the Cryostat

3.6.2 – Is this step optional? How is still power reduced? Is this heater power?

3.6.3 – Shouldn't this step be done first?

3.6.4 – Is this step required or not? What happens if the Autofill does start during the process?

3.6.4.1 – Can't a switch be incorporated into this system?

3.6.4.2 – Where is the 110 VAC source?

3.6.4.3 – What extension cord? Isn't the device already powered?

3.6.4.4 – This is not a step.

3.6.5 – How do we know when the magnet is fully charged?

3.6.6.2 – What do you do if the parameters do change? Are there any hazards associated with a parameter change?

3.6.7 – Are there any figures for this? How do we know what the proper nomenclature is?

3.6.7.1 – How do we connect this?

3.6.7.2 – Should we purge this area after pumping? If there will be LHe in there, we should do pump and purge three times. Is the pumping port obvious?

3.6.7.3 – What valves? What valve numbers?

3.6.7.5 –6 – How?

3.6.7.7 - What valves? What valve numbers?

3.6.7.8-9 – How?

3.6.8.1 – Do we need to set the clamp pin (3.6.6.2)?

3.6.8.2 – What do you do if there are impacts to the tipping?

3.6.9.1 – How, and what pressure is to be avoided/maintained?

3.6.9.2 – How? You need to note the power level at step 3.6.2.

cc:
R. Travis
A. Sandorfi

Reply to Memo 1

Schematic:

The Schematic is incorrect. I am advised that Orifices OR 1 and OR2 no longer exist, but are shown on the schematic. Also, There is no indication or reference to the gas recovery connection. This will need to be controlled for some of these steps, but is not.

The schematic has been updated to reflect the absence of OR1 and OR2. The gas recovery connection is indicated to the left of the gas totalizer, located in the upper left corner, and is present in both versions. It is not necessary to modify this connection.

Step 3.1 Prior to Cooldown

3.1.2 – How does one check that the relief valves are in working order? If this is an important step, then this needs some detail.

The phrase "and appear to be in working order" has been deleted.

3.1.4 – What are "reasonable" values? Do you mean room temperature/1 atm pressure? This needs to be specified.

The wording has been altered to read "that none of the displayed values are 'NaN'".

3.1.5 – The end of the last sentence talks about disconnecting something, but it is not clear if it is the pump, the gauge, or the controller. Which is it?

The word "it" has been replaced with "the local controller"

3.1.7.1 – How many times should the reservoir be purged? We usually advocate three times, but the procedure only indicates one. How is the helium-4 reservoir evacuated? Through what port/valve? Also, nomenclature may need adjusting; I see He4 bath and He4 dump, but I do not see He4 reservoir on the schematic.

The step is changed to require 3 purges. All references to "reservoir" in the manual have been changed to "bath", which appears on the schematic. Sentences are added to describe utilizing a spare NW16 port and removing the delivery lance with valve VFILL.

3.1.7.2 – Where does the flow go to? To Recovery? When did we activate this?

As indicated on the schematic, the flow goes to the totalizer and thence to the permanent recovery connection. No activation is required.

3.1.8.1 – What service pump? Connected through what port/valve? What LN2 "cooled gas cleaners"? I see LN2 traps on the schematic.

The phrase “the service pump” is changed to “a mechanical vacuum pump with thermocouple pressure gauge”. All references to “gas cleaner” in the manual have been replaced with “LN2 trap”.

3.1.8.3 – This is a redundant system. What about the lines to V15 and V1a?

The step has been altered to read “from V15 and V16” and “to V1 and V1a”.

3.1.8.4 – How does gas get in? V24/V16/V4 is closed.

The line from the back of the mechanical pumps M152a and M151b to the dump cannot be evacuated by the pumps and thus contains mixture at the dump pressure following shutdown. This step utilizes that gas.

3.2 - Why are these systems not diagramed and labeled?

As noted earlier, “LN2 reservoir” is now “LN2 bath”, “LHe reservoir” is now “LHe bath”, “gas cleaner LN2 reservoir” is now “LN2 trap dewar”, and “gas cleaner” is now “LN2 trap”.

3.2.1 – Will operators be exposed to cryogenic fluid during the solenoid connect/disconnect evolution. Seems awfully inelegant for a foreseeable situation.

With CVLN2 and the supply dewar valve closed, and with the connection warmed and vented through SLN2, there is no exposure. The solenoid valve name, CVLN2, has been added to the text. We agree that operating a solenoid valve by plugging and unplugging its power is crude.

3.2.2.2 – How do we know when it is approximately 6 inches above being fully pushed in? is this marked on the device?

The step is altered to read “approximately six inches of the ½” diameter section is above the port”. Also a similar alteration is made in step 3.2.2.14.

3.2.2.7 – Is this some valve that is not on any schematic?

Valve name VFILL is added here and in step 3.2.2.5.

3.3.3 – Will operators be exposed to cryogenic fluid during the solenoid connect/disconnect evolution. Seems awfully inelegant for a foreseeable situation.

The vent out of which liquid nitrogen spills is located well away from the power connection for the solenoid CVLN2. It is the power which is being connected and disconnected. The word power has been added to the text as well as a more complete description of the autofill system‘s operation. “connect” and “disconnect” are replaced with “plug” and “unplug”.

3.3.4 – Into where do we pour the liquid nitrogen? How doe we siphon the liquid nitrogen in the last sentence?

Sentences are added to describe removing the purge manifold and placing a funnel in the fill port. The siphoning process is done by referral to step 3.3.5.1, which has been expanded to provide a more complete description of the process.

3.3.5.2 – Removing the pressure gauge seems to defeat the purpose of having leak checked everything. Potential for air to get in to the system.

This procedure to check for blocks in the 1K and 2K systems has been rewritten to utilize the room temperature method used in step 3.1.7.3. The only difference is that at LN2 temperatures valves CV1K and CV2K must be heated to open.

3.3.6 – When was VFILL opened following 3.3.6.1? I see it was closed in 3.3.8.

Steps 3.3.6.2, 3 and 4 are combined into a single step, because 2 and 3 were not really steps, and the sentence “Open VFILL” is added

3.3.6.5 – What 5 valves? Must be specific.

The phrase “the 5 valves above” is replaced with “the valves BR3, 4, 5, 6, and 7” in this step, now 3.3.6.3.

Reply to Memo 2

Step 3.4 - After the Liquid Helium Reservoir is Full

When did CVLN2 get put into AUTO? It is not discrete in the procedures.

CVLN2 is in AUTO when plugged into the power from the PLC and closed when unplugged. It was plugged in during Step 3.3.3. The name CVLN2 was missing from that step and is now included. Note that it is unplugged during shutdown in Step 3.9.5.

3.4.3 – How is one to monitor the flow rate? Using what sensor? At what point do you want the operator to begin closing CVBY? How low do you want the temperature set-point to go? Is there any problems if the set-point is lowered too fast/slow? How do you want the operator to adjust CVCF? Is there a secondary indication that you want the operators to use other than 10 minutes? What if 10 minutes is not enough/too much?

The phrases “on mass flow meter F150” and “on temperature sensor Ti102” are added. The valve for regulating the flow is changed to the manual valve RTBY, rather than the thermally controlled CVBY to improve response time. Decrements of 10K are given for adjusting CVCF. The 10 minute time delay is to allow any LHe to drain before sealing off this section of the return line. There is no sensor that would reveal if there is or is not liquid present. There is no hazard because of the relief valve SBY, only possible inefficient use of mixture.

3.5 – Cooing The Refrigerator To The Operating Temperature

3.5.1 – This is not really a step.

The paragraph has been combined with the introductory one and the numbering updated.

3.5.2 - Is there a secondary indication that you want the operators to use other than 5 minutes? What if 5 minutes is not enough/too much?

Now 3.5.1. Five minutes is used to pump the last dregs of mixture out of the dump. The pressure gauge in that portion of the system is too coarse to indicate this. The only consequence is possible inefficient use of mixture.

3.5.3 – Perhaps this step should include a table to indicate to the operator the effects of each tuning parameter manipulation. Is there a preferred order to use these two parameters? Should there be a maximum increment, after which you would want the operator to wait to see what the effect will be? Perhaps give the operator a feel for how much a particular adjustment will effect the temperature so as to prevent large excursions.

Now 3.5.2. The phrases “in steps of 10 mW”, “in steps of 5K”, and “in steps of 2” on the tank pressure gauge” are added. Thirty minutes is required between steps of any parameter. A phrase discouraging the adjustment of the He3 ratio is added.

Reply to Memo 5

Step 3.6 - Loading the Target into the Cryostat

Note that 3.6 “Loading” is a parallel to 3.8 “Removing” and that most of the comments and responses are repeats from Memo 4.

3.6.2 – Is this step optional? How is still power reduced? Is this heater power?

Step interchanged with 3.6.1 and made identical to the new 3.8.1, where the same comments were handled in Memo 4.

3.6.3 – Shouldn’t this step be done first?

It is actually easier to transfer LHe when the cryostat is pulled back away from the detector.

3.6.4 – Is this step required or not? What happens if the Autofill does start during the process?

Step is now identical to the new 3.8.4, former 3.8.3, where first comment already fixed. An Autofill while tipped has some possibility of not stopping because the level sensors are located on the high side.

3.6.4.1 – Can’t a switch be incorporated into this system?

See answer to same comment on former 3.8.3.1, new 3.8.4.1, in reply to Memo 4.

3.6.4.2 – Where is the 110 VAC source?

There is a bank of outlets on the wall just south of the cryostat. An extension cord will be required.

3.6.4.3 – What extension cord? Isn’t the device already powered?

The power to the solenoid CVLN2 is being disconnected in this step when the bath is full. It was powered from the wall because the PLC does not think a transfer is necessary and so is not supplying power.

3.6.4.4 – This is not a step.

It is after the missing action to plug the solenoid power back into the PLC is added.

3.6.5 – How do we know when the magnet is fully charged?

Step is identical to the new 3.8.5, former 3.8.4, where the same comments were handled in Memo 4.

3.6.6.2 – What do you do if the parameters do change? Are there any hazards associated with a parameter change?

One would have to evaluate this. Assuming that it is real, it means something is loose inside. One might be able to live with it until the next maintenance or one may have to stop and open up.

3.6.7 – Are there any figures for this? How do we know what the proper nomenclature is?

As for the new 3.8.7, former 3.8.6, the old write up failed to account for the existing detailed procedures in the Transfer Cryostat Manual, Procedures 3.11 "Attaching to the InBeam Cryostat", 3.16 "Placing a Target" and 3.12 "Detaching from the InBeam Cryostat".

3.6.7.1 – How do we connect this?

3.6.7.2 – Should we purge this area after pumping? If there will be LHe in there, we should do pump and purge three times. Is the pumping port obvious?

3.6.7.3 – What valves? What valve numbers?

All 3 dealt with in Transfer Cryostat (TC) Procedure 3.11. Hence 3 steps now combined into single step to do that procedure.

3.6.7.5 –6 – How?

Use TC Procedure 3.16 for these two steps. Hence both are now combined.

3.6.7.7 - What valves? What valve numbers?

3.6.7.8-9 – How?

Steps 3.6.7.7 and 3.6.7.9 dealt with in TC Procedure 3.12. Hence both are now combined. Procedure 3.6.7.8, now 3.6.7.4, is done by rotating the shutter control lever on the upstream end of the cryostat.

3.6.8.1 – Do we need to set the clamp pin (3.6.6.2)?

Yes, sentence added

3.6.8.2 – What do you do if there are impacts to the tipping?

Same answer as in 3.6.6.2.

3.6.9.1 – How, and what pressure is to be avoided/maintained?

The pressure check is not necessary. Step now just turns off Low Speed mode as in new step 3.8.9.1.

3.6.9.2 – How? You need to note the power level at step 3.6.2.

Step is now identical to new step 3.8.9.2 where same comment was handled in Memo 4.

Reply to Memo 3

Step 3.7 - 7k Test Instructions

This has en extended lead-in discussion which is uncharacteristic of the other steps. It is the first time we see Dilution Refrigerator mode mentioned. If some of this is important, I suggest a principles of operations section. The second paragraph has a warning to proceed with extreme caution, right after the first paragraph states that the procedure will not overshoot the temperature. These are contradictory, and lowers ones expectation of the procedure.

The first paragraph gives the goal, no temperature overshoot, and explains why. The second warns that this is difficult to achieve and explains why. Where is the contradiction? To emphasis that the first paragraph is stating a goal, the phrase “is to allow” is changed to “has the goal of”. It is an oversight that the manual fails to mention that this device is a dilution refrigerator. That fact has been added to the Summary at the beginning and emphasized by changing the title of step 3.5.3 (now 3.5.2) to “Dilution refrigerator mode tuning”.

3.7.1 – This is not a step.

Numbering is removed and text is combined with introductory paragraphs.

3.7.3.1 – The turbo pumps referred to in this step ae TP1 and TP1a? References to equipment need to be consistent. How does one set the speed? This is the first time in the procedure we are setting a speed. Before we turned it on and off.

Names of pumps added. “Low speed mode off” added to step 3.3.2. The low speed mode is a toggle switch right next to the on-off toggle switch. Step is now 3.7.2.1.

3.7.3.2 – Different format from other steps. Why? Second bullet – what is the gas cleaner? The LN2 trap? V12 is already open. What valve? Third bullet – How do we heat the still and mix? Nomenclature? Last bullet – What valve? Nomenclature?

Step is broken up into four steps. First bullet, now 3.7.2.2, has dump name and a check on V30 added. Second bullet, now 3.7.2.3, has “gas cleaner” replaced with “LN2 trap” and valve name V16 added. Third bullet, now 3.7.2.4, has heater names, HMIX and HStill, and increment step sizes added. Fourth step, now 3.7.2.5, has “gas cleaner” replaced with “LN2 trap” and valve name V16 added.

3.7.3.3 – What valve?

Step, now 3.7.2.6, has valve name V30 and dump name M155d added.

3.7.3.4 & 5 – What does the parenthetical tell the operator? I’m confused by this step. What do I set, and to what do I set it? How do I set it?

Step 3.7.3.4, now 3.7.2.7, is expanded to read “Click CV1K on the LabVIEW CONTROLS tab page to MANUAL. Enter a temperature set point of 160K (valve temperature will read 152K at equilibrium).”

3.7.3.6 – It looks like some words are missing in this sentence. I can’t discern what is supposed to be done. Is it more than one operation?

Step 3.7.2.9 is expanded to read “Activate the 1K pot heater controls in the PLC by entering 8 for QPHASE on the LabVIEW CONTROLS tab page. Enter a 1K pot set temperature of 3K. Click He1K to AUTO.”

3.7.3.7 – Yet another format for multiple steps within a “step.” First sentence – what is supposed to be monitored? How? Third sentence (second paragraph?) How rapid is rapid? Fifth sentence – Does the operator reduce the heat to about 1% or will the system do it? Eighth sentence – Does the operator have to turn the heat mode on and off manually? Can’t this be automated? Isn’t there a more elegant way to do this? Ninth sentence – Is QPHASE=8 ON and QPHASE=5 OFF? We can’t make the display indicate ON and OFF? Tenth sentence – Increases or decreases?

Step 3.7.3.7, now 3.7.2.10, has been drastically simplified. By utilizing a lower temperature setpoint, the PLC algorithm will catch the emptying of the pot without an overshoot and without operator intervention. The step is now:

> Wait and monitor the 1K pot temperature Ti1K and the He1K heater duty cycle while the 1K pot slowly empties of liquid He-4.
>
> Emptying the 1K pot takes about 1 hour starting at 10% full. Half of that time the level reading is zero (below the level sensor), but do not be fooled! As long as there is a large heat input and a cool temperature there is still liquid boiling. The duty cycle will remain at about 6% while there is liquid and drop to 1% once the pot is empty.

3.7.3.8 – How do we increase the set point?

3.7.4.2 – How do we turn on the 7k set point? How do we gradually increase the set point? The desired temperature is 7K, right? How do we turn the 7K mode off?

3.7.4.3 – How do we switch the 1K pot heater to manual?

3.7.5.1 – How do we switch off the 7K heat mode?

3.7.5.2 - How do we switch back to “normal” operation?

3.7.5.3 – How do we switch back to automatic?

The relevant LabVIEW control’s name, location and input method are added to these steps. There is a missing final step to this which is to execute step 3.4.3 and procedure 3.5 to return to full dilution refrigerator operation and which is added.

It appears to me that this procedure may be using the LabView program to run the operation, but I can't tell from this procedure. This should be more clear. On LabView, we would use "select [icon]" or type something. Until I saw a QPHASE=8, we could be using a switch panel.

Every LabVIEW control in this procedure is now specifically identified as such.

Reply to Memo 4

Step 3.8 - Removing the Target from the In-beam Cryostat

End of lead-in paragraph – Need to note Still power for Step 3.8.7.2.

Sentence to that effect is added. The actions in this paragraph are separated into a new step.

3.8.3 – This is a procedure. Is this supposed to be done or not?

The phrase “It is prudent to do” is replaced with “Do”.

3.8.3.1 – Is this the most elegant way to accomplish this task? This is a foreseeable event. Can’t there be a switch or something?

We agree this is crude. We intend to look into the PLC and LabVIEW re-programming required to have a manual override available in the LabVIEW interface.

3.8.3.4 – Do you need to reconnect the connector?

Yes. Sentence added.

3.8.4 – How long to we wait for magnet current to ramp up? Is there an indication when it is ramped up?

There is a plot and a digital display on the indicated LabVIEW page as well as a panel meter on the magnet power supply in the electronics rack.

3.8.6 – Figures? Nomenclature? This is too abstract to be useful to the intended audience.

The previous set of steps failed to take account of the detailed Transfer Cryostat (TC) procedures already written, approved and in use, TC procedures 3.11 “Attaching to the InBeam Cryostat”, 3.15 “Retrieving a Target” and 3.12 “Detaching from the InBeam Cryostat”. The sub-steps have been re-written and simplified by doing the TC procedures.

3.8.7.2 – Need to reclamp the tilting handwheel.

Sentence added.

Paragraph after 3.8.7.2 – Why would one wish to keep the refrigerator running? By turbo pump do you mean TP1 or TP1a? How does one turn on still power? Is that the still heater power?

One would wish to do so to load and run on another target. Paragraph no longer optional and is now a set of 3 steps. “3.8.9.1 Turn the Low Speed off for the turbopump(s) in use (TP1 and/or TP1a). 3.8.9.2 On the LabVIEW CONTROLS tab page, return the still heater power HStill back to the value used before removal of the target. 3.8.9.3 Tune the refrigerator as in section3.5.3.”

3.9 – Warming the In-Beam Cryostat

3.9.1 – How much of a ramp? How?

Step is expanded to read “On the LabVIEW MAGNET tab page, enter a Set Current of zero and a Ramp Rate of 1.3 A/sec. Click Press to Start to ramp down. After reaching zero current, turn off the magnet power supply in the electronics rack.”

3.9.1 – How substantially? Can’t you use a level indication? How high is too high? How does one not let the pressure rise too high?

Numerical values are added to 3.9.2.1 and 2 LabView information to 3.9.2.2 and 3..

3.9.5 – How does one turn off the LN2 filler?

Step 3.9.5 now reads “Unplug the power for the LN2 solenoid valve CVLN2 from the PLC.”

3.9.6 – How does one close CV1K and CV2K?

Step 3.9.6 now reads “On the LabVIEW CONTROLS tab page, close CV1K and CV2K by entering 70K for their set points.”

3.9.9 – Shouldn’t there be some valves in the LN2 and LHe circuits be left open to let the rest of the gas escape? Will the BRx valves do this?

The LN2 and LHe bath vents are still “open”, actually, still have 1 psi relief valves, SLN2a and S3b. What might be of concern are the 1K and 2K circuits, which are relying on 5 psi relief valves S6 and S16.

3.10 – After the Cryostat has Warmed

3.10.1 – What pumps? The procedure has all the pumps off before this step.

Reference to pumps is deleted.

Reply to Memo 6

The following paragraph has been added to the beginning of Chapter 3 in order to more clearly define the goal of this manual.

"This is an Operations Guide designed to cover all steps related to personnel and equipment safety, but not necessarily including all possible functioning scenarios of the device and how these could impact the polarized targets that are transferred into and out of the cryostat. The latter requires extensive on the job training by LEGS polarized target experts."

New Procedure, and Reply to Memo 1 – I am still not comfortable with the totalizer and how it fits into this system. I don't know how it fits in. The procedure provides no indication that the totalizer is connected to the system, and there is no check to ensure the totalizer and its downstream connection is open, closed, or otherwise. In installing this system and doing its initial checkout, There needs to be a reference to another procedure for the installation/ connection, and there needs to be a check that the downstream system is open, closed or otherwise.

The totalizer is a permanent part of the system and requires no installation. It has no settings or controls, only a readout. There is a similar one on every natural gas hookup in the country. The operation of the helium recovery system, which is part of the helium liquifer, is not covered in this manual.

Reply to Memo 1 – There should be list of equipment necessary for the procedure. As an example, the extension cord for the LN2 solenoid valve and the "mechanical vacuum pump with thermocouple pressure gauge. Getting half way into a procedure is not the time to find out they are missing equipment.

This is not a safety issue but is rather part of work planning. Check lists are used to optimize such steps.

Step 3.2.1 – Is there a potential for the operator to be exposed to cryogens as LN2 is relieved through SLN2?

The venting is through SLN2<u>a</u>, a 1 psi relief valve which is 9 feet off the floor. There is no exposure to the plume and no safety issue.

3.6.4 – What are the consequences if Autofill starts while the cryostat is tipped?

The stated purpose of the procedure is to preclude the annoyance of this happening so the comment is irrelevant.

3.7.2.1 – Now that I understand that speed will be used for controlling the turbo pumps, speed should be added to the state tables. Even if it is off, the proper speed should be preselected for the next time it is to be turned on.

The turbopumps transition from OFF to ON in Step 3.3.2 where there already is a check that Low Speed mode is not toggled on. Low speed mode is only utilized in Procedure 3.7 so its state would never changes in the state table and so putting it there is superfluous. This is not a safety issue.

3.7.2.7 – I am still not clear on the information trying to be conveyed in the parenthetical. Does this tell the operator that, even though the set point was set to 160, the valve temperature will indicate 152? This is not proper control logic. The normal condition is when the set point and the indication are the same. Other indications mean the system is not operating properly. This can be a cause for unstructured operator inputs which can lead to system unbalance, loss of the sample, and maybe a hazard.

This is precisely the expected operation of a proportional temperature controller, which generates a heater current proportional to the difference. More complicated and less reliable PID controllers require careful tuning in order to achieve the purely aesthetic effect of having the controlled value equal the setpoint without annoying oscillations. This is not a safety issue. Note that it is an integral design feature, demonstrated and agreed to in the committee reviews, that loss of cooling is not a hazard to personnel or equipment.

3.7.3.7 – This comment addresses the entire procedure, and not just this step. The procedure needs to reference the software version of the LabVIEW program. Now that the procedure, that manual and LabVIEW have been changed, without this indication, the PLC controls can be reacting in a manner inconsistent with the obsolete procedure the operator is using. This can be a safety hazard and also lead to loss of operations. A first step should be to verify the software version with the manual.

There was no LabVIEW change. If there was, it is the duty of the expert making the change to update the desktop icon to point to the new version. The operator is already required in Step 3.1.3.1 to utilize this icon for precisely this reason, as stated in the step.

Reply to Memo 4, Step 3.9.9 – Now that you have mentioned the concern for retained pressure in the 1k and 2k circuits, what should be done to resolve the safety issue?

