Safety Report

15-Foot Bubble Chamber

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Safety Report

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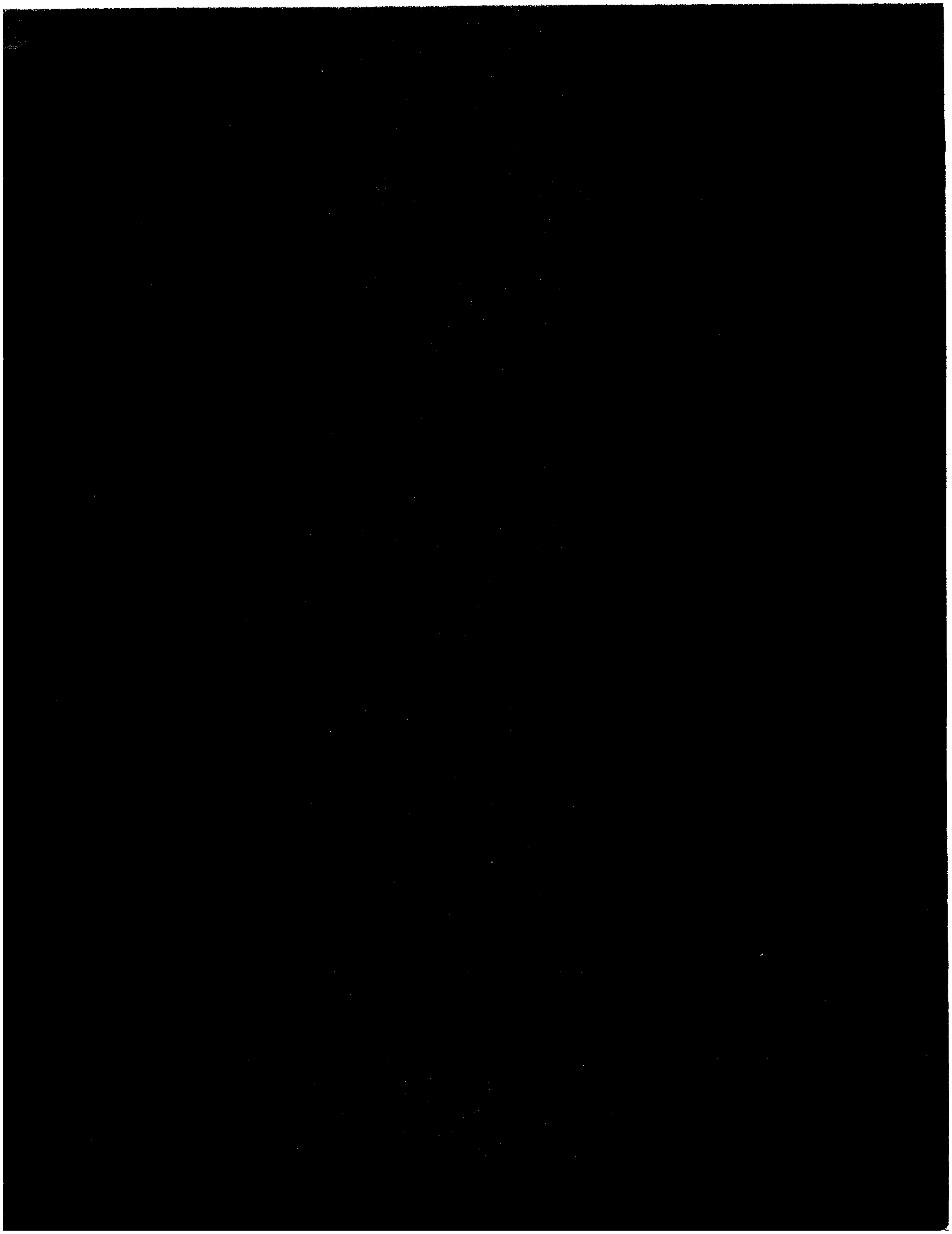


V. CRYOGENICS

A. Hydrogen System Design Report

Prepared by

P.C.VanderArend

V. A. HYDROGEN SYSTEM DESIGN REPORT

(1) CRITERIA

Design of the system has been based on the following criteria:

a. Safety criteria in accordance with those outlined on Pages 3, 4, and 5 of the Safety Report of the 15 Foot Bubble Chamber.

