Report for Brookhaven National laboratory
E951 Cryo Operating Procedures
September 20, 2002

E951 Cryo Operating Procedures

Preface

The following operating procedures are written to support a particular E951 cryogenic system design to cool the Pulsed Solenoid Magnet before all the equipment has been acquired and purchased and any of the equipment is pre-tested and installed. It will demonstrate that the proposed cryogenic design is fully operable and serves the functional requirements specified. A thorough review of these procedures for the as-built and installed system by E951 and the appropriate BNL experimental, cryogenic and safety committees is necessary before putting these Operating Procedures to use.

The main body of these operating procedures addresses the installed and commissioned equipment. That is it operates, but does not commission the equipment. The attached addendum addresses the minimum requirements for the re-certification or use-certification of major system, especially equipment components that have been out-of-service for sometime or those being operated for the first time. These Operating Procedures will, at the outset, assume that in each case such equipment certifications and all the standard, installation and equipment commissioning testing have been successfully completed.

General Description

The E951 cryogenic system is designed to cryogenically cool an experimental, conventional copper, Pulsed Solenoid Magnet (PSM). Five modes of cooling are supported by the cryogenic system design:

Mode	Temp	Field	Coolant	Press.	GHe HE
1	81 K	5 T	LN_2	1 atm	
2	70 K	10 T	LN_2	0.2 atm	
3	81 K	5 T	LN_2	1 atm	100 g/s
4	81 K	10 T	LN_2	0.2 atm	100 g/s
5	26 K	15 T	LH_2	1 atm	100 g/s

Modes 1, 2: LN_2, Pumped LN_2 Direct

In the operating modes 1 (5 T) and 2 (10T), and after a slow, deliberate, cooldown to near LN_2 temperature, liquid nitrogen is admitted to the PSM cryostat to contact and directly cool the, i.e., directly in contact with the liquid. In the first case the liquid boils at ca. 1 atmosphere, 77.4 K. In the second case the admitted liquid is vacuum pumped to less than the 66 K vapor pressure, i.e., 0.203 atm.

Direct cooling has the advantage of a high heat transfer coefficient, but the liquid must be removed from the cryostat volume before for each beam pulse for LN_2 beam irradiation reasons. The design approach provides for that cyclic liquid removal/restoration operation.

Modes 3, 4: GHe Cooled by LN_2, Pumped LN_2

In the operating mode 3 (5 T), and after a slow, deliberate, cooldown to near LN_2 temperature, the Circulator/HE bath filled with 1 atmosphere (LN_2, 77.4 at 1 atm.) cools a pump circulated, nominal 12 atmosphere, GHe stream to cool the PSM. The 12 atmosphere GHe Cryostat environment can be safely exposed to the beam.

In the operating mode 4 (10 T), and after a slow, deliberate, cooldown to near LN_2 temperature, the Circulator/HE bath filled with 1 atmosphere (LN_2) and vacuum pumped to 0.2 atm. (66 K at 0.203 atm.) cools a pump circulated, nominal 12 atmosphere, GHe stream to cool the PSM.

The Mode 3 and 4 operations provide continuous PSM cooling, i.e.; not discontinuous, no equipment state changes are required with each magnet pulse as in the Modes 1 and 2.

Modes 5: GHe Cooled by LH_2

In the operating modes 5 (15 T), and after a slow, deliberate, cooldown to near LN_2 temperature, the Circulator/HE bath filled with 1 atmosphere liquid Hydrogen (LH_2, 20.39 K at 1 atmosphere) cools a pump circulated, nominal 12 atmosphere pressure, GHe stream to cool the PSM. The 12 atmosphere GHe Cryostat environment can be exposed to the beam. The Mode 5 operation makes the PSM cooling essentially continuous, i.e.; no equipment state changes are required as in the Modes 1 and 2.

Schematic Representations

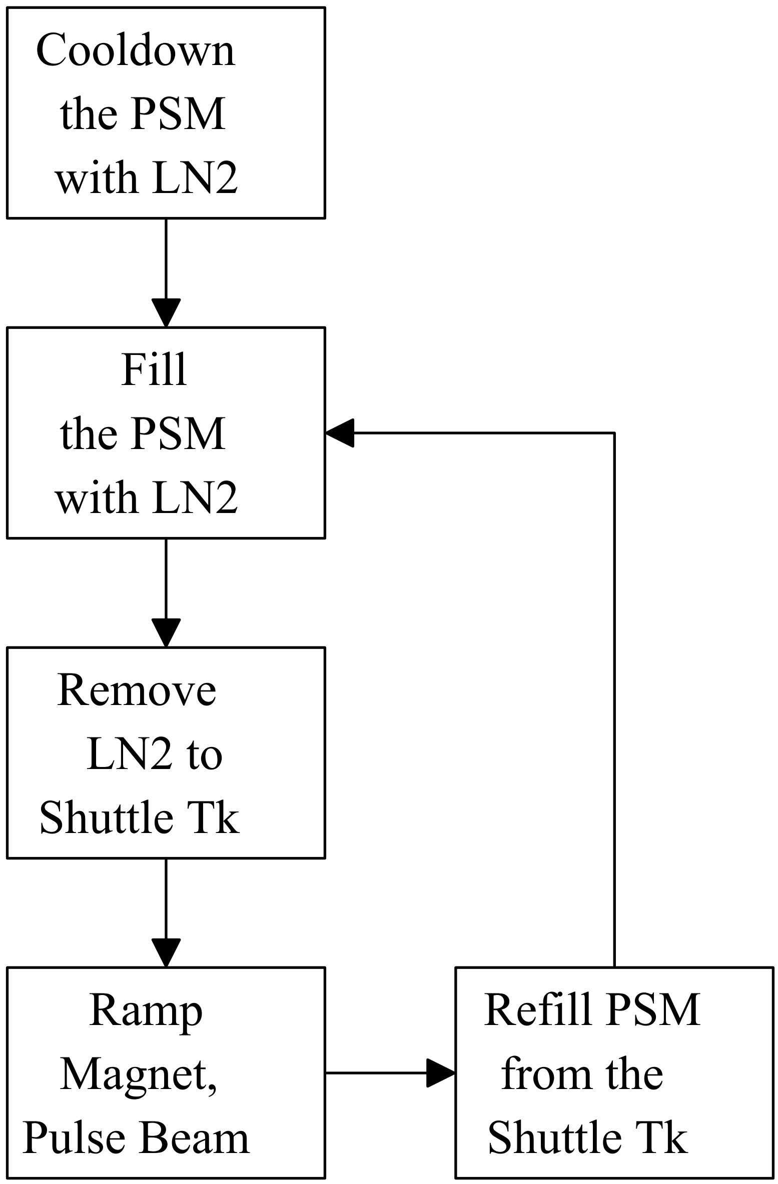
A general arrangement (GA) schematic representation, see figure __, shows the necessary LN_2 and LH_2 dewars, the Circulator/HE, the Process and Purge (P&P) vacuum pumps, the PSM and the connecting, relief, vent and ambient heater piping. While this small GA schematic isn't complete - to allow for clarity of illustration - it does provide an important overview of the system and the component interdependence.

The GA schematic is immediately followed by five major-component banner drawings that capture the details of the system. You are referred to the GA drawing for orientation and the individual: LN_2, LH_2, Circ/HE, Vacuum, and PSM drawings for details, as required.

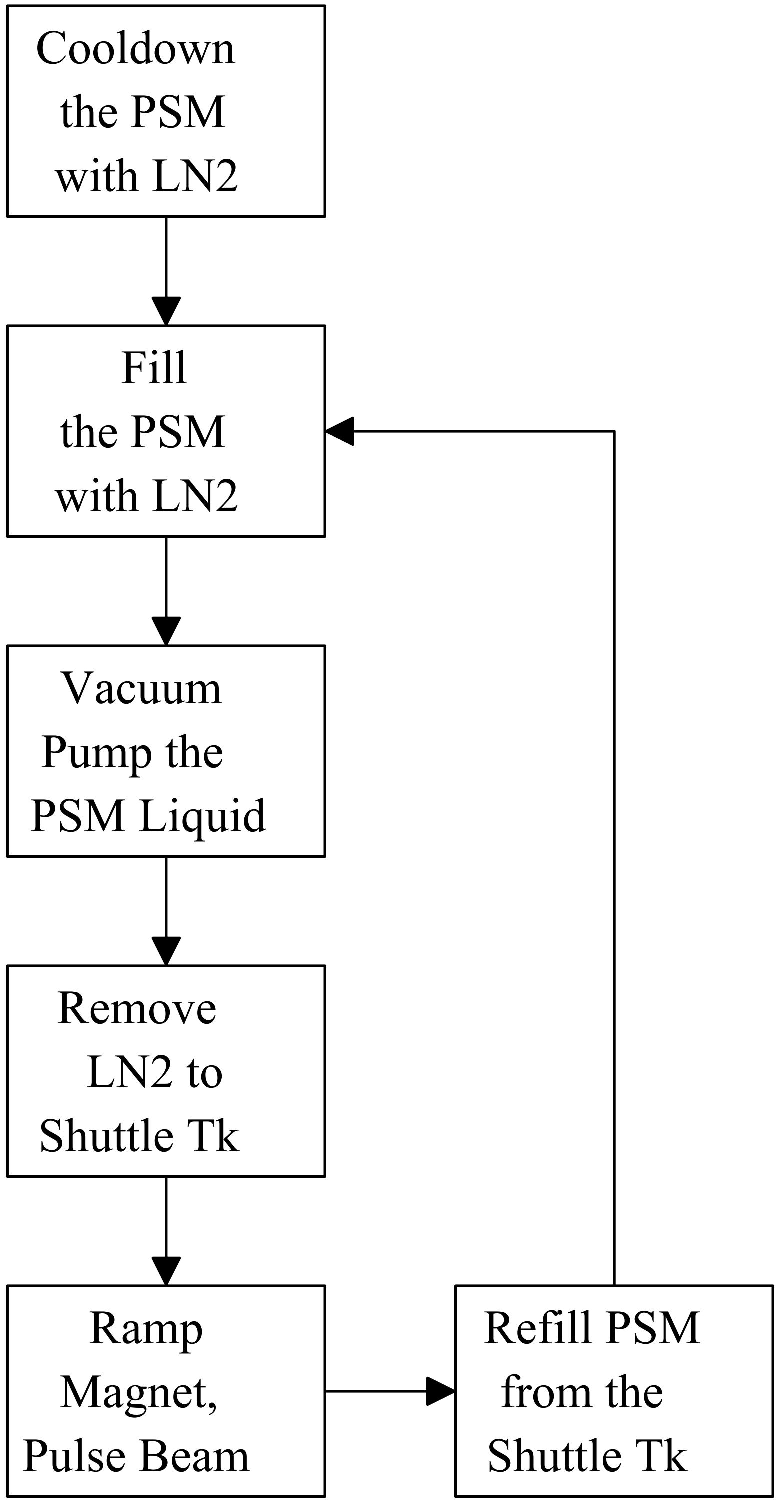
An Instrument and Valve summary listing supports the system's schematic drawings. This major element grouped listing describes the system item size and range parameters and particular requirements or attributes.

Although usually more useful to the system acquisition and installation, an Interconnection schematic and Line summary are included for completeness.

