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CCI Report 806-2

SPILLING OF HELIUM GAS FROM THE 20K SHIELD INTO THE TUNNEL

Submitted by

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I. INTRODUCTION

A previous CCI report (1) has dealt with the events and consequences of a break in the vacuum shell and 80K cooled shield line. It is to be expected, that when this break occurs, also helium gas and/or liquid lines may be ruptured. This report deals with the consequences of a break in the 20K cooled shield line.

The probability of breaking the 20K shield line is not discussed to this report. Also, the flow area of the break has arbitrarily been chosen to be half of the flow area of the pipe. This assumption is an important one and for this reason the anatomy of a break in the shield line should be studied.

Consideration of the cross-section of the magnets and the spoolpieces leads to the conclusion, that it is not probable that all helium carrying lines will be broken simultaneously in a major mishap.

For this reason, the 20K shield line break should be considered together with the 80K shield line break, since both lines are located on the same side of the cryostat and cryostat spoolpieces. A second probable scenario of failure deals with removal of "U" tubes from bayonets, in preparation for warming or cooling of a one km long section of magnets. It is assumed that these failures occur as single events. In other words, at time of failure, none of the other "U" tubes of other fluid circuits will fail.

(1) CCI Report 806-1, "Spillage of 80K Shield Line Contents into the Tunnel of the SSC", November 25, 1987

II. ASSUMPTIONS

The 20K shield line has the following characteristics:

1) Line diameter is 3 inches (ID).

2) Line volume for L = 8,200 m is 3.74×10^7 cc.

3) Average temperature in the line is 20K.

4) Average pressure in the line is 2.5 ata.

5) Normal pressure drop in the line for a flowrate of 100 grams/sec is approximately one atmosphere.

6) Normal heatleak in 8,.200 meters of line is 2,000 W.

7) Normal inventory in the line is 2.29×10^5 grams (503.7 lbs.).

8) Flow area of the break is 22.8 cm^2.

III. DISCUSSION

1) It is postulated that the line breaks due to a mechanically induced failure of the vacuum wall of the cryostat and penetration of the liquid nitrogen cooled shield. In general, the following will happen:

   1.1) When the line breaks, helium gas will rapidly flow out into the tunnel.

   1.2) The gas remaining in the line is subjected to an isentropic expansion except for the addition of normal heatleak to the 20K shield in all but 114 meters of line.

   1.3) Initial velocity of helium in the break will be sonic. Duration of this is less than .1 second, because of high pressure drop in the line.

   1.4) Mass flowrate out of the hole will decrease rapidly with time. This flowrate may be reasonably well estimated by assuming a linear pressure distribution between a point upstream of the break at some distance from the break and calculating the mass flowrate sustaining this pressure distribution. By equaling mass ejected and mass change in the line section, length of time, during which flowrate is maintained, can be estimated. With increasing time, pressure differential occurs over longer sections of line and flow-rate decays.

Total mass vented into the tunnel can be estimated reasonably well from isentropic expansion. Table I shows the conditions of the gas in the line at start and end of ejection process.

TABLE I

MASS AT START AND END OF BLOWDOWN OF 20K SHIELD LINE

START	FINISH
p = 2.5 ata	p = 1.0
T = 20K	T = 13.85K
H = 117.1 Joules/g	H = 85.5 Joules/g
S = 15.38 Joules/gK	S = 15.38 Joules/gK
V_S = 163 cc/g	V_S = 281 cc/g
M = 2.29 x 10^5 grams	M = 1.33 x 10^5 grams

A total of 96,000 grams (211.5 lbs.) has been vented to the tunnel. This is roughly 40% of the initial inventory of the system.

That isentropic expansion occurs in the line, can be shown as follows: If we assume that the process occurs over a period of ten minutes, total heat added to the line system will have been 1.2×10^6 Joules. Roughly half of this will have been removed by the gas flowing to the tunnel and the remaining heat has been deposited in the gas. This then increases the enthalpy roughly by 5.5 Joules per gram, with a resultant temperature rise of 1K. Remaining mass is then 1.23×10^5 grams of 1 ata pressure and temperature of ~ 15K. Vented mass is 1.06×10^5 grams (233.5 lbs.).

2) RATE OF VENTING INTO THE TUNNEL

A reasonably accurate rate of venting as a function of time can be made as follows:

2.1) Velocity in the break initially is sonic.