b. In order to accommodate operation of the chamber with various fluids, such as hydrogen, deuterium, or neon-hydrogen mixtures, cooling of the chamber will be accomplished through the use of an intermediate fluid, whenever necessary. For instance, when a neon-hydrogen mixture with a temperature of 30°K or higher is present in the chamber, it is difficult to use liquid hydrogen as the cooling medium with full control over the loop. In this case, the intermediate fluid may be selected to have a boiling point between 30 and 23°K and liquid hydrogen can be conveniently used at a low pressure.

c. The chamber will be cooled from ambient to operating temperature in a period of 48 hours. This length of time is primarily governed by the rate at which the glass windows may be cooled.

d. Chamber cooling will be accomplished by external means. During cooldown the chamber will be filled with hydrogen gas and the external cooling loops will be utilized to cool the chamber.

e. A numbering system will be used for valves, instruments, and lines for complete identification. No single number will be used more than once.

f. The size of the hydrogen refrigerator was chosen after a study was made of the economics of hydrogen refrigeration required for the overall system. A major parameter of this study was the total number of pulses to be made in the course of a year.

g. Removal of liquid from the chamber in case of emergency will be through return to the storage tank over a period of approximately 20-30 minutes. In order to carry out this transfer, gas of a temperature of approximately 80°K will be added to the top of the chamber.

h. Venting of the chamber to the stack will be through a valve located at the top of the chamber into a "knockout drum". This vessel will serve to lower the rate of gas generation through storage of vented liquid in a vessel with nominal insulation.

i. Liquid deuterium and neon storage tanks will be arranged in such a way that good inventory control and knowledge is available at all times. Both deuterium and neon systems will be isolated from the hydrogen refrigeration system through double blocks and bleeds or by removal of spool pieces in connecting lines.

j. Under normal operation conditions, the hydrogen refrigerator will supply refrigeration. In case of refrigerator breakdown, cooling loops of the chamber may be supplied with liquid hydrogen from the hydrogen storage tank.

(2) DEVELOPMENT OF DESIGN

In order to arrive at a complete system with the capability of handling startup, steady state, shutdown, and emergency conditions, a flow sheet was developed and the system operated on paper from this flow sheet. Drawing No.'s 2625.ME-25050, -25051, -25052, -25053, -25054, and -25055 represent the complete flow sheet of the hydrogen system of the bubble chamber. Drawing No.'s 2625.ME-33424, -33425, -33426, and -33427 represent the flow sheet of the helium system of the superconducting magnet. The flow sheets represent the "bible" of the system. Development of system layout, component sizing and specifications, and valve and instrument requirements followed systematically from the flow sheet. Logical arrangement of piping valves and instruments resulted in the development of a number of "racks" in which valves, instruments, and piping are concentrated. This arrangement made it possible to have the major portion of all piping shop-fabricated under high quality control standards. All connecting piping was detailed on spool sheets and prefabricated on-site. Installation of completely clean, pretested piping, spool pieces, and racks required few welds.

(3) SPECIFICATIONS

All components of the hydrogen system were specified and obtained from industry on a competitive basis. Specifications included pressure ratings, material requirements, and tests to be performed. Components of the hydrogen system were defined in sufficient detail so that interfaces with piping and/or other components were clearly defined. With this definition available it was possible to proceed with piping layouts without having to wait for certified drawings from the vendors.

Critical component specifications included performance requirements, and in some cases, acceptance tests were spelled out.

(4) VACUUM JACKETED PIPING

There are five separate lines connecting the bubble chamber with liquid storage tanks and refrigerator. The lines are enclosed in a single vacuum jacket with bayonets located near the various components to which the lines connect. All bayonets are arranged in the vertical direction to make sure that the O-ring seal remains warm.

The lines which connect the storage tanks and the transfer line assembly can be removed, in order to make sure that there is no possibility of leakage from hydrogen into deuterium tank and vice versa. All liquid and cold gas lines are rated at 150 psig pressure.

(5) STORAGE TANKS

All storage tanks of the hydrogen system are powder insulated. Pressure ratings and volumes of the tanks are as follows:

	Pressure in Psig	Volume in Gallons
Liquid Hydrogen (A)	150	15,500
Liquid Deuterium (D)	75	11,300
Liquid Neon (C)	75	11,300
Liquid Nitrogen (U)	50	13,500

Liquid deuterium and neon tanks are equipped with a conducting shield in order to reduce the rate of pressure rise due to stratification. It is anticipated that these tanks may be sealed off for a period in excess of one week before refrigeration needs to be applied.

(6) HYDROGEN REFRIGERATOR

The hydrogen refrigerator employs liquid nitrogen precooling and J-T expansion of high pressure gas. The refrigerator receives cold vapor from the cooling loops of the bubble chamber and makes liquid into the liquid hydrogen storage tank. Liquid hydrogen for cooling in the various loops of the bubble chamber is drawn from the liquid tank.