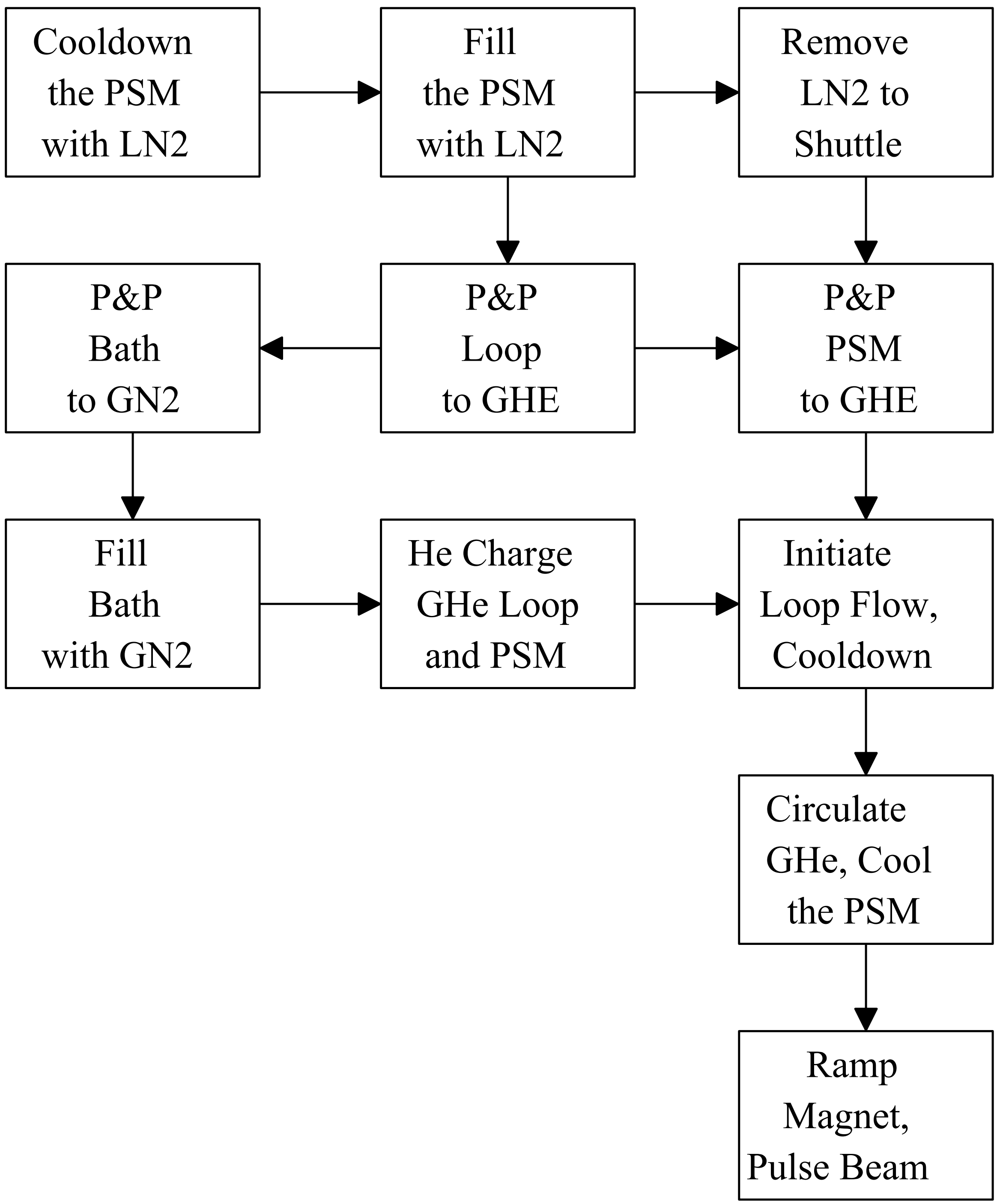
Mode 1: Liquid Nitrogen Direct Cooling



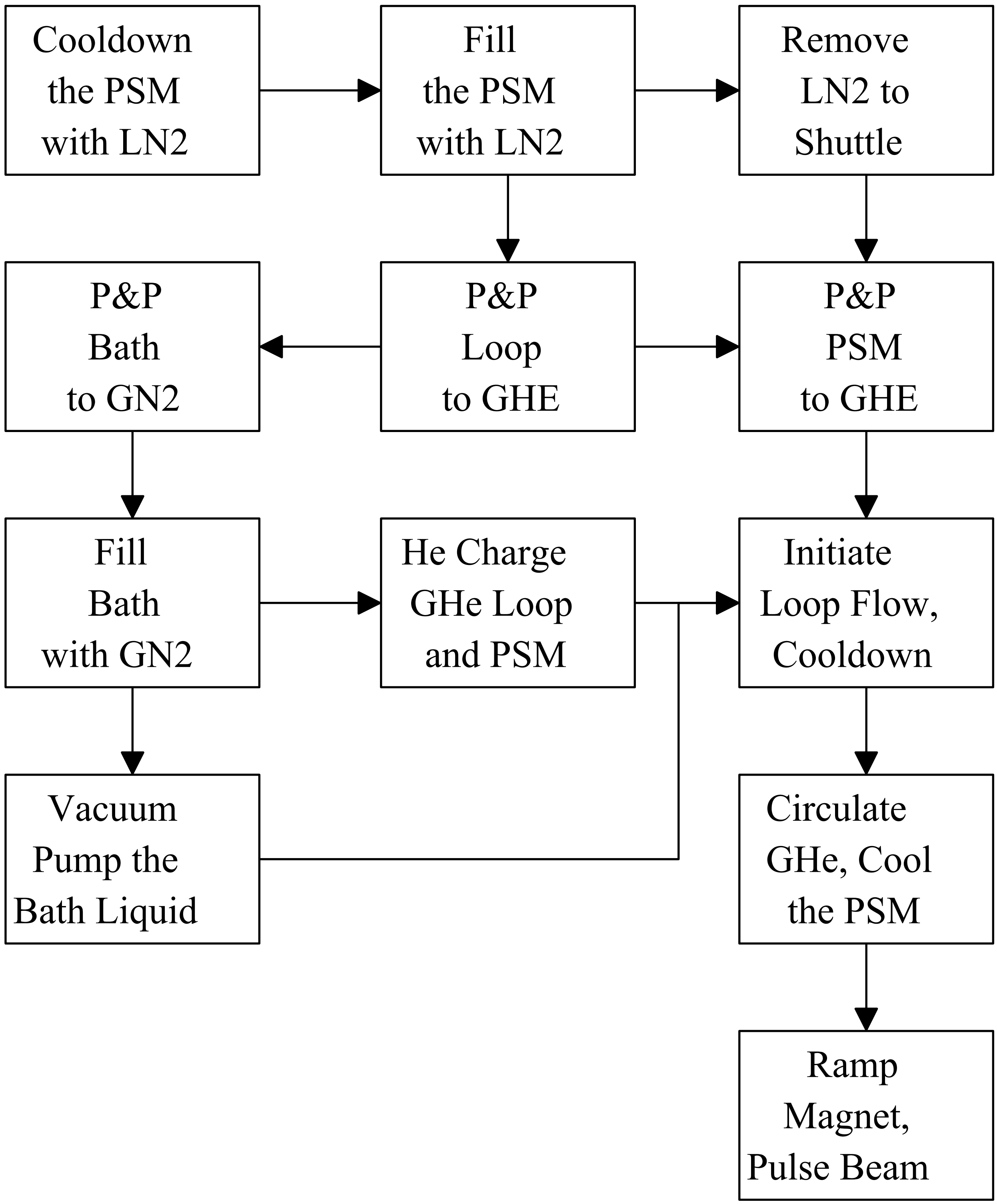
Mode 2: Pumped Liquid Nitrogen Direct Cooled



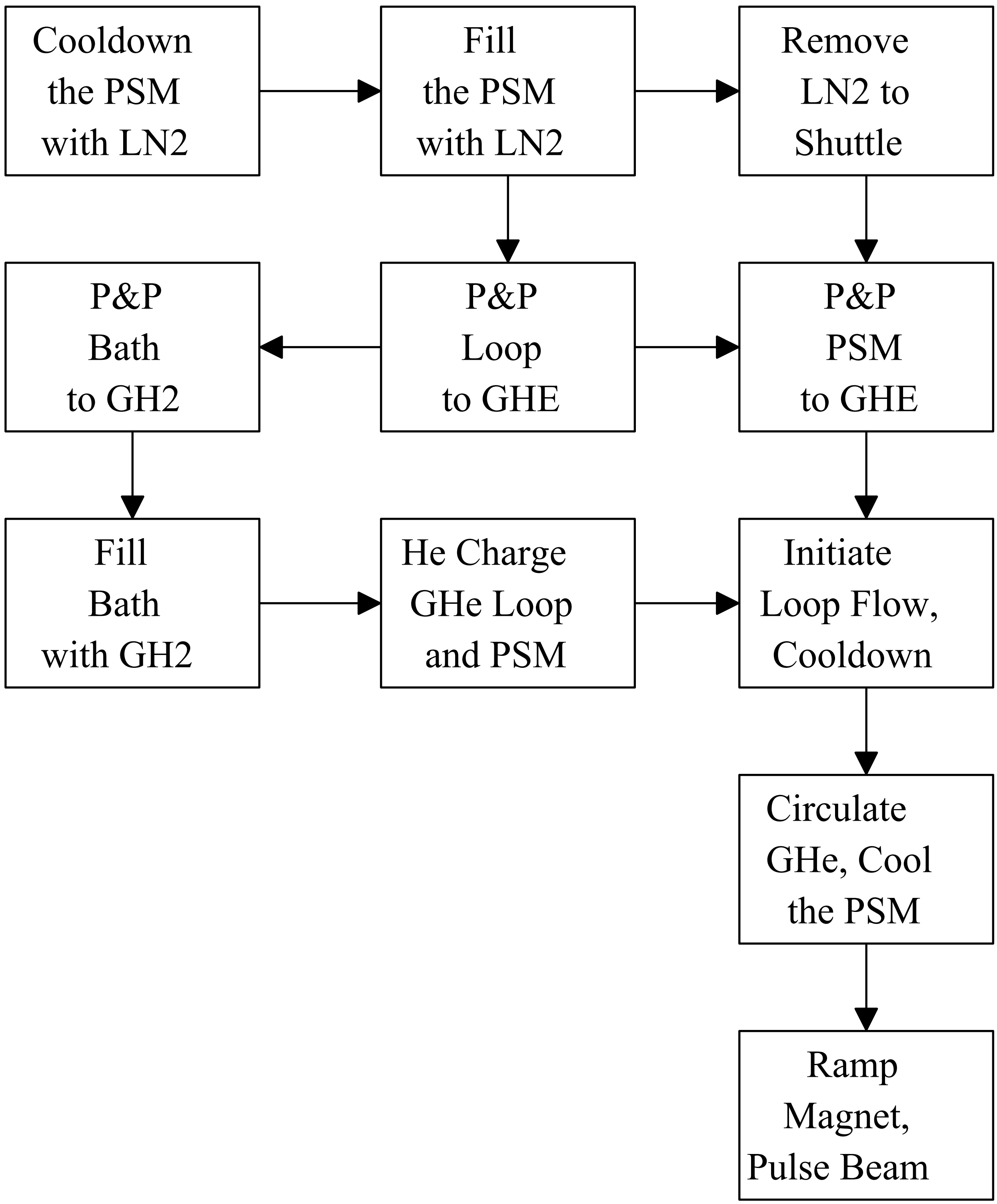
Mode 3: Liquid Nitrogen Cooled GHe



Mode 4: Pumped Liquid Nitrogen Cooled GHe



Mode 5: Liquid Hydrogen Cooled GHe



Cooldown: Pulsed Solenoid Magnet (PSM) Cooldown

1) The PSM is cooled from room temperature to ca. 100 K with a carefully temperature controlled flow of gaseous nitrogen (GN_2). It is important that the magnet not be temperature shocked in the cooldown process and steps to ensure a magnet cooldown that proceeds no faster than __ K/hr will dictate the process.

2) In general, all valves not specifically required to be open should be closed. Close and verify closed all of the system's process valves.

3) The instrumentation shutoff valves should, in every case, be open. The Instrument and Valve (I&V) summary is a convenient list to use for use in the valve set-up effort.

4) It is a good idea to put an annotated valve Open/Closed list in the logbook especially when operating for the first time.

5) There are two VJ jumpers in the system used for positive isolation. They are the "A" jumper, JPA514, and Jumper "B" JPB706. Jumper 'A" selects the liquid nitrogen or the liquid hydrogen dewar, one or the other but not both, as the source dewar for the Circulator/HE bath. Its purpose is to define the mode of operation in that regard at the outset.

6) Jumper "B" is used only to connect the Circulator/HE bath to the Process Vacuum pump. Its absence (withdrawal) assures that the Circulator/HE, when filled with liquid hydrogen can communicate only between the Liquid Hydrogen Dewar and the Vent Stack and no other part of the system.

7) The disposition of these jumpers is an important part of these Operating Procedures. Initially both the "A" and "B" jumpers are removed and the associated five bayonet ports properly capped with relieved, vented and gauged bayonet caps[1].

8) The previously commissioned 5,880-gallon liquid nitrogen (LN_2) dewar is assumed operationally full[2] and regulator controlled at a dewar pressure of 30

[1] The vent valve allows a test of line pressure before removing, the gauge reads the pressure, and the thermal relief guards against trapped volumes.

[2] Definition: Sufficiently full to proceed and arrangements to refill-as-required are in place.

psig, read PI607. The operating relief pressure should be set to 65 psig. All of the dewar equipment functions are assumed tested and available. Detailed LN_2 dewar operating instruction can be found in the manufacturer's literature.

9) The dewar should be inspected for any odd or unexpected sweating or ice and these problems should be properly addressed before proceeding.

10) The following valves should be tightly closed. Check the following CLOSED,

   a) MV602, LN_2 Dewar Withdrawal valve
   b) RV604, LN_2 Cooldown Diverter valve
   c) RV621, LN_2 Cooldown Liquid valve
   d) RV622, LN_2 Cooldown Gas valve
   e) RV100, PSM LN_2 Inlet valve
   f) MV617, LN_2 Keep Full isolation valve

11) Open the PSM Process Vac./Vent valve and complete a path through the process vacuum HE, HTR704, and MV703 to vent the PSM to atmosphere. OPEN the following,
   a) RV101, PSM Process Vac./Vent
   b) MV703, Process Vacuum Bypass

12) Start a PSM cryostat purge flow[3].
   a) MV602, OPEN (LN_2 Dewar Withdrawal valve)
   And CRACK
   b) RV622 (LN_2 Cooldown Gas valve)

13) Continue to slowly open the Cooldown Gas valve, RV622, and look for signs that a purge flow has been established. After some minutes the Cooldown Module ambient HE, HTR621, should begin to get cold. As soon as a purge flow is established the exhaust of the process vacuum pump will be flowing. Note that the detection of small flows may take careful observation at the vacuum pump exhaust.

14) If the ambient HE, HTR621is overwhelmed by flow, or ices up, the temperature at the Cooldown Module outlet, TI623, will significantly decrease.

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[3] Alternatively, the PSM Cryostat can be pumped and purged to GN_2. See those instructions later in these procedures in the GHe cooling mode initialization.

(Note that the 4 ton (4000 kg) PSM requires the removal of ca. 75j/g*4,000,000 = 300E6 joules. At an effective constant 10 kW cooling rate, it takes 300E6/1E4 = 300E2 seconds (8.33 hours, 220/8.33 = 26.4 K/h) to cool the PSM to nitrogen temperature.)

15) When the PSM is thoroughly purged, the cooldown can begin along the same flow path by CRACKING RV621, the LN_2 Cooldown Liquid valve, effectively bypassing the HE with some liquid. Set the Cooldown Module valves, RV621 and RV622 to provide a cooldown gas temperature of 250 k and use the inlet valve, RV100, to control the mass flow. NOTE that this is a continuously planned manned operation and SHOULD NOT be left unattended.

16) The power leads represent a large heat leak and will seriously impede the cooldown unless separately cooled. Crack RV619 to cool the leads. Since the power leads and the PSM flow in parallel from a single source and that source must be temperature controlled for PSM cooldown rate reasons, a total mass flow and the balance between the parallel paths will have determined by trial and error. (In the worst case conflict of requirements, it may be necessary to supply the power leads from a full 100 liter auxiliary dewar until liquid can be supplied directly to the PSM cryostat.)

17) This is a time consuming operation, be patient. Monitor the rate of magnet cooldown by reading the PSM temperature indicators and increase or decrease the cooldown gas temperature lead, ($T_{AVG} - T_{IN}$), and mass flow to control the cooldown rate. DO NOT exceed the maximum PSM cooldown rate: __ K/hr[4]. (In protracted continuous duty the ambient HE may ice up and make it difficult to maintain the desired cooldown temperature, i.e. get too cold. Should that occur, defrost the HE by cycling the HE sections and/or spray with water if the weather allows.)

18) The RO, Restricting Orifice sets an upper limit on the liquid flow as a safeguard against an accidental excessive cooling rate. Note that the series valve, RV621, can be used to further throttle the LN_2 flow from zero to the orifice flow limit.

19) When the PSM has been cooled to ca. 100 K, RV622, the Cooldown Gas valve, can be closed completely. RV604, the Cooldown Diverter valve can be fully opened against a throttled PSM inlet valve, RV100. When RV100 flow

[4] TBD.

control is established, RV621 and RV622 can be tightly closed to remove the Cooldown Module from the circuit.

20) Cool and then fill the PSM with LN_2 from the dewar. Secure the auxiliary cooling that may have been provided to the power leads and provide the cooling from the LN_2 source dewar. Open the LN_2 Keep Full isolation valve, MF617, to put the keep full valve online. (The Keep Full will automatically keep the end of the long LN_2 line wet, or Full even if the flow demand periodically goes to zero.)

21) After the cooldown has been initiated and to intercept the heat conducted down the power leads, initiate the LN2 lead intercept flow, OPEN, and adjust Rotameter flow as required
  a) RV619, OPEN
  b) RM627, SET to ____ standard liters/min[5].

22) Fill the PSM to __ in. H_20[6] and allow the magnet to come to thermal equilibrium as evidenced by its electrical resistance. When the PSM is properly full and cold, the rapid liquid nitrogen removal and reinstatement trials, shuttling can begin.

