CCI Report 806-3

BREAK IN 4K VAPOR AND/OR 4K LIQUID HELIUM LINE

Submitted By

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I. INTRODUCTION

It has been assumed, that a break occurs in either the 4K vapor or liquid helium line, or that both lines are ruptured in the same accident.

It also has been assumed, that the 80 and 20K shield lines will not break in the same accident, because they are located at the other side of the cryostat.

Under normal operating conditions, the 4K vapor line is under a partial vacuum of roughly .9 ata. The 4K liquid line may be at a pressure between 2 and 4 ata, but is filled with liquid helium of a temperature of roughly 4.3K.

Tunnel air will initially flow into the broken vacuum space, where it mixes with liquid helium flowing from the break in the liquid line. The inflowing air liquefies through heat transfer with venting helium and through contact with the cold surfaces of 20K shield and magnet mass.

It takes a period of 5-15 seconds to bring the pressure in the vacuum space up to atmospheric pressure. At that time flow reverses through the break in the vacuum wall and primarily helium vents into the tunnel. The flow will continue until a total of some 740 liters of liquid helium have been removed from the 4K liquid line.

II. DISCUSSION

Figure 1 shows the cross-section of the dipole cryostat. It is expected that the general location of the pipes in the spoolpieces, which connect the cryostats, will be roughly the same.

The postulated rupture of the 4K vapor and/or liquid lines is a result of a penetration by mechanical means of the wall of the cryostat. It is assumed that, because of location, the 80K and 20K shield lines will not break in this same accident. Consequently, tunnel air only will flow into the broken vacuum and will mix with helium from the 4K lines.

The sequence of events is roughly as follows:

a) Air will rush into the broken vacuum space. This space is roughly 115 meters long and has a volume between 80K shield and cold mass of the magnet, of some 8.0×10^6 cc. The inrushing air will cool and condense through heat transfer with the helium leaking from the 4K liquid line, and from thermal contact with the 20K shield and cold magnet mass. It appears, that there is sufficient refrigeration available to liquefy all incoming air. The 20K shield and cold magnet mass located in 115 meters of broken vacuum space, in warming to 75K, will make available roughly 1.5×10^8 Joules of refrigeration. This is sufficient to condense 3×10^5 grams of air (8500 scft). The maximum rate at which air flows into the vacuum space is determined by sonic velocity in the break and the flow area of the break. At time zero, with full vacuum in the broken vacuum space, air flow rate per cm^2 of flow area is roughly 19 g/sec cm^2. If we postulate a flow area of 25 cm^2 (a break of 10 inches long by one cm wide) mass flowrate at time zero will be roughly 485 g./sec.

b) If the 4K vapor helium line breaks, helium gas will initially flow into the vacuum space. The initial pressure in the line is of the order of .9 ata. The gas in the line will expand isentropically for some 5-10 seconds. After this length of time flow reverses, and a mixture of helium gas and air will re-compress the remaining helium to a pressure of one atmosphere.

c) If the 4K liquid helium line breaks, a mixture of liquid and gaseous helium will flow into the vacuum space. The initial mass flow is two phase, because pressure in the liquid line near the rupture will decay to below the boiling point. Table I shows, that liquid at an initial temperature and pressure of 4.3K and 3.0 ata, will start boiling at a pressure of roughly .8 ata.