In case the refrigerator goes down, the mode of chamber cooling remains the same, but the gas from the cooling loops will vent instead of being reliquefied.

Capacity of the refrigerator is flexible. Basic capacity is 6.7 KW employing liquid nitrogen precooling at a temperature of 65°K. Through the addition of an expansion engine in the future, the capacity may be raised to 8.7 KW. The capacity may also be raised through the consumption of liquid hydrogen. For instance, 8.7 KW of refrigeration will be realized without expansion engine through consumption of 16 pounds/hour of liquid hydrogen.

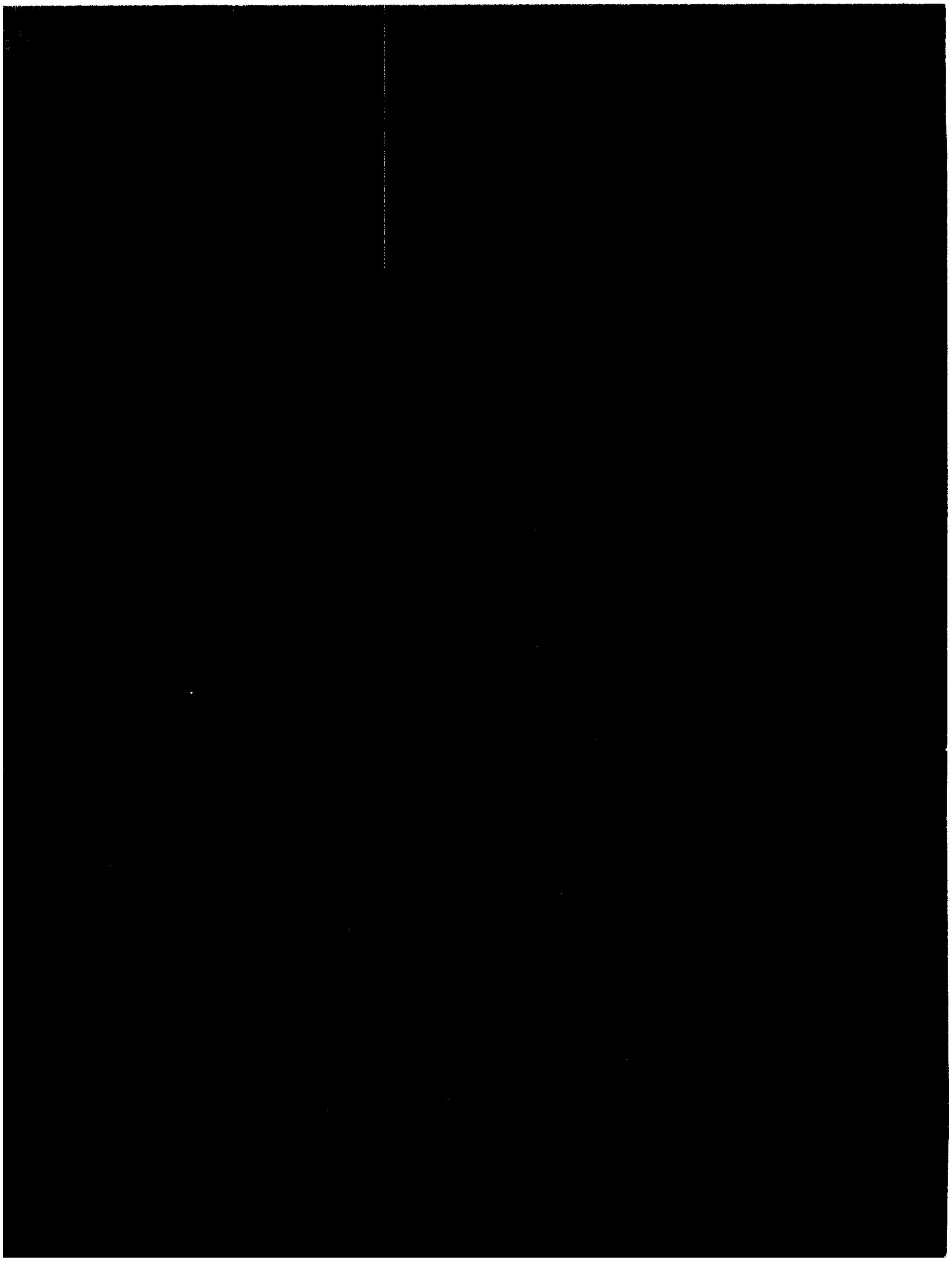
(7) GAS STORAGE FACILITY

The system contains two gas storage bottles, B and B-B. The gas is used to change inventory in the bubble chamber system and to pressurize the chamber for removal of liquid. Vessel B is used for chamber operation, while B-B is used for the target in the chamber.