23) Set the liquid nitrogen fill valve, RV100, in AUTOMATIC to maintain the PSM liquid level.
  a) RV100, AUTOMATIC

24) The PSM can stay indefinitely in this condition so long as the liquid nitrogen dewar deliveries are maintained and the automatic controls continue to function.

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[5] The necessary value is to be experimentally determined.

[6] To be determined

Shuttling Liquid Nitrogen: PSM LN_2 Removal and Refilling

25) To avoid beam irradiation, the liquid nitrogen is removed after it has cooled the PSM, but before the magnet pulsing and beam exposure. The PSM can be immediately refilled thereafter.

a) Removal is accomplished by isolating the PSM, pressuring the gas above the liquid in the PSM, opening a connecting valve at the bottom of the PSM to a vented, vacuum insulated, tank called a shuttle tank and pushing the liquid from the PSM cryostat to the Shuttle Tank.

b) The liquid is returned to the vented PSM by isolating the Shuttle Tank, pressurizing the gas above the liquid in the shuttle tank and pushing the liquid through a pipe entry at the bottom of the shuttle tank back thru the connecting valve to the PSM.

26) The rapid cycle for this operation requires that special fast acting valves be operated electronically[7]. Beginning with the PSM full (ca. 300 liters) of liquid the empty and refill sequence for the LIQUID NITROGEN cooled, 5 T, mode is as follows,

a) Open the Process Vent valve, MV703 at the Process Vacuum Pump
   i) MV703, OPEN

b) Check RV102 CLOSED and then OPEN the Cold GN2 Pressure Source isolation valve
   i) MV103, OPEN

c) CLOSE or CHECK CLOSED all the PSM Cryostat Valves
   i) RV100, CLOSED
   ii) RV101, CLOSED
   iii) RV102, CLOSED
   iv) RV104, CLOSED
   v) RV105 , CLOSED
   vi) RV106, CLOSED

d) Check RV300 , the Shuttle Tank Vent, OPEN
   i) RV300, OPEN

[7] With, e.g., a PLC.

e) CLOSE or CHECK CLOSED Shuttle Tank Valve
   i) RV301, CLOSED

f) Read the PSM liquid level on LT109 and the PSM pressure on PTH111.
   i) LT109, READ
   ii) PTH111, READ

g) OPEN the Shuttle valve and OPEN RV102 to pressurize the PSM to ca. 2 atm. to REMOVE the liquid from the PSM.
   i) RV106, OPEN
   ii) RV102, OPEN

h) Close the pressurization valve, RV102, when the PSM liquid level falls to empty[8] AND its pressure falls to <1.2 atm.
   i) RV102, CLOSED

i) Read the Shuttle Tank level on LT302 and pressure on PT303.
   i) LT302, READ
   ii) PT303, READ

j) CLOSE Shuttle Valve, RV106, and Shuttle Tank vent, RV300. OPEN the Shuttle Tank pressurization loop, RV301, and pressurize to ca. 2 atm.
   i) RV106, CLOSED
   ii) RV300, CLOSED
   iii) RV301, OPEN

k) Provide a CRYOGENIC ENABLE signal to system command, signaling that the magnet is ready to pulse.

l) When signaled that the magnet and beam pulse cycles are complete, REFILL ENABLE, initiate the PSM nitrogen REFILL sequence.

m) OPEN the PSM Vent Valve, RV101 and Check MV703 OPEN.
   i) RV101, OPEN
   ii) MV703, OPEN

n) OPEN RV106 to REFILL the PSM.

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[8] Empty is to be defined.

i) RV106, OPEN

o) Close the Shuttle Tank Valve, RV106, and the Shuttle Tank pressurization valve, RV301, when the Shuttle Tank liquid nitrogen level falls to the minimum level[9].
   i) RV102, CLOSED
   ii) RV106, CLOSED

p) OPEN RV100 to top-off the PSM to the required level[10] as indicated on LT109, and then close RV100.
   i) RV100, OPEN
   ii) RV100, AUTOMATIC

q) The PSM is REFILLED and ready and awaits the command to REMOVE the liquid nitrogen for the next cycle.

27) Note that all the valves that require REMOVE/REFILL cycling are RV (Remote Valve, i.e., actuated remotely) and that all the necessary instrumentation is provided in transmitter form (notation is LT, PT). The operation of this cycle is intended as a fully automated and automatically executed once initiated by command.

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[9] The connecting pipe should always be under the shuttle tank liquid. A minimum Shuttle Tank level will be defined.

[10] Define the required level.

Magnet Pulsing with Liquid Nitrogen

28) Liquid Nitrogen cooled magnet pulsing to 5 T occurs, as described above, between the CRYOGENIC ENABLE and the REFILL ENABLE signals.

Magnet Pulsing with Pumped Liquid Nitrogen

29) Magnet pulsing to 10 T is similar to the magnet pulsing to 5 T with the exception that the liquid filling of the PSM is vacuum pumped and the PSM temperature reduced before removing the liquid for the magnet/beam pulse. The entire sequence will be presented to avoid the difficulties of providing an out-of-context alternative to the earlier procedure.

30) The rapid cycle for this operation requires that special fast acting valves be operated electronically. Beginning with the PSM full (ca. 300 liters) of liquid the empty and refill sequence for the PUMPED LIQUID NITROGEN cooled, 10 T, mode is as follows,

a) Open the Process Vent valve, MV703 at the Process Vacuum Pump
   i) MV703, OPEN

b) Check RV102 CLOSED and then OPEN the Cold GN2 Pressure Source isolation valve
   i) MV103, OPEN

c) CLOSE or CHECK CLOSED all the PSM Cryostat Valves
   i) RV100, CLOSED
   ii) RV102, CLOSED
   iii) RV104, CLOSED
   iv) RV105 , CLOSED
   v) RV106, CLOSED

d) START VP700, the process vacuum pump.
   i) VP700, START

e) Check RV101 OPEN and the PSM pressure is <1.2 atm. OPEN RV701 and start the PSM vacuum pump down.

f) Check RV300 , the Shuttle Tank Vent, OPEN

i) RV300, OPEN

g) CLOSE or CHECK CLOSED Shuttle Tank Valve
   i) RV301, CLOSED

h) Vacuum pump the PSM to 0.2 atm as read on PTL110.
   i) PTL110 to 0.2 atm.

i) Read the PSM liquid level on LT109 and the PSM pressure on PTL110, verify the pressure is <0.2.
   i) LT109, READ
   ii) PTL111, READ, Verify less than 0.2 atm

j) Close RV101 to isolate the vacuum pump from the PSM.
   i) RV101, CLOSED

k) OPEN RV102 to pressurize the PSM to ca. 2 atm. and then OPEN the Shuttle valve, RV106, and REMOVE the liquid from the PSM.
   i) RV102, OPEN, then
   ii) RV106, OPEN

l) Close the pressurization valve, RV102, when the PSM liquid level falls to empty[11] AND its pressure falls to <1.2 atm.
   i) RV102, CLOSED

m) Read the Shuttle Tank level on LT302 and pressure on PT303.
   i) LT302, READ
   ii) PT303, READ

n) CLOSE Shuttle Valve, RV106, and Shuttle Tank vent, RV300. OPEN the Shuttle Tank pressurization loop, RV301, and pressurize to ca. 2 atm.
   i) RV106, CLOSED
   ii) RV300, CLOSED
   iii) RV301, OPEN

o) Provide a CRYOGENIC ENABLE signal to system command, signaling that the magnet is ready to pulse.

[11] Define empty.

p) When signaled that the magnet and beam pulse cycles are complete, REFILL ENABLE, initiate the PSM nitrogen REFILL sequence.

q) OPEN the PSM Vent Valve, RV101 and Check MV703 OPEN.
   i) RV101, OPEN
   ii) MV703, OPEN

r) OPEN RV106 to REFILL the PSM.
   i) RV106, OPEN

s) Close the Shuttle Tank Valve, RV106, and the Shuttle Tank pressurization valve, RV301, when the Shuttle Tank liquid nitrogen level falls to the minimum level[12].
   i) RV106, CLOSED
   ii) RV102, CLOSED

t) OPEN the Shuttle Tank Vent, RV300, to blown it down.
   i) RV300, OPEN

u) OPEN RV100 to top-off the PSM to the required level[13] as indicated on LT109, and then close RV100.
   i) RV100, OPEN
   ii) RV100, AUTOMATIC

v) The PSM is REFILLED and ready and awaits the command to PUMP the liquid nitrogen for the next cycle.

31) Note that all the valves that require REMOVE/REFILL cycling are RV (Remote Valve, i.e., actuated remotely and rapid cycling) and that all the necessary instrumentation is provided in transmitter form (notation is LT, PT). The operation of this cycle is intended as fully automated and automatically executed in each direction: remove and refill, once initiated by command.

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[12] The connecting pipe should always be under the shuttle tank liquid. A minimum Shuttle Tank level will be defined.

[13] Define the required level.

Magnet Pulsing with Liquid Nitrogen Cooled GHe

32) Earlier in these procedures liquid nitrogen and pumped liquid nitrogen were used to directly cool the PSM. The primary coolant came in direct contact with the PSM. In this section, and for the rest of these procedures, the primary coolant will cool a gaseous helium (GHe) stream and the GHe stream will cool the PSM. The GHe loop is closed and continuously circulated by a centrifugal pump through cooling cools submerged in a bath of the primary coolant: liquid nitrogen or liquid hydrogen, to the PSM and back again.

33) All of the three (liquid nitrogen, pumped liquid nitrogen and liquid hydrogen) Cooled GHe Modes begin after the magnet has been cooled by liquid nitrogen as described in the section Cooldown: Pulsed Solenoid Magnet (PSM) Cooldown. This procedure will begin by assuming that the PSM is full of liquid nitrogen and operate from there. When ready to replace the liquid nitrogen direct cooling with GHe cooling, the liquid nitrogen will be removed and the cold PSM P&P to GHe.

34) To set up mode 3, the "A" jumper will be installed in the procedure below to connect the liquid nitrogen dewar to the Circulator/HE and must be secured properly in place. The "B" jumper will be set aside – DO NOT INSTALL the "B" jumper.

a) To install the "A" jumper check closed or CLOSE [FAILURE TO CHECK MV421 CLOSED and/or improperly removing the bayonet cap(s) can result in spilled LN_2 and cryogenic burns.]
   i) MV421, CLOSED
   ii) RV418, CLOSED
   iii) TEST for pressure and then remove the "A" jumper bayonet caps numbers 2 and 3.
   iv) JPA514, INSTALL and secure between the Nitrogen Dewar and the Circulator/HE inlet.

b) OPEN P&P isolation, and Pump and Purge the liquid nitrogen dewar-to-circulator bath inlet connecting line. This qualifies the connecting line tight.
   i) MV810, OPEN to access the P&P lines.
   ii) MV809, OPEN, evacuate to 100 microns, CLOSE
   iii) MV808, OPEN, purge to GN2, CLOSE

c) P&P the Circulator bath, then isolate P&P connection.
   i) RV418, OPEN
   ii) MV809, OPEN, evacuate to 100 microns, CLOSE
   iii) MV808, OPEN, purge to a few psig GN2, CLOSE
   iv) MV810, CLOSE

d) Use this opportunity to SET/CHECK the Circulator/HE bath pressure regulator setting. Pressurize from the P&P purge line as required.
   i) MV810, MV808, RV418, OPEN, Pressurize Cir./HE bath to 12 psig, CLOSE MV808
   ii) RG401, SET/CHECK to relieve at 10 psig.
   iii) MV401. OPEN to vent the Cir./HE to 2 psig, CLOSE
   iv) RV418, CLOSED
   v) MV810, CLOSE, to isolate the P&P

e) P&P the GHe cooling loops and connecting lines to GHe up to the closed RV104, RV105, as follows,
   i) MV807, OPEN to access the P&P lines.
   ii) MV805, OPEN pump to 100 microns, CLOSE
   iii) RG422, SET to few psig
   iv) MV423, OPEN to purge to GHe first time, CLOSE
   v) MV805, OPEN pump to 100 microns, CLOSE
   vi) MV423, OPEN to purge to GHe second time, CLOSE
   vii) MV807, CLOSE, to isolate the P&P

35) Remove the liquid nitrogen from the PSM as follows,

a) CLOSE or CHECK CLOSED all the PSM Cryostat Valves
   i) RV100, CLOSED
   ii) RV101, CLOSED
   iii) RV102, CLOSED
   iv) RV104, CLOSED
   v) RV105 , CLOSED
   vi) RV106, CLOSED

b) Check RV300 , the Shuttle Tank Vent, OPEN
   i) RV300, OPEN

c) CLOSE or CHECK CLOSED Shuttle Tank Pressurization Valve

i) RV301, CLOSED

d) Read the PSM liquid level on LT109 and the PSM pressure on PTH111.
   i) LT109, READ
   ii) PTH111, READ

e) OPEN the Shuttle valve and OPEN RV102 to pressurize the PSM to ca. 2 atm. to REMOVE the liquid from the PSM.
   i) RV106, OPEN
   ii) RV102, OPEN

f) Close the pressurization valve, RV102, when the PSM liquid level falls to empty[14] AND its pressure falls to <1.2 atm.
   i) RV102, CLOSED

g) Read the Shuttle Tank level on LT302 and pressure on PT303.
   i) LT302, READ
   ii) PT303, READ

h) CLOSE the Shuttle Valve, RV106.
   i) RV106, CLOSED

i) The liquid nitrogen is now boiling quietly away in the Shuttle Tank.

36) The PSM needs to be pumped and purged to GHe in preparation for operating the GHe loop circuit. Note that the Power Lead LN_2 cooling, once initiated by this procedure, must be continuously maintained to reduce the heat leak to the magnet.

a) To P&P the PSM CLOSE, check CLOSED,
   i) RV100, CLOSED
   ii) RV101, CLOSED
   iii) RV102, CLOSED
   iv) RV103, CLOSED
   v) RV104, CLOSED
   vi) RV105, CLOSED

[14] Define empty.

b) Pump the PSM with the Process Pump and purge it with the P&P purge line, as follows,
   i) RV101, Open to process pump, pump to 100 microns.

c) When the PSM has been pumped to 100 microns, P&P as follows,
   i) RV101, CLOSE to isolate the PSM
   ii) RV104, OPEN
   iii) MV423, OPEN to purge PSM to GHe first time, CLOSE
   iv) RV101, OPEN pump to 100 microns, CLOSE
   v) MV423, OPEN to purge PSM to GHe second time, CLOSE
   vi) RV101, OPEN pump to 100 microns, CLOSE
   vii) MV423, OPEN to purge PSM to GHe third time, CLOSE

d) Now that all the communicating GHe volumes: loops, lines and PSM, are purged to GHe, the Circulator bath can be filled with liquid nitrogen. Set up to liquid nitrogen fill the Circulator Bath,
   i) RV418, CLOSED, inlet valve
   ii) RV401, OPEN to vent the bath
   iii) HTR424, ACTIVATE[15] flow interlocked water-cooling if required.
   iv) JPA514, INSTALLED, previously installed.
   v) MV421, OPEN, connects to LN_2 source.

e) Crack the fill valve to cooldown the Cir./HE bath, then fill the bath.
   i) RV418, CRACK, cooldown Circulator bath, check vent T.
   ii) RV418, MODULATE to fill slowly, see LI/LT402 rate.
   iii) RV418, AUTOMATIC fill control.

f) When the Circulator HE is full and controlling in automatic at the set point, the Circulator loop and can be charged.
   i) RG422, SET POINT to 10 psig, read PI413.
   ii) RV104, OPEN
   iii) RV105, OPEN
   iv) MV423, OPEN, pressurize to 10 psig.
   v) RG422, INCREASE SET POINT to 12 atm, read PI413.
   vi) RG422, LOCK SET POINT

g) Check Tube Bank Pressure, to assure sufficient supply.