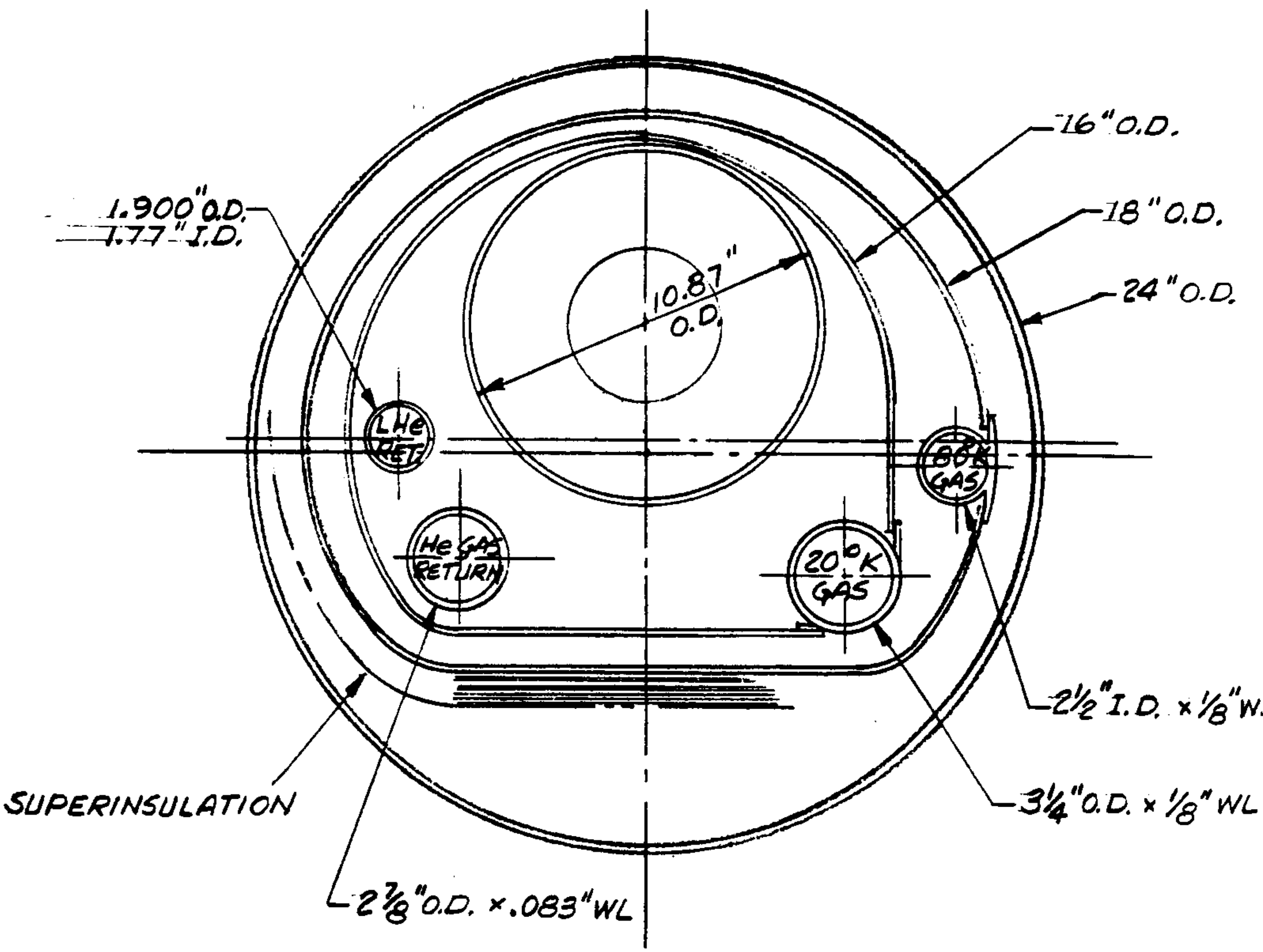

FIGURE - 1

SSC DIPOLE CRYOSTAT CROSS-SECTION

TABLE I

EXPANSION OF LIQUID HELIUM IN THE LIQUID LINE NEAR THE RUPTURE

INITIAL CONDITION	BOILING POINT
p = 3.0 ata	p = .845 ata
T = 4.3K	T = 4.05K
H = 10,559 J/g	H = 8.874 J/g
S = 3.286 J/gK	S = 3.281 J/gK
Vs = 7.485 cc/g	Vs = 7.803 cc/g

Volume expansion is roughly 4.2%

The rate at which the liquid exits from the pipe is primarily determined by the force available to accelerate the liquid and the ratio of rupture flow area and normal pipe cross-sectional flow area. It is impossible to sustain sonic velocity in the break, because of the limited driving force available. For a worst case scenario, one can assume the rupture to have a flow area of 10 cm^2 (pipe cross-section is 15.6 cm^2). In that case, flowrate in the rupture is primarily determined by the force needed to accelerate the mass in the pipe. As an example, consider the first 25 meter upstream of the rupture. The sonic wave reached this point in .139 seconds. At that time the force available to accelerate 25 meters of mass is of the order of 2.5 ata. This is the equivalent of an accelerating force of 39,000 grams working on a mass of 5217 grams. Exit velocity then reaches a value of 1592 cm/sec at t = .139 sec. The amount of fluid vented in this time is then

$$\frac{74.3 \times 15.62}{7.76} = 149.5 \text{ grams.}$$

Rate of fluid flow has been 1075 grams/sec. The velocity head associated with the exit velocity is of the order of .16 ata, while pressure drop in the 25 meter of line is of the order of .071 ata. Therefore, most of the available pressure difference is used to accelerate the fluid.

Applying the same reasoning to a section of pipe of 50 meters length shows that:

1) Time required for sonic wave to reach 50 meters upstream of the break is .278 seconds.

2) Accelerating force available is 2.5 ata.

3) Mass accelerated is 5217 grams.

4) Exit velocity remains at 1592 cm/sec.

5) Mass ejected in .278 seconds is 300 grams and mass flowrate has been 1075 g/sec.