There was no safety issue in the original comment, which dealt with 1 psi relief valves, and which was emphasized by pointing to these spaces with 5 psi relief valves where there is again no safety issue.

3.3.3 – Next to last sentence – How is VGCC to be turned on? Last sentence – how is the thermocouple gauge controller disconnected?

The location of this switch is not a safety issue. A gauge controller is disconnected from a gauge by removing the cable from the gauge. This is not a safety issue. Operators become familiar with these controls as part of training.

3.3.5.1 – More unlisted equipment. Is this gas connection supposed to have a regulator and relief valve attached? What is the setting for the relief valve? What ½” plug? When did we remove it?

Equipment lists are part of work planning and not a safety issue. The setting for relief valve S3 is 4 psi and already given in Table 2 and the schematic. A clause has been added to the beginning of the step instructing the operator to remove the plug before inserting the lance.

3.3.5.2 – How do we open CV1K and CV2K? LabVIEW? If so, the entire procedure has not been gone through to ensure the references to LabVIEW are complete. Next to last sentence – Does this mean that there is no nitrogen? If it is not adequate, then what is to be done?

Location of controls is part of operator training and not a safety issue. The instruction "If too slow, repeat the test until adequate" is added.

3.3.6.1 – Is the second sentence correct? Should it read; "Install the lance <u>through</u> the shut-off…"?

Parentheses on VFILL removed and "into" substituted for "to" to make the meaning clearer.

3.3.6.3 – How are VP1 and VP2 to be turned on? LabVIEW or switches on the pumps? LabVIEW requires more instruction; for switches this is okay.

Location of controls is part of operator training and not a safety issue.

3.4.3 – How is flow monitored, on LabVIEW or directly?

Either, but location of readouts is part of operator training and not a safety issue.

3.5 – is something missing from the second paragraph?

Extraneous words appearing as a paragraph removed.

3.5.2 – Is this all done on LabVIEW? Can we distinguish that?

Location of controls is part of operator training and not a safety issue.

3.6.4.2 – Add "using an extension cord." to the end of the first sentence.

This is part of work planning and not a safety issue.

3.6.6.2 – Original questions are still unanswered. What is the operator to do if the parameters change? I believe this also applies to the corresponding section in 3.8. Same goes for the response to our comments to 3.6.8.2; what does the operator do if there are impacts during tipping?

The instruction "Inform a local expert otherwise" has been added.

3.6.9.1 – How does the turbo pump allow or not allow? What is the indication the operator is looking for?

See reply to next comment.

3.6.9.2 – Another place where the LabVIEW control is not adequately described. This step is refereeing to still heater power?

Editing errors now corrected. These steps should have been identical to 3.8.9.1 and 2. However, neither comment is a safety issue.

3.7.2.7 – What does the parenthetical tell us? Why is it parenthetical? Why doesn't read 160 if we set it to 160?

This is a repeat of the comment on this step above. See answer there.

3.7.4.2 – Already set to 8 at step 3.7.4.2.

8 corrected to 5.

3.8.4.2 – Add "using an extension cord." to the end of the first sentence.

This is part of work planning and not a safety issue.

3.8.6.2 – Need to add the step to reclamp the handwheel.

Instruction added to step.

3.8.6.2 & 3.8.8.2 – What is the operator supposed to do if there are impacts? You are telling them to monitor this for a reason, right?

The instruction "Inform a local expert otherwise" has been added to both steps.

3.9.2.1 – how is the operator supposed to not let PI2 rise above 20 mBar?

As the step clearly implies, by controlling how he opens the valves. This comment is part of operator training. It is not a safety issue.

Still Orifice Pressure Rise

April 20, 2004

The question has arisen as to the maximum pressure rise seen by the inbeam cryostat's still in a catastrophic loss of vacuum incident. This is an issue due to the presence of a quarter inch orifice on the pump line exit.

The mass boiling rate is given by the following expression.

$$\dot{m}_{boil} = \frac{A_b \dot{q}}{\Delta H}, \tag{1}$$

where A_b is the surface area of metal in contact with the liquid, $\dot{q}$ is the heat transfer rate and ΔH is the enthalpy change in going from liquid at operating temperature (< 1 Kelvin) to vapor at the boiling temperature corresponding to the still pressure.

The mass flow out an orifice is given in standard vacuum references for both molecular and viscous flow regimes. We anticipate that the pressure is such that the viscous regime is appropriate in which case

$$\dot{m}_{orifice} = r^{\frac{1}{\gamma}} \sqrt{\frac{2\gamma}{\gamma - 1}(1 - r^{\frac{\gamma-1}{\gamma}})} \sqrt{\frac{Mol.Wt.}{RT}} P A_o, \tag{2}$$

where r is the ratio of the downstream to upstream pressure, γ is the ratio of heat capacities, R is the gas constant, T and P are the upstream temperature and pressure, and A_o is the orifice area. Note that the expression has been modified from the standard volume units to mass units.

Flow at or below the so-called critical ratio of downstream to upstream pressure is saturated because the velocity of the flow has reached the speed of sound in the fluid.

$$r_{critical} = (\frac{2}{\gamma + 1})^{\frac{\gamma}{\gamma+1}} = 0.487 \tag{3}$$

for an ideal monatomic gas. We expect to be well below this ratio so

$$\dot{m}_{orifice} = 0.7262 \sqrt{\frac{Mol.Wt.}{RT}} P A_o. \tag{4}$$

Equating the two mass rates, equations (1) and (4), and solving for the upstream pressure yields

$$P = 1.377 \frac{A_b}{A_o} \frac{\dot{q}}{\Delta H} \sqrt{\frac{RT}{Mol.Wt.}}. \tag{5}$$

Note that the pressure P must be the vapor pressure of the liquid at temperature T and that $\triangle H$ is also a function of T.

In order to evaluate equation (5), we must determine A_b, the area in contact. For the still this is straight forward. The diameter of the still and height of the liquid up the side are given in the spreadsheet sent to Steve Kane in August. The area is 118 cm^2. However, the mixing chamber, interconnecting lines and counterflow heat exchanger are also filled with liquid. For the small diameter lines and heat exchanger, it is clear that the first bubbles will quickly carry the liquid out and then vapor lock them. This will also happen for the mixing chamber because its exit is at the bottom. The accumulating gas will rapidly eject the low viscosity liquid. The amount of liquid is small compared to that in the still so the height there is not changed.

The area of the orifice is 0.317 cm^2. We take $\dot{q}$ from the reference in the ODH submission, 3.8 W/cm^2. A number of iterations suggests a guess for the temperature T of 3.75 K. This implies an enthalpy change $\Delta H = 27.5$ J/g. $R = 8.3145$ J/K and $Mol.Wt. = 4$ g. Then $P = 6.26 \times 10^4$ Pa $= 0.618$ atm $= 9.1$ psi. (The vapor pressure of ^{4}He at 3.75 K is 9.2 psi.)

Thus the maximum pressure rise is safely within the pressure specification of all components.

Quantum Quantum Technology Corp.

LASER ELECTRON GAMMA SOURCE:

IN-BEAM CRYOSTAT MANUAL

MODEL Q02-P153

Quantum Technology Corporation USA

PMB 183, 250 H Street
Blaine, WA 9823 USA

T (888) 271-9466
F (888) 711-5222

Email: quantum@quantum-technology.com
Web: http://www.quantum-technology.com

Quantum Technology Corporation

BC Research & Innovation Complex
3650 Westbrook Mall
Vancouver BC V6S 2L2 CANADA

T (604) 222-5539 (General Office)
T (604) 224-4331 ext 580
F (604) 677-5826

Email: quantum@quantum-technology.com
Web: http://www.quantum-technology.com

APPROVAL

Quantum Technology Corp.

Title: **LASER ELECTRON GAMMA SOURCE: IN-BEAM CRYOSTAT MANUAL**

Name: Dr. Calvin Winter

Name: Dr. Dennis Healey

Name: Dr. Terry Templeton

Date Approved:

SHIPPING LIST

	Item	Description	Qty	Box
1.	Main system	Cryostat, consists of the dilution refrigerator, iris, snout, and vacuum chamber: as drawing number	1	B
		Tip trolley, include Lock arms and all screws	1	G
2.	Pump stand/ flow control valve unit	Varian DS202 Mechanical Pump/ for 1K pot line S/N 204489	1	A
		Varian DS202 Mechanical Pump/ for 2K pot line S/N 207608	1	A
		Varian TV1001 Turbo Pump, S/N 201823	1	G
		Varian 1000HT Turbo Pump Controller, S/N 222662	1	G
		Alcatel 2063H Mechanical Pump, S/N 399727	1	C
		Edwards speed valve	2	F
		Edwards Active Pirani Gauge	1	G
		Omega Pressure Transducer	2	G
		VRC Gate Valve	1	F
		LN_2 Trap	1	G
3.	Gas Cylinders	He.4 Dump/ 108L Cylinder	1	D
		He.3+4 Dump/ 108L Cylinder	1	D
		He.3 Dump/ 216L Cylinder	1	D
		He.3 Dump/ 21.6L Cylinder	1	D
4.	Tubing	ISO160 Flex Hose (He3 return line)	1	F
		ISO160 Angle (on the gate valve)	1	F
		KF40 Flex Hose (TP to Valve Control)	1	F
		KF25 Flex Hose (1K pot line)	1	F
		KF25 Flex Hose (2K pot line)	1	F
		KF16 Flex Hose (He dumps, LN2 trap)	1	F
		KF25 Flex Hose (to Alcatel)	1	F
		KF40 Flex Hose (to Alcatel)	1	F
		Clamps, center rings, Cross and Tees	many	F
		LHe Transfer line	1	G
5.	Control unit + connecting cable	Main Control Rack	1	E
		Connecting Cables for control	1	G
		Connecting Cables for magnet power supply	1	G

6.	Literature	Instruction manual	1	G
7.	Spare Parts	Top Flange O-ring (AS568A-469)	2	G
		Bottom Flange O-ring (AS568A-385)	2	G
		Side Flange O-ring (AS568A-382)	4	G
		Iris Flange O-ring (AS568A-376)	2	G
		Snout Flange O-ring (AS568A-368)	2	G
		Screws Nuts + Washers for The Top Flange (1/2"-13 stud L3.0" + 1/2" Heavy Hex Nuts)	9 sets	G
		Screws Nuts + Washers for The Bottom Flange (3/8"-16 Flat Head L2.0" + 3/8" Heavy Hex Nuts)	9 sets	G
		Screws Nuts + Washers for The Bottom Side Flanges(3/8"-16 stud L2.5" + 3/8" Heavy Hex Nuts)	20 sets	G
		Screws + Washers for Turbo Pump on the stand/ M6 – L50mm	6	G
		CFF34 Gasket	4	G
8.	Tools	Tool box	1	G
9.	Returning BNL equipment	Magnetometer, Hall Probe	1	G
10.				
11.				

Package:
A= H64" × W36" × D35.5"(inside dimension) CRATE FOR Pump Stand, On 4' × 4' Skid (Box 1 of 8)
B= H79" × W21" × D72"(inside dimension) CRATE FOR CRYOSTAT, On 6' × 4' Skid (Box 2 of 8)
C= H24" × W46" × D13" CRATE (Use Original Crate) for Alcatel Pump, On 4' × 4' Skid (Box 3 of 8)
D= H58" × W48" × D48" CRATE for gas cylinders, On 4' × 4' Skid (Box 4 of 8)
E= On 4' × 4' Skid + covering panels for Control Rack (Box 6 of 8)
F= On 4' × 4' Skid/ Cardboard Box for 6" tube, other tubing, clamps, etc (Box 7 of 8)
G= On 4' × 4' Skid/ Tip trolley, spare parts, etc (Box 8 of 8)

Summary

The LEGS group operates a spin polarized solid HD target in conjunction with a unique polarized photon source

Three key cryostats are used: One is with a high magnetic field for target polarization which requires a few weeks. Up to three targets are polarized at the same time. They are mounted vertically on a copper support in a ~20 milliKelvin dilution refrigerator for this purpose.

A portable transfer cryostat (TC) is used to remove a target from the polarizing cryostat and to carry it to the in beam cryostat. The in beam cryostat must tilt nose down to accept the sample from the transfer cryostat. After disconnecting the in beam cryostat is tilted back so that the target is horizontal.

This manual describes the operation of the in beam cryostat. It is a dilution refrigerator that maintains previously frozen spin polarization of the target at ~250 mK in a magnetic field of 1 Tesla. In addition, in a spin polarization calibration mode, it can warm up and maintain the target at ~7K.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Design goals:

Maintain Target below 0.5K prefer below 0.2K

Maintain target polarization at all times with a magnetic field.

~1Tesla around target during experiment

~0.1T in transfer position

Field homogeneity in region of target: 10-3

Experiment duration: 2 weeks or more

Autonomy of target and magnetic field: 5 minutes without electric power (able to recover automatically from a short power failure).

Liquid helium fills: once per day. (No continuous transferring of liquid helium required.

Liquid nitrogen fills: once per day (or if more frequent an auto-fill system is required)

Compatible with existing transfer cryostat.

Axial force on LN_2 shield iris opener: 150 pounds (700 N).

Torque on solid hydrogen target when inserting: 24 foot-pounds (34 N-m) Measured value was 16 foot-pounds (190 inch-pounds) +/-10%.

Equipment protection from failure:

Quench protection for superconducting magnet

Relief valves on all cryogen spaces.

Specification of cryostat dimensions are shown on the attached drawing. Several of these dimensions are critical to compatibility of equipment.

Inlet vacuum flange: ISO63. (The transfer cryostat has ISO63K [clamp style]) The target cryostat has an ISO63 bolted flange gate valve to match.

2 SYSTEM SPECIFICATIONS

2.1 Cryostat volume:

Vacuum vessel volume: 230 liters

2.2 Volumes in the cryostat:

LHe bath: 45 liters

LN_2 bath: 5 liters

2.3 SC Magnet:

Magnetic Field: 1 Tesla @ 100A

2.4 Snout dimensions:

Target snout outside diameter: 80 mm

Target holder diameter: 35 mm

2.5 Operating parameters:

Target operating temperature: ~250 mK

Cooling power: 1 mW @ 375 mK
2 mW @ 634 mK

2.6 Cryogen consumption:

100 LHe liters per day

50 LN_2 liters per day

2.7 Materials around the target in radial direction:

Table 1 Materials around the target in radial direction.

O:\2004\MANUFACTURING\P153-LEGS\EXCEL\BNL6-r4_material near tgt.XLS — 1/27/2004

Materials around the target in the radial direction		UPDATED 1/27/2004	1/26/2004			1/26/2004			1/26/2004		1/26/2004		1/26/2004	Energy Loss from centre of target	1/26/2004	
Item	Material	Radius outside mm	Outside Radiu mm ## (AMS)	Radius outside mm	Radial space to next shield (mm)**	Material Thickne mm ## (AMS)	Thickness mm	Density gm/cm^3	Density gm/cm^3	Areal Density mg/cm^2	density x thick g/cm^3	Radiation Length cm	Rad Length cm	Fractional Radiation Length	fractional Rad Lengt cm	Fraction of Loss
Target	HD				2.5*	12.6	15	0.12	0.147	180	0.185	800	783	0.0019	0.0016	0.026
target cooling wires (Al 20% by wt.)	Aluminum wire		12.6			12.6			& 0.04		0.046		986		0.0013	
Target container	mylar		13.1	15	1.5	0.5	0.08	1.4	2.14	11	0.107	19	162	0.0004	0.0003	0.006
NMR Former	Kel-F		15.5	16.5	0	1	1	1.4	2.14	140	0.214	19	162	0.0053	0.0006	0.073
Magnet former, inner	Aluminum	26	27.3	26	0	1	0.75	2.7	2.7	203	0.270	9	8.9	0.0083	0.0112	0.115
Holding coil	Cu, NbTi***	27.21	29.7	26	0	1.778	0.4445	9	# 8.2	314	1.968	1.4	1.59	0.0318	0.1118	0.437
Magnet former, outer	Aluminum	30.5	30.5	28.5	2.5	1	0.75	2.7	2.7	203	0.270	9	8.9	0.0083	0.0112	0.115
20 K shield	Aluminum	33.9	34	31.5	1	0.66	0.2	2.7	2.7	54	0.178	9	8.9	0.0022	0.0074	0.031
77 K shield	Aluminum	35.9	35.9	33.5	3	1	0.2	2.7	2.7	54	0.270	9	8.9	0.0022	0.0112	0.031
30 layers SI	mylar					0.19	0.2	1.4	1.4	28	0.027	19	28.7	0.0011	0.0007	0.015
Vacuum shell	Aluminum	40.1	40	39		1	1	2.7	2.7	270	0.270	9	8.9	0.0111	0.0112	0.153
Totals								TOTALS:		1456				0.0726	0.1687	
													sum if yellow H16-H20 used		0.0748	

* Note: Radial space from the target to the magnet former is measured from the outside of the refrigerator housing

** These radial spaces are construction clearances. They may not match thickness and radii around target because several shields are machined thinner in the target section.

*** Radiation length of copper was used. The ratio of Copper to superconductor is Cu:Sc = 1.34:1 (by volume?). Composition of NbTi is approx. 46.5 - 50% weight percent Ti.

as taken from BNL 45-P.dwg

& effective Al density taken as 0.037 to give 20% Al by mass

density of 4x0.6 mm wire = 8.96*(1.34/2.34) + [(4.54+9.92)/2]*(1/2.34) = 8.2

2.8 Pump Specifications:

2.8.1 2K Pot Varian DS 202

VARIAN DS 202 - ROTARY VANE TWO STAGE PUMP

Model L580PR

No 204490-2002

Pumping speed: 6CFM @ 60 Hz (2.832 l/s)

Ultimate Total Pressure: 2 x 10-3 Torr

Weight: 55 lbs

Inlet and exhaust port size: NW25KF

100-120 V, 60 Hz, 1720 RPM, 0.55 kW, power factor>0.8, 8.8 A

2.8.2 1K Pot Varian DS 202

VARIAN DS 202 - ROTARY VANE TWO STAGE PUMP

Model L580PR

No 105962-2001

Pumping speed: 6CFM @ 60 Hz (2.832 l/s)

Ultimate Total Pressure: 2 x 10-3 Torr

Weight: 55 lbs

Inlet and exhaust port size: NW25KF

100-120 V, 60 Hz, 1720 RPM, 0.55 kW, power factor>0.8, 8.8 A

2.8.3 Varian Turbo Pump

He_3 VARIAN TURBO PUMP – WATER COOLED

Model 9698931

No 201823

Input 650 Hz

N2: 790 l/s, He 820 l/s, H2: 860 l/s

2.8.4 Alcatel 2063H

He_3 HERMETIC PUMP – WATER COOLED

No 399727

208, 60 Hz, 750 RPM, 3.00 HP, 0.87 PF, 9.90 A

60 Hz, 42.4 CFM, 20 l/s

3 OPERATING INSTRUCTIONS

This is an Operations Guide designed to cover all steps related to personnel and equipment safety, but not necessarily including all possible functioning scenarios of the device and how these could impact the polarized targets that are transferred into and out of the cryostat. The latter requires extensive on the job training by LEGS polarized target experts.

These instructions are referenced to Table 3 Cryostat Device State Tables, Figure 6 Gas Flow Schematic, and

Table 2 Relief Valves.

Table of Relief Valves		
Revised Mar 15/04		
Name of Relief Valve	Valve Setting	Location of the Relief Valve
S13	5 psig*	On valve above turbo-pumps
S14	1 psig*	Alcatel pump M151a exhaust
S15	1 psig*	Alcatel pump M151b exhaust
S10	5 psig*	After absorber, on back of pump stand panel
S11	10 psig*	On LN2 trap
S12	10 psig*	On LN2 trap
S11a	30 psig*	On pump stand at LN2 trap inlet
S12a	30 psig*	On pump stand at LN2 trap inlet
S9	<0.1 psig#	On cryostat
S7	15 psig*	On He-3 return line, on back of flow panel (on side of cryostat)
SBY	15 psig#	Bypass return relief, on back of flow panel (on side of cryostat)
S6	5 psig*	1K pot pump line, on top of cryostat
S16	5 psig*	2K pot pump line, on top of cryostat
S3b	1 psig*	Helium bath (at totalizer inlet), to maintain bath pressure
S3	4 psig#	Helium recovery line, high capacity, on top of cryostat
SLN_2	10 psig*	LN_2 delivery line to cryostat, beside solenoid valve
SLN_2a	1 psig*	Cryostat LN_2 bath exhaust line

* - Purchased valve, set at factory, NOT adjustable
# - Adjustable valve

Table 3 Cryostat Device State Table.

	BNL In-Beam Cryostat Device State Table											Revised 25 Mar/04	
Status at the beginning of the Steps in the Operating Procedures					Step 3.1	Step 3.3	Step 3.4	Step 3.5	Step 3.6	Step 3.7	Step 3.8	Step 3.9	Step 3.10
						Preparations Complete	LN2 & LHe Reservoirs Full	Magnet Cold	Refrigerator Operating	Target Loaded	7K done	Target Removed	
Name	Physical Location	Control	Description	Function	Initial Conditions	Ready to Fill Reservoirs	Ready to Cool Pots and Precool Reservoirs	Ready to Operate Refrigerator	Ready to Load Target	Ready for 7K Operation	Ready to Remove Target	Ready to Warm Cryostat	Ready for Final Shutdown
BR3	Cryo. Panel	manual	flow meter	1st 4He counter-flow hEX	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR4	Cryo. Panel	manual	flow meter	current lead	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR5	Cryo. Panel	manual	flow meter	current lead	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR6	Cryo. Panel	manual	flow meter	20K shield & Iris Opener vent	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
BR7	Cryo. Panel	manual	flow meter	Magnet can gas vent	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
CV18	Pump panel	manual/PLC	solenoid	valve to dumps for MIX	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
CV1K	inside IBC	PLC	thermal CV	needle valve for 1K pot	CLOSED	CLOSED	OPEN	AUTO	AUTO	AUTO	AUTO	AUTO	CLOSED
CV2K	inside IBC	PLC	thermal CV	needle valve for 2K pot	CLOSED	CLOSED	OPEN	AUTO	AUTO	AUTO	AUTO	AUTO	CLOSED
CV5	Alcatel M151a	PLC	solenoid	equalize pressure on power loss	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
CV9	Alcatel M151b	PLC	solenoid	equalize pressure on power loss	OPEN	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	OPEN
CVBY	inside IBC	PLC	thermal CV	needle V bypass to cool MC	CLOSED	CLOSED	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
CVCF	inside IBC	PLC	thermal CV	needle V, Dilution Refrigerator flow impedance	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
CVLN2	LN2 supply dewar	PLC	solenoid	auto fill for IBC LN2 reservoir	CLOSED	CLOSED	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	CLOSED
M151a	Pump Stand	manual/PLC	Alcatel MP	Rotary Pump for MIX circulation	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
M151b	Pump Stand	manual/PLC	Alcatel MP	Rotary Pump for MIX circulation	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
NV17	Main Panel	manual	Needle V	Meter gas into refrigerator	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
RTBY	Cryo. Panel	manual	gas valve	seals off CVBY bypass	CLOSED	OPEN	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
Shutter	IBC beam port	manual	rotating rod	100K and 4K radiation shutters	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
TP1	Pump Stand	manual	Turbo-left	Varian Turbo for IMX circulation	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
TP1a	Pump Stand	manual	Turbo-right	Varian Turbo for IMX circulation	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
V1	Main Panel	manual	Gate valve	Isolation Valve for Turbo-left	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V1a	Main Panel	manual	Gate valve	Isolation Valve for Turbo-right	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V10	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
V11	Main Panel	manual	gas valve	LN2 trap F152 inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V12	Main Panel	manual	gas valve	LN2 trap F151 inlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V13	Main Panel	manual	gas valve	LN2 trap F152 service valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V14	Main Panel	manual	gas valve	LN2 trap F151 service valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V15	Main Panel	manual	gas valve	LN2 trap F152 outlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V16	Main Panel	manual	gas valve	LN2 trap F151 outlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V17	Main Panel	manual	gas valve	Coarse gas inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V19	He-4 dump tank	manual	gas valve	Isolate He-4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V19a	He-4 dump tank	manual	gas valve	Isolate He-4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V1K	1K pot pump	manual	gas valve	I K Pot Pump Valve	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V2	Main Panel	manual	gas valve	Gas inlet shut-off valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V20	He3/4 dump tank	manual	gas valve	Isolate He3/He4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V20a	He3/4 dump tank	manual	gas valve	Isolate He3/He4 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V21	Main Panel	manual	gas valve	Evacuate He3 return line	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V23	Main Panel	manual	gas valve	Isolate TP1 (turbo-left) exhaust	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V23a	Main Panel	manual	gas valve	Isolate TP1a (turbo right) exhaust	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V24	Main Panel	manual	gas valve	Remove gas in F151 gas cleaner	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V25	Main Panel	manual	gas valve	Remove gas in F152 gas cleaner	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V26	He3 dump tank	manual	gas valve	Isolate He3 dump tank	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V27	Main Panel	manual	gas valve	Adsorber inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V28	Main Panel	manual	gas valve	Adsorber inlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V2a	Main Panel	manual	gas valve	Gas inlet needle valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V2b	Pump Stand	manual	gas valve	Gas inlet port pump-out valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V2K	2K pot pump	manual	gas valve	2K Pot Pump Valve	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V30	Mixture tank	manual	gas valve	Isolate mixture tank	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V3	Main Panel	manual	gas valve	Alcatel inlet valve	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
V4	Main Panel	manual	gas valve	Alcatel inlet valve	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED
V6	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
V7	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
V8	Main Panel	manual	gas valve	Alcatel oil return valve	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
VFILL	Cryostat	manual	LHe valve	Shut-off LHe fill	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
VHB	top of cryostat	manual	gas valve	vent helium reservoir to totalizer	CLOSED	CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
VHBa	on totalizer	manual	gas valve	vent helium reservoir to atm	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
VP1	Pump Stand	manual	Varian MP	1K pot pump	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
VP2	Pump Stand	manual	Varian MP	2K pot pump	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF
VP25	Cryostat	manual	gas valve	Cryostat evacuation valve	CLOSED	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
VP26	Pump Stand (on V1a)	manual	gas valve	Evacuate 6" flex line	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED

3.1 Prior To Cooldown:

This section describes the procedures that are necessary to establish the insulation vacuum in the cryostat and to purge and leak check the internal gas circuits in the cryostat. These procedures prepare the cryostat for the initial cooling.