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[15] HTR24 is sized for the ca. 10 kW average load of Mode 5. It might be useful to exercise that function before the full effect is required.

i) PI414, READ, calculate margin.
ii) ORDER HP GHe tubes as may be required

37) Initiate the Circulator Pump flow
a) Check the connections and power source available to the centrifugal pump Variable Frequency Drive (VFD).
i) Operate VFD in strict accordance with mfg. Instructions.
ii) VFD410, CP409, START, slowly at first
iii) VFD410, CP409. INCREASE SPEED
iv) FT116, MONITOR GHe flow.
v) VFD, CP409, SET SPEED corresponding to 100g/s[16].

b) When the temperature sensors indicate the PSM is at the ENABLE temperature the CRYOGENIC ENABLE can be issued.
i) CRYOGENIC ENABLE

38) The magnet pulsing and the beam exposure will perturb the loop pressure and temperature momentarily, but should operate without manual intervention. Monitor especially, the GHe storage pressure.
a) A constantly falling pressure means gas is being lost from the system. Find the cause and repair the problem.
i) PI414, READ, monitor for GHe loses

[16] Assumes CP409 is compatible with liquid temperature operation.

Magnet Pulsing with Pumped Liquid Nitrogen Cooled GHe

39) Magnet pulsing with vacuum pumped Liquid Nitrogen Cooled GHe is very similar to the pumped Liquid Nitrogen Cooled GHe operation except for a few steps. In order to present an easily understood procedure the entire procedure will be presented with the modification in context.

40) All of the three (liquid nitrogen, pumped liquid nitrogen and liquid hydrogen) Cooled GHe Modes begin after the magnet has been cooled by liquid nitrogen as described in the section Cooldown: Pulsed Solenoid Magnet (PSM) Cooldown. This procedure will begin by assuming that the PSM is full of liquid nitrogen and operate from there. When ready to replace the liquid nitrogen direct cooling with GHe cooling, the liquid nitrogen will be removed and the cold PSM P&P to GHe.

41) To set up mode 4, the "A" jumper will be installed in the procedure below to connect the liquid nitrogen dewar to the Circulator/HE and must be secured properly in place. The "B" jumper will be in the procedure below to connect the Circulator/HE bath to the Process Vacuum Pump.

a) To install the "A" jumper check closed or CLOSE [FAILURE TO CHECK MV421 CLOSED and/or improperly removing the bayonet cap(s) can result in spilled LN_2 and cryogenic burns.]
   i) MV421, CLOSED
   ii) RV418, CLOSED
   iii) TEST for pressure and then remove the "A" jumper bayonet caps numbers 2 and 3.
   iv) JPA514, INSTALL and secure between the Nitrogen Dewar and the Circulator/HE inlet.

b) OPEN P&P isolation, and Pump and Purge the liquid nitrogen dewar-to-circulator bath inlet connecting line. This qualifies the connecting line tight.
   i) MV810, OPEN to access the P&P lines.
   ii) MV809, OPEN, evacuate to 100 microns, CLOSE
   iii) MV808, OPEN, purge to GN2, CLOSE

c) To install the "B" jumper, check CLOSED or CLOSE the Circulator /HE bath shutoff valve and the PSM connecting valve.
   i) MV420, CLOSED

ii) RV101, CLOSED
iii) RV701, CLOSED
iv) TEST for pressure and then remove the “B” bayonet caps.
v) JPB706, INSTALL and secure.

d) To test the line tightness, pump on it with the Process Vacuum Pump.
   i) VP700, OPERATE
   ii) RV701, OPEN, pump to 10 microns at VG705
   iii) RV701, CLOSED
   iv) MV709, OPEN, to vent the volume to atmosphere.

e) P&P the Circulator bath. Pump with the Process Vacuum Pump and purge with the P&P purge line. Then isolate P&P connection.
   i) RV418, OPEN
   ii) MV420, OPEN
   iii) RV701, OPEN, evacuate to 100 microns, CLOSE
   iv) MV808, OPEN, purge to a few psig GN2, CLOSE
   v) MV810, CLOSE

f) Use this opportunity to SET/CHECK the Circulator/HE bath pressure regulator setting. Pressurize from the P&P purge line as required.
   i) MV810, MV808, RV418, OPEN, Pressurize Cir./HE bath to 12 psig, CLOSE MV808
   ii) RG401, SET/CHECK to relieve at 10 psig.
   iii) MV401. OPEN to vent the Cir./HE to 2 psig, CLOSE
   iv) RV418, CLOSE
   v) MV810, CLOSE, to isolate the P&P

g) P&P the GHe cooling loops and connecting lines to GHe up to the closed RV104, RV105, as follows,
   i) MV807, OPEN to access the P&P lines.
   ii) MV805, OPEN pump to 100 microns, CLOSE
   iii) RG422, SET to few psig
   iv) MV423, OPEN to purge to GHe first time, CLOSE
   v) MV805, OPEN pump to 100 microns, CLOSE
   vi) MV423, OPEN to purge to GHe second time, CLOSE
   vii) MV807, CLOSE, to isolate the P&P

42) Remove the liquid nitrogen from the PSM as follows,

a) CLOSE or CHECK CLOSED all the PSM Cryostat Valves
   i) RV100, CLOSED
   ii) RV101, CLOSED
   iii) RV102, CLOSED
   iv) RV104, CLOSED
   v) RV105 , CLOSED
   vi) RV106, CLOSED

b) Check RV300 , the Shuttle Tank Vent, OPEN
   i) RV300, OPEN

c) CLOSE or CHECK CLOSED Shuttle Tank Pressurization Valve
   i) RV301, CLOSED

d) Read the PSM liquid level on LT109 and the PSM pressure on PTH111.
   i) LT109, READ
   ii) PTH111, READ

e) OPEN the Shuttle valve and OPEN RV102 to pressurize the PSM to ca. 2 atm. to REMOVE the liquid from the PSM.
   i) RV106, OPEN
   ii) RV102, OPEN

f) Close the pressurization valve, RV102, when the PSM liquid level falls to empty[17] AND its pressure falls to <1.2 atm.
   i) RV102, CLOSED

g) Read the Shuttle Tank level on LT302 and pressure on PT303.
   i) LT302, READ
   ii) PT303, READ

h) CLOSE the Shuttle Valve, RV106.
   i) RV106, CLOSED

i) The liquid nitrogen is now boiling quietly away in the Shuttle Tank.

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17 Define empty.

43) The PSM needs to be pumped and purged to GHe in preparation for operating the GHe loop circuit. Note that the Power Lead LN_2 cooling, once initiated by this procedure, must be continuously maintained to reduce the heat leak to the magnet.

a) To P&P the PSM CLOSE, check CLOSED,
   i) RV100, CLOSED
   ii) RV101, CLOSED
   iii) RV102, CLOSED
   iv) RV103, CLOSED
   v) RV104, CLOSED
   vi) RV105, CLOSED

b) Pump the PSM with the Process Pump and purge it with the P&P purge line, as follows,
   i) RV101, Open to process pump, pump to 100 microns.

c) When the PSM has been pumped to 100 microns, P&P as follows,
   i) RV101, CLOSE to isolate the PSM
   ii) RV104, OPEN
   iii) MV423, OPEN to purge PSM to GHe first time, CLOSE
   iv) RV101, OPEN pump to 100 microns, CLOSE
   v) MV423, OPEN to purge PSM to GHe second time, CLOSE
   vi) RV101, OPEN pump to 100 microns, CLOSE
   vii) MV423, OPEN to purge PSM to GHe third time, CLOSE

d) Now that all the communicating GHe volumes: loops, lines and PSM, are purged to GHe, the Circulator bath can be filled with liquid nitrogen. Set up to liquid nitrogen fill the Circulator Bath,
   i) RV418, CLOSED, inlet valve
   ii) RV401, OPEN to vent the bath
   iii) HTR424, ACTIVATE[18] flow interlocked water-cooling if required.
   iv) JPA514, INSTALLED, previously installed.
   v) MV421, OPEN, connects to LN_2 source.

e) Crack the fill valve to cooldown the Cir./HE bath, then fill the bath.
   i) RV418, CRACK, cooldown Circulator bath, check vent T.

[18] HTR24 is sized for the ca. 10 kW average load of Mode 5. It might be useful to exercise that function before the full effect is required.

ii) RV418, MODULATE to fill slowly, see LI/LT402 rate.
iii) RV418, AUTOMATIC fill control.

f) When the Circulator HE is full and controlling in automatic at the set point, the Circulator loop and can be charged.
   i) RG422, SET POINT to 10 psig, read PI413.
   ii) RV104, OPEN
   iii) RV105, OPEN
   iv) MV423, OPEN, pressurize to 10 psig.
   v) RG422, INCREASE SET POINT to 12 atm, read PI413.
   vi) RG422, LOCK SET POINT

g) Check Tube Bank Pressure, to assure sufficient supply.
   i) PI414, READ, calculate margin.
   ii) ORDER HP GHe tubes as may be required

44) Initiate the Circulator Pump flow

a) Check the connections and power source available to the centrifugal pump Variable Frequency Drive (VFD).
   i) Operate VFD in strict accordance with mfg. Instructions.
   ii) VFD410, CP409, START, slowly at first
   iii) VFD410, CP409. INCREASE SPEED
   iv) FT116, MONITOR GHe flow.
   v) VFD, CP409, SET SPEED corresponding to 100g/s[19].

45) Pump the Circulator bath 0.2 atm to lower the liquid nitrogen temperature with the Process Vacuum Pump. Note that each time the PSM returns to the pumped liquid nitrogen ENABLE temperature the magnet/beam can be pulsed.

a) To connect the PVP to the Circ. HE bath,
   i) MV420, OPEN
   ii) MV709, CLOSE
   iii) RV701, OPEN pump to 0.2 atm on PT403.
   iv) RV701, AUTOMATIC to control bath pressure at 0.2 atm on PT403

b) When the temperature sensors indicate the PSM is at the ENABLE temperature the CRYOGENIC ENABLE can be issued.

[19] Assumes CP409 is compatible with liquid temperature operation.

i) CRYOGENIC ENABLE

46) The magnet pulsing and the beam exposure will perturb the loop pressure and temperature momentarily, but the system should allow continuous operation to the maximum cycle time without manual intervention. Monitor especially, the GHe storage pressure and the cumulative icing condition of HTR704.

a) A constantly falling GHe loop pressure means gas is being lost from the system, e.g., through a relief valve weeping at peak pressure. Find the cause and repair the problem.
   i) PI414, READ, monitor for GHe long term loses, repair as req'd.

b) In continuous duty and especially high humidity and/or cold weather the ambient vaporizer will ice up and lose some of its effectiveness over time, even if significantly oversized. Monitor the temperature indicator at vacuum pump inlet and assure that it stays above 0˚C. Reconfigure as a dual/selected ambient vaporizer or otherwise enhance the performance as may be necessary.
   i) TI710, MONITOR, for abnormally cold suction temperature.

Magnet Pulsing with Liquid Hydrogen Cooled GHe

47) ***Note that this procedure will use liquid hydrogen as a coolant and vent it to the Vent Stack. The area access must be controlled and posted LIQUID HYDROGEN AREA whenever liquid hydrogen is in the area. All signage required by NFPA 50 B and the BNL safety requirements must be met before proceeding. Make a logbook entry when the appropriate signage is in placed and have that entry endorsed by the appropriate safety department representative before introducing any liquid hydrogen into the area.***

48) The previously commissioned 14,000-gallon liquid hydrogen (LH_2) dewar is assumed operationally full[20] and regulator controlled at a dewar pressure of 30 psig, read PT/PI507. The operating relief pressure should be set to 65 psig. All of the dewar equipment functions are assumed tested and fully available. Detailed LH_2 dewar operating instruction can be found in the manufacturer's literature or will be separately made available.

49) All of the three (liquid nitrogen, pumped liquid nitrogen and liquid hydrogen) Cooled GHe Modes begin after the magnet has been cooled by liquid nitrogen as described in the section Cooldown: Pulsed Solenoid Magnet (PSM) Cooldown. This procedure will begin by assuming that the PSM is full of liquid nitrogen and operate from there. When ready to replace the liquid nitrogen direct cooling with GHe cooling, the liquid nitrogen will be removed and the cold PSM P&P to GHe.

50) To set up mode 5, the “A” jumper will be installed in the procedure below to connect the liquid hydrogen dewar to the Circulator/HE and must be secured properly in place. The “B” jumper will be set aside – DO NOT INSTALL the “B” jumper.

a) To install the “A” jumper check CLOSED or CLOSE [FAILURE TO CHECK MV501, RV502 CLOSED and/or improperly removing the bayonet cap(s) can result in spilled LH_2 and cryogenic burns.]
   i) MV501, CLOSED
   ii) RV502, CLOSED
   iii) RV418, CLOSED

[20] Definition: Sufficiently full to proceed and arrangements to refill-as-required are in place.

iv) TEST for pressure and then remove the "A" jumper bayonet caps numbers 1 and 2.
v) JPA514, INSTALL and secure between the Hydrogen Dewar and the Circulator/HE inlet.