(8) VALVE BOXES R AND J

All valves used in the cooling loops of the chamber are located in valve boxes R and J. Valve box R contains the liquid control valves and a counterflow heat exchanger used for cooldown of the chamber. Valve box J contains manual shutoff valves in the cold hydrogen vapor return to the refrigerator. All vacuum jacketed lines connecting the chamber and cooling loops enter or leave through the valve boxes.

Both valve boxes are isolated from the chamber vacuum space through a barrier.



V. CRYOGENIC SYSTEMS

B. Cooling Loops

Prepared by

P. C. Vander Arend

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V. CRYOGENIC SYSTEMS

B. Cooling Loops

LIST OF FIGURES

V. B. COOLING LOOPS

(1) INTRODUCTION

This document describes the various cooling loops of the 30,000 Liter Liquid Hydrogen Bubble Chamber. Functionally, the loops belong in one of three categories. In the first category, cooling loops intercept heat which flows from the environment at ambient temperature to the cold chamber. In the second category, cooling loops remove heat which penetrates through the cooling loops of the first category and also heat generated in the cold chamber during the expansion-recompression process. In the third category, cooling loops control the pressure of the chamber.

Preferably, loops of the first category should intercept all heat flowing from the environment to the chamber. In practice, it will be sufficient if 98 percent of the heat flowing from the environment is removed before it reaches the cold chamber. To make control of the loops in the first category relatively simple and cheap, location of the loops relative to the chamber is such that they are very loosely coupled to the chamber.

Cooling loops removing heat from the chamber itself need to be located in the top of the chamber. Removal of heat from the piston ring area is accomplished at the bottom of the chamber in the immediate vicinity of the piston rings.

Cooling loops controlling the pressure of the chamber are located in the two-phase region below the piston. The method by which pressure is controlled in a chamber equipped with piston is considerably different from that in a chamber equipped with omega bellows. The chamber system equipped with omega bellows does not contain a vapor bubble and therefore pressure control is exercised by volume and temperature control. The chamber system equipped with a piston has a constant volume. The volume below the piston contains a two-phase gas-liquid system. Because of this, there is equilibrium at the liquid surface and this liquid is considerably warmer than that in the chamber. Since the liquid in the chamber is colder, a region of stratification needs to be provided for separation of warm and cold liquid. Also, mixing of cold and warm liquid needs to be avoided in order to prevent the transfer of heat and loss of pressure control of the chamber.

The need for extreme uniformity of temperature throughout the visible volume of the chamber requires a low rate of heat transfer between cooling loop and chamber liquid or the use of a shroud. With a low rate of heat transfer temperature differences between wall and liquid are small enough to prevent the occurrence of a "rain" of cold liquid from the walls of the chamber into the visible volume.

At present the cooling loop located in the beanie head transmits cooling to the chamber fluid without the use of a shroud. In case thermal disturbances are visible from the windows, a shroud may be installed conforming to the shape of the beanie head and located at a distance of 3-4 inches from the head.

The shroud has the following functions:

1) Liquid of non-uniform temperature leaving the heat exchanger is hidden from observation for some length of time. During this time mass and heat transport makes the liquid acceptably uniform in temperature.

2) Liquid enclosed between shroud and chamber has a slightly lower temperature than the liquid in the visible part of the chamber. A flow of liquid is established through the slight differences in temperature and density. This flow is downward between shroud and wall and upward through the chamber. Flow rate is a function of geometry of shroud, heat exchanger, and heat load in the chamber.

The discussion of the cooling loops is clarified by figures. These figures are based on the actual designs of the loops. A list of pertinent drawings is included in (2) GENERAL DISCUSSION.

(2) GENERAL DISCUSSION

The chamber is equipped with the following loops:

1) Bubble condenser located at the very top of the chamber.
2) Main chamber loop covering most of the wall of the top hemispherical part of the chamber.
3) Window cooling loops located at each chamber window.
4) Chamber cone cooling loop located at the conical section of the chamber wall.
5) Chamber support skirt cooling loop.
6) Piston ring area loop consisting of two separate finned tubes located above and below the piston rings.
7) Chamber pressure control loop located in the two-phase region below the piston.