3.1.1 Pre-cool check.

Check that all devices are correctly set as designated by the State Table, the column labelled "Step 3.1". Note that CV5 and CV9 are N.O. electric solenoid valves and are open when the associated Alcatel pump is off

3.1.2 Relief-valve check.

Check that all relief valves are unobstructed. The relief valves and their locations are listed in the Table of Relief Valves.

3.1.3 LabVIEW program startup procedure.

3.1.3.1 Locate the latest version of LEGS program which is linked to a desktop shortcut LEGS.

3.1.3.2 Double click to start LabVIEW program.

3.1.3.3 Check the settings for data file save (frequency) and recommended directory for storing data on LabVIEW tab. Decide if you want to APPEND data to the existing file or CREATE a new one.

3.1.3.4 Make sure that "Enable DAQ" switch is ON and click on white arrow to start the program (See Fig. 1), the arrow will change to black.

3.1.3.5 Pop-up windows show that you use to select the location and the name of the file.

3.1.3.6 To stop the program press "Enable DAQ" switch once and wait for the loop to finish (~1.5 s). Arrow should revert back to white form.

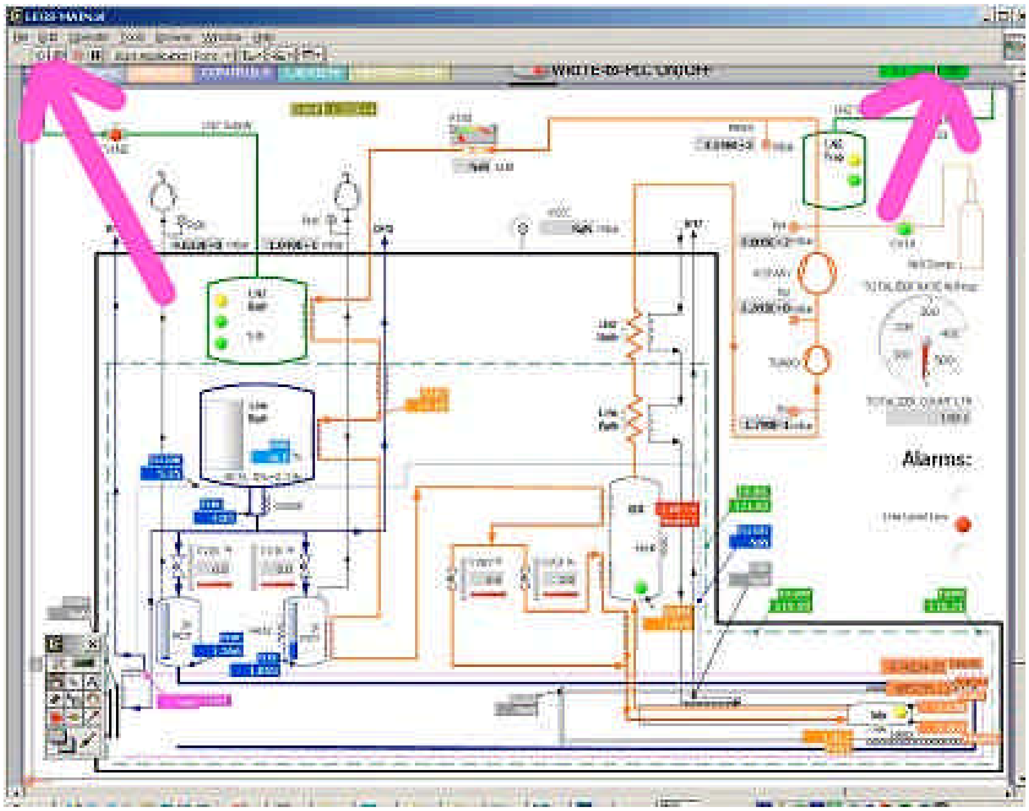


Figure 1 Start LabVIEW buttons.

CAUTION: If you use the same file name AND you selected "CREATE new file" settings you will write over the existing data file.

3.1.4 Control program check.

Check that the PLC and LabVIEW control programs are running and that none of the displayed values are "NaN" (i.e.: that it looks like all the pressure, temperature and level sensors are hooked up and functioning).

3.1.5 Pump-down.

Evacuate target cryostat through valve VP25 using a mechanical vacuum pump to twenty microns, monitoring the visual dial gauge (for pressures between 760 Torr and approximately 10 Torr) and the thermocouple gauge (a local controller will have to be provided for this gauge – the local controller can be disconnected once cooling starts, see step 3.3.3).

Note: The pump-out should be done slowly over about five minutes to avoid disturbing the superinsulation.

3.1.6 Leak test.

3.1.6.1 Attach a helium leak detector to the cryostat. This can be in parallel with the mechanical pump if this pump is required to maintain low pressure in the cryostat. Check the cryostat for leaks from atmosphere by spraying the joints and welds with a low flow of helium gas. Any detected air leaks with a leak rate greater than 10E-5 atm-cc/sec must be repaired. Note that helium permeates rapidly through the Mylar beam exit window so leaks detected in this region may be due to permeation.

3.1.6.2 Check that no detectable helium leak is present inside the cryostat. The leak detector should have a helium sensitivity of at least 10E-8 atm-cc/sec. The checking will occur automatically as the helium circuits are purged with helium in the following sections.

3.1.7 Purging.

3.1.7.1 Purge the helium-4 bath three times by evacuating to about 10 Torr and back filling with helium to about 3 psig. Maintain this pressure during the following operations. This evacuation and refill is done through the blanked off NW16 port on the tee leading to the safety blowoff S3 by a mechanical vacuum pump with a manifold that allows both pumping and back-filling with helium and that contains a thermocouple pressure gauge. Remove the fill lance with its valve VFILL and insert the ½" plug into the port. This procedure automatically checks the helium bath and the magnet container for leaks.

3.1.7.2 Purge the helium-4 circuits. In sequence slightly open and leave open the flow meter valves BR3, BR4, BR5, BR6, and BR7 and ensure that flow exists. Leave the helium flowing for 5 minutes at a rate of about 1 liter/minute. Close BR3, BR4, BR5, BR6, and BR7 and leave the helium-4 bath pressurized at 3 psig.

3.1.7.3 Purge the 1 K and 2 K Pots. Turn on the 1 K Pot and 2 K Pot pumps (VP1 and VP2) and open their associated valves (V1K and V2K). Once the pots are pumped to a stationary pressure (in about a minute or less), then close V1K and V2K and observe the pressure rising in the pots on PI1K and PI2K as helium comes in through the valves CV1K and CV2K. Note that these valves will be open because the LN_2 bath is still warm. The pressure rise is slow because CV1K and CV2K are quite restrictive. Letting the pressure rise to about half an atmosphere is adequate to leak check the 1K and 2K pots. Turn off VP1 and VP2.

3.1.8 Preparing the refrigerator circuit

3.1.8.1 Prepare the LN_2 cooled LN2 traps (F151 and F152). Evacuate both traps using a mechanical pump with a thermocouple gauge through valves V13 and V14 until a pressure of 30 microns is reached. Close V13 and V14.

3.1.8.2 Open RTBY. Evacuate the refrigerator with a mechanical pump via VP26 and V21 (connected together and teed to the mechanical pump via a separate service valve) to a pressure of less than 10E-1 Torr (PI1) and close the service valve once this pressure is reached, to avoid oil back streaming into the refrigerator. Close VP26 and V21.

3.1.8.3 At this point one should leak check the two pipes connecting the pump stand to the cryostat. First connect a helium leak detector to V21 and check the line from V15 and V16 to the cryostat for air leaks (including the leg that includes RTBY). Then connect the leak detector to VP26 and check the pump line from the cryostat to V1 and V1a for air leaks. The leak detector connected to the cryostat may be borrowed for this function, and then returned to the cryostat.

3.1.8.4 Cool both LN2 traps F151 and F152. This cooling is done manually by transferring LN2 from a transport dewar into the LN2 trap dewar until the liquid level is about six inches from the top of the LN2 trap dewar. (If one is using the LN2 trap dewar supplied by Quantum Technology, then this dewar should be refilled manually every three days. If some other LN2 trap dewar is used, then the level must be monitored manually during the first use to determine the proper refill schedule.) The LN2 level is monitored by two discrete sensors and displayed on the Main LabVIEW page. If the level drops below the lower level, then an alarm condition is displayed on this page. Let in pump gas by opening V12 and V28. Leave the cleaner to cool for 20 minutes.

NOTE: In the following procedures, reference is made only to TP1 and M151b. In fact there are two turbopumps and two mechanical pumps which can be used in any one of four combinations (along with associated valves). If pumps other then TP1 and M151b are to be used, then the instruction pump and valve names must be modified accordingly. The valves associated with the four pumps are shown below:

Table 4 Valves controlling the pumps.

Turbopump TP1	**Inlet valve V1**	**Outlet valve V23**
Turbopump TP1a	Inlet valve V1a	Outlet valve V23a
Alcatel pump M151b	**Inlet valve V4**	**Outlet valve V28**
Alcatel pump M151a	Inlet valve V3	Outlet valve V27

3.1.8.5 Turn on the rotary pump M151b.

3.1.8.6 Open V23 and open V4 so now M151b is backing TP1.

3.1.8.7 After 5 minutes, open V1.

3.1.8.8 Open V16 to let helium that was in the mechanical pump into the refrigerator. One will see a momentary flow in F150 and see a pressure rise in PIMXS.

3.1.8.9 Open V30 and then slowly open NV17 to meter helium gas into the refrigerator to a pressure of 700 mBars, as read by PI4, then close NV17.

3.1.8.10 Helium is now flowing slowly through the refrigerator, metered by CVCF and CVBY in parallel. Check the function of the flow meter F150 and the pressure gauge PIMXS by closing and opening V16. Finish with V16 open.

3.1.8.11 Turn off M151b. Gas will flow into the refrigerator via CV9. As the pressure rises in the pump line, then leaks from this space into the cryostat become more easily detected.

This completes the purging, flow testing, and leak testing of all flow loops and the system is now ready for cooldown. If there is any uncertainty, go back and recheck the system. A few minutes of checking out at room temperature can save days in preventing a faulty cooldown.

3.2 Standard Procedures:

Following are the procedures to be followed for refilling the cryostat LN2 bath, refilling the cryostat LHe bath, refilling the LN2 trap bath, and cleaning the LN2 trap.

3.2.1 LN2 transfer procedure for the cryostat LN2 bath:

- On average the refill happens once every three hours.
- Make sure that the LN_2 tank is full before starting the tipping procedure.
- Make sure that the LN_2 tank is disconnected (manual valve closed) during tipping procedure.
- Make sure that dewar is fitted with low pressure relief valve ~5 PSI.

As long as the nitrogen transport dewar is connected to the cryostat, then refills of the cryostat liquid nitrogen bath are automatically controlled by the PLC, governed by the level sensors in the bath. The transport dewar pressure should be in the range 3-5 psig. To change the transport dewar, close its manual valve and also unplug 110 VAC cable to the solenoid valve CVLN2 in the cryostat liquid nitrogen line. If necessary, warm the connection to the transport dewar with a hot air gun. After replacing the transport dewar and checking that its delivery pressure is in the range 3-5 psig, open the valve on the transport dewar and reconnect the 110 VAC cable to the solenoid valve CVLN2 in the cryostat liquid nitrogen line.

3.2.2 LHe transfer procedure:

<u>Please Note:</u> *In the following "Supply line" means the long flexible line from the Supply dewar and "Cryostat Line" means the short rigid section which stays in the cryostat.*

3.2.2.1 Reduce the magnet current to 30 A.

3.2.2.2 Push the cryostat line down so that approximately six inches of the 1/2" diameter section of the lance is above the port.

3.2.2.3 Close the pressure relief valve on the transport dewar.

3.2.2.4 Begin installing the supply line to the dewar, slowly so as to avoid pressure build-up in the dewar beyond about 2 psig.

3.2.2.5 At the same time, open the valve on the cryostat line VFILL slightly so some cooling gas comes out of this line. When white vapor is coming from the cryostat line, close the valve.

3.2.2.6 Some cooling gas will begin coming from the supply line as it is lowered. Wait until there is almost a plume of cold gas and then connect the two halves of the transfer line together. Wear gloves and eye protection for this procedure to avoid injuries.

3.2.2.7 Open the cryostat line valve VFILL fully.

3.2.2.8 Raise the transport dewar pressure to 4-6 psig (with an external helium gas source or with the heater on the transport dewar, if it is supplied with such).

3.2.2.9 Observe the gas totalizer (the exhaust gas meter). It will spin rapidly for the final cooling of the transfer line and then slow down as the transfer starts.

3.2.2.10 While transferring, monitor the totalizer, the transport dewar pressure, and the level meter reading. Keep the dewar pressure steady. The totalizer rate should be about 6 sec/rev during filling and the level meter should show a steady increase towards 100%. As the level meter nears 100%, a sudden increase in the totalizer rev rate will indicate that the cryostat is full.

- Totalizer rate conversion (4-6 s/rev. during fill)
  1 rev=0.05m^3 so the boil off during fill is as follows:
  0.05m^3/5seconds*1/750 Liquid L/gaseous L*60s/min*60 min/hour
  Boil off=0.048m^3/hour=48L/hour

3.2.2.11 When the cryostat is full, close the cryostat line valve and open the valve to the transport dewar relief valve.

3.2.2.12 Remove the supply line from the transport dewar and close the transport dewar ball valve.

3.2.2.13 Disconnect the supply line from the cryostat line.

3.2.2.14 Raise the cryostat line so about 15 inches of the 1/2" diameter section of the lance is above the cryostat entry port fitting (do not pull it out of the cryostat).

3.2.2.15 Raise the magnet current back to its initial operating point.

Check the transport dewar pressure. It should be back down to about 1 psig and gas should be venting slowly from the low pressure relief valve.

3.2.3 Refill of the LN2 trap dewar.

Refill is done manually by transferring LN_2 from a transport dewar into the LN2 trap dewar until the liquid level is about six inches from the top of the LN2 trap dewar. (If one is using the LN2 trap dewar supplied by Quantum Technology, then this dewar should be refilled manually every three days. If some other LN2 trap dewar is used, then the level must be monitored manually during the first use to determine the proper refill schedule.) The LN_2 level is monitored by two discrete sensors and displayed on the Main LabVIEW page. If the level drops below the lower level, then an alarm condition is displayed on this page.

3.2.4 Cleaning of the LN2 traps.

There are two parallel LN2 traps (called LN_2 trap in Figure 6 Gas Flow Schematic) in the gas handling system. These are meant to remove contaminants (principally air and light oil vapors) from the helium gas stream before it is sent back to the refrigerator. Only one is used at a time, the second one being kept as clean and ready for use when the first must be cleaned. For the following it is presumed that the LN_2 Trap F151 is being used and LN_2 Trap F152 is on standby (this follows the convention above, see paragraph 3.1.8.4). If the situation is reversed, then change the valve names according to Table 5 Valves controlling the cold traps.

Table 5 Valves controlling the cold traps.

Trap F151	Inlet Valve V12	Outlet Valve V16	Evacuation Valve V24
Trap F152	Inlet Valve V11	Outlet Valve V15	Evacuation Valve V25

To clean trap F151

3.2.4.1 Open V15. Wait one minute and then open V11.

3.2.4.2 Close V12 and then close V16. This procedure will have changed the gas flow from F151 to F152.

3.2.4.3 Slowly open V24. This is done slowly so as not to introduce a large pressure rise on the outlet of the turbopump. There is no instantaneous pressure readout at this point so it is best to be guided by the turbopump power and try to open V24 at such a slow rate that the turbopump power does not rise more than 10% above its value before V24 was opened.

3.2.4.4 Once V24 is fully open, wait one minute and then close V24. This procedure will have removed almost all the helium from the trap.

3.2.4.5 It will be instructive to learn how much air has been collected in the LN2 trap. Do this by attaching a small volume pressure gauge (range –30" to 30 psi) to V14 and then opening V14. (The small volume applies to both the gauge and the short length of small diameter tubing connecting it to V14.) The pressure gauge will drop from a reading of zero to –30". Next remove the LN2 trap from the LN_2 dewar and allow it to warm to room temperature. As it warms, air will be evolved from the charcoal and the pressure shown will rise. At 30 psi, the relief valve S11 will open to limit the pressure rise. A pressure rise to less than 0 psi on the gauge is ok (it indicates that not much air has collected in the cleaner and there is little danger that any air has passed the cleaner and gone on to the refrigerator). A pressure rise to above 5 psi indicates that the LN2 trap should have been changed earlier.

3.2.4.6 Close V14 and remove the pressure gauge.

3.2.4.7 Attach a mechanical vacuum to V14 and evacuate F151 for 5 minutes. Then close V14.

3.2.4.8 Remove the mechanical pump from V14 and place the LN2 trap back into the LN_2 dewar to cool. Leave it cooling for 30 minutes before passing any helium through it (i.e.: before changing back from the other cleaner).

3.3 Cooldown Procedure:

This section describes the procedures used to cool and fill the LN_2 and LHe baths. It also describes starting the flow through the refrigerator and through the 1K and 2K pots to start cooling these elements.

3.3.1 Disconnect the leak detector.

Close the vacuum pumping port VP25, leaving the leak detector and mechanical pump connected for later use. VP25 can be re-opened momentarily to check for helium accumulation in the cryostat, which may occur during cooling and filling. Continue to observe the cryostat pressure with the thermocouple gauge.

3.3.2 Start turbo pumps.

Turn on the mechanical circulation pump (M151b). After one minute, turn on the turbopump TP1. Make sure low speed mode is turned off. Set the CVCF and CVBY temperature setpoints to 200K so these valves will stay open during cooling, and so allow helium to flow through the refrigerator during the cooling procedure. Maintain PI4 at about 700 mBar using NV17 to admit gas as required.

3.3.3 Initial cooling.

Fill the cryostat LN_2 bath using the autofill system by plugging CVLN2 into the power from the PLC. The source dewar for the LN_2 should have a pressure of about 3-5 psi. It takes about ninety minutes for the LN_2 bath to cool sufficiently for the autofill system to function properly. During this period, liquid spills from the bath vent before the top level sensor is covered. Each time liquid spills, the flow control solenoid CVLN2 power must be unplugged, and then re-plugged when vapor stops flowing from the vent. This phase requires manual monitoring. Eventually the auto system will take over. Wait two hours to allow the 80K shield to begin cooling. Charcoal mounted on the 80K shield will begin to cryopump as it cools. As the pressure reading on the thermocouple gauge falls to less than two microns, the cold cathode gauge (VGCC) can be turned on. When it comes on scale due to the cryopumping of the charcoal, the thermocouple gauge controller can be disconnected.

3.3.4 Precool.

Remove the purge manifold from the NW16 port (see Step 3.1.7.1) and re-seal the port. Open VHB and VHBa. Remove the plug from the fill port and insert a funnel. Start cooling the helium bath by pouring in about ten liters of liquid nitrogen (by hand to get a fairly accurate measurement). This should boil away completely in cooling the bath. After this, liquid nitrogen may be added 3-4 liters at a time to cool the shield. The magnet is connected to the bath by a 6 mm ID copper pipe and some liquid nitrogen may run down this pipe into the magnet bath. This will only cause a problem if liquid nitrogen begins to collect in the magnet bath, so the temperature of the magnet bath must be monitored to insure that it does not fall below 100K (monitor using the magnet temperature sensor

TI202). If the magnet bath approaches 100K, then the remaining liquid nitrogen in the helium bath should be removed by siphoning as in step 3.3.5.1.

3.3.5 LN_2 removal.

Liquid nitrogen cooling of the helium bath and shield will take about 3-4 hours. When the shield has cooled to less than 150K (as measured by TI1201 at the bottom of the helium shield), remove the remaining LN_2 from the helium bath (by siphon).

3.3.5.1 Remove the ½" plug and place the siphon line in the LHe bath fill port. Place a gas connection to a helium gas cylinder with regulator in the NW16 port on the tee leading to safety valve S3. Close VHB and VHBa. Pressurize the bath to 3 psig. Once LN2 has stopped exiting the siphon, turn off the helium supply, remove the siphon line, replace the ½" plug, and pressurize to 3 psig. Siphoning the liquid nitrogen from the helium bath will leave some liquid remaining in a 1.5" dia by 4" long SS pipe, which extends down from the bottom of the helium bath. There is a 5/16" OD copper tube connecting the bottom of the SS pipe to the magnet bath (this tube carries the current leads and supplies helium to the magnet). The copper pipe has a heater and a temperature sensor (TI4K) mounted at its center. Now one can get rid of the remnant liquid nitrogen by turning on the heater at full power and leaving it on until TI4K rises above 80K (this will take about ten minutes). Then turn the heater off. Check that TI4K and TI202 stay above 80K to ensure that liquid nitrogen is gone from the bath and the magnet bath.