2.2) With time, velocity in exit is determined from

$$\Delta P_{tot} = 1/2\ \rho V^2_{exit} + \Delta P_L$$

where

ρ = density in exit
V_{exit} = exit velocity
ΔP_L = pressure drop in line between break and upstream point
ΔP_{tot} = total available pressure drop

2.3) With time, mass spilled in tunnel is determined as the difference between initial mass in a line section and the mass at the time when pressure gradient is linear.

2.4) Mass flowrate out of pipe at time t is determined from velocity and density in exit.

2.5) A comparison with the length of pipe over which the sonic wave has travelled with time and the length over which the new pressure gradient occurs shows that choked flow only occurs for a period of .5-.6 seconds. From this time on, pressure drop in the pipe will essentially determine the flowrate.

Figure 1 shows the rate of venting and the total mass spilled as a function of time, from one half of the break. In approximately 7 seconds the rate of venting drops below 500 g/sec.

3) ATMOSPHERE IN THE TUNNEL

During the first 5-10 seconds, helium gas will mix with a relatively large volume of air in the tunnel. If we assume, that some 40 feet of tunnel length is involved in the mixing process, oxygen concentration will drop to 9%. Assuming that tunnel ventilation is in progress, we find that the tunnel atmosphere, with a flowrate of 800 grams per second of helium, will have an oxygen concentration of roughly 8-9%. The temperature of the mixture will be of the order of -120°F. Exact value depends on the water vapor content of the air. Another way of looking at the event is to indicate the rate at which refrigeration is supplied to the tunnel. This rate, at a helium mass flowrate of 800 g/sec, is of the order of 1,200 kW.

Figure 1 indicates that decay of the venting rate is slow, unless some measures are taken to reduce the section of shield line participating in the event.