In all cooling loops, heat removal is accomplished by vaporization of liquid hydrogen. The vaporized liquid is returned to the refrigerator where it is liquefied again and becomes ready for use as a refrigerant in the cooling loops.

Heat transfer between chamber liquid and liquid hydrogen in the cooling loop is accomplished indirectly in the main chamber and chamber cone cooling loop. In these loops an intermediate fluid, which may be hydrogen or mixtures of hydrogen, deuterium or neon, is used to control the temperature difference between chamber liquid and cooling loop fluid and reduce the thermal turbulence of the chamber liquid.

The flow of refrigerant is controlled by level or pressure. Since accurate level control in liquid hydrogen is difficult and expensive, the level controlled systems have been designed so that inaccurate level control can be tolerated. In some cases level control is proportional, while in other cases the level is controlled between two specific points. In that case, the valve admitting liquid hydrogen operates between two specific positions with either too much or too little flow for the equilibrium condition.

All cooling loops are connected by means of a gas and liquid line to gas and liquid headers in the so-called valve boxes. As the name implies, the valve boxes contain all the liquid level and gas pressure control valves of all the cooling loops of the bubble chamber.

Table I shows the capacity for heat removal of the cooling loops. The numbers are based on operation of the chamber with liquid hydrogen, a hydrogen refrigerator operating at a suction pressure of the compressor of 10 psig and the chamber pulsing at a rep rate of once per second. Column 1 shows the maximum capacity of the loop; Column 2 shows the anticipated load during bubble chamber operation. The numbers in Column 2 are estimated. The estimates may be greatly in error because data on heat generation and removal in bubble chambers equipped with pistons are almost non-existent. The total of the heat loads of the various loops represents the load on the refrigerator. This total number is probably more accurate than the individual numbers for the various loops.

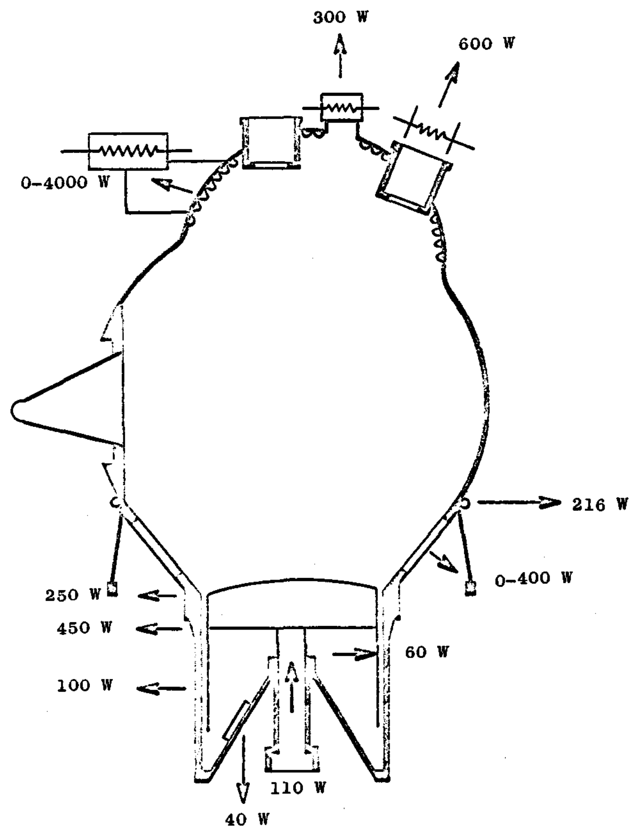
TABLE I

Item	Capacity in Watts 1	2
Bubble Condenser	300	100
Main Chamber Loop	4,000	0-4,000
Window Cooling Loop	1,000	500-600
Chamber Cone Loop	450	0-400
Chamber Support Skirt Loop	500	216
Piston Ring Area Loop	1,000	0-1,000
Chamber Pressure Control Loop	600	10-40

Figure 1 schematically shows the general arrangement of the chamber with the locations of the cooling loops and the anticipated steady state rate of heat transfer from the chamber fluid to the loops.