3.3.5.2 Check that there is no nitrogen in the lines feeding the 1K and 2K pots. First open CV1K and CV2K by setting their temperature set points to 200K and waiting until the temperature readbacks are above 180K. Turn on the 1 K Pot and 2 K Pot pumps (VP1 and VP2) and open their associated valves (V1K and V2K). Once the pots are pumped to a stationary pressure (in about a minute or less), then close V1K and V2K and observe the pressure rising in the pots on PI1K and PI2K as helium comes in through the valves CV1K and CV2K. The pressure rise is slow because CV1K and CV2K are quite restrictive. A pressure rise to about half an atmosphere in five minutes is adequate. If too slow, repeat the test until adequate. Turn off VP1 and VP2.

3.3.5.3 Check that there is no nitrogen in the other helium lines by pressurizing the helium bath to 3 psig and opening BR3 (for the counterflow heat exchanger), BR6 (for the 20K shield and Iris Opener heat exchangers), and BR7 (for the magnet bath helium flow) and observing gas flow for five minutes. If gas does not flow properly, wait until it does. Then close BR3, BR6, and BR7.

3.3.6 Start a helium transfer in the cold gas flow mode.

3.3.6.1 The helium transfer line is in two parts. Install the lance with the shut-off valve VFILL into the liquid helium bath, right to the bottom of the bath. Check that VFILL is closed. Connect the other half of the transfer line to the valve section and install the other end very slowly into the helium transport dewar. The speed of this insertion is governed by the rate of boil-off that one is willing to accept from the helium transport dewar.

3.3.6.2 Do not transfer any liquid at this stage. It is preferable to use a slow flow of cold gas directed right to the bottom of the bath for a long time - about 6 hours - to cool the cryostat. Putting in more liquid can waste a huge amount of liquid helium and will not appreciably shorten the cooldown time (which is limited by thermal diffusion time constants).

This slow cold gas transfer mode is achieved by throttling the exit helium flows and connecting a very small overpressure to the helium supply vessel.

To do this set the valves BR4 and BR5 to ½ turn open and BR3, BR6 and BR7 each to 1 turn open. Pressurize the helium source vessel to 3 psig (0.2 bar). Open VFILL. The desired total flow rate during this phase is 3 liquid liters per hour (40 gas liters per minute). Adjust BR3, BR4, BR5, BR6, and BR7 to achieve this rate, monitoring the gas totalizer.

3.3.6.3 Turn on the 1K and 2K pot pumps (VP1 and VP2). Open V1K and V2K to start helium gas flow through the 1K and 2K pots. Reduce the flow through BR3, BR4, BR5, BR6, and BR7 to maintain a flow rate of 3 liquid liters/hr. This will start cooling the 1 K Pot and the 2 K Pot.

3.3.7 Start the LHe fill.

Once the helium-4 bath is below 40K (as measured by TI1200 on the top plate of the helium shield) for 1 hour it is possible to fill the bath with liquid. This is done by fully opening all flow control valves BR3, BR4, BR5, BR6 and BR7. Open Ball Valve VHB to allow a large gas flow. Monitor the liquid helium level gauge. The desired transfer rate is 1 liquid liter per minute. Initially this will cause a gas flow rate of 750 gas liters/minute, but as liquid begins to accumulate in the bath, this rate will drop. About 40 minutes is required for the transfer. Adjust the liquid supply dewar pressure as necessary to achieve this. Again monitor the flow rate using the gas totalizer.

If liquid fails to accumulate after 15 minutes close the ball valve VHB and continue with cold gas flow cooling for 1 hour. Then open VHB and repeat the liquid transfer procedure.

3.3.8 Finish the LHe transfer.

Once the liquid helium bath is full as shown on the superconducting liquid helium level gauge LM2, then close VFILL and vent the LHe supply cryostat. Remove the flex section of the transfer line from; the source dewar and disconnect it from the section remaining in the cryostat. Raise that portion of the transfer line which is in the helium bath by 15 inches but do not take it out of the top of the helium bath.

3.4 After The Liquid Helium Bath Is Full:

This section describes cooling the 1K and 2K pots to their operating points, and cooling the mixing chamber to below 10K.

3.4.1 1 K Pot operation.

As the 1 K Pot starts to fill with liquid helium the flow through the needle valve CV1K will become excessive (PI1K too high). Switch CV1K to automatic control. The automatic control (PLC) uses the level sensor to monitor the 1 K Pot cooldown and closes the valve CV1K gradually to prevent excessive flow.

3.4.2 2 K Pot operation.

Similarly, the 2 K Pot flow control valve (CV2K) should be switched to automatic when it starts to fill. Note that the magnet is cooled by a heat exchanger between CV2K and the 2K pot, and that cooling and filling the 2K pot will automatically cool the magnet bath to the same temperature. Since the magnet bath is directly connected to the helium bath at about 1 psig by an open pipe, this means that the magnet bath will automatically fill with helium at the 2K pot temperature.

3.4.3 Flow rate monitoring.

Monitor the flow rate on mass flow meter F150 and the cooling of the mixing chamber on temperature sensor Ti102. As the flow rate rises, slowly close RTBY to keep the flow rate just below 1.5 liters/min. When the mixing chamber reaches 5K, close RTBY, leaving the flow through CVCF only. It may be necessary to adjust CVCF down in steps of 10K to keep the flow rate below 1.5 liters/min. After ten minutes, close CVBY by setting its temperature to the bottom value of 70 K .

3.5 Cooling The Refrigerator To The Operating Temperature:

This section describes filling the refrigerator with its operating mixture of He-3 and He-4 from the storage dumps in the pump stand, and bringing the refrigerator to its operating temperature.

By this point the refrigerator has achieved 2K operating conditions; i.e., the liquid nitrogen and liquid helium baths have been filled, the magnet bath has been cooled to about 2 K, and the mixing chamber has been cooled to about 2 K. Helium gas is slowly circulating through the refrigerator through CVCF.

3.5.1 NV17 control.

Slowly open NV17 to meter the working mixture into the system, maintaining a condensing pressure of less than 700 mBar (PI4). When NV17 is fully open, then open V17. After five minutes close V17 and NV17.

3.5.2 Dilution refrigerator mode tuning.

Once the fluid has been condensed to the mixing chamber and the still, tune the refrigerator for the desired low temperature. The parameters to use are the still heater power in steps of 10mW and the setting of the flow restriction valve above the counterflow heat exchanger (CVCF) in steps of 5K. After each single step change of a single parameter, allow the refrigerator to come to equilibrium (approx. 30 minutes). The mixture ratio is optimized during commissioning so adjustment should not be necessary but the refrigerator may also be sensitive to the amount of He_3 condensed in the system. This may be varied by adding or removing gas in the circulation stream, using the He3 dump M155C as the source or dump for the gas in steps of 2” on the tank pressure gauge Pi7.

3.6 Loading The Target Into The Cryostat:

This section describes the procedures to be followed to load a target into the IBC and return the refrigerator to its operating temperature.

3.6.1 Prepare the refrigerator.

Before the target retraction device (assumed to be at about 2 K) can be attached to the target, the refrigerator must be prepared for the accompanying temperature rise. Turn on Low Speed for the turbopump(s) in use (TP1 and/or TP1a). Allow 30 minutes for the turbopump(s) to slow. Make a note of the still heater power HStill on the LabVIEW CONTROLS tab page and then set the still heater power to zero.

3.6.2 Roll the IBC back to the tipping location.

3.6.3 Check the level in the cryostat LHe bath

One will have to determine if there is enough helium (~25% full, ~11 liters LHe) in the bath to last for the time required to load the target. If not, then a helium refill transfer should be done. Note that when the cryostat is tipped, there will be a step change in the helium level read-out. This is because the helium level sensor is located on the high side (when the cryostat is tipped) of the helium bath.

3.6.4 Refill the cryostat LN2 bath

Do a manual fill of the cryostat liquid nitrogen bath before tipping and starting the target load (if only to avoid the shock of an automatic fill starting when engaged in the loading procedure). Do this fill by:

3.6.4.1 Unplug the power to the LN2 fill solenoid CVLN2 from the PLC.

3.6.4.2 Connect this plug to a 110 VAC source. This will start an LN2 flow into the LN2 bath.

3.6.4.3 Monitor the LabVIEW MAIN tab page. When the LN2 Bath top light (of 3) turns green, disconnect the power to the LN2 fill solenoid CVLN2 to stop the LN2 flow.

3.6.4.4 Plug the power for the LN2 fill solenoid CVLN2 back into the PLC. This fill will last about 3 hours before another fill is required.

3.6.5 Energize the magnet.

On the LabVIEW Magnet page set the magnet current setpoint to 100 A. Wait for the magnet to be fully charged.

3.6.6 Tip the cryostat to 25 degrees snout down.

3.6.6.1 Release the hold down screws on the two zero-degree posts and release the clamp on the tilting handwheel.

3.6.6.2 Slowly turn the handwheel, lowering the snout until one reaches the 25-degree stop posts. Install the holding screws into these posts and apply the clamp on the tilting handwheel. During the lowering procedure, monitor the target parameters (principally turbo inlet pressure and helium bath exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level.

3.6.7 Procedure for target installation

3.6.7.1 Connect the transfer cryostat to the in-beam cryostat using Transfer Cryostat Procedure 3.11, “Attaching to the InBeam Cryostat”.

3.6.7.2 Open the in-beam cryostat shutter

3.6.7.3 Insert the target using Transfer Cryostat Procedure 3.16, "Placing a Target".

3.6.7.4 Close the in-beam cryostat shutter

3.6.7.5 Disconnect the transfer cryostat from the in-beam cryostat using Transfer Cryostat Procedure 3.12, "Detaching from the InBeam Cryostat".

3.6.8 Tip the cryostat back to zero degrees

3.6.8.1 Release the hold down screws on the two 25-degree posts and release the clamp on the tilting handwheel.

3.6.8.2 Slowly turn the handwheel, raising the snout until one reaches the zero degree stop posts. Install the holding screws into these posts and apply the clamp on the tilting handwheel. During the raising procedure, monitor the target parameters (principally turbo inlet pressure and helium bath exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level. Inform a local expert otherwise.

3.6.9 Cooling the refrigerator back down

3.6.9.1 Turn the Low Speed off for the turbopump(s) in use (TP1 and/or TP1a).

3.6.9.2 On the LabVIEW CONTROLS tab page, return the still heater power HStill back to the value used before removal of the target.

3.6.9.3 Tune the refrigerator as in section 3.5.3.

3.7 7K Test Instructions:

This section describes the 7K mode operation. This mode is unique to this refrigerator and has the goal of a gentle warming of the target to a controlled temperature, **WITHOUT OVERSHOOTING THE TEMPERATURE**. An overshoot (for example to 9K) would cause the hydrogen to sublime and spoil the vacuum and the target would be lost.

In Dilution Refrigerator (DR) mode of operation the target temperature is very stable because of the large thermal heat capacity of the liquid helium in the mixing chamber. In the "7K" mode that helium is boiled off and there is little heat capacity left. At constant heat there will be a huge change in the slope of the temperature graph. While the helium is liquid the temperature will remain constant. When the liquid is all gone the temperature will rise suddenly and rapidly. **PROCEED WITH EXTREME CAUTION!!!**

The theory of operation is as follows. The 1K pot valve is set to a fixed manual constant value to provide a constant amount of cooling. The CVBY valve is opened to bypass the heat exchanger and provide the cooling directly to the mixing chamber. One automatic control loop controls the temperature of the 1K pot. After the liquid has all boiled out of the 1K pot then its temperature rises above 4K enabling a software interlock so that a second control loop can be activated. This second loop controls the temperature of the mixing chamber by slowly ramping it up to the desired set point. (The 4K interlock [PLC address v3700] is to prevent heating the mix while liquid He-3/4 is still condensing in the heat exchanger on the 1K pot because injecting slugs of liquid rather than a continuous flow of cold gas will cause severe temperature swings).

It is also possible to make this happen by setting the controls manually, but this is not recommended because of the overshoot hazard.

NOTE: in either case this involves removing a substantial quantity of liquid from the DR and returning it to the dump tanks.

3.7.1 Before starting:

Get ready for about 1-1/2 hours of concentration (refreshments? ...)

3.7.2 Procedure for Helium removal from 1K pot.

3.7.2.1 Turn both Turbo Pumps TP1 and TP1a ON and toggle Low Speed (LS) on for both pumps. Set the turbo pumps to low speed mode, just to protect them because this procedure vents a lot of gas.

3.7.2.2 Prepare to remove manually He-3 to working mixture storage dump M155d. Confirm V30 is open. Open valve CV18 to let gas back to storage dump.

3.7.2.3 Close the LN2 trap outlet valve V16.

3.7.2.4 Slowly raise the still heater HStill power on the LabVIEW CONTROLS tab page in steps of 10 mW to a maximum of 200 mW to heat Ti104 to 2-3 K while keeping Pi1 below 0.1 Torr. At the same time slowly raise the mixing chamber heater HMIX power in steps of 5 mW to a maximum of 50 mW to heat Ti102 to 2-3 K.

3.7.2.5 Close CV18 to stop removing He-3. Slowly open the LN2 trap valve V16 to let some gas circulate again.

3.7.2.6 Ensure that the valve V30 on the working mixture storage dump M155d is open (it is normally always open when operating), also open the manual bypass valve RTBY on the cryostat.

3.7.2.7 Click CV1K on the LabVIEW CONTROLS tab page to MANUAL. Enter a temperature set point of 160K (valve temperature will read 152K at equilibrium). This sets the required cooling flow of He-4.

3.7.2.8 Enter a CVBY temperature set point of 182K (valve reads 172K) on the LabVIEW CONTROLS tab page. This sets the required flow of He-3/He-4 mixture.

3.7.2.9 Activate the 1K pot heater controls in the PLC by entering 8 for QPHASE on the LabVIEW CONTROLS tab page. Enter a 1K POT Setpoint temperature of 3K. Click He1K to AUTO.

3.7.2.10 Wait and monitor the 1K pot temperature Ti1K and the He1K heater duty cycle while the 1K pot slowly empties of liquid He-4.

Emptying the 1K pot takes about 1 hour starting at 10% full. Half of that time the level reading is zero (below the level sensor), but do not be fooled! As long as there is a large heat input and a cool temperature there is still liquid boiling. The duty cycle will remain at about 6% while there is liquid and drop to 1% once the pot is empty.

3.7.2.11 Once the 1K pot temperature Ti1K has stabilized around 3K then increase the 1K POT Setpoint on the LabVIEW CONTROLS tab page to 4.5K and wait 5 minutes for stabilization.

3.7.3 Procedure for steady MIX chamber warmup to 7 K.

3.7.3.1 Wait for 1K pot temperature Ti1K to stabilize.

3.7.3.2 Click cryostat heaters HMIX and HStill both to AUTO mode on the LabVIEW CONTROLS tab page. Then click 7K MIX Control to ON and enter a 7K MIX Setpoint temperature of 3.5K, again on the LabVIEW CONTROLS tab page.

After temperature Ti102 has stabilized, gradually increase 7K MIX Setpoint until the desired temperature is reached. In the event of any difficulty click the 7K MIX Control to OFF and leave it off for 5 minutes, then click to ON again. The ramp up will automatically recommence slowly. Do not turn off then immediately back on – it may cause an overshoot.

3.7.3.3 Once everything is stabilized, it is possible to improve the temperature stability by clicking the 1K pot heater He1K to MANUAL. As an initial setting use a little less heat than the automatic mode. ~ 1% duty cycle.

3.7.4 Return to cold operation.

3.7.4.1 Click 7K MIX Control to OFF on the LabVIEW CONTROLS tab page. (This turns off the HMIX and HStill heaters)

3.7.4.2 Enter 5 for QPHASE on the LabVIEW CONTROLS tab page. This turns off the 1K pot heater controls.

3.7.4.3 Click the 1K valve control CV1K on the LabVIEW CONTROLS tab page back to AUTO. This allows it to automatically keep the 1K pot full.

3.7.4.4 Execute Step 3.4.3 and Procedure 3.5 to return to dilution refrigerator operation.

3.8 Removing The Target From The In-Beam Cryostat:

This section describes the removal of the target from the IBC and return of the refrigerator to its operating temperature.

3.8.1 Prepare the refrigerator

Before the target retraction device (assumed to be at about 2 K) can be attached to the target, the refrigerator must be prepared for the accompanying temperature rise. Turn on Low Speed for the turbopump(s) in use (TP1 and/or TP1a). Allow 30 minutes for the turbopump(s) to slow. Make a note of the still heater power HStill on the LabVIEW CONTROLS tab page and then set the still heater power to zero.

3.8.2 Move the in-beam cryostat to the insertion position.

3.8.3 Check the level in the cryostat LHe bath.

One will have to determine if there is enough helium in the bath to last for the time required to load the target; for example; if the job may take up to 3 hours, the bath should be at least 25% full, ~11 liters. If not, then a helium refill transfer should be done. Note that when the cryostat is tipped, there will be a step change in the helium level read-out. This is because the helium level sensor is located on the high side (when the cryostat is tipped) of the helium bath.

3.8.4 Refill the cryostat LN2 bath

Do a manual fill of the cryostat liquid nitrogen bath before tipping and starting the target load (if only to avoid the shock of an automatic fill starting when engaged in the loading procedure). Do this fill by:

3.8.4.1 Unplug the power to the LN2 fill solenoid CVLN2 from the PLC.

3.8.4.2 Connect this plug to a 110 VAC source. This will start an LN2 flow into the LN2 bath.

3.8.4.3 Monitor the LabVIEW MAIN tab page. When the LN2 Bath top light (of 3) turns green, disconnect the power to the LN2 fill solenoid CVLN2 to stop the LN2 flow.

3.8.4.4 Plug the power for the LN2 fill solenoid CVLN2 back into the PLC. This fill will last about 3 hours before another fill is required.

3.8.5 Energize the magnet.

On the LabVIEW MAGNET tab page, set the magnet current setpoint to 100 A. Wait for the magnet current to ramp up.

3.8.6 Tip the cryostat to 25 degrees snout down.

3.8.6.1 Release the hold down screws on the two zero degree posts and release the clamp on the tilting handwheel.

3.8.6.2 Slowly turn the handwheel, lowering the snout until one reaches the 25 degree stop posts. Install the holding screws into these posts and apply the clamp on the tilting handwheel.. During the lowering procedure, monitor the target parameters (principally turbo inlet pressure and helium bath exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level. Inform a local expert otherwise.

3.8.7 Procedure for target removal

3.8.7.1 Connect the transfer cryostat to the in-beam cryostat using Transfer Cryostat Procedure 3.11, "Attaching to the InBeam Cryostat".

3.8.7.2 Open the in-beam cryostat shutter.

3.8.7.3 Remove the target using Transfer Cryostat Procedure 3.15, "Retrieving a Target".

3.8.7.4 Close the in-beam cryostat shutter

3.8.7.5 Disconnect the transfer cryostat from the in-beam cryostat using Transfer Cryostat Procedure 3.12, "Detaching from the InBeam Cryostat".

3.8.8 Tip the cryostat back to zero degrees

3.8.8.1 Release the hold down screws on the two 25 degree posts and release the clamp on the tilting handwheel.

3.8.8.2 Slowly turn the handwheel, raising the snout until one reaches the zero degree stop posts. Install the holding screws into these posts and apply the clamp on the tilting handwheel. During the raising procedure, monitor the target parameters (principally turbo inlet pressure and helium bath exhaust rate) for unusual changes. Tipping should result in no changes other than a step change in the helium level.

3.8.9 Cooling the refrigerator back down

3.8.9.1 Turn the Low Speed off for the turbopump(s) in use (TP1 and/or TP1a).

3.8.9.2 On the LabVIEW CONTROLS tab page, return the still heater power HStill back to the value used before removal of the target.

3.8.9.3 Tune the refrigerator as in section 3.5.3.

3.9 Warming The In-Beam Cryostat:

This section describes the procedures to be followed to recover the operating gas mixture from the refrigerator, turn off the magnet, turn off the pumps, set the valves, and allow the IBC to warm to room temperature.

3.9.1 Ramp the magnet down.

On the LabVIEW MAGNET tab page, enter a Set Current of zero and a Ramp Rate of 1.3 A/sec. Click Press to Start to ramp down. After reaching zero current, turn off the magnet power supply in the electronics rack.

3.9.2 Recover the gas from the refrigerator

3.9.2.1 Open CV18 and close V11 and V12. After PIMXS drops below 50 mBar, open V24 and V25 slowly (don't let PI2 rise above 20 mBar).

3.9.2.2 On the LabVIEW CONTROLS tab page, enter 100 mW for the mixing chamber heater HMIX and enter 200 mW for the still heater HStill.

3.9.2.3 When the mixing chamber temperature rises above 2 K, reduce the mixing chamber heater HMIX to maintain this temperature. When the pressure at PI1 drops to zero (all gas recovered), enter zero for the mixing chamber heater HMIX and the still heater HStill. Close CV18 and V30.

3.9.2.4 Close V15, V16, V24 and V25.

3.9.2.5 On the LabVIEW CONTROLS tab page, close CVCF by entering 70K.

3.9.3 Turn off He3 pumps.

3.9.3.1 Close V1, V1a, V23, and V23a and turn off TP1 and TP1a.

3.9.3.2 Close V3, V4, V27, and V28 and turn off the rotary mechanical pumps M151a and M151b.

3.9.4 Stop LN2 fills.

Unplug the power for the LN2 solenoid valve CVLN2 from the PLC.

3.9.5 Stop 1K and 2K pots.

3.9.5.1 On the LabVIEW CONTROLS tab page, close CV1K and CV2K by entering 70K for their set points.

3.9.5.2 Close V1K and V2K.

3.9.5.3 Turn off 1K pot and 2K pot pumps.

3.9.6 Leave cryostat to warm naturally (about 2 days) to above 273 K.

3.10 After The Cryostat Has Warmed:

This section describes the procedures required for the final shut-down of the IBC. After the cryostat has warmed to above 273 K.

3.10.1 Close all remaining valves.

4 ASSEMBLY PROCEDURE

4.1.1 Preparation of the cryostat vertical insert:

4.1.1.1 Wiring complete and extending to bottom ready to solder.

4.1.1.2 Helium shield installed and insulated, NMR leads checked for shorts to ground and each other.

4.1.1.3 Nitrogen shield installed and NMR leads checked for shorts

4.1.1.4 Bypass LN_2 heat exchanger bolted on outside of LN_2 shield (near top) with thermal grease.

4.1.1.5 Iris opener LN_2 heat exchanger bolted on with thermal grease.

4.1.1.6 LN_2 snout heat exchanger fitted for close fit to braid, checked for flat, bolted to braid and soldered lightly at two holes in Cu plate. Use sanding block to confirm that the Cu plate is reasonably flat.

4.1.1.7 Attach LN_2 shield sensor (Ti 1301 - RED) to the LN_2 shield.

4.1.1.8 Tape wires for Ti 200 (VIOLET) and T1 1300 (YELLOW) to the LN_2 shield with excess

4.1.1.9 Super-insulate LN_2 shield.

4.1.1.10 Check NMR cables again.

4.1.2 Install the snout on the cryostat.

(The snout assembly must be complete with NMR cables installed and alignment finished and checked.) The heat exchanger for the magnet must be installed.

4.1.3 Install three LN_2 shield extensions.

Install three LN_2 shield extensions to the snout LN_2 shield root. For each shield use 2 x ¼” x 10-32.