51) Pump and Purge the Hydrogen Dewar to Circulator bath inlet connection line to GN2.

a) OPEN P&P isolation, and Pump and Purge the liquid hydrogen dewar-to-circulator bath inlet connecting line to GN2. This qualifies the connecting line tight.
   i) MV504, MV807, MV813, CLOSED and LOCKED, secure all other P&P operations system wide.
   ii) MV810, OPEN to access the P&P lines.
   iii) MV809, OPEN, evacuate to 100 microns, CLOSE
   iv) MV808, OPEN, purge to GN2, CLOSE

b) P&P the Circulator bath to GN2, then isolate P&P connection.
   i) RV418, OPEN
   ii) MV809, OPEN, evacuate to 100 microns, CLOSE
   iii) MV808, OPEN, purge to a few psig GN2, CLOSE
   iv) MV810, CLOSE

c) Use this opportunity to SET/CHECK the Circulator/HE bath pressure regulator setting. Pressurize from the P&P GN2 purge line as required.
   i) MV810, MV808, RV418, OPEN, Pressurize Cir./HE bath to 12 psig, CLOSE MV808
   ii) RG401, SET/CHECK to relieve at 10 psig.
   iii) MV401. OPEN to vent the Cir./HE to 2 psig, CLOSE
   iv) RV418, CLOSED
   v) MV810, CLOSE, to isolate the P&P

52) Pump and purge the Hydrogen Dewar to Circulator bath and inlet connection line to GH2.

a) P&P the Circulator bath to GH2, then isolate P&P connection.
   i) RV418, OPEN to connect bath to the inlet line
   ii) MV810, OPEN, access to the P&P manifolds
   iii) MV809, OPEN, evacuate line/bath to 100 microns, CLOSE

iv) MV501, CLOSED, check
v) RV502, OPEN, access to the Hydrogen Dewar
vi) MV501, CRACK, purge line/bath to a few psig GH2, CLOSE
vii) MV810, CLOSE and LOCK to isolate the Hydrogen circuit from the P&P manifold.

b) P&P the GHe cooling loops and connecting lines to GHe up to the closed RV104, RV105. Unlock, as required, the P&P manifold access valves except for MV810. Do not unlock MV810.
i) RV140, RV105, CLOSED, check
ii) MV807, OPEN to access the P&P lines.
iii) MV805, OPEN pump to 100 microns, CLOSE
iv) RG422, SET to few psig
v) MV423, OPEN to purge to GHe first time, CLOSE
vi) MV805, OPEN pump to 100 microns, CLOSE
vii) MV423, OPEN to purge to GHe second time, CLOSE
viii) MV807, CLOSE, to isolate the P&P

53) Remove the liquid nitrogen from the PSM as follows,

a) CLOSE or CHECK CLOSED all the PSM Cryostat Valves
i) RV100, CLOSED
ii) RV101, CLOSED
iii) RV102, CLOSED
iv) RV104, CLOSED
v) RV105 , CLOSED
vi) RV106, CLOSED

b) Check RV300 , the Shuttle Tank Vent, OPEN
i) RV300, OPEN

c) CLOSE or CHECK CLOSED Shuttle Tank Pressurization Valve
i) RV301, CLOSED

d) Read the PSM liquid level on LT109 and the PSM pressure on PTH111.
i) LT109, READ
ii) PTH111, READ

e) OPEN the Shuttle valve and OPEN RV102 to pressurize the PSM to ca. 2 atm. to REMOVE the liquid from the PSM.
   i) RV106, OPEN
   ii) RV102, OPEN

f) Close the pressurization valve, RV102, when the PSM liquid level falls to empty[21] AND its pressure falls to <1.2 atm.
   i) RV102, CLOSED

g) Read the Shuttle Tank level on LT302 and pressure on PT303.
   i) LT302, READ
   ii) PT303, READ

h) CLOSE the Shuttle Valve, RV106.
   i) RV106, CLOSED

i) The liquid nitrogen is now boiling quietly away in the Shuttle Tank.

54) The PSM needs to be pumped and purged to GHe in preparation for operating the GHe loop circuit. Note that the Power Lead LN_2 cooling, once initiated by this procedure, must be continuously maintained to reduce the heat leak to the magnet.

a) To P&P the PSM CLOSE, check CLOSED,
   i) RV100, CLOSED
   ii) RV101, CLOSED
   iii) RV102, CLOSED
   iv) RV103, CLOSED
   v) RV104, CLOSED
   vi) RV105, CLOSED

b) Pump the PSM with the Process Pump and purge it with the P&P purge line, as follows,
   i) RV101, Open to process pump, pump to 100 microns.

c) When the PSM has been pumped to 100 microns, P&P as follows,
   i) RV101, CLOSE to isolate the PSM
   ii) RV104, OPEN

21 Define empty.

iii) MV423, OPEN to purge PSM to GHe first time, CLOSE
iv) RV101, OPEN pump to 100 microns, CLOSE
v) MV423, OPEN to purge PSM to GHe second time, CLOSE
vi) RV101, OPEN pump to 100 microns, CLOSE
vii) MV423, OPEN to purge PSM to GHe third time, CLOSE

55) Now that all the communicating GHe volumes: loops, lines and PSM, are purged to GHe, the Circulator bath can be filled with liquid hydrogen. Set up to liquid hydrogen fill the Circulator Bath,
i) RV418, CLOSED, inlet valve
ii) RV401, OPEN to vent the bath
iii) HTR424, ACTIVATE[22] flow interlocked water-cooling if required.
iv) JPA514, INSTALLED, previously installed, double check that it is secure.
v) MV501, CLOSED, check
vi) RV502, OPEN, provides access to LH_2 dewar
vii) MV501, CRACK, open in a restricted way

b) Crack the fill valve to cooldown the Cir./HE bath, then fill the bath. Slowly open MV501 until it is fully open as required.
i) NV501, CRACKED, will have to be opened slowly
ii) RV418, CRACK, cooldown Circulator bath, check vent T.
iii) RV418, MODULATE to fill slowly, see LI/LT402 rate.
iv) RV418, AUTOMATIC fill control at half full.
v) RV418, AUTOMATIC fill control at three quarters full.
vi) RV418, AUTOMATIC fill control at full.

c) When the Circulator HE bath is full of liquid hydrogen and controlling the bath level in automatic at the set point, the Circulator Loop and can be charged with GHe.
i) RG422, SET POINT to 10 psig, read PI413.
ii) RV104, OPEN
iii) RV105, OPEN
iv) MV423, OPEN, pressurize to 10 psig.
v) RG422, INCREASE SET POINT, slowly, to 12 atm, read PI413.
vi) RG422, LOCK SET POINT at 12 atm.

[22] HTR24 is sized for the ca. 10 kW average load of Mode 5. It might be useful to exercise that function before the full effect is required.

d) Check Tube Bank Pressures and capacity, to assure sufficient supply.
   i) PI414, READ, calculate margin.
   ii) ORDER HP GHe tubes as may be required

56) Initiate the Circulator Pump flow
   a) Check the connections and power source available to the centrifugal pump Variable Frequency Drive (VFD).
      i) Operate VFD in strict accordance with mfg. Instructions.
      ii) VFD410, CP409, START, slowly at first
      iii) VFD410, CP409. INCREASE SPEED, slowly
      iv) FT116, MONITOR GHe flow.
      v) VFD, CP409, SET SPEED corresponding to 100g/s[23].

   b) When the temperature sensors indicate the PSM is at the ENABLE temperature the CRYOGENIC ENABLE can be issued.
      i) CRYOGENIC ENABLE

57) The magnet pulsing and the beam exposure will perturb the loop pressure and temperature momentarily, but should operate without manual intervention. Monitor especially, the GHe storage pressure.
   a) A constantly falling pressure means gas is being lost from the system. Find the cause and repair the problem.
      i) PI414, READ, monitor for GHe loses

58) The magnet peak currents should be approached slowly so that the system operation can be monitored and fine-tuned as may be required.
   a) Monitor the following items/parameters.
      i) RV418, Valve position, operation, i.e., sufficient capacity.
      ii) Liquid hydrogen dewar pressure.
      iii) Liquid hydrogen standby consumption rate
      iv) Liquid hydrogen operating consumption rate
      v) TI411, value.
      vi) TI411, LT402 relationship
      vii) HTR424 inlet/outlet temperatures as a F{magnet energy}.
      viii) Others?

[23] Assumes CP409 is compatible with liquid temperature operation.

Shutdown and Securing the System

59) The previous sections presented operating procedures for operation the cryogenic system. When the magnet work has been completed for the day, the system must be put in a STANDBY mode for overnight or weekend periods. When the magnet work is done for moment and the off period will be more than a few days the system should be SHUTDOWN and secured, i.e., the system safety exposure reduced to a minimum.

60) The STANDBY mode will keep the coolant, liquid nitrogen or liquid hydrogen, in the operating vessel. In the case of direct cooling the operating vessel is the PSM, and in the case of GHe cooling is the Circulator/HE bath.
  a) Standby Maintained
    i) When the experiment's operation takes a brief pause the operating vessel levels can be maintained by automatic equipment. Interlocks provided on especially the liquid hydrogen system will close RV502, the liquid hydrogen dewar source valve, in such a way that it will stay closed and must be physically reset to resume cooling. After some experience with the system, brief pause may come to mean standby-maintained overnight.
  b) Standby Attrition
    i) When the experiment's operation takes a longer pause the operating vessel levels can be allowed to boil away to vents and the automatic equipment, except for the safety interlocks shutdown. The Cir./HE filled with liquid hydrogen will take ca. 3 days @ a 100 W standby load to go dry and the PSM cryostat filled with liquid nitrogen will take ca. one day (24 hours) @ a 500 W heat load to go dry heat load.

61) The SHUTDOWN mode will secure the coolant, liquid nitrogen or liquid hydrogen, feed lines to the operating vessels, dry up all the lines and leave the liquid nitrogen and liquid hydrogen dewars secured. There are no means to return the liquid inventory of the operating vessel to the source dewar in any of the operating modes. The operating vessels will be allowed to boil-off at their natural evaporation rates.
  a) Once the source is isolated the liquid nitrogen will dry up in the PSM cryostat in about a day without intervention.
    i) If required heat can be safely added to cryostat by eliminating the power lead intercepts and by partially spoiling the insulating vacuum to hurry

the dry up process significantly. Additionally some heat can be introduced by a current flow through the magnet itself.

b) Once the source is isolated the liquid hydrogen will dry up in the Cir./HE in about three days without intervention.
   i) If required heat can be safely added to Cir./HE by circulating GHe and the associated pump loses to GHe HE and/or by partially spoiling the insulating vacuum to hurry the dry up process significantly.
c) The liquid hydrogen dewar cant be emptied of liquid at a rate greater of 10's of kW, i.e., 48 hours to dry if full at 14,000 gallons and a 10 kW load, by operating its already present pressure building coil. There is no convenient means to significantly increase that shutdown rate.

Last page of the Operating procedure

Appendix 1

Use-certification of Equipment

1) Liquid Nitrogen Dewar
   a) Current Parameters
      i) Condition: Excellent, of recent manufacture (19__).
      ii) MAWP = 250 psig, ASME coded? (couldn't find a stamp)
      iii) Current relief setting: 70 psig
      iv) Current operating set pressure: 40 psig
   b) Use-certification Procedure
      i) Inspect carefully, pressure test/pump as may be required, to assure that the equipment is serviceable.
      ii) Remove rusted equipment, upgrade for outdoor operation. Scrape, sand and prime vacuum vessel scratches/abrasions, accessories and paint as maybe required.
      iii) Vacuum pump the insulating vacuum to <100 microns and until the vacuum tank will hold 100 microns warm for a week or more. Consult the manufacturer's instructions in this regard and follow the most stringent of these requirements.
      iv) Vacuum pump the inner vessel to <100 microns and until the inner vessel will hold 100 microns warm for a week or more. Dismount or plug leaking valves and accessories to qualify the vessel and then properly repair the leaks. Back fill with dry GN_2.
      v) Qualify the LN2 dewar at the storage site by pneumatic pressurization to 125% of the relief pressure: 1.25*(70+14.7) –14.7 =91.175 psig. (Relief pressure could be set lower.)
      vi) Install and test the installed dewar to the relief pressure: 70 psig to qualify the installation and demonstrate the relief function in situ.

Appendix 2

2) Liquid Hydrogen Dewar
   a) Current Parameters
      i) Condition: Neglected, the vacuum tank badly needs a sandblasting, primer and final paint job. Insulating vacuum 400 microns after n years of non-use.
      ii) MAWP = 140 psig, ASME coded (Fab. 1963)
      iii) Current relief setting: 140 psig
      iv) Current operating set pressure: unknown psig
   b) Use-certification Procedure
      i) Inspect carefully, pressure test/pump as may be required, to assure that the tank is serviceable.
      ii) Disassemble all the valves, replace the trim and valve packings (with original parts if possible), repair to as new condition, test seating and leakage and reinstall.
      iii) Sandblast, prime and paint the vacuum tank.
      iv) Vacuum pump the insulating vacuum to <100 microns and until the vacuum tank will hold 100 microns warm for a week or more. Consult the manufacturer's instructions in this regard and follow the most stringent of these requirements.
      v) Purge the inner vessel to dry GN_2 and then vacuum pump the inner vessel to <100 microns and until the inner vessel will hold 100 microns warm for a week or more. Dismount or plug leaking valves and accessories to qualify the vessel and then properly repair the leaks. Back fill with dry GN_2.
      vi) Qualify the LH_2 dewar at the storage site by pneumatic pressurization to 125% of the required relief pressure: $1.25*(70+14.7) - 14.7 = 91.175$ psig. (Note that the new relief set pressure is lower than the MAWP.)
      vii) Install and test the installed LH_2 dewar to the new relief pressure: 70 psig to qualify the installation and demonstrate the relief function in situ.

Appendix 3

3) Circulator/Heat Exchanger
   a) Current Parameters
      i) Condition: Good, of recent manufacture (1992), vacuum tank stored outside and the accessories are rusted
      ii) MAWP = 150 psig, ASME coded (Drawings say yes, couldn't find the ASME stamp on the equipment (?))
      iii) Current relief setting: 135 psig
      iv) Current operating set pressure: unknown psig
   b) Use-certification Procedure
      i) Inspect carefully, pressure test/pump as may be required, to assure that the equipment is serviceable.
      ii) Make the necessary internal piping modification and leak and pressure test. See addendum; Circulator/HE modifications.
      iii) Remove rusted equipment, upgrade for outdoor operation. Prime vacuum vessel, accessories and paint as maybe required.
      iv) Vacuum pump the insulating vacuum to <100 microns and until the vacuum tank will hold 100 microns warm for a week or more. Consult the manufacturer's instructions in this regard and follow the most stringent of these requirements.
      v) Purge the inner vessel to dry GN_2 and then vacuum pump the inner vessel to <100 microns and until the inner vessel will hold 100 microns warm for a week or more. Dismount or plug leaking valves and accessories to qualify the vessel and then properly repair the leaks. Back fill with dry GN_2.
      vi) Qualify the Circulator/HE vessel at the storage site by pneumatic pressurization to 125% of the required relief pressure: 1.25*(70+14.7) – 14.7 =91.175 psig. (Note that the new relief set pressure is lower than the MAWP.)
      vii) Install and test the installed LH_2 dewar to the new relief pressure: 70 psig to qualify the installation and demonstrate the relief function in situ.
      viii) Qualify the HE piping at the storage site by pneumatic pressurization to 125% of the required MAWP: 1.25*(200) –14.7 = 250 psig. (Note that the new relief set pressure equal to the HE piping MAWP.)
      ix) Install and test the installed LH_2 dewar to the new relief pressure: 200 psig to qualify the installation and demonstrate the relief function in situ.