The complete list of drawings of all cooling loop components is as

FIGURE 1



SCHEMATIC ARRANGEMENT OF
COOLING LOOPS IN CHAMBER

follows:

		Drawing No.
1.	Bubble Condenser	
	Chamber Bubble Condenser Port Detail	2621.MD-25368
	Flange Details - Bubble Condenser	2625.MD-25102
	Bubble Condenser and Valve PV-190	2625.MD-25104 2625.MD-25092
2.	Main Chamber Loop	
	Chamber Head	2621.ME-25134
	Main Heat Exchanger	2625.ME-25094
	Mounting Details, Main Exchanger	2625.MD-33435
3.	Window Cooling Loop	
	Mounting Details, Window Heat Exchanger	2625.MD-33435
	Window Cooling Loop	2625.MD-25089
	Optical Fish-eye Assembly (Section)	2623.ME-25250
	Optical Fish-eye Assembly, #2 Window Flange Section	2623.ME-25256
	Optical Fish-eye Assembly, #2 Window Flange Plan View	2623.ME-25257
	Optical Fish-eye Assembly, Machine and Weld Drawings	2623.ME-25258
4.	Chamber Cone Cooling Loop	2621.ME-25172
5.	Chamber Support Skirt Loop	2625.MD-33420
6.	Piston Ring Area Loop	
	Lip Seal Section	2621.MC-25336
	Lower Piston Ring Cooling Loop	2625.MD-33418
	Upper Piston Ring Cooling Loop	2625.MD-33419
	Cylinder-Rod Guide Spacer Ring	2621.MC-25248
	Pump Loop Heat Exchanger	2625.MD-25091
7.	Chamber Pressure Control Loop	
	Piston and Ring Guide Assembly	2621.MD-25378
	Cylinder-Rod Guide	2621.ME-25163

The complete flow diagram of all the cooling loops of the chamber is shown on Drawing No. 2625.ME-25054.

All hydrogen systems of the cooling loops have been designed for a maximum pressure of 150 psig. All intermediate fluid systems have been designed for a maximum pressure of 150 psig. Every system which may be closed in by valves is protected by a full flow relief valve. These valves are capable of handling the maximum rate of vapor generation from heat transfer to the chamber. Calculations made to size and design the cooling loops are not given in detail in this report. They have been compiled in a notebook entitled, "Cooling Loop Calculations for the NAL 30,000 Liter Bubble Chamber".

(3) COOLING LOOPS

1. <u>Bubble Condenser Cooling Loop</u>

The loop has two functions, as follows:

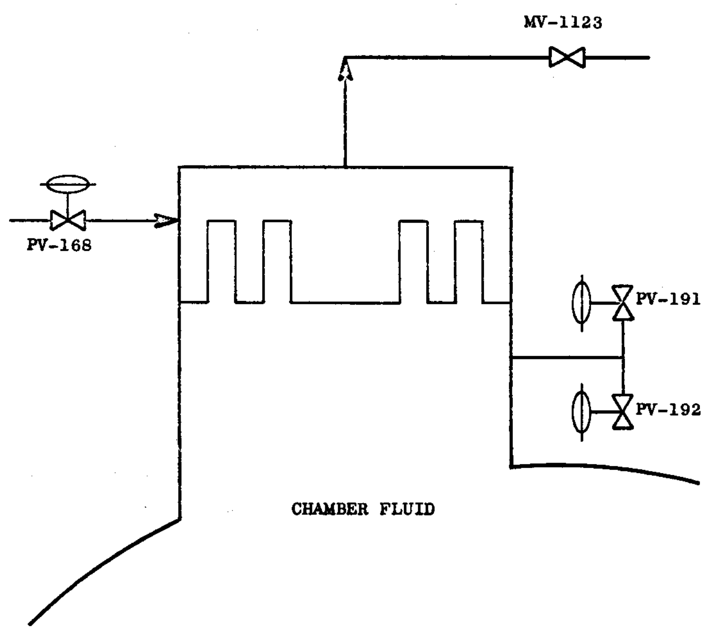
a) Condenses the vapor bubble in the top of the chamber during filling of the chamber.

b) Maintains the chamber full of liquid during normal operation of the chamber.

The flow schematic of the cooling loop is shown in Figure 2. The rate of condensation is constant until the 1" diameter tubes start to fill with liquid. The calculated rate of condensation is 300 watts, assuming liquid hydrogen boils in the condenser at 22.8°K and hydrogen vapor condenses at 5 atm in the chamber. At this rate vapor disappears at a rate of 145 cc per second.

Right below the bubble condenser there is an amount of vapor volume which cannot be condensed by the main chamber heat exchanger. The volume of this vapor is 17,000 cc. Therefore, the final vapor bubble in the chamber can be condensed in approximately two minutes, as long as liquid is supplied at the same time to the chamber from the space below the piston.