6) Pressure drop in the line has doubled to .142 ata, while the velocity head at the exit has remained the same.

d) From a) and c) above we find that 1075 g/sec of liquid helium and 485 g/sec of air mix. To liquefy all of the air, some 218 kW of refrigeration needs to be applied. The liquid helium will make this available in vaporizing and warming to roughly 40K. If we assume, that this happens, we can estimate how fast the pressure in the vacuum space will rise. Volume of the vacuum space is approximately 8×10^6 cc inside the 80K shield. If the helium gas occupies this volume, specific volume at one second will be of the order of 7400 cc/gram. At 40K, pressure will be of the order of .1 ata. With rising pressure air flowrate will decrease, and helium will not warm as much. It appears, that reversal of flow from the broken vacuum space to the tunnel will not occur until some 10-15 seconds have passed from the time of failure.

e) At the time of flow reversal, the vacuum space contains some 10750 grams of helium vapor at 40K and 4850 grams of liquid air. Continued helium flow from the broken liquid helium line will add no more than 8000 cc/sec of volume to the vacuum space. If we assume that no significant heat transfer takes place with the cold magnet mass, flowrate out of the vacuum break will be 8000 cc/sec. If it is all liquid, mass flowrate into the tunnel is 1000 g/sec; if it is all gas, flowrate is reduced by at least an order of magnitude.

f) It is assumed, that the tunnel ventilation rate will have been increased to the maximum flowrate of 4200 grams per second. Mixing 4200 grams of air with 100 grams of helium gas of 5K will result in a mixture with an oxygen concentration of 17% and a temperature of 270K. The resulting mixture will rapidly demix, with helium flowing at the top of the tunnel. The volume of the helium flowrate of 100 g/sec at 270K will be approximately 20 cft/sec. Layer thickness of the helium will be of the order of 2 feet. Volume of air flow will be of the order of 120 cft/sec. Helium therefore will occupy less than 14% of tunnel cross-section.,

Since flow reversal through the vacuum wall break does not occur until some 10 seconds after initiation of the break, flowrate out of the liquid helium line will have been reduced to less than half of the original flowrate at time zero. Pressure drop in the liquid helium line is now the governing factor for the determination of flowrates.

If all of the fluid from the 4K line manages to escape through the vacuum wall break, flowrate into the tunnel will be at 500 grams per second or less. Mixing this helium with tunnel air will yield an oxygen concentration of 10.7% and a temperature of 200K. Demixing will yield a helium and air volume flowrate of 66 cft/sec and 76 cft/sec respectively. This means that the helium will occupy some 45% of the tunnel cross-section.

g) The duration of the total event is determined from the total amount of helium vented and the rate, at which it vents. In section c) it was shown that volume expansion in (8200-115) meters of 4K liquid line will yield

$$.042 \times \frac{15.62 \times 100}{7.76} \times 80.85 = 68350 \text{ grams}$$

of vented fluid.

In addition to this, all of the liquid in the non-insulated 115 m long section located in the broken vacuum space will vent. This is another 23150 grams. The vacuum space will hold at least 10000 grams of cold vapor. The tunnel will receive therefore some 81500 grams of helium (~ 650 liters of liquid). If flowrate is 100 grams per second, time is of the order of 15 minutes. With liquid venting directly into the tunnel time.of the event may be shortened to some 3 minutes. Under the worst of conditions, the major event will be over in 3 minutes. Under the best of conditions, it is not a dangerous event.

III. CONCLUSIONS

1) A worst case scenario is assumed to have:

   a) An outer vacuum wall break with a flow area of 25 cm^2.

   b) 4K liquid and gaseous helium line break flow areas of 10 cm^2 each.

2) A worst case scenario leads to an event, in which the tunnel atmosphere in the immediate vicinity of the break will have an oxygen concentration of roughly 10% and a temperature of 200K for a period of less than 3 minutes.

3) Immediately upstream of the failure, tunnel conditions will not be affected by the event.

4) Downstream of the failure helium gas will separate from air in the tunnel and flow along the top of the tunnel. At least 50-60% of the tunnel cross-section (lower half) will be essentially free of helium.

5) In the worst case scenario, at least 10 seconds are required for inflow of tunnel air into the broken vacuum space. Flow reversal, with essentially pure helium flow, will take place after 10 seconds.

6) If helium gas, rather then helium liquid, vents from the broken vacuum space in the worst scenario case, local oxygen concentration will not drop below 17% and local temperature will be 270K or warmer.

7) A less than worst case scenario assumes the flow areas of 1) above, but a misalignment between outer vacuum wall break and liquid helium line break. As a result helium gas will spill from the vacuum space rather than liquid. This event generates oxygen concentration of 17% and temperatures of 270K for a period not exceeding 15 minutes.

IV. RECOMMENDATIONS

1) The major recommendation to be made is the location of 4K helium lines and 20K and 80K shield lines relative to the tunnel traffic area. It is strongly recommended that the 4K lines be located closest to the tunnel traffic area. The 20K and 80K lines should be located on the wall side of the tunnel.