Appendix 4

4) Pulsed Solenoid Magnet Cryostat
   a) Current Parameters
      i) Newly fabricated. Factory tested.
      ii) MAWP = 250 psig, not ASME coded.
      iii) Current relief setting: 250 psig
      iv) Current operating set pressure: 200 psig
   b) Use-certification Procedure
      i) Inspect carefully, pressure test/pump up to the fabrication blanks as required assuring that the equipment is fully serviceable.
      ii) Make the necessary piping connections and leak and pressure test.
      iii) Vacuum pump the insulating vacuum to <10 microns and until the vacuum tank will hold 20 microns warm for a week or more. Consult the manufacturer's instructions in this regard and follow the most stringent of these requirements.
      iv) Purge the inner vessel to dry GN_2 and then vacuum pump the inner vessel to <100 microns and until the inner vessel will hold 100 microns warm for a week or more. Dismount or plug leaking valves and accessories to qualify the vessel and then properly repair the leaks. Back fill with dry GN_2.
      v) Qualify the PSM Cryostat vessel at installation by pneumatic pressurization to 125% of the required relief pressure: 1.25*(250+14.7) –14.7 = 316 psig. (Note that the relief set pressure is equal to the MAWP.)
      vi) Install and test the installed LH_2 dewar to the relief pressure: 250 psig to qualify the installation and demonstrate the relief function in situ. (Be careful not to include the HE in this test, i.e., provide positive isolation.)

Appendix 5

5) Circulator/HE modifications

a) The Circulator/HE was meant to subcool a liquid He stream and consequently has connections between the cooling coils (heat exchanger, HE) and the cooling bath vessel. The new application requires a bath coolant (LN2, LH2) different from the circulated GHe and a set of piping modification are required to positively separate the bath and cooling loop functions.

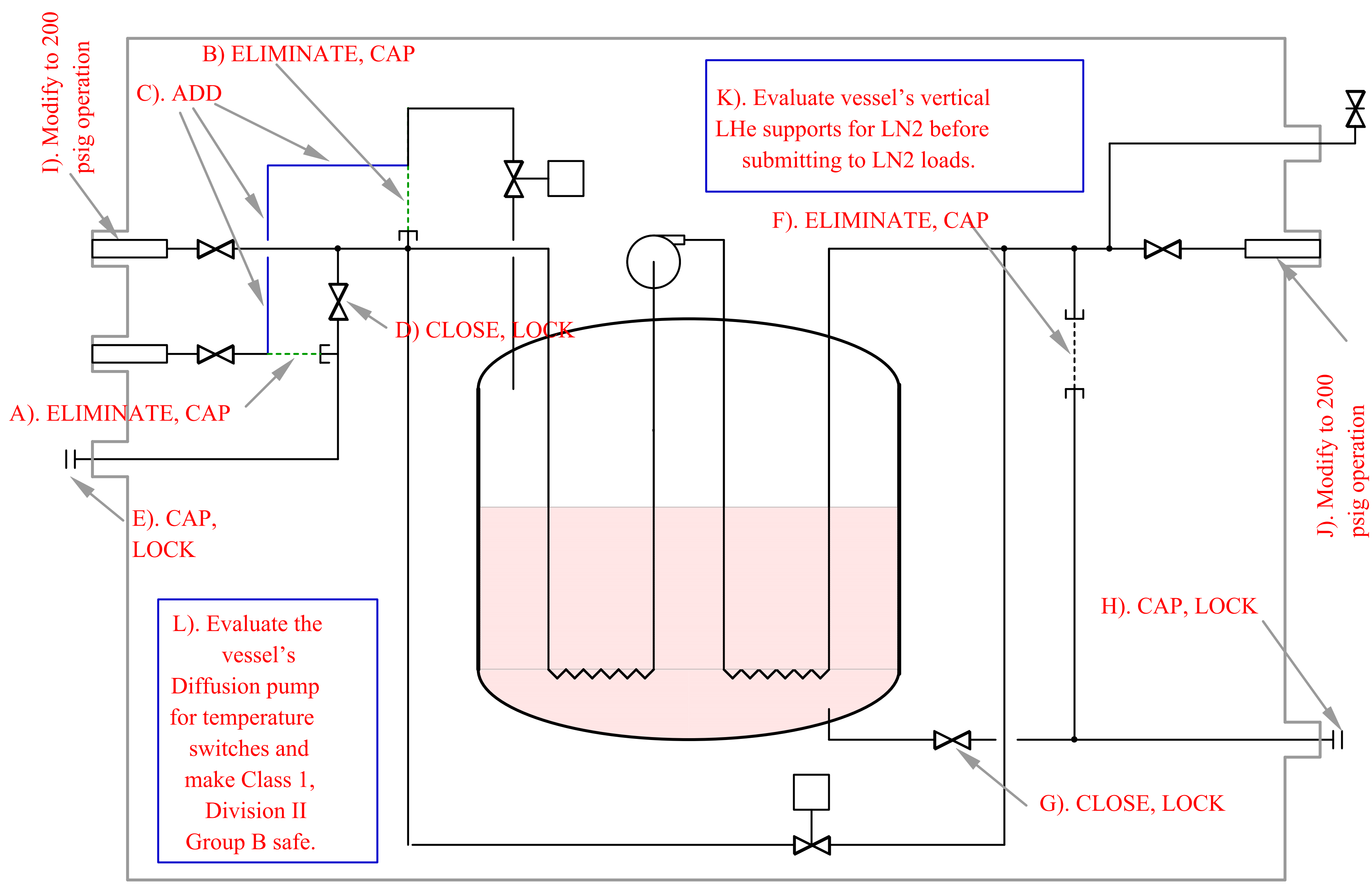
b) The three modifications and two important considerations are shown on a following page of the sketch Required Cir./HE Modifications, Simplified and listed below:

   i) Provide a new, pump loop independent, bath fill line.
      (1) See the Sketch items A, B, C, D and E. The indicated actions separate the inlet cooling loop and bath lines and secure the deadheaded line.
   ii) Provide separation of the outlet pump loop and the bath.
      (1) See the Sketch items F, G and H. The indicated actions separate the bath and cooling loop outlet and secure the deadheaded line.
   iii) Modify 150 psig bayonets as required to 200 psig service.
      (1) See the Sketch items I and J. The indicated actions (change to field connections) will upgrade the connection service pressure to 200 psig.
   iv) The bath vessel was designed to contain LHe. LN2 is ca. 6.5 times heavier than LHe. If the bath vessel is to contain LN2 it must inspected to determine that has sufficient support strength.
      (1) See the Sketch reminder box in the upper right.
   v) The Cir./HE was designed to operate with LHe and as such does not have the hydrogen, Class 1, Division II, Group B electrical equipment required. In particular the Diffusion pump temperature switches are identified as a likely non- compliant.
      (1) Upgrade all the electrical controls for hydrogen operation and, in particular, upgrade the Diffusion pump controls or it will have to be removed. See the sketch reminder box in the lower left corner.

***

Required Cir./HE Modofications, Simplified

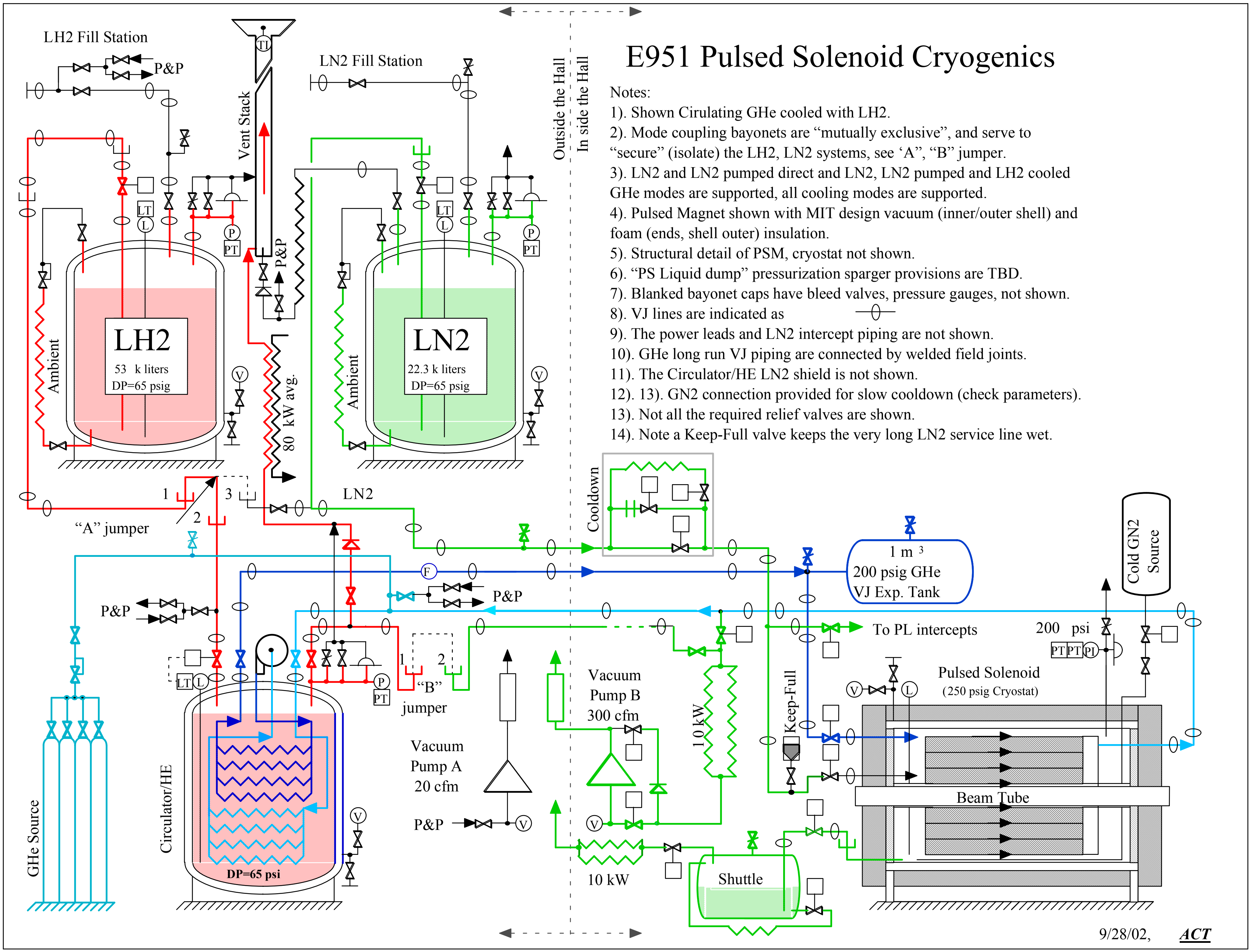
(Only the modification affected areas are shown/described.)