FIGURE 2



FLOW SCHEMATIC OF
BUBBLE CONDENSER LOOP

To maintain the chamber full of liquid during steady state operation, some heat needs to be removed from the top of the chamber. This is done by maintaining a level of boiling liquid hydrogen above the tubes of the bubble condenser. Control over the temperature of the boiling is possible, since the vapor space is in connection with the suction of the compressor through pressure control valve PV-188. If valve PV-188 is wide open, the maximum temperature difference and cooling rate is in existence. The exact rate of cooling is difficult to calculate because the coefficient inside the 1" diameter tube cannot be calculated exactly. In order to transfer heat in these tubes, warm liquid from the chamber needs to rise in the tubes and cold liquid will flow along the wall of the tubes in a downward direction.

2. Main Chamber Loop

The functions of the main chamber loop are as follows:

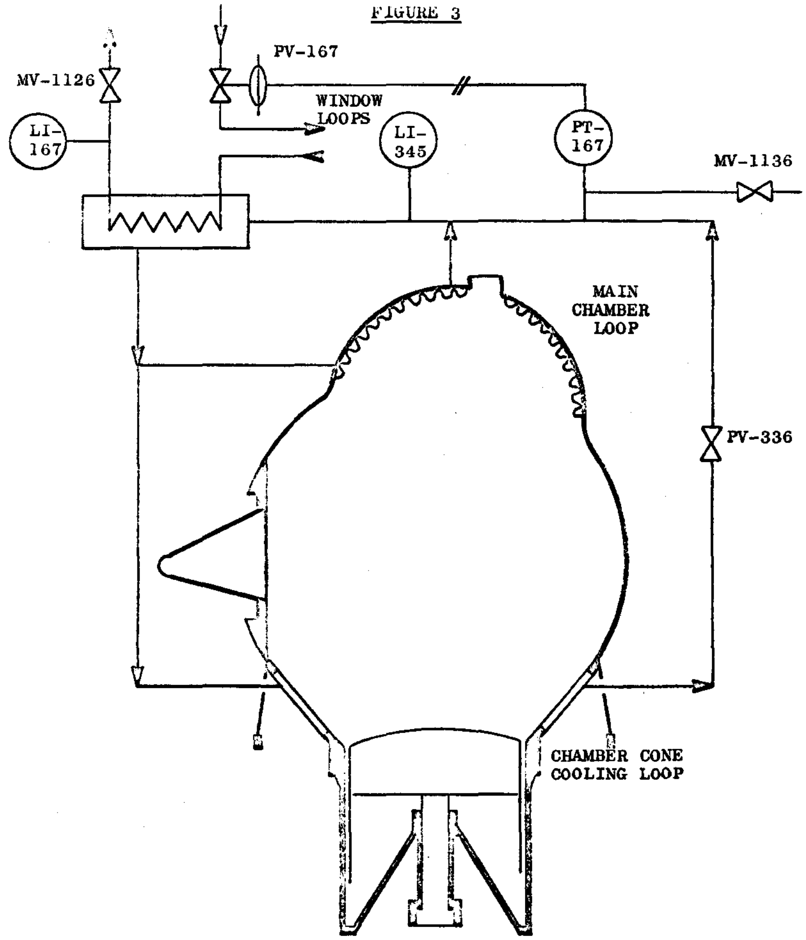
a) Maintain chamber liquid at a constant temperature during bubble chamber operation.

b) Provide cooling in a controlled way during cooldown of the chamber.

The flow schematic of the loop is shown in Figure 3. Figure 3 shows that the main chamber loop is tied in with the chamber cone cooling loop. During steady state conditions of bubble chamber operation, the heat exchangers in head and cone of the chamber contain a liquid which may be different from that of the chamber. This fluid in the cooling loop is called the intermediate fluid. The composition of the intermediate fluid depends on the composition of the chamber fluid. By changing composition of the intermediate fluid it is possible to match the boiling points and temperature difference between chamber and intermediate fluid, without the need for raising the pressure of the liquid hydrogen coolant to a very high value. The intermediate fluid transfers heat from the chamber to liquid hydrogen coolant in the main exchanger.

Liquid hydrogen from the hydrogen storage tank flows through con-

FIGURE 3



FLOW SCHEMATIC OF
MAIN CHAMBER LOOP

trol valve PV-167 to the main exchanger, after first having passed through the window cooling loop heat exchanger and window cooling loops. Hydrogen vapor returns through valve MV-1126 to the refrigerator. In the main exchanger hydrogen liquid level is maintained as a function of the pressure of the intermediate fluid. The control signal is provided by pressure sensor PT-167. In the main exchanger the intermediate fluid is condensed and the liquid runs under gravity force back to the exchangers located in the head and cone of the bubble chamber. Driving force is provided through the difference in density between liquid and liquid-vapor return column. The dimpled plate exchanger in the head of the chamber always operates in a flooded condition. That is, liquid intermediate fluid enters at a rate greater than required for 100 percent vaporization and a mixture of liquid and vapor returns from the dimpled plate exchanger to the main exchanger. The flow rate to the chamber cone loop can be controlled through valve PV-336 from the control panel in the control room.