4.1.4 Drop the vertical cryostat insert into the cryostat

Drop the vertical cryostat insert into the cryostat (feeding the magnet wire from the snout into the connection port). Stop the drop when there is still about one inch to go, for the next step. (Before dropping the insert in, it must be complete with all wiring done and properly anchored, shields in place, and super-insulation installed.) shields (all three) reaching up from below go outside the 80K leg reaching down from above and inside the 80K superinsulation.

4.1.5 Attach the thermal connections.

Attach the thermal connections from the vertical section LN_2 shield to the snout LN_2 shield root using five 3/4” 10-32 screws. Use lift to rotate flange after getting 1 started.

4.1.6 Remove flange.

If it has been removed, then install the cut-out in the 4K shield (this cut-out allowed access to install the screws in part 5 above). Hold this cut-out in with aluminium tape applied along the joint on the inside of the shield. Fold up the aluminium tape from the 20K shield aluminium extension tube. Add more tabs hanging down from the taped in aluminium half moon.

4.1.7 Mount the temperature sensor.

Mount the temperature sensor to the copper tab on the 20K shield (4-40 screw and nut).

4.1.8 Connect the 20K shield heat exchanger.

Connect the 20K shield heat exchanger with three 3/8” or 1/2” 10-32 screws.

4.1.9 Install the indium gasket on the snout magnet connection port.

Lower the insert further so that this joint can be bolted using (4) ½” 6-32 screws. Arrange the nuts so that there is minimum projection towards the Iris Opener.

4.1.10 Connect Ti 202 sensor directly to Magnet flange.

Use Indium gasket and ½” x 4-40 screw with washer and lock washer.

4.1.11 Make the magnet electrical connections in two lap joints.

The individual leads from the magnet are three wires twisted and soldered together. The six wires from the power supply are wrapped as a sheath around these three wires, in the same direction as the three wires are twisted. Then the whole bundle is wrapped with a bare copper wire, with a pitch of 1 mm. This results in a joint about 4”-5” long. This joint is fluxed with acid flux and soldered with aqua-sol solder, using a large iron. The flux is washed away with a wet cloth. This process is repeated for the second connection.

4.1.12 Lap joint installation.

Cover each lap joint with heat shrink tubing and install a one inch length of teflon tubing around both leads and into the tee-joint. (This teflon tubing must be of sufficiently small diameter to fit into the tube that forms the cap over the lap joints. The tube acts as a shield under the soft solder joint that will be made soon.)

4.1.13 Solder the magnet lap joint cover.

(Cool the indium joint when doing this soldering.) Leak check this connection and the indium joint.

4.1.14 Final leak check.

[OPTIONAL: leak check all of these joints now. Repeat leak test will be made with the cryostat evacuated.]

4.1.15 Connect the five gas joints to the snout.

(MC supply, top, and return, bottom, Magnet bath vent line (from side of elbow into Magnet bath), and Magnet root heat exchanger (2 lines on bottom side). Check these pipes for flow

Air flow rate: 3He cvcf + bypass=410cc/30s; @15psi air
3He cvcf only=175 (+/-10) cc / 60s; @15psi air
Magnet vent = huge @ 4psi air.

[OPTIONAL: leak check all of these joints now. Repeat leak test will be made with the cryostat evacuated.]

4.1.16 Do sensitive leak test of all internal cryostat plumbing.

Put the bottom, two sides and back (iris port) cover plates on to leak check everything inside vacuum can. During leak checking, some open gas connections on top of the dewar should be plugged and all internal plumbing should be pumped out. Backfill each section of internal plumbing to leak check.

After leak checking, the main vacuum vessel should be SLOWLY vented to atmosphere for Iris opener insertion.

4.1.17 Install the Iris Opener.

The LN_2 tabs on the 77K shield will have to be tied down with steel wire, and the vertical insert will have to be raised ~1/2" to provide clearance. The installation is done with the leading edge raised, to help get by the shields of the vertical insert.

Align the Iris opener with the inner tube of the snout by pushing Iris opener UP AND TO RIGHT before tightening the bolts. Keep trying until it is right.

Lower cryostat top plate to seal upper O-ring. Insure that the upper O-ring is clear (no superinsulation across the O-ring).

4.1.18 Connect the thermal straps.

Connect the thermal straps from the vertical insert LN_2 shield to the Iris Opener 77K shield with ¼-20 x 0.58" long hexagon head screw. Put on lower straps first on both side of the Iris opener. Put Apiezon-N grease under the thermal strap for thermal contact.

4.1.19 Connect the 4K heat exchanger.

Connect the 4K heat exchanger to the Iris Opener 4K shield with Apiezon-N thermal grease.

4.1.20 Fold down Al flaps from 4K shield to iris opener 4K Cu can.

4.1.21 Attach the Iris Opener 77K and 4K thermal sensors.

4.1.22 Make the electrical connections to the snout.

(M/C heater, 4 M/C temperature sensors, 2 of 4 NMR cables, currently using #2 and #3). Check the connections for continuity and grounding.

At this time, all sensors except Ti1201 (Bottom of 4K shield) Should be connected and functioning. Use the LabView Main Page and Controls Page to read the temperatures. Sensors T1 102, 104 and MxBNL are RuOx and do not function at RT. These resistances can be measured directly, as well as the resistances of all heaters (Table 6 Connector M pin assignment.).

It is difficult to see the pin numbers on Connector M. A sketch is shown here:

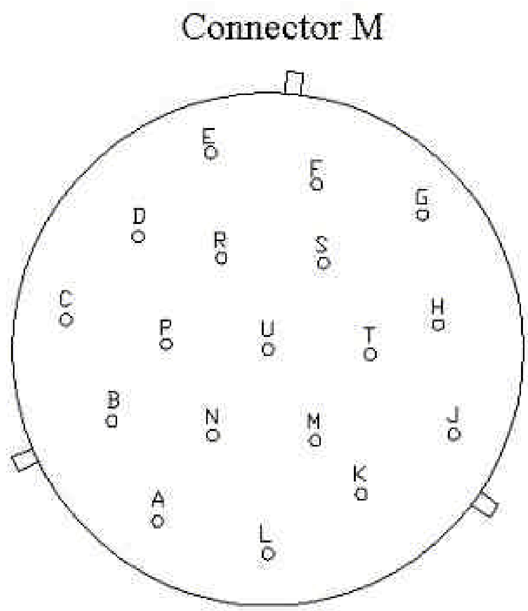


Figure 2 Connector M pin assignment.

Table 6 Connector M pin assignment.

Conn.	Pins	R	Object
A	AB	1062	Ti 102, I+/-
A	CD	1062	Ti 102, V+/-
A	BH	1023	Ti 104, I+/-
A	JK	1023	Ti 104, V+/-
B	JK	549	1K Pot Heater (Spare)
C	GH	2086	Ti MxBNL, I+/-
C	JK	2086	Ti MxBNL, V+/-
E	AH	366	Film Burner
E	BC	27	CH200
E	BD	546	1K Pot Heater
E	EF	480	Still Heater
E	EG	477	Mix Chamber Heater
E	JK	513	2K Pot Heater
M	MN	467	Still Heater (Spare)
M	GL	49	CV1K Actuator Heater
M	TK	47	CV2K Actuator Heater
M	JU	47	CVCF Actuator Heater
M	PH	50	CVBY Actuator Heater

4.1.23 Install the bottom of the 4K shield.

Use Apiezon-N on the bolt tabs at the top. Use (4) ½” x ¼ - 20 bolts. Use Al tape to cover the crack between top and bottom shield sections.

4.1.24 Connect the 4K shield thermal sensor.

Cover two large holes in 4K shield with Al plate and tape.

4.1.25 Install the two 4K side shield cut-outs.

Use Al tape to seal the gap. Complete the superinsulation.

4.1.26 Install the bottom of the 77K shield.

The three LN_2 shield extensions attached to the snout have to be outside the 77K can and the can has to be in between the Al posts (4K and 77K). Use Apiezon-N on (4) vertical tabs at top, bolt with (4) ½” ¼ x 20 hex head bolts.

4.1.27 Install LN_2 cooling pipe to the bottom half of 77K shield.

Use Thermal grease under Cu connection plates. Complete the superinsulation.

4.1.28 Install the bottom cover flange.

4.1.29 Install the two side access flanges.

Use long studs in 4 locations on each side plate, as marked, for tip trolley hard stops.

4.1.30 Pump cryostat down.

Do a final overall leak. First check all flanges and top plate connections at RT. Then (OPTIONAL - cool to LN_2 temperature overnight to) leak check by pumping each distinct volume in the cryostat and back-filling each with helium to 1 atm. (This includes the He-3 system and the He-4 system.) Also blow some helium into the LN_2 bath and out its vent line.

4.1.31 Install the cryostat to the tip trolley.

5 GENERAL SYSTEM DRAWINGS

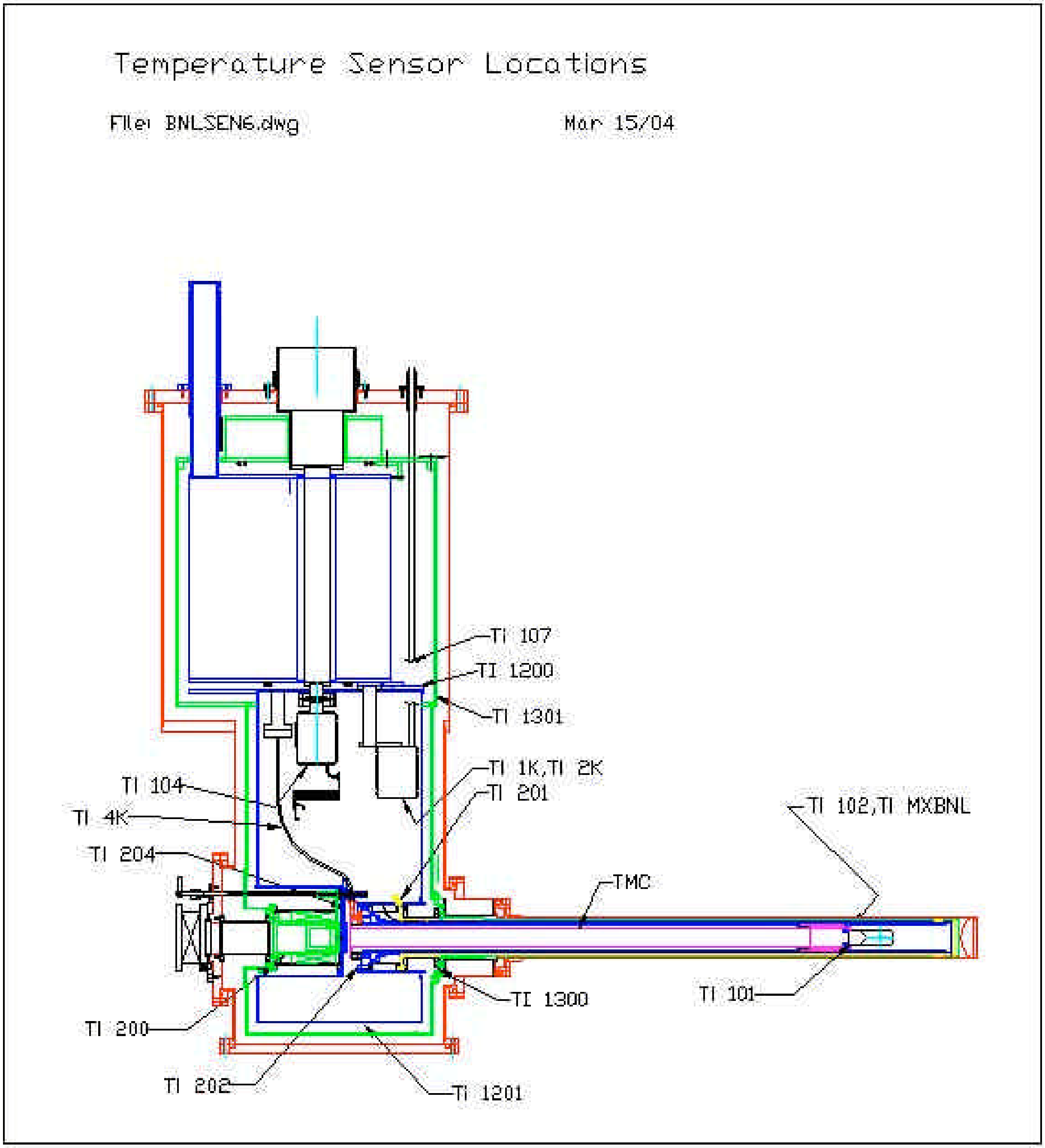


Figure 3 Physical location of temperature sensors.

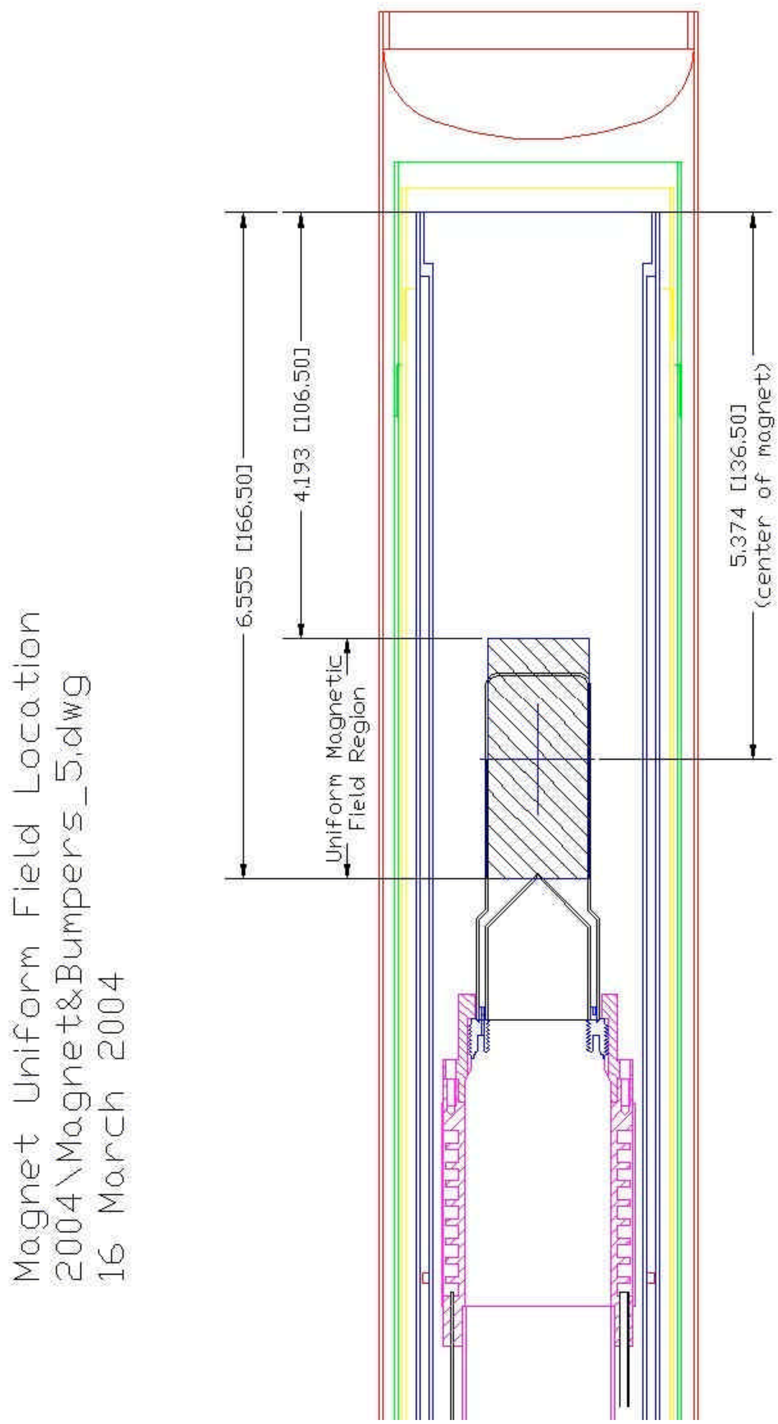


Figure 4 Magnet Uniform Field Location.