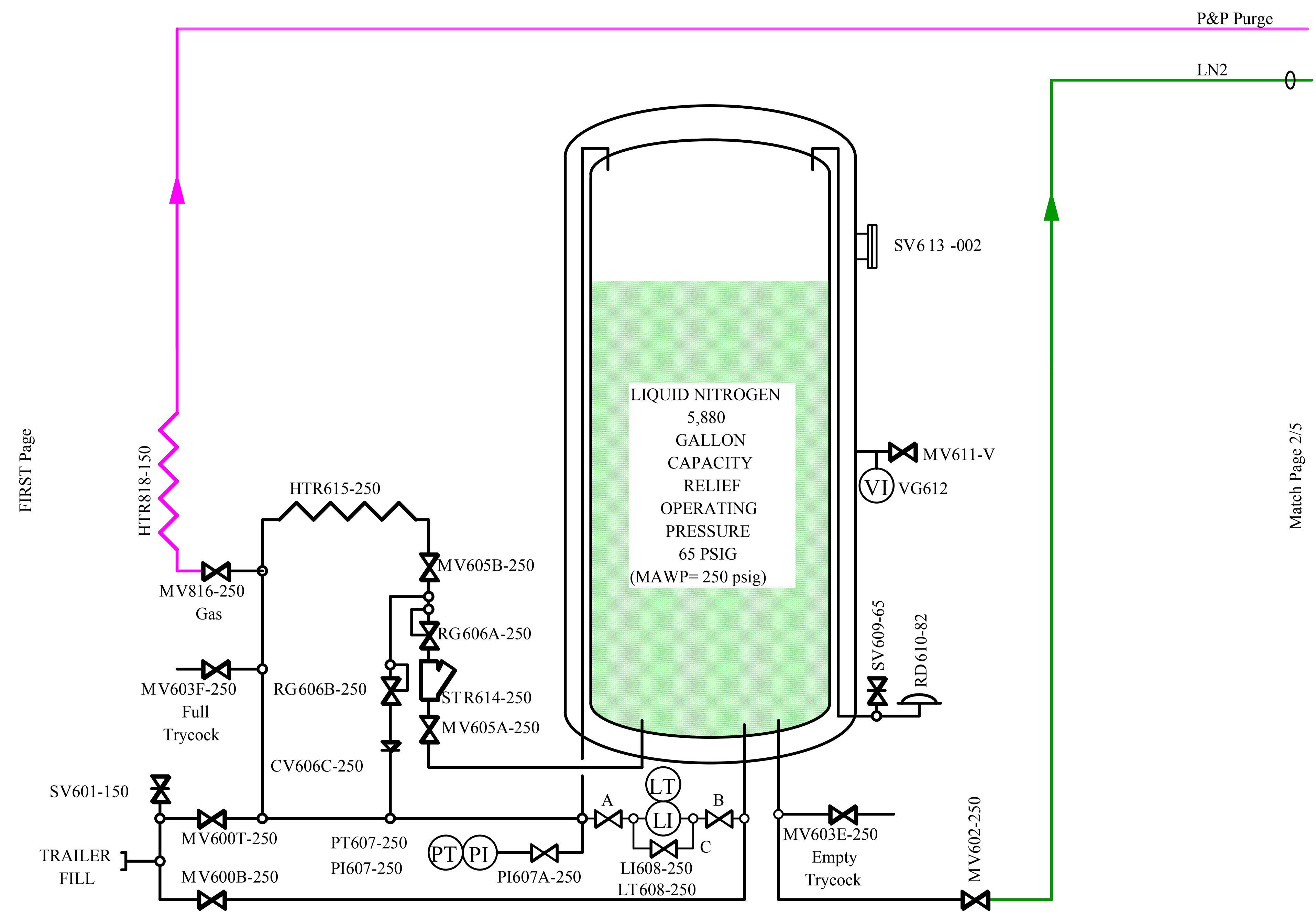
E951 Pulsed Solenoid Cryogenics

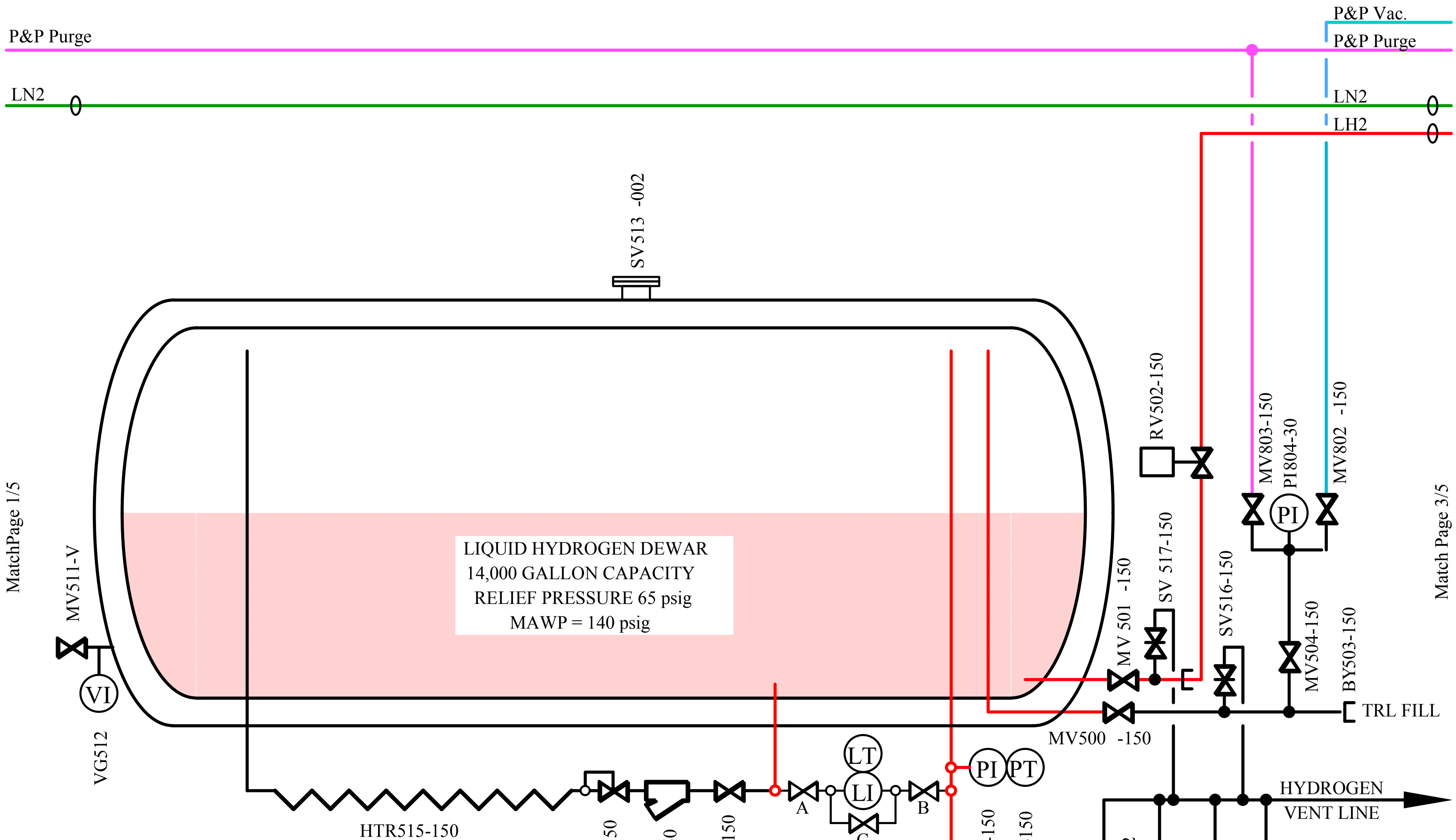
Notes:

1). Shown Cirulating GHe cooled with LH2.
2). Mode coupling bayonets are "mutually exclusive", and serve to "secure" (isolate) the LH2, LN2 systems, see 'A", "B" jumper.
3). LN2 and LN2 pumped direct and LN2, LN2 pumped and LH2 cooled GHe modes are supported, all cooling modes are supported.
4). Pulsed Magnet shown with MIT design vacuum (inner/outer shell) and foam (ends, shell outer) insulation.
5). Structural detail of PSM, cryostat not shown.
6). "PS Liquid dump" pressurization sparger provisions are TBD.
7). Blanked bayonet caps have bleed valves, pressure gauges, not shown.
8). VJ lines are indicated as
9). The power leads and LN2 intercept piping are not shown.
10). GHe long run VJ piping are connected by welded field joints.
11). The Circulator/HE LN2 shield is not shown.
12). 13). GN2 connection provided for slow cooldown (check parameters).
13). Not all the required relief valves are shown.
14). Note a Keep-Full valve keeps the very long LN2 service line wet.

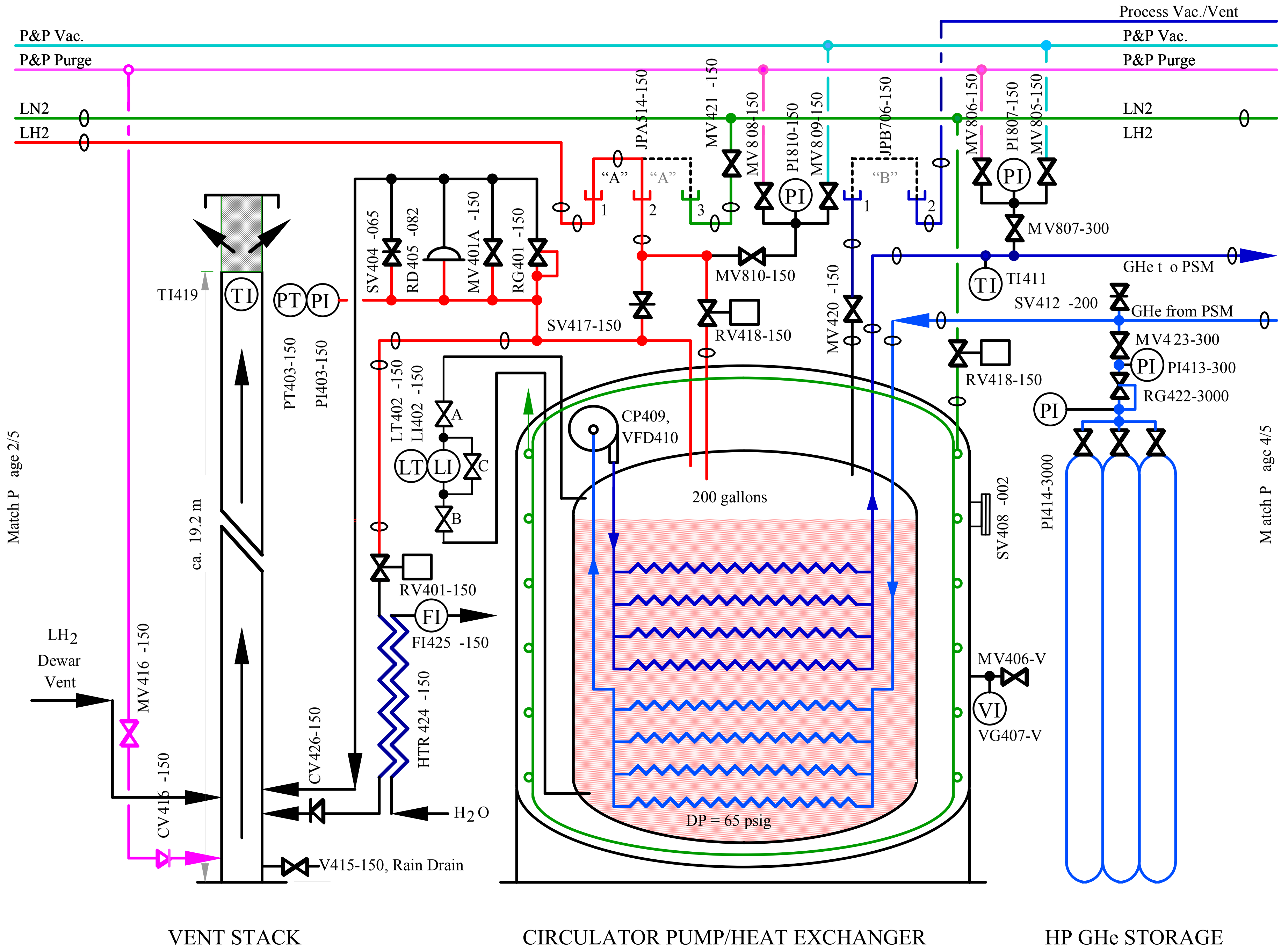


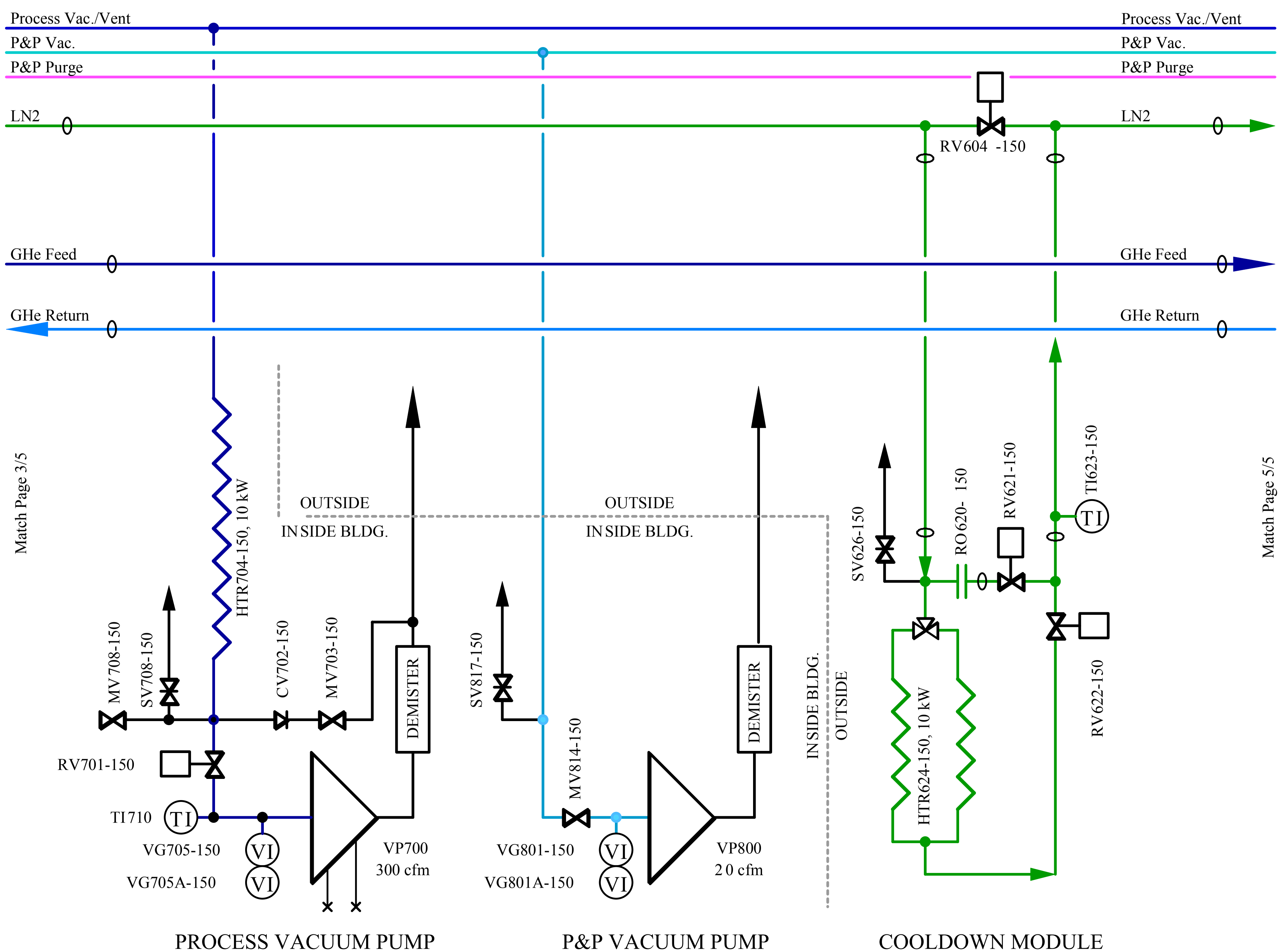
9/28/02, ***ACT***


P&P Purge
LN2
SV6 13 -002
LIQUID NITROGEN
5,880
GALLON
CAPACITY
RELIEF
OPERATING
PRESSURE
65 PSIG
(MAWP= 250 psig)
MV611-V
VI
VG612
Match Page 2/5
FIRST Page
HTR818-150
HTR615-250
MV816-250
Gas
MV605B-250
RG606A-250
MV603F-250
Full
Trycock
RG606B-250
STR614-250
MV605A-250
CV606C-250
SV609-65
RD610-82
SV601-150
LT
LI
A
B
C
MV600T-250
PT607-250
PI607-250
PT
PI
PI607A-250
LI608-250
LT608-250
MV603E-250
Empty
Trycock
MV602-250
TRAILER
FILL
MV600B-250