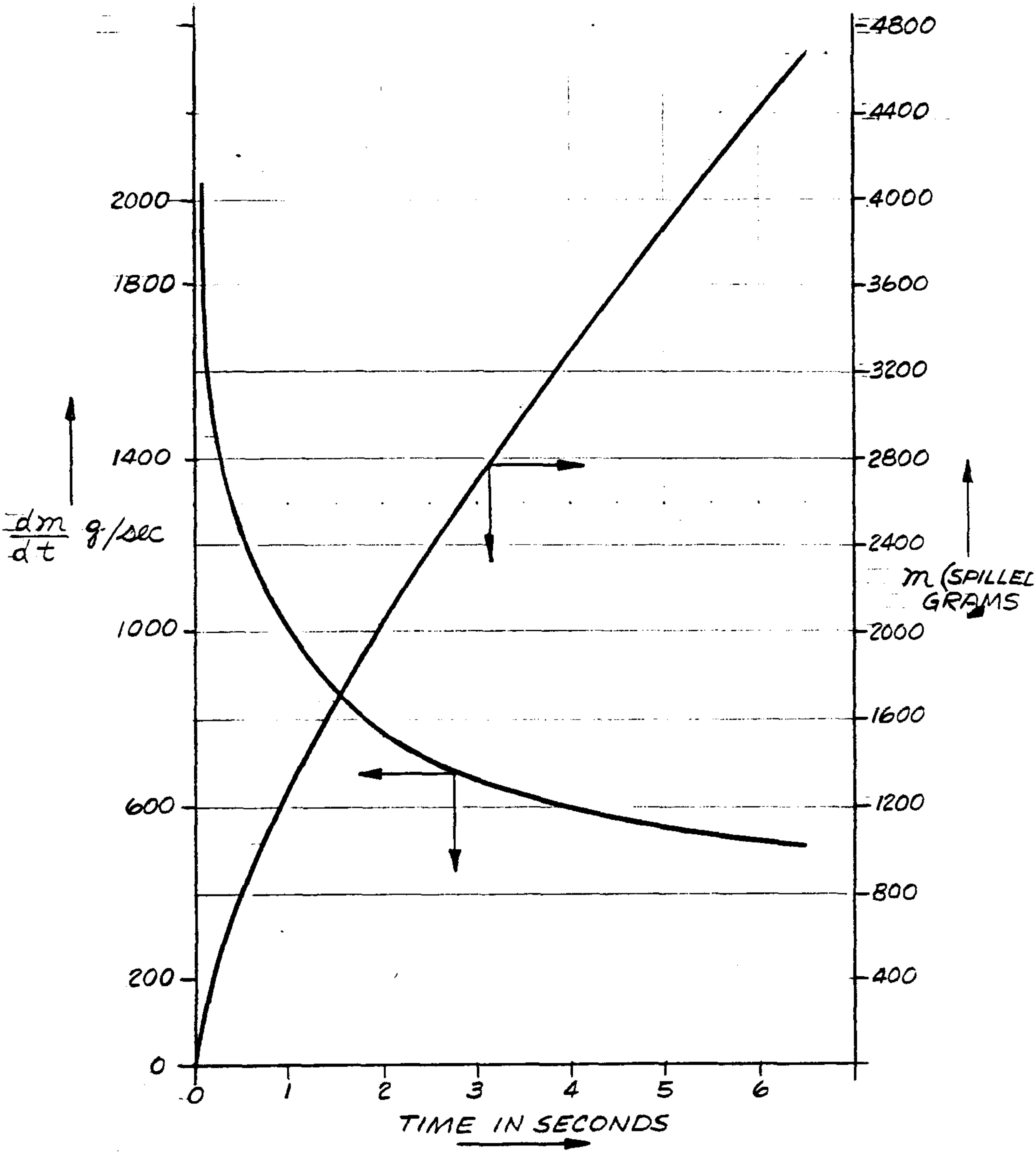
4) EFFECT OF FLOW AREA OF THE BREAK

There is not a great difference in the rate of spilling and amount of spilled helium as a function of time between breaks with full and half sized pipe area flow areas. At small flow area of the break, velocity in the break will be sonic. Mass spilled is then roughly 96 g/sec per cm^2 of flow area. Clearly pressure drop in the line is of no consequence, when the break has a flow area of 1 cm^2. Even at this relatively small break, oxygen concentration in the tunnel drops to 15% and supply of refrigeration is of the order of 280 kW.

5) MEANS TO REDUCE THE FLOW OF HELIUM INTO THE TUNNEL

5.1) Check valves will reduce the flow into the tunnel to roughly the values shown in Figure 1.

5.2) Open valves between 20K shield system and the warm helium collection header in the tunnel. Each valve and line can handle some 100 grams per second of flow. the warm header contains approximately 34,000 grams of gas per 8.2 km length. If all of the header is available, it will be possible to store at least 50,000-60,000 grams of extra vapor. Since this vapor is cold, when stored (~ 80K), volume to be generated for this gas is 1174 x 60,000 = 70 x 10^6 cc at T = 80K and p = 1.4 ata. This is 4% of the total line volume. Consequently pressure in the header does not change very much.



RATE OF HELIUM SPILLED AND ACCUMULATION
IN TUNNEL FROM ONE SIDE OF THE BREAK

FIGURE - 1

Check valves in the lines connecting 20K shield line and warm collection header will prevent reversal of flow.

- By opening the vent valves to the warm header, flowrate into the tunnel through the rupture will decrease faster from roughly 3-4 seconds into the event. At that time, pressure waves moving from the break and the nearest vent point (1 km away) will meet.

5.3) The total amount of gas vented into the tunnel will be reduced when employing check valves and opening the vent valves. In fact, the total amount vented can probably be reduced to roughly 10% of 211.5 lbs, or some 20 lbs.

5.4) The most significant approach to limiting flow of helium gas into the tunnel is protecting the 20K shield line from rupturing badly. This can be done by designing the spoolpiece in such a way, that a wide open rupture is impossible to generate.

6) DETECTION OF A 20K SHIELD LINE RUPTURE

It appears that a local pressure reading in the area of the rupture will be the most immediate indication of a leak. In order for the rupture to occur, the vacuum of the spoolpiece and adjoining magnets will go bad. This event can be used to have the tunnel ventilation system go into high gear.

Opening of the bypass valves between 20K shield line and warm gas collection header should only be initiated from a signal, that pressure is lost locally in the 20K shield line.

IV. CONCLUSIONS AND RECOMMENDATIONS

1) A large break in the 20K shield line, after a rupture of the vacuum space has occurred, will lead to a very dangerous situation in the area of the rupture. Both oxygen concentration and temperature will be lowered to a level lethal to humans in the area.

2) Some measures in the system can be taken to reduce the flowrate of helium, seconds after the rupture occurs.

3) Pressure sensors should be located at one km intervals, in order to warn of a major failure.

4) Spoolpiece and magnet cryostat design should be carried out to minimize the chance of generating a major rupture.