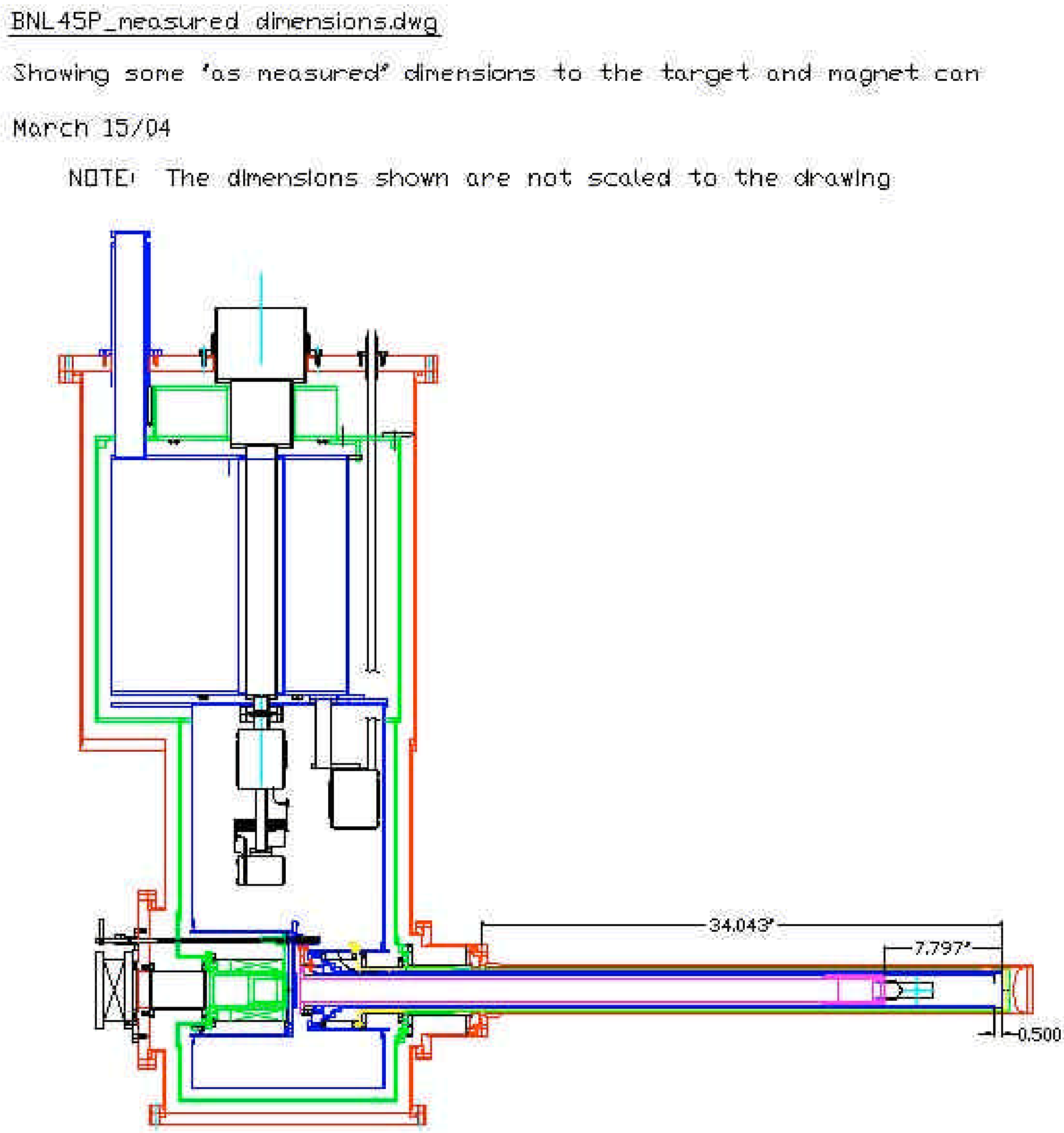


Figure 5 Target Location Measured Dimensions

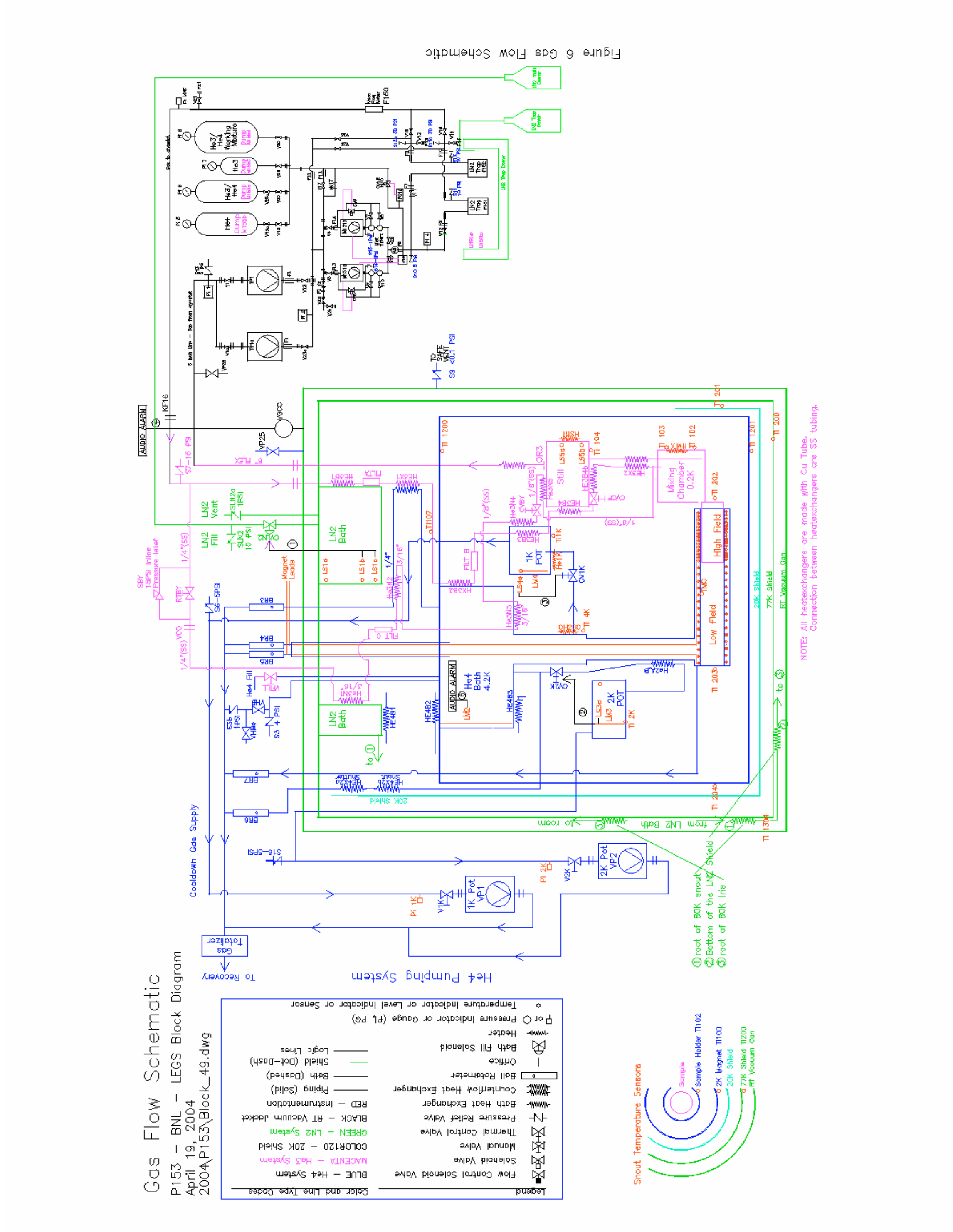


Figure 6 Gas Flow Schematic

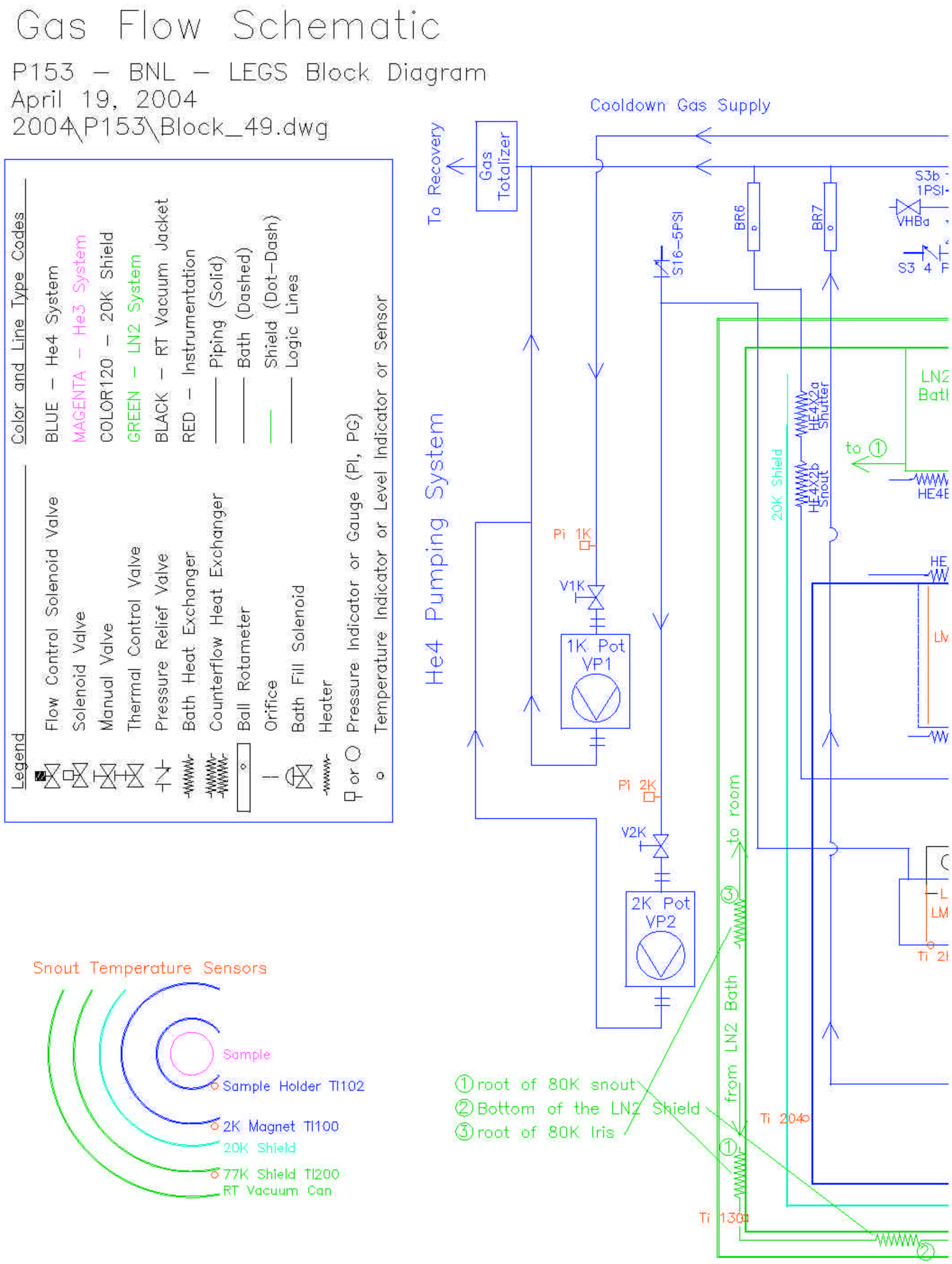


Figure 6a Gas Flow Schematic

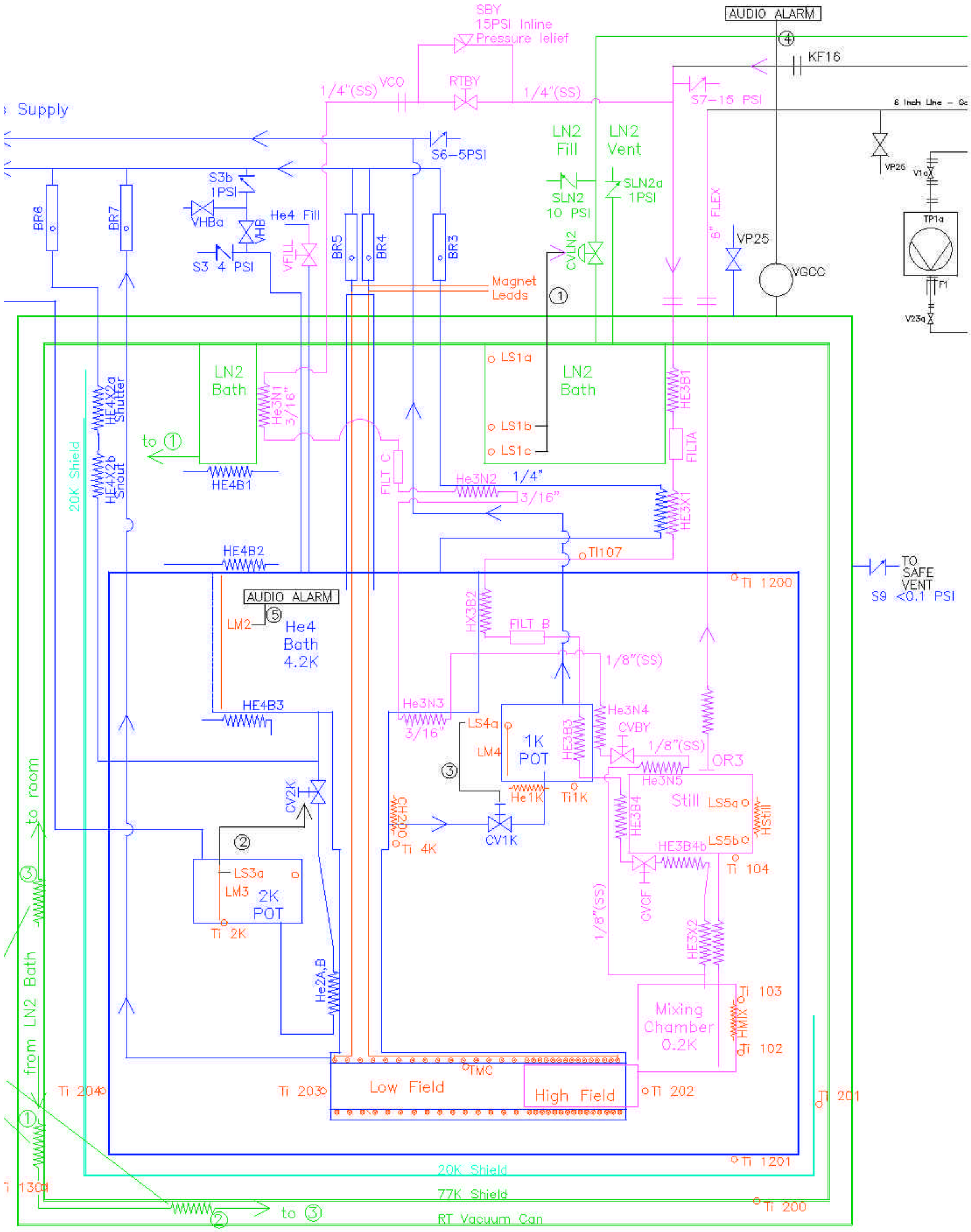


Figure 6b Gas Flow Schematic

NOTE: All heatexchangers are made with Cu Tube.
Connection between heatexchangers are SS tubing.

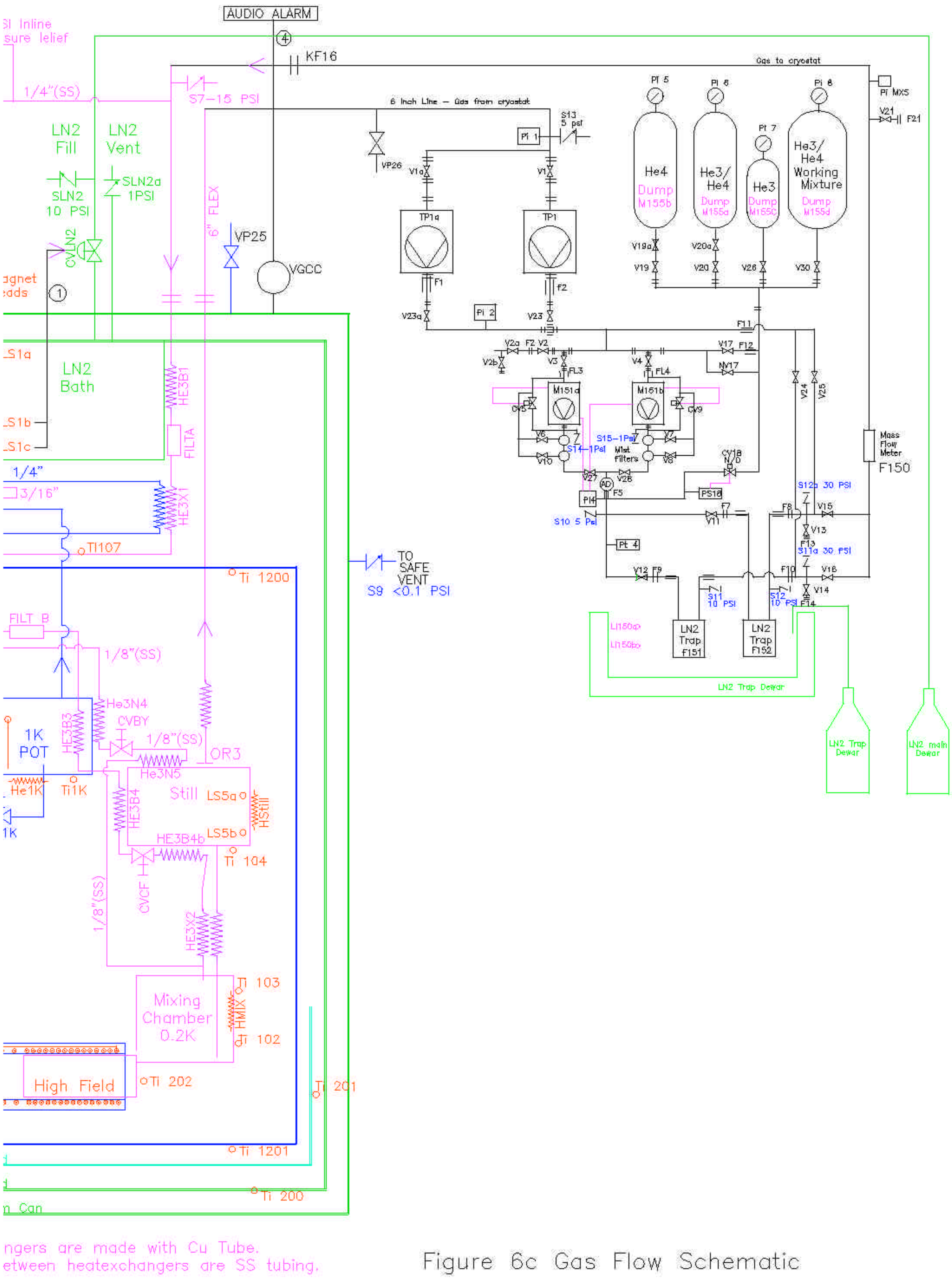


Figure 6c Gas Flow Schematic

6 PICTURES

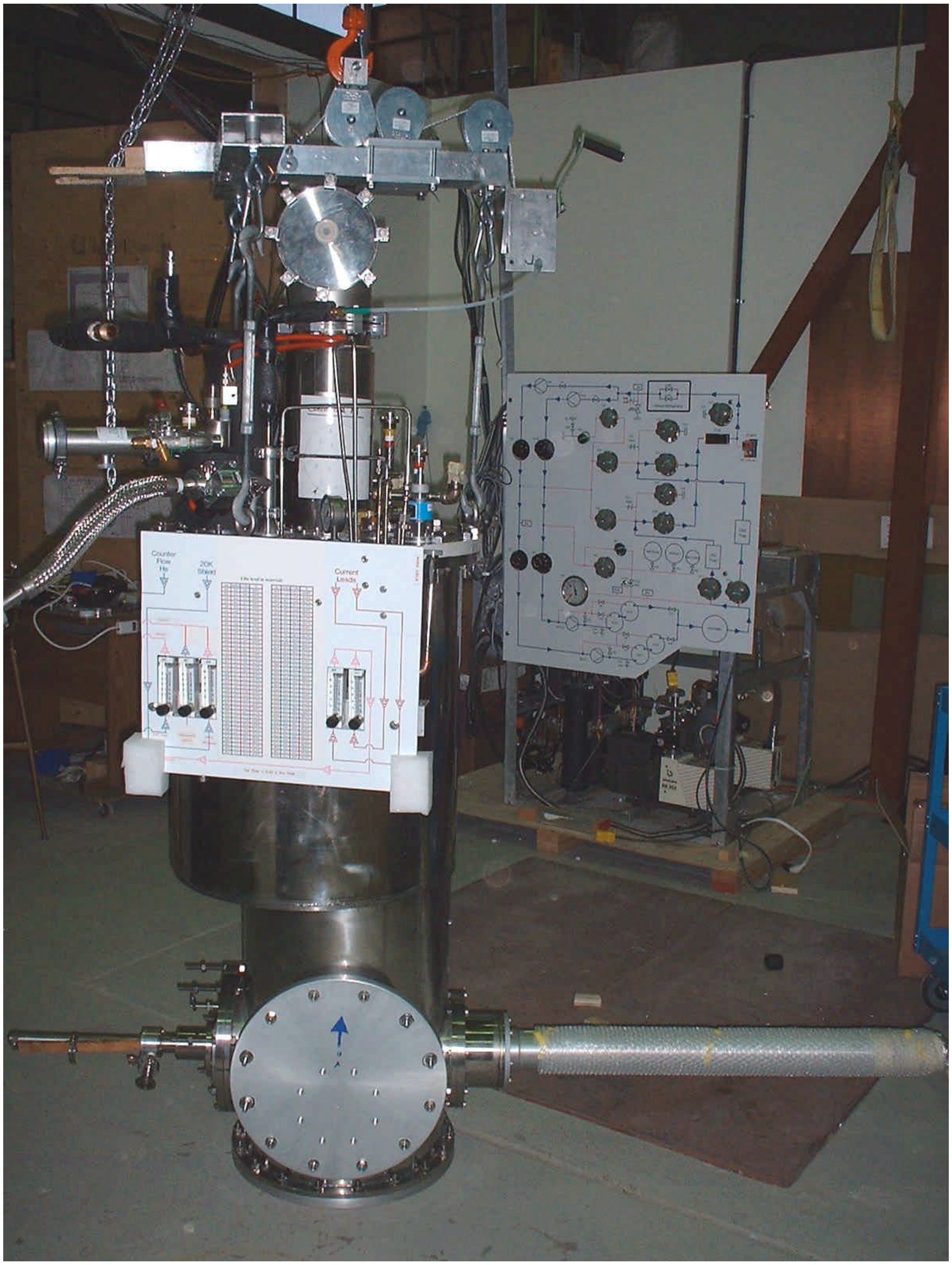


Figure 7 General view.

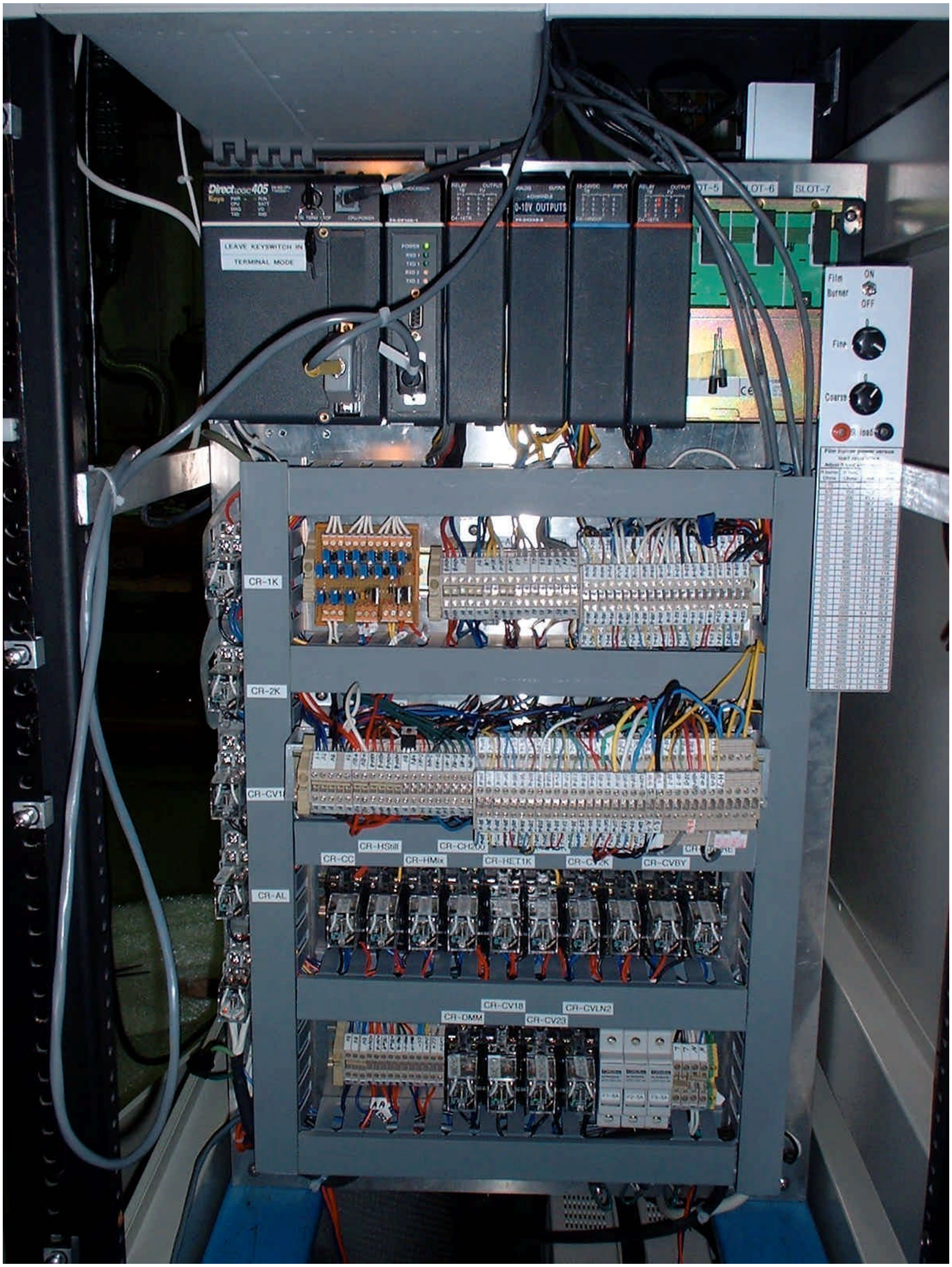


Figure 8 Electrical rack.

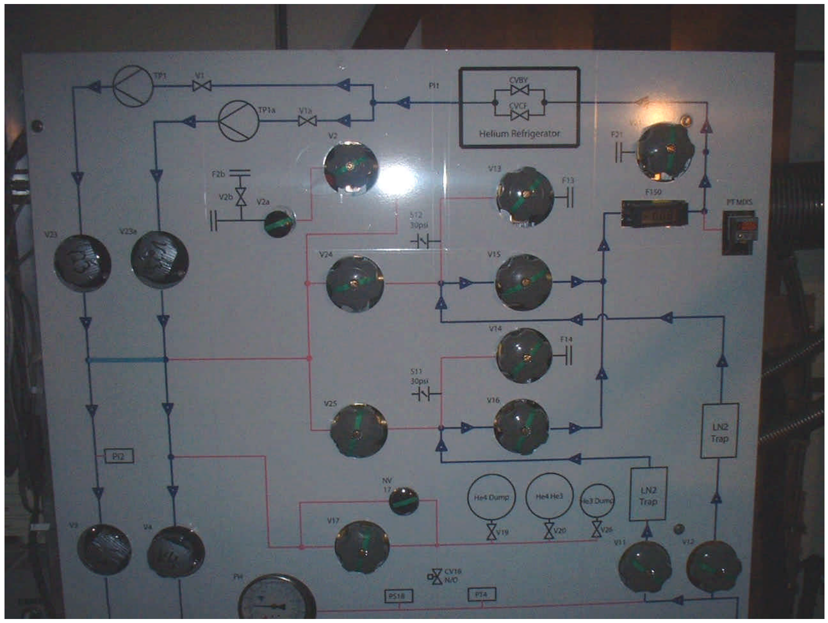


Figure 9 Gas Flow System.

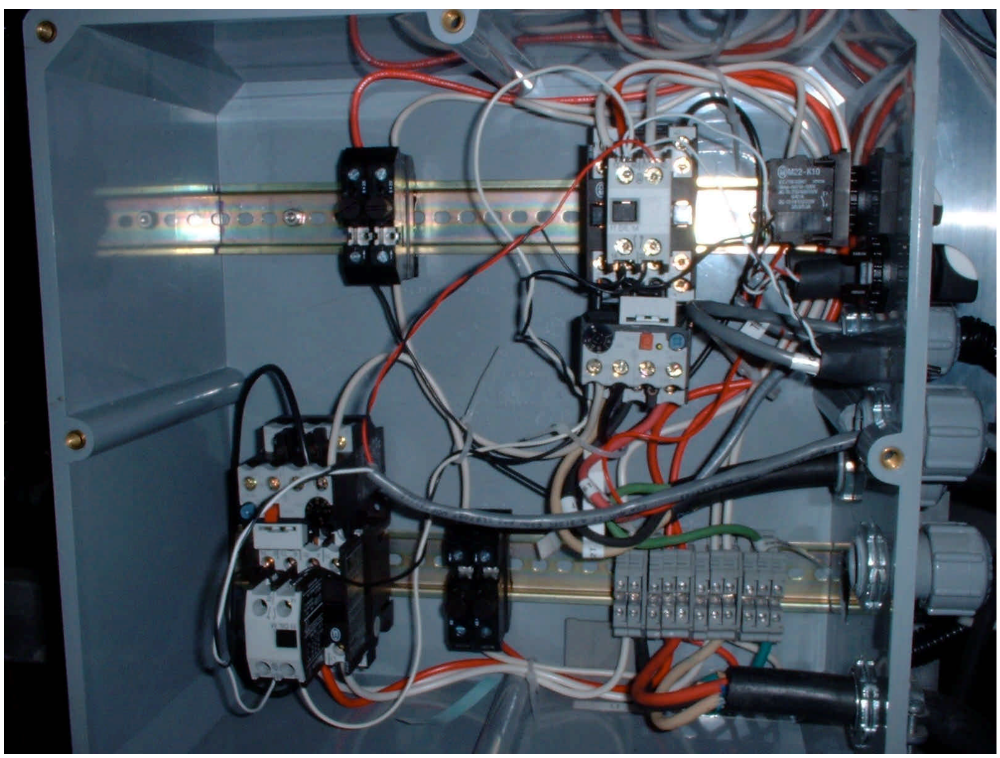


Figure 10 Pump control box.