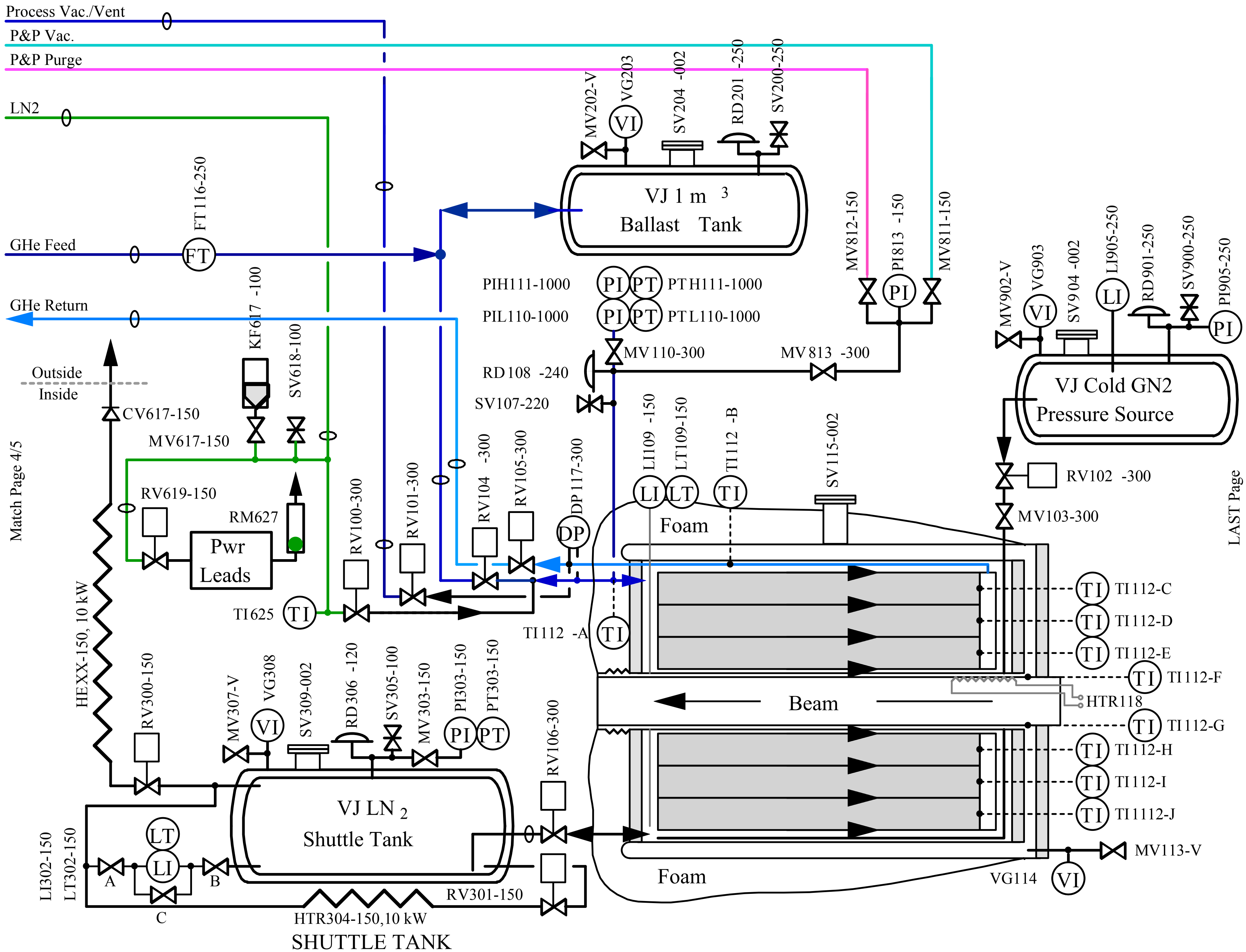


Note: That the delivery bayonet must be seal welded or removed to meet the standard NFPA 50B.


P&P Vac.
P&P Purge
LN2
LH2
Process Vac./Vent
Match P age 2/5
M atch P age 4/5
JPA514-150
"A"
MV421 -150
MV808-150
PI810-150
MV809-150
JPB706-150
"B"
MV806-150
PI807-150
MV805-150
MV807-300
MV810-150
GHe t o PSM
TI411
SV412 -200
GHe from PSM
MV423-300
PI413-300
RG422-3000
PI414-3000
SV404 -065
RD405 -082
MV401A -150
RG401 -150
SV417-150
RV418-150
MV420 -150
TI419
PT403-150
PI403-150
LT402 -150
LI402 -150
CP409,
VFD410
200 gallons
DP = 65 psig
SV408 -002
MV406-V
VG407-V
RV401-150
FI425 -150
HTR 424 -150
H_2O
CV426-150
V415-150, Rain Drain
ca. 19.2 m
LH_2
Dewar
Vent
MV416 -150
CV416 -150
VENT STACK
CIRCULATOR PUMP/HEAT EXCHANGER
HP GHe STORAGE

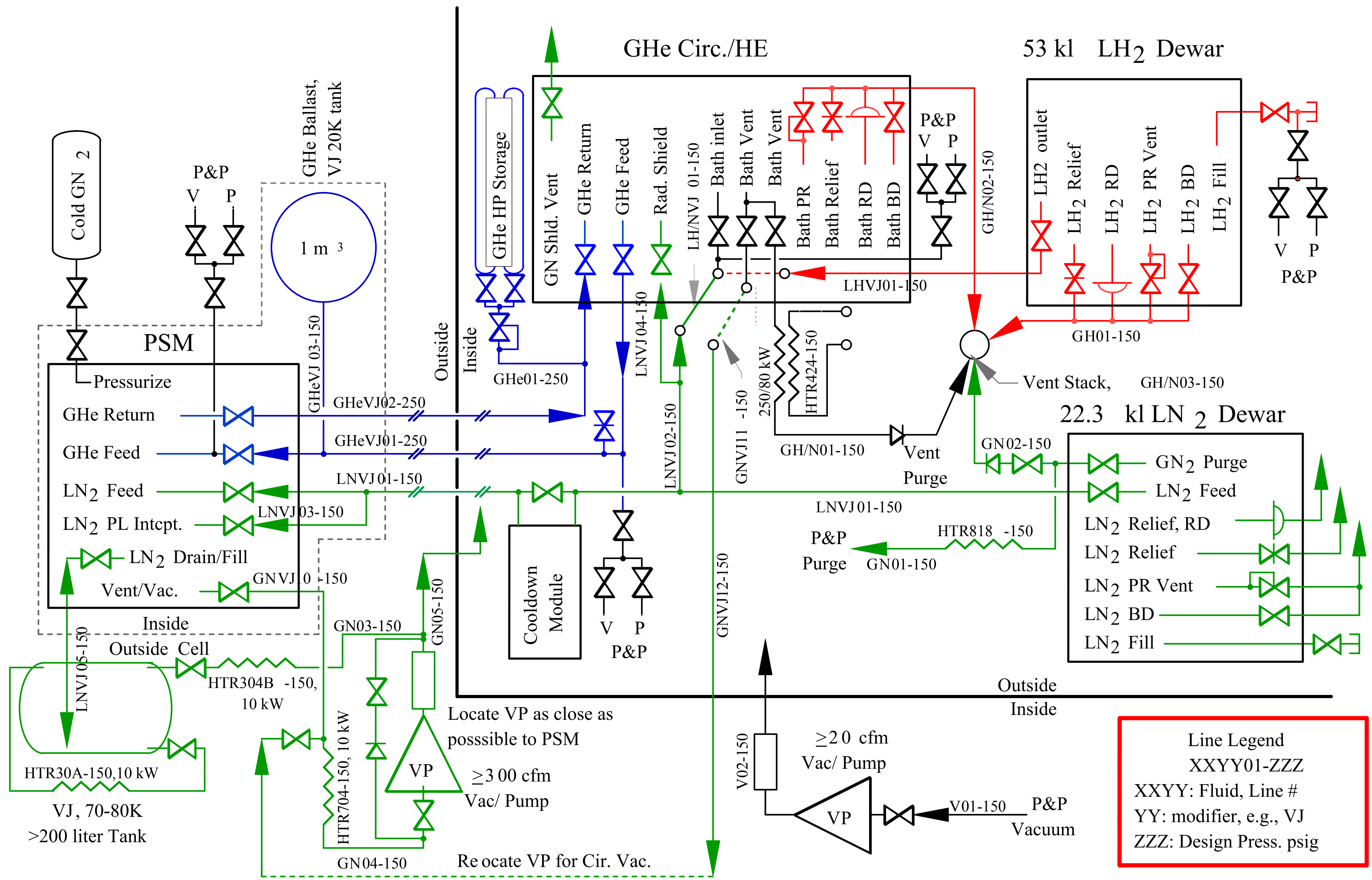


Process Vac./Vent
P&P Vac.
P&P Purge
LN2
GHe Feed
GHe Return
Process Vac./Vent
P&P Vac.
P&P Purge
LN2
GHe Feed
GHe Return
RV604 -150
Match Page 3/5
Match Page 5/5
HTR704-150, 10 kW
OUTSIDE
INSIDE BLDG.
OUTSIDE
INSIDE BLDG.
INSIDE BLDG.
OUTSIDE
MV708-150
SV708-150
CV702-150
MV703-150
DEMISTER
RV701-150
TI710
TI
VG705-150
VG705A-150
VI
VI
VP700
300 cfm
SV817-150
MV814-150
DEMISTER
VG801-150
VG801A-150
VI
VI
VP800
20 cfm
SV626-150
RO620- 150
RV621-150
TI623-150
TI
HTR624-150, 10 kW
RV622-150
PROCESS VACUUM PUMP
P&P VACUUM PUMP
COOLDOWN MODULE



Process Vac./Vent
P&P Vac.
P&P Purge
LN2
GHe Feed
GHe Return
FT116-250
FT
VJ 1 m 3
Ballast Tank
MV202-V
VG203
SV204 -002
RD201 -250
SV200-250
PIH111-1000
PIL110-1000
PTH111-1000
PTL110-1000
MV110-300
RD108 -240
SV107-220
MV813 -300
MV812-150
PI813 -150
MV811-150
MV902-V
VG903
SV904 -002
LI905-250
RD901-250
SV900-250
PI905-250
VJ Cold GN2
Pressure Source
RV102 -300
MV103-300
LAST Page
Match Page 4/5
Outside
Inside
CV617-150
KF617 -100
SV618-100
MV617-150
RV619-150
RM627
Pwr
Leads
TI625
RV100-300
RV101-300
RV104 -300
RV105-300
DP117-300
LI109 -150
LT109-150
TI112 -B
SV115-002
Foam
TI112 -A
TI112-C
TI112-D
TI112-E
TI112-F
HTR118
Beam
TI112-G
TI112-H
TI112-I
TI1112-J
MV113-V
VG114
HEXX-150, 10 kW
RV300-150
MV307-V
VG308
SV309-002
RD306 -120
SV305-100
MV303-150
PI303-150
PT303-150
RV106-300
VJ LN 2
Shuttle Tank
LI302-150
LT302-150
A
B
C
RV301-150
HTR304-150,10 kW
SHUTTLE TANK

E951 Line Summary Diagram



E951 Cryo Line Summary

#	Line Designation	Functional Description	Extant or New	Type, Kind	OD, Sch OD/ID	Length Est., m	Max. Flow g/s	Fluid Flowing	WC Press. atm.	WC Temp. K	ΔP atm.	Comments, Remarks
1	GN01-150	P&P GN2 Purge	New	Warm	1,40	30	1.52	GN2	3.0	300	see ΔP	
2	GN02-150	GN Stack GN2 Purge	New	Warm	1,40	5	2.22	GN2	3.0	300	see ΔP	
3	GN03-150	Shuttle Tank Vent line	New	Warm	1.5,10	25	200.00	GN2	1.0	300	see ΔP	
4	GN04-150	GN2 PVP suction line	New	Warm	1.5,10	5	40.00	GN2	0.1	300	4367.3	l/s @ 1 atm., 300 cfm VP.
5	GN05-150	GN2 PVP/Vent discharge	New	Warm	3,10	25	200.00	GN2	1.0	300	see ΔP	
6	GNVJ10-150	PSM Vent/Vac. Line	New	VJ	1.5/3.5	10	52.00	GN2	1.0	80	see ΔP	Positive pressure
6a	GNVJ10-150	PSM Vent/Vac. Line	New	VJ	1.5/3.5	10	52.00	GN2	0.1	80	1143.4	l/s @ 1 atm., Vacuum service
7	GNVJ11-150	"B" Jumper	New	VJ	2/4	2	71.50	GN2	0.1	80	1129.3	l/s @ 1 atm.
8	GNVJ12-150	Circ/HE Pumped Bath	New	VJ	3.0/5	40	71.50	GN2	0.1	80	285.9	l/s @ 1 atm. Move VP closer.
8a	GNVJ12-150	Circ/HE Pumped Bath	New	VJ	1.5/3.5	10	71.50	GN2	0.1	80	1143.4	l/s @ 1 atm. Alt. location
9	LNVJ01-150	LN2 Dewar Feed	New	VJ	1/3	40	200.00	LN2	3.0	80	see ΔP	
10	LNVJ02-150	GHe Circ/HE LN2 Feed	New	VJ	1/3	15	78.65	LN2	3.0	80	see ΔP	
11	LNVJ03-150	Circ/HE LN2 Shield	New	VJ	0.5/2	2	1.00	LN2	3.0	80	see ΔP	
12	LNVJ04-150	PSM Heat LN2 Intercept	New	VJ	0.5/2	2	2.00	LN2	3.0	80	see ΔP	
13	LNVJ05-150	PSM-Shuttle tank	New	VJ	1.5/3.5	2	4000.00	LN2	2.0	80	see ΔP	Peak flow @ 300 l/m
14	GH/N01-150	Circ/HE Vent Stack line	New	Warm	3,40	10	78.65	GN2	1.0	300	see ΔP	GN2 is the ΔP Worst Case
15	GH/N02-150	Circ/HE Relief/RD Vent	New	Warm	2,40	10	see R	GH2/GN2	1.0	300	see ΔP	GH2:28.39, GN2: 82.07 g/s,
16	GH/N03-150	Vertical Vent Stack	New	Warm	12/40	20	Calc.	GH2/GN2	1.0	300	see ΔP	>63' high stack
17	GH01-150	LH2 Dewar Relief/RD Vent	New	Warm	3,40	15	Calc.	GH2	1.0	300	see ΔP	
18	LHVJ01-150	LH2 to Circ/HE	New	VJ	1/3	20	80.19	GH2	3.0	20	see ΔP	
19	GHe01-250	GHe HP Pressurization	New	Warm	0.5,40	10	17.14	GHe	13.0	300	see ΔP	
20	GHeVJ01-250	PSM Feed	New	VJ	1.5/3.5	40	100.00	GHe	12.0	30	see ΔP	
21	GHeVJ02-250	PSM Return	New	VJ	1.5/3.5	40	100.00	GHe	12.0	90	see ΔP	
22	GHeVJ03-250	Ballast Tank Connect	New	VJ	1.5/3.5	3	257.14	GHe	12.0	30	see ΔP	
23	VP01-150	P&P VP suction	New	Warm	2,10	20	see R	GN2/Vac	0.0001	300	10.9	l/s @ 1 atm., 20 cfm VP
24	VP02-150	P&P VP Discharge	New	Warm	2,10	5	see R	GN2	1.0	300	see ΔP	20 cfm VP

Notes:

1). The three trailing digits of the line designation indicate the required line design pressure in psig.

2). All lines are pipe unless otherwise specified. VJ lines are sch 10.

3). Lines are preliminarily sized: diameter and length. Length must be determined in a layout.

4). Solutions in RED above require the equipment mode change indicated, e.g., 8, 8a.

5). Vacuum lines are sized in the viscous, laminar gas flow region.

6). Vacuum parameters in l/s are conductances; should be a few times the necessary VP pumping speeds.