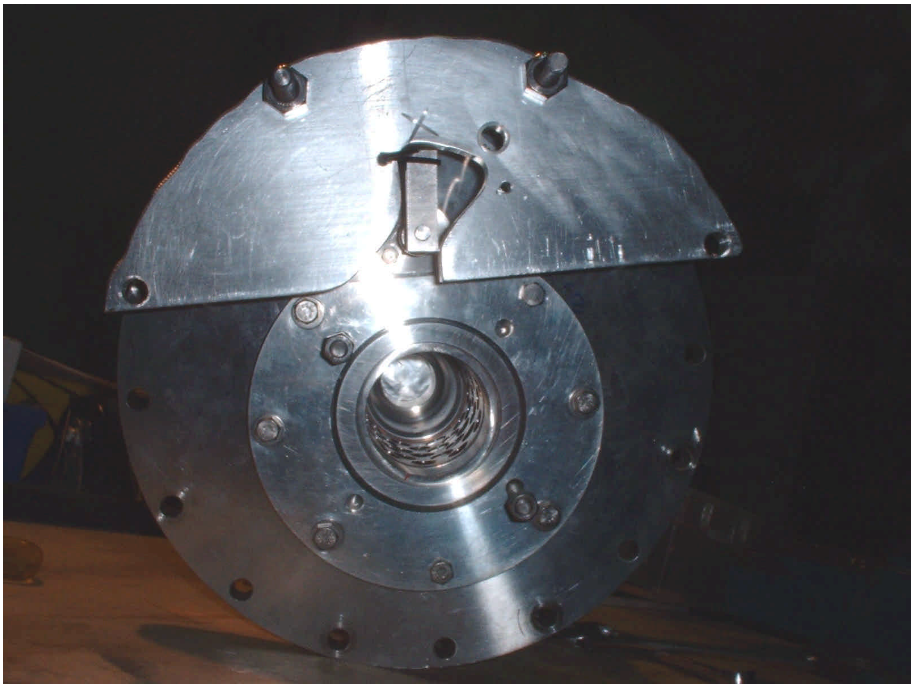


Figure 11 Shutter control lever in CLOSED position.

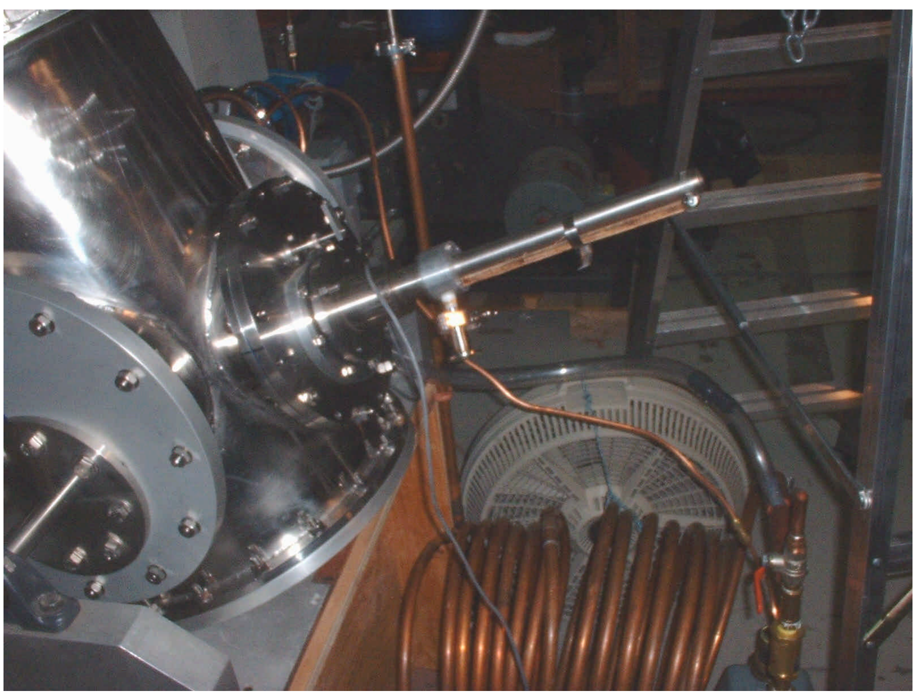


Figure 12 Cryostat in tilt position.

7 TROUBLESHOOTING

7.1 Plugging of He_3 return line.

If the refrigerator should block, causing the flow of helium-3 to stop, then the mixing chamber will begin to warm. It is almost certain that the blockage is at the level of the liquid helium bath. In this case one can open RTBY and CVBY and operate the refrigerator, probably somewhere between 0.7K and 1.0K for a sufficiently long period to recover the target.

Before doing this, it would be a good idea to change LN2 traps and to pump all of the gas in the helium-3 return line to the cryostat back into the pumps, so that it can have one more pass through a fresh LN2 trap before it goes into the refrigerator.

7.2 Response to a pump failure:

7.2.1 The four pumps and their associated inlet and outlet valves.

Turbopump TP1	Inlet valve V1	Outlet valve V23
Turbopump TP1a	**Inlet valve V1a**	**Outlet valve V23a**
Alcatel pump M151b	Inlet valve V4	Outlet valve V28
Alcatel pump M151a	**Inlet valve V3**	**Outlet valve V27**

Table 4 Valves controlling the pumps.

7.2.2 Abnormal pump functioning indicators.

There must be some reason that one suspects that a pump is not running properly. Perhaps the pump inlet pressure is unusually high, or a turbopump front display panel indicates off, or an Alcatel pump is to quiet or vibration free. Two things to check are the circuit breaker for the pump and the cooling water flow (if the cooling water to the Alcatel fails, then the pump will overheat and turn off on an overtemperature switch. When the Alcatel goes off, then the turbopump also turns off.).

7.2.3 General pump switching notes.

If one decides that one wants to switch to another pump (maybe to let the original one cool), then close the pump inlet and outlet valves and set the pump ON/OFF switch to OFF.

7.2.4 Switching to another Alcatel pump.

If the failed pump is an Alcatel mechanical pump and the turbopump still seems to be running (probably at full power and reduced speed, due to excessive exhaust pressure.), then open the replacement pump exhaust valve and turn the replacement pump on. Determine that the pump seems to be running (noise and/or vibration) and then open the replacement pump inlet valve SLOWLY. This valve is opened slowly while monitoring the local pressure dial gauge PI4 which measures the Alcatel pump outlet pressure. Try to keep this pressure below –10", to avoid dumping gas back to the dump tank via CV18.

7.2.5 Switching to alternative Varian turbo-pump.

If the failed pump is a turbopump and the backing Alcatel still seems to be running, then open the replacement turbo inlet valve and then the replacement turbo outlet valve. Open the outlet valve SLOWLY, watching PI4 as in the previous paragraph. When the exhaust valve is fully open, then turn on the turbopump.

7.2.6 Pump switching order.

If both the turbopump and the Alcatel are to be replaced, then first get the Alcatel pump running and then get the turbopump running by:

7.2.6.1 Open the replacement Alcatel exhaust valve

7.2.6.2 Turn on the replacement Alcatel pump

7.2.6.3 Open the replacement Alcatel pump inlet valve

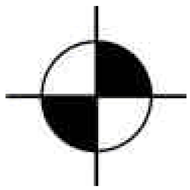
7.2.6.4 Open the replacement turbopump inlet valve

7.2.6.5 Open the replacement turbopump outlet valve SLOWLY (monitoring the local pressure gauge PI4 as in paragraph 7.2.4 above)

7.2.6.6 Once the replacement turbopump outlet valve is fully open, then turn on the replacement turbopump.

8 LABELS, CERTIFICATES

Label 4: Quantity 5 Size 2" x 2" Black letters on self adhesive white background

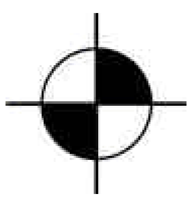


Center of Mass
Weight 920 lbs

Label 5: Quantity 3 Size: 8" x 4" White letter on blue background

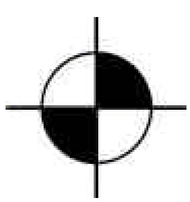
QUANTUM TECHNOLOGY CORP.
MODEL: Q02.5 - P153
IN BEAM CRYOSTAT SYSTEM
HELIUM DILUTION REFRIGERATOR

Label 6: Quantity 3 Black letters on white background size 2" x 2"



Center of Magnet
when warm
(when cold moves ~3mm)

Label 7: Quantity 3 Black letters on white background size 2" x 2"



Stop on Target Holder
when warm
(when cold moves ~3mm)

Label 8: Quantity 20 Size: 2" x 4" Blue letter on White background

Made in Canada
Quantum Technology Corp.
3650 Wesbrook Mall
Vancouver BC V6S 2L2
tel: 604-222-5539
fax: 604-677-5826
email: sales @ quantum-technology.com
www . quantum-technology . com

Label 9: Quantity 2 Size 4x4" blue letter white background

Model: Q02.5 - P153 Control System
Certified to conform to
Underwriters Laboratory (UL) standards
Made in Canada
Quantum Technology Corp.
3650 Wesbrook Mall
Vancouver BC V6S 2L2
tel: 604-222-5539
fax: 604-677-5826
email: sales @ quantum-technology.com
www . quantum-technology . com
Power: 115V 1Phase 60Hz 15A
⚠ Disconnect all supplies and UPS before servicing

Label 10: Quantity 2 Size 4x4" blue letter white background

Model: Q02.5 - P153 Pump Control
Certified to conform to
Underwriters Laboratory (UL) standards
Made in Canada
Quantum Technology Corp.
3650 Wesbrook Mall
Vancouver BC V6S 2L2
tel: 604-222-5539
fax: 604-677-5826
email: sales @ quantum-technology.com

www . quantum-technology . com
Power: 208V 3Phase 60Hz 30A
Internally protected
⚠ Disconnect all supplies and UPS before servicing.

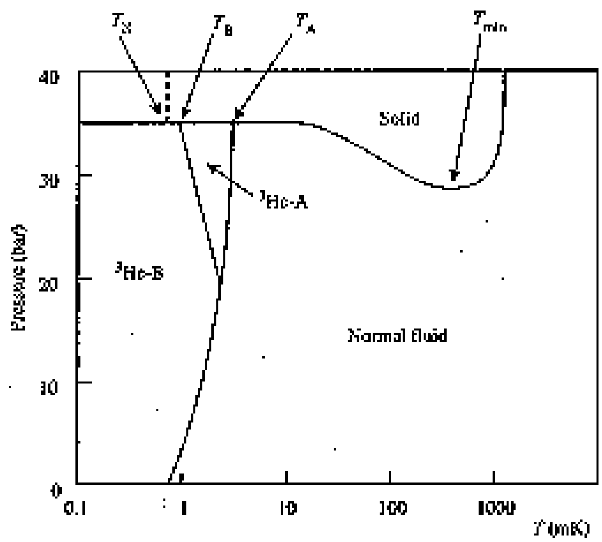
9 REFERENCES, THEORETICAL MODELS

9.1.1 Thermophysical properties of He_3.

^{3}He / ^{4}He Properties (liquid phase at boiling point)

Fluid	Boiling Point (K)	Density (kg/m^3)	Volume Ratio (Gas:Liquid)	Latent Heat of Vaporization (kJ/kg)	Heat Capacity (kJ/kg-K)	Viscosity (mN-s/m^2)	Thermal Conductivity (mW/mK)
^{3}He	3.20	8.9	600:1	8.48	4.6	0.00162	17.1
^{4}He	4.215	25	600:1	20.7	4.56	0.00357	27.0

^{3}He Phase Diagram - (from D.S. Greywall, Phys. Rev. **B33**, 7520 (1986).



4-Helium Properties

Helium Properties at 101.325 kPa

Temp. [K]	Density [kg/m^3]	PV/RT	Energy [J/g]	Enthalpy [J/g]	Entropy [J/g-K]	Cv [J/g-K]	Cp [J/g-K]	Conductivity [W/m-K]	Viscosity [microPa-s]
1	146.9	0.3321	0.0165	0.7063	0.0162	0.1023	0.1023		
2	147.5	0.1653	1.641	2.328	0.9658	5.228	5.25		
3	143.4	0.1134	4.923	5.63	2.372	2.016	2.494		
4.222	124.9	0.0925	9.208	10.02	3.575	2.552	5.255	0.0187	3.263
4.222	16.84	0.6859	24.72	30.74	8.473	3.238	9.144	9.04E-03	1.242
5	11.98	0.8145	28.21	36.67	9.767	3.159	6.77	0.0102	1.392
8	6.433	0.9478	38.76	54.51	12.58	3.111	5.581	0.0145	1.959
10	5.016	0.9724	45.3	65.5	13.81	3.115	5.429	0.0169	2.293
20	2.44	0.9995	77.06	118.6	17.5	3.121	5.251	0.0262	3.624
40	1.216	1.003	139.7	223	21.12	3.119	5.206	0.0405	5.52
100	0.4871	1.001	326.8	534.9	25.88	3.117	5.194	0.0737	9.543
200	0.2437	1.001	638.5	1054	29.48	3.116	5.193	0.118	15
300	0.1625	1	950.1	1574	31.58	3.116	5.193	0.156	19.92

10 APPENDICES

10.1 APPENDIX A: SAFETY ANALYSIS

Following are a number of unusual circumstances which may arise in the operation of the IBC, and the expected response of the IBC to these circumstances, in the absence of operator intervention.

10.1.1 LEGS Cryostat Safety Review Notes

10.1.1.1 Replacement Cryostat

This is a safety review of a replacement cryostat which is very similar to a cryostat which passed safety review and has raised no safety concerns during the three years that it has been on site at BNL.

10.1.1.2 Overview of Cryostat:

Purpose - maintain a solid spin polarized HD target (0.03 liters)

Method: Permanently evacuated (not pumped) vacuum insulated vessel with the following cooling systems:

a) Liquid nitrogen (77K) cooled shields

b) Liquid helium (4.5K) cooled shields

c) Pumped liquid helium (2K) cooled superconducting magnet (1T)

d) Pumped liquid helium (1.5K) heat exchange bath to condense helium-3 mix.

e) Still to evaporate helium-3 mix (0.8K)

f) Dilution refrigerator where helium-3 rich fluid mixed with helium-4 rich fluid (0.2K)

Helium-4 boiloff from the main helium bath and the 2K and 1K pot pumps is normally recovered to an external helium recovery system (and liquefier).

Helium-3 mix is always below atmospheric pressure, it is circulated closed-cycle by a turbopump and hermetic vacuum pump.

Control system: The system operates on a PLC on a UPS independent of computers. Operator interface to change parameters is through Labview software on an external computer.

Design Parameters:

Maximum design/Allowable working pressures:

Cryostat outer vacuum vessel (stainless steel)

Operating pressure: vacuum
Relief port: 25mm diameter vented to a 2" OD pipe for connection to a 350 cfm fan which is on emergency power.

Relief port pressure setting: 0 (gravity operated)

Volume of vacuum vessel is: 230 litres

Volume of vacuum = 230 liters - 45L LHe - 5L LN_2 = 180 liters

ASME code safe internal working pressure approx: 87psig

Liquid nitrogen vessel (stainless steel)

Operating pressure: 1 PSIG

Vented to atmosphere

Volume approximately 5 litres

ASME code safe internal working pressure approx: 92psig

Liquid helium vessel (stainless steel)

Volume approx. 45litres

Operating pressure: 1 psig

Normal Vented through recovery system

Safety relief vent to room: 2.35 sq.in. orifice set pressure < 5psig.

ASME code safe internal working pressure approx: 92psig

2K pot helium vessel (copper)

Volume approx. 1/2 liter

Relief valve: 1/2 diameter (0.4" diameter orifice)

ASME code safe internal working pressure >100 psi

1K pot helium vessel (copper)

Volume approx 1/2 liter

Relief valve: 1/4 diameter pipe (0.2" diameter orifice) set at 5 PSIG

ASME code safe internal working pressure >100psi

He-3 mix volume (copper)

Volume approx 1/3 liter (total volume of mix ~200 atm. liters)

Relief valve: 1/4 diameter pipe (0.2" diameter orifice) set at 15psig

Total volume of pumping tube = 100 liters

(so maximum pressure is 200atm.liters/100liters = 2 absolute atmospheres = 15psig)

Note in the event of a power failure the He-3 gas will bypass the hermetic pump and return to the dump tank as long as the valves are left open (normal operating mode).

10.1.1.3 Potential Hazards Identified:

- **Oxygen Deficiency Hazard (ODH):**

  This will be operated in an experimental area which has already been approved by the safety review committee for a 250 liter liquid helium transport dewar. The volume of the experimental area is 27,000 cubic feet. This experimental area is equipped with exhaust fans on emergency power.

  The volume of liquid helium stored in the cryostat is only 45 liters. After expansion to room temperature 45 liters of liquid helium x 750/28.3 = 1,200 cubic feet of helium gas, which is less than 5% of the volume of the room (could reduce 21% O_2 to 20%). This volume of helium would be safe in this room even without ventilation according to the BNL ODH rules (19.5% mininum O_2).

  The main ODH is in helium transfers and with the storage vessel. However, this has already been approved by a safety committee based on the ventilation in the room.

  The volume of liquid nitrogen stored in the cryostat is only 5 liters. After expansion to room temperature 5 liters of liquid nitrogen x 646/ 28.3 = 114 cubic feet of nitrogen gas, which is less than 1% of the volume of the room.

  Physical layout: Please see drawing DRLayout_2.dwg

  Piping and instrument drawing: Please see drawing: Block_48.dwg

- **Power failure:**

  System designed and tested to withstand power failures. In the event of a power failure, the pumps will cease operating and certain electrically driven valves may change state. The circulation pumps (typically TP1 and M151b) switch off. CV9 and CV18 open. There is an orifice in series with CV9 which will pass high pressure gas slowly from the exhaust of M51b to the turbo exhaust, causing the turbo to decelerate slowly.

The helium liquid in the refrigerator will evaporate slowly and pass back to the storage tanks via the normally open valves CV9 and CV18. If power is restored before all the liquid has evaporated, then the circulation pumps can be restarted and the refrigerator brought back into operation. If for some reason V1 has been closed so the gas can't get back to the storage tanks, then the volume of the flexible pump line (6" ID x approx 13 ' long) will allow the pressure to rise to about 1.3 bar, whereupon some gas may vent through S13.

The 1K and 2K pot pumps likewise stop, and the fill valves for these pots close slowly, with an approximate five minute time constant. The liquid trapped in these two pots evaporates slowly and escapes through relief valves to the experimental hall.

There is no pump on the insulation vacuum space of the cryostat and the vacuum will be maintained by cryopumping to the helium bath so long as there is liquid helium in the bath. Depending on the depth of helium at the time of the power failure, this should be several hours. The hold time of the IBC bath is expected to be in excess of 12 hours.

The polarization holding magnet power supply should be on UPS and see no loss of field until the magnet warms due to the loss of the 2K pump.

The thermally actuated valves (CV1K, CV2K, CVBY, and CVCF) are operated by heaters (the valves are opened by the differential expansion of two metals) that are located outside the cryostat. Power on causes the valves to open and when the power fails they will close slowly as the actuators cool.

Superconducting magnet is powered by a very low power supply rated at 100A and 3V.

- **Loss of service air pressure**

The IBC does not use service air.

- **Loss of cooling water**

The bearings of the turbopump are water cooled. In the event of the loss of cooling water, the bearing temperature will rise and the turbopump power supply will shut off the pump. This will leave only the mechanical pump circulating the refrigerator helium and one will see (a possibly considerable) target temperature rise.

- **Liquid nitrogen failure**

Liquid nitrogen is held in a small bath in the IBC to cool the outermost shield, and in another small dewar in the pumping package to cool a flow through LN2 trap. The bath is automatically refilled from a large transport dewar. The small dewar is manually filled every other day. If the transport dewar goes empty, then the small bath will not refill, causing excessive heating in the IBC (due to the outer shield failure). Failure to fill the small dewar may cause possible plugging of the refrigerator (if the flow through the LN2 trap warms.

- **Atmospheric pressure on the IBC**

There are two areas of concern about the external atmospheric pressure on the IBC, the thin walled snout and the mylar beam exit window. The snout is an aluminium tube 80 mm OD, 1 mm wall, and about 1 m long. It's calculated collapsing pressure is 41 PSID. The mylar beam exit window glued into the end of this tube is torospherical in shape and between 4 and 5 thousandths of an inch thick. Several windows were manufactured, one, which was good looking, was glued into the tube and another (not quite so good looking) was glued into a test jig where it was subjected to a pressure test and burst at 100 PSI differential pressure.

If the thin walled snout collapses under the atmospheric load, it will come to rest against the LN_2 cooled shield and the effect of this will be to warm this shield and increase the heat load on the refrigerator. Since there are still two more shields around the target, it is not expected that the target will warm to the subliming temperature.

- **Vacuum leaks**

A slow air leak from the outside will simply condense on the helium bath and will not be noticed until this bath is deliberately warmed at the end of the run.

A slow helium leak inside the cryostat will degrade insulation vacuum and cause an increasing heat leak to the cryogen baths and to the refrigerator. Eventually the target will begin to sublime, but even if it vaporizes entirely, it will only raise the pressure inside the cryostat to about 80 Torr.

- **Catastrophic loss of insulating vacuum**

If this occurs due to a sudden dump of helium into the vacuum space, then the target will sublime rapidly, mix with helium at a very low density, and be blown out through the downstream window and/or through the IBC vent in the top plate. There should be no explosion hazard.

If the occurrence is due to a catastrophic air leak, then a similar scenario would ensue except the approximately 20 atmospheric liters of hydrogen from the target would be mixed with air, and the potential for a small combustion event would exist for a few seconds.

In either case, the pressure in the helium bath would rise to maybe 5 atm (all the liquid converted to a supercritical gas at about the same temperature). The stress in the stainless steel walls of the helium bath would rise to about 10,000 psi and the gas would vent through a 2” dia tube (about 16” long) to the experimental hall in one or two seconds. The total amount of gas involved would be about 40,000 atm-liters. The vent is about 8 feet above the floor and as long as it is directed up, there should be no personnel hazard.

- **LN_2 trap plugging:**

  He-3 will return to dump tanks. The LN_2 traps are equipped with 30psi relief valves.

- **Potential for a combustion of hydrogen:**

  The volume of the target is 30cm^3 which corresponds to 3 grams of HD.

  The total energy of combustion is similar to burning 1 tablespoon of gasoline.

Hydrogen burns with an almost invisible flame to produce water.

The net heat of combustion is 120kJ/gram for hydrogen (about 80kJ/gm for HD). The total energy released by combustion of the target would thus be 80kJ/gm x 3 gm = 240kJ.

For hydrogen the lower flammable limit is 4% in air.

The lower explosive limit is 18% in air.

It is difficult to construct a scenario, which would result in ignition of the hydrogen before it would be so diluted with air that it would not ignite.

For example, if the mylar window breaks then air rushing past the target will evaporate it to make 24 litres of HD gas mixed with 180 litres of air.

In the first instant this would be 13% hydrogen, or still a flammable mixture. Air will continue to flow slowly into the cryostat, condensing on the liquid helium cooled surfaces. This will soon dilute the mixture to below the flammable threshold. Even if there was ignition the heat would be mainly dissipated inside the cryostat resulting in an insignificant (~1K) increase in average cryostat temperature.

In another example, suppose that someone removes the blankoff port and opens the vacuum pumpout valve on the main cryostat. In this case the cryostat will fill with air from the other end, causing the target to evaporate.

In this case there will be a hydrogen rich region in the target snout end, however ignition is unlikely.

The natural concern with hydrogen is the "pop" small explosion, which can occur when an appropriate mixture of hydrogen and air is ignited. However, in our case the amount of hydrogen is so small that even if this were to occur after the cryostat vacuum vessel was filled with air and somehow be so well mixed that the entire volume could participate in the explosion, the internal pressure would only rise (instantaneously) to 84psi. This is within the design pressure of the vacuum vessel so the vacuum vessel would not break, and the hot air would be exhausted out the relief port (and possibly out the snout mylar window).

The principal hazard to personnel is the potential for hearing damage due to the loud pop. Given the small size of this target, the distance to personnel and lack of ignition sources we consider this risk of hearing damage in the event of an explosion to be very low and risk of a "pop" to be remote.

High pressure on cold gauge triggers alarm through PLC program.

Thermocouple gauge is interlocked to switch off high voltage supplies to detectors.

- **Quench protection:**

Very small superconducting magnet 100A at 0.1 H so stored energy is 500 Joules. This will cause a temperature rise of the coil from 2.K to 4K.

- **Electrical equipment:**

Industry standard equipment, Agilent digital voltmeter, power supply, pressure and temperature sensors, vacuum pumps are used. The custom superconducting magnet power (3V 100A) supply has been built using rated components to industry standard. The control rack has been built to industry standard and is fully enclosed in a grounded metal case. Quantum Technology Corp. certifies that this equipment meets North American electrical codes.

- **Static Magnetic Field**

  The 60mm diameter (2.3") solenoid field is 1T, 250mm (10") long.

  We have reviewed BNL's Static Magnetic Field Standard. We provided 5Gauss line and 600Gauss line contour plots on the physical layout drawing.

  This cryostat will require Sign # 1 - Safety Sign External field. It will also require following BNL guidelines re: medical electronic devices (e.g. cardiac pacemakers).

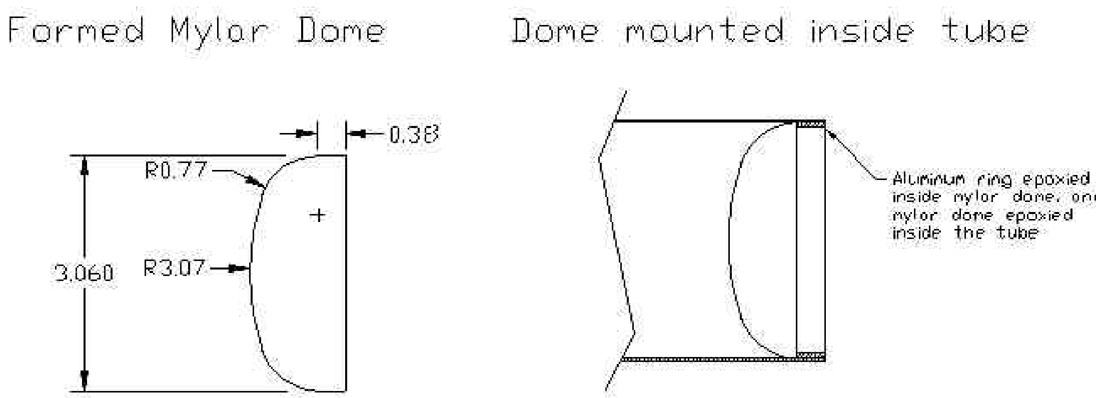
  The 600G field contour is essentially confined within the apparatus. The 5G field contour is generally within the area of cryostat and detectors. Please see contour plot.

10.1.1.4 IBC Mylar Vacuum Window

10.1.1.4.1 Description of the mylar window

The window is a heat formed mylar dome which is epoxied into the end of an aluminum tube with an aluminum retainer ring on the inside, as shown below. The dome has a cylindrical section 0.38" long, followed by a curved section of radius 0.77", capped by a section of a sphere with radius 3.07". The three sections meet tangentially; that is, with no corners.

A description of the forming of the window is given in Appendix 10.1.1.4.2A and a description of the gluing procedure is given in Appendix 10.1.1.4.2B.



10.1.1.4.2 Compliance with Occupational Health and Safety Guide Interim 1.4.2; see the web site at https://sbms.bnl.gov/ld/ld08/ld08d141.pdf

Using the Guide numbering scheme, the relevant sections are:

IV.B. Radiation Damage:

1.4.2 Figure 7 shows no degradation in mylar properties for doses less than $3x10^{14}$ particles per cm^2. Radiation length of mylar is 28.7 cm so the window itself is $4.4x10^{-4}$ radiation lengths. The target and its shell are just under $2x10^{-2}$ radiation lengths. The beam is 10^7 gamma's per second, spread over 5 cm^2. Radiation is dominated by pair production, so there are two charged particles per interaction. Overall, this is $8x10^4$ particles per cm^2 per sec. A dose of 3 $x10^{14}$ particles per cm^2 takes $3.75x10^9$ sec or 120 years.

IV.B.1.a. The window has passed the deflection test; see Appendix 10.1.1.4.2C.

IV.B.1.c. The window was visually inspected during the deflection test of Appendix 10.1.1.4.2C. No scratches, pockmarks or wrinkles were present on the window.

IV.B.1.d. The window material, mylar, is compatible with the vessel contents, vacuum.

V.A This window is deemed to be Held-But-Not-Fixed.

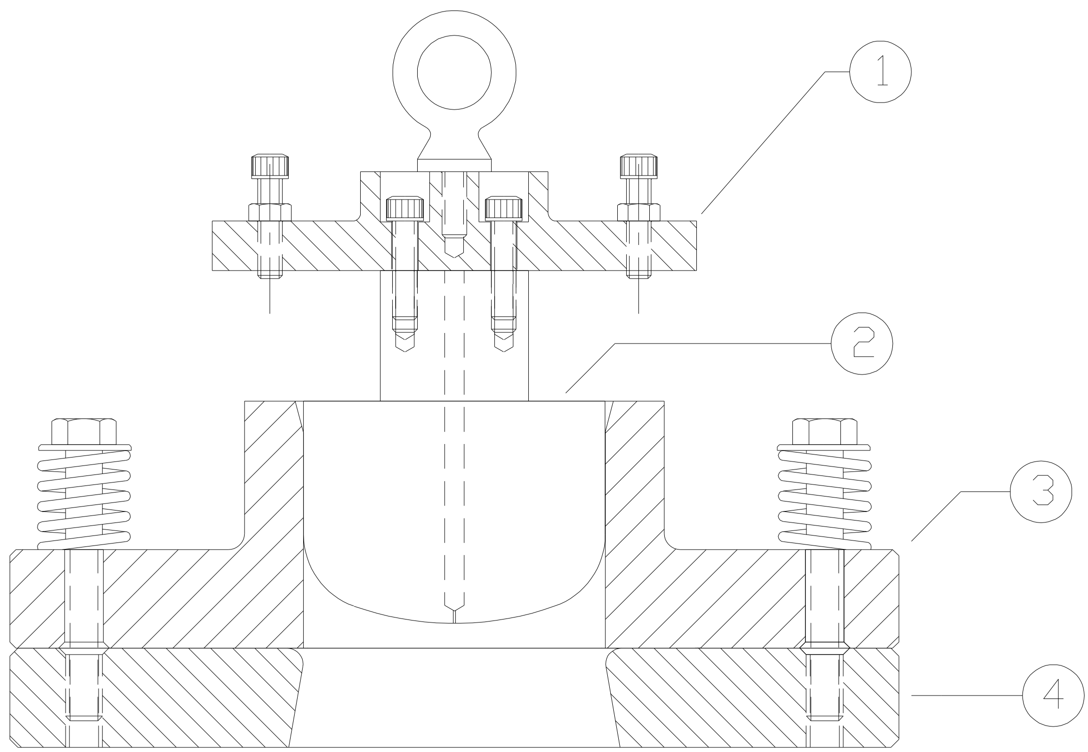
V.B.2.d. The mylar is held in the aluminum tube with epoxy and there is the concern that this may give rise to stress concentrations in the mylar due to irregularities in the epoxy edge. The product description pages for DP-460 do not show measured overlap shear values for aluminum and mylar. The shear stress for an aluminum overlap joint is 5700 psi and for a plastic like ABS it is 575 psi. Therefore, it is assumed that the shear stress between aluminum and mylar is below the mylar maximum design stress of 9500 psi.

V.C.1.c The window is deemed to to be in a frame with an infinite radius of curvature, leaving the frame with theta angle zero.

V.C.8. The maximum tensile stress in the window is calculated to be 4938 psi; see Appendix 10.1.1.4.2D.

Appendix 10.1.1.4.2A: Formation of the mylar dome

The dome is formed from a 0.005" thick mylar disc in the brass die illustrated below.



The mylar disc is clamped between the pieces numbered 3 and 4. This assembly is heated to 180C and then a room temperature punch (2) is installed into the assembly and driven down to a stop determined by the stop screws in item 1. Mylar in contact with the room temperature punch does not stretch and the material which forms the dome is drawn from that part of the mylar disc clamped between items 3 and 4. The springs under the screws holding items 3 and 4 together provide the correct tension to allow the mylar to slide between items 3 and 4. The setting of this tension is a matter of trial and error.

Appendix 10.1.1.4.2B: Installation of the dome in the IBC snout

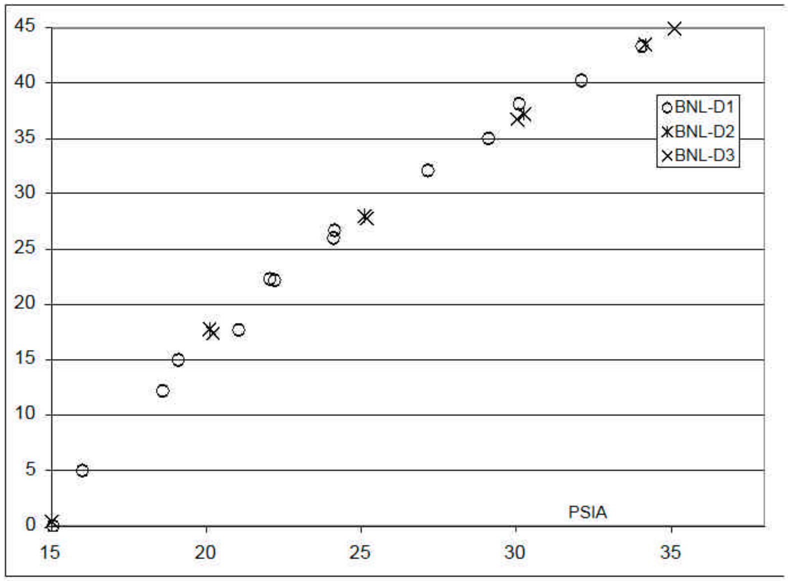
The mylar dome is epoxied into the end of the aluminum tube which forms the vacuum wall for the IBC snout, with an aluminum ring serving as a retainer on the inner diameter of the cylindrical section of the dome. The inside of the aluminum tube and the outside of the aluminum ring were roughened with Scotch Brite and both sides of the cylindrical section of the mylar dome were lightly roughened with Scotch Brite. All four surfaces were lightly coated with a 24 hour curing epoxy (3M Scotch-Weld Epoxy Adhesive DP-460) and the three pieces assembled and left to cure with the tube vertical (dome concave down). The aluminum pieces were machined to leave a nominal 0.005" epoxy gap.

Appendix 10.1.1.4.2C: Window deflection tests and visual inspection were carried out at BNL on March 29, 2004 and witnessed by Jim Durnam. He is sending separately a document memo. A graph of the results is included below.

29 March 2004 - Test for safety committee using calibrated gauge

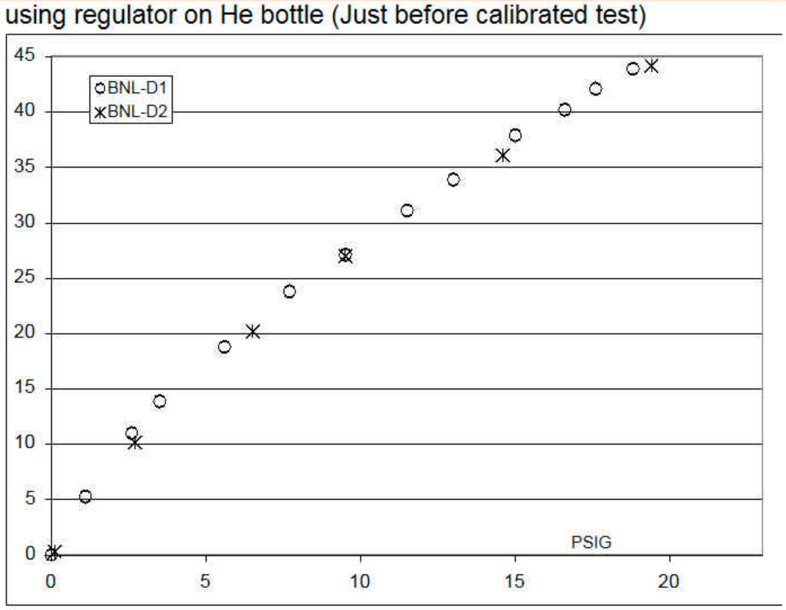
Note that this effectively calibrates the regulator gauge used in the previous test.

Psig	BNL-D1	BNL-D2	BNL-D3
15.06	0		
16.01	5		
18.6	12.2		
19.1	15		
21.05	17.7		
22.05	22.3		
22.2	22.2		
24.1	26		
24.1	26		
24.14	26.7		
27.15	32.1		
29.1	35		
30.09	38.1		
32.1	40.2		
34.05	43.3		
35.18	45.1		
36.1	46.7		
37.13	48.1		
20.1		17.8	
25.1		28	
30.25		37.2	
34.15		43.5	
36.12		46.3	
37.07		48	
15.02			0.4
20.21			17.4
25.18			27.8
30.02			36.7
35.1			44.9
36.03			46.3
37.09			48.1



29 March 2004 - Test using regulator on He bottle (Just before calibrated test)

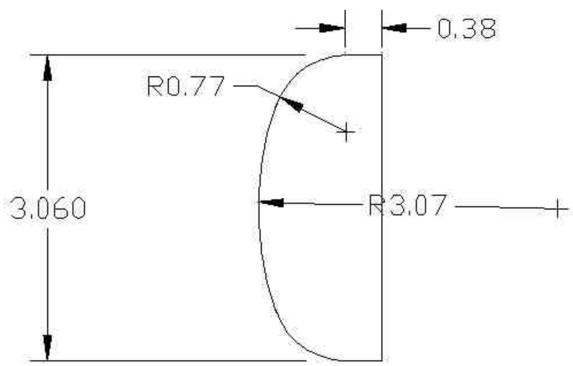
Psig	BNL-D1	BNL-D2
0	0	
0.1		0.3
1.1	5.3	
2.6	11	
2.7		10.2
3.5	13.9	
5.6	18.8	
6.5		20.2
7.7	23.8	
9.5	27.1	
9.5		27
11.5	31.1	
13	33.9	
14.6		36.1
15	37.9	
16.6	40.2	
17.6	42.1	
18.8	43.9	
19.4		44.2



Appendix 10.1.1.4.2D - Mylar window stress

Dennis Healey

March 25, 2004



The dimensions of the mylar window are shown above. The window was formed in three shapes. The outermost section is a cylindrical piece 3.06" dia x 0.38" long. The next section has radius 0.77" and the final inner section is a portion of a sphere of radius 3.07". The three sections join tangentially. The window was formed from 0.005" thick mylar. After forming, the mylar thickness was 0.0043" thick at the center of the large dome and 0.0039" thick in the cylindrical piece. (The actual window glued to the cryostat was not measured. These thicknesses were the mean values for the two spare windows.)

mylar thickness in the cylinder $t_C := 0.0039 \cdot in$

mylar thickness in the dome $t_D := 0.0043 \cdot in$

atmospheric pressure $P := 14.7 \cdot psi$

1. Stress in the cylindrical section

cylinder diameter $d := 3.06 \cdot in$

longitudinal force on cylinder $F_c := \pi \cdot \frac{d^2}{4} \cdot P$

stress in cylinder wall $S_c := \frac{F_c}{\pi \cdot d \cdot t_C}$

$S_c = 2.883 \times 10^3 psi$

2. Stress in the large central radius

This section is a portion of a sphere. The stress in a sphere of radius R and thickness t due to an internal pressure P is

$$S = \frac{R \cdot P}{2 \cdot t}$$

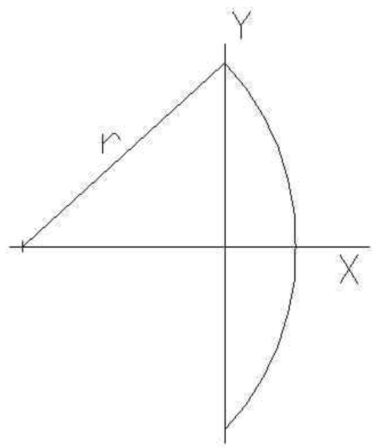
The spherical section of the dome is illustrated below. For the unstressed dome, the Y intercept is

$$y := 1.53 \cdot in$$

The radius of the sphere is $r := 3.07 \cdot in$

This gives the X intercept as $x := r - \sqrt{r^2 - y^2}$

$$x = 0.408\,in$$



Measurements of the deflection of the dome under atmospheric pressure showed that the end of the dome moved about 0.03". Assuming that most of this motion was due to deformation of the large sperical portion of the dome, and that the perifery of this section does not move much, then the X intercept changes to

$$x_{15} := x + 0.03 \cdot in$$

Then the new radius of curvature of the large shperical section of the dome is

$$R := \frac{x_{15}^2 + y^2}{2 \cdot x_{15}}$$

$$R = 2.889\,in$$

so the stress is

$$S := \frac{R \cdot P}{2 \cdot t_D}$$

$$S = 4.938 \times 10^3\,psi$$

3. Stress in the small radius section between the cylinder section and the large radius section

The stress in this section varies continuously and monotonically in this section from the cylindrical boundary (where the stress is a minimum of 2883 psi) to the large radius boundary (where the stress reaches the maximum of 4938 psi)

4. Bursting pressure

One of the visually less than perfect windows (it had some wrinkles around the cylindrical section) was glued into a test frame and increasing pressure was applied to the concave side of the window until it burst at 100 psi differential. The burst appeared to initiate near the center, in the large radius section, where the stress is supposed to be largest.

No meaurement was made of the deflection of the test dome as it neared bursting. Suppose that the deformation was linear. Then one supposes that the deformation of the dome due to 100 psi would be

$$\delta := 0.03 \cdot in \cdot \frac{100 \cdot psi}{15 \cdot psi}$$

Then the X intercept of the dome, as illustrated in section 2 above, would be

$$x_{100} := x + \delta$$

and the radius of curvature of the deformed spherical section would be

$$R := \frac{x_{100}^2 + y^2}{2 \cdot x_{100}}$$

$$R = 2.228\,in$$

at the pressure $P := 100 \cdot psi$

This gives the stress in the spherical section of the dome at the bursting pressure as

$$S := \frac{R \cdot P}{2 \cdot t_D}$$

$$S = 2.591 \times 10^4 \, psi$$

This measurement gives an ultimate tensile stress

$$UTS := \frac{S \cdot 100 \cdot psi}{P}$$

$$UTS = 2.591 \times 10^4 \, psi$$

This is in good agreement with the tensile strength (25000 psi @ 70 F) listed for mylar in Table II (Typical Properties of Plastics) of Section 1.4.2 of the Occupational Health and Safety Guide Interim.

APPENDIX B1: MECHANICAL DRAWINGS (BINDER)

10.2 APPENDIX B2: MECHANICAL DRAWINGS (BINDER)

10.3 APPENDIX C: ELECTRICAL DRAWINGS (BINDER)

10.3.1	Instrument Rack Layout Rev.J (Rear & Front View, 14 Pin Connector Coding)	B-Sch-00-1
10.3.2	Plc Pin Connections Rev.K (Schematic Diagram, Rs-232 Cables)	B-Sch-00-2
10.3.3	120v Power Supply Rev.K (Fuses, Main Lines, Ups)	B-Sch-00-3
10.3.4	Temperature Sensors Rev.L (Ti102, Ti103, Ti104, Mxbnl)	B-Sch-01
10.3.5	Temperature Sensors Rev.L (Ti4k, Ti2k, Xxxx, Ti204)	B-Sch-02
10.3.6	Temperature Sensors Rev.L (Tmc, Ti201, Ti1200, Ti101)	B-Sch-03
10.3.7	Temperature Sensors Rev.K (Xxxx, Ti1201, Ti107, Ti202)	B-Sch-04
10.3.8	Temperature Sensors Rev.I (Ti1k, Xxxx)	B-Sch-05
10.3.9	Level Sensors Rev.I (Ls3a, Ls3b, Ls4a, Ls4b)	B-Sch-06
10.3.10	Misc Rev.I (Lm2, Sc V Taps, Ls3l, Ls4l)	B-Sch-07
10.3.11	Level Sensors Rev.J (Ls1a, Ls1b, Ls1c, Fi51, Fi52)	B-Sch-08
10.3.12	Flowmeters Rev.H (F150)	B-Sch-12
10.3.13	Pressure Transducers Rev.H (Pt4, Vgcc, Vgcv)	B-Sch-15
10.3.14	Pressure Transducers Rev.I (Pi1, Pi2, Ptimx)	B-Sch-16
10.3.15	Pressure Transducers Rev.I (Pi1k, Pi2k)	B-Sch-17

10.4 APPENDIX E: INSTRUMENTATION (BINDER)

10.5 APPENDIX G: PROGRAMMING (BINDER)

10.5.1 PLC Program Structure

10.5.2 PLC Ladder Program

10.5.3 List of Scanned Sensors

10.5.4 PLC Notes and Memory Map

10.5.5 DL450 Products

10.5.6 FACTS Basic Program: P153x41.abm

10.5.7 OPC Server

10.5.8 LabVIEW

10.5.9 SCPI Command Summary

10.6 APPENDIX H: EQUIPMENT MANUALS (BINDER)

10.6.1 AGILENT 34970A DMM MANUAL

10.6.1.1 Quick Reference Guide

10.6.1.2 Online User’s Guide

10.6.1.3 Product Overview

10.6.1.4 User’s Manual

10.6.2 F4-CP128-1 MANUAL (PLC)

10.6.3 EXTENDED BASIC REFERENCE MANUAL (PLC)

10.7 APPENDIX I: DL-405 MANUAL (PLC) (BINDER)

10.7.1 GETTING STARTED

10.7.2 INSTALLATION, WIRING, & SPECIFICATIONS

10.7.3 CPU SPECIFICATIONS & OPERATION

10.7.4 SYSTEM DESIGN & CONFIGURATION

10.7.5 STANDARD RLL INSTRUCTIONS

NOTE: FOR OTHER MANUALS CHECK APPENDIX E.

BROOKHAVEN
NATIONAL LABORATORY

Building 911
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-4250
Fax 631 344-5954
Lessard@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: *Thursday, April 29, 2004*

To: *A. Sandorfi*

ETL

From: *E. Lessard, Chair, Laboratory Environmental, Safety and Health Committee*

Subject: *Commencement of LEGS Commissioning*

Thank you for submitting additional ODH calculations to address fan "failure to start" and "failure to restart after one cycle." Thank you for implementing recommended changes to the operating procedures, changes that resulted from Committee review. I want to take this opportunity to thank Steve Kane who gave up his weekend to do an exhaustive review of the procedures. I feel it is important to note that based on Steve's review, you have indicated that implementation of some of the recommended procedure changes will be via the use of operations and equipment checklists, on-the-job training and regular work-planning exercises.

Based on these submissions and commitments, LEGS commissioning may commence.

Copy to:

S. Kane
J. Tarpinian
R. Travis