During steady state operation, the intermediate fluid space is sealed off at valve MV-1136 and contains a fixed inventory. Gas can be added or removed from the system through this valve, which connects to hydrogen, neon, or deuterium storage tank and gas storage vessel B. The proper amount of intermediate fluid is indicated by LI-345. Since liquid hydrogen coolant is added to the system upon demand from PT-167, it is conceivable that the hydrogen could overflow when cooling is demanded in excess of the capacity of the exchanger. LI-167 is provided to cut off the liquid flow through closure of valve PV-167 at high levels.

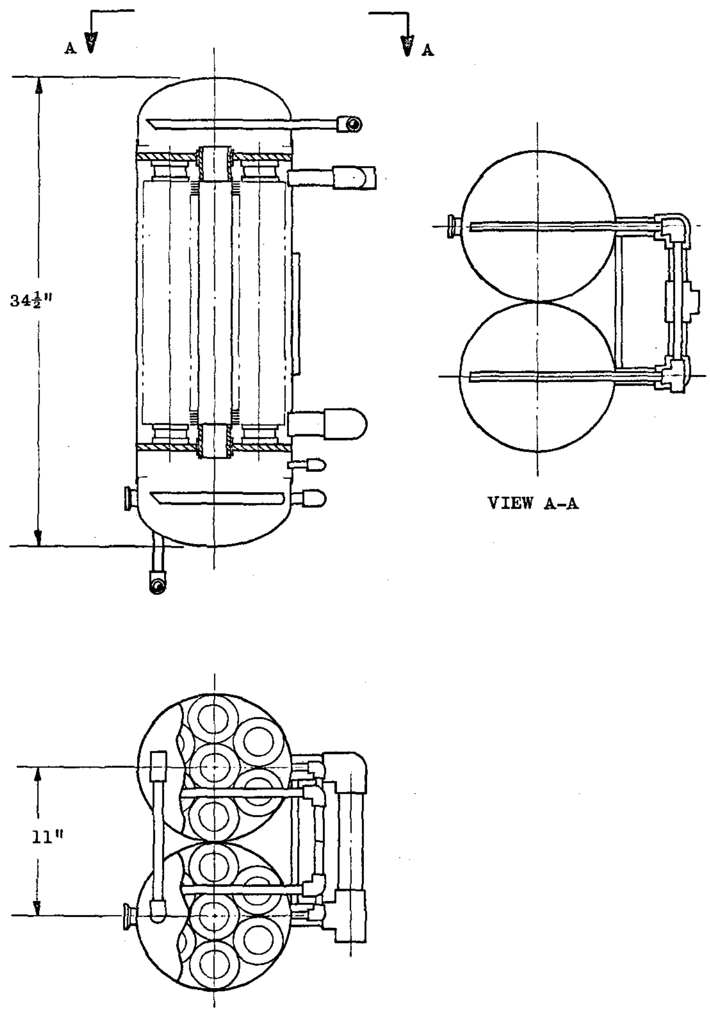
Control of cooling rate of the chamber during steady state is exercised through temperature control of the intermediate fluid. By maintaining the intermediate fluid temperature constant, chamber liquid temperature is held constant. It is possible that small variations occur in the rate of heat gain of the chamber liquid during operation. It is not necessary to control the main chamber loop for these perturbations, because the 30,000 liters of chamber liquid represent a tremendous heat sink. A persistent unbalance between heat input and heat removal from the chamber will show up as a drift of the chamber fluid temperature.

It is difficult to calculate the rate of cooling required from the main exchanger. In a reversible expansion and compression of the chamber liquid, a very small amount of heat is generated in the bulk of the fluid. Large amounts of heat may be generated in the piston ring area due to piston ring friction and leakage from cavitation or from effects on the walls of the chamber. It was decided that the main chamber loop should be designed to remove 4,000 watts of heat from the intermediate fluid, when chamber fluid is at 26°K and liquid hydrogen in the main exchanger boils at 22.8°K. By controlling valve PV-336 more or less of the 4,000 watts cooling capacity can be utilized in the chamber cone loop. Under normal conditions it is anticipated that the cone loop will provide little cooling to the chamber.

Figure 4 shows the main exchanger in which the intermediate fluid is condensed. Condensation takes place on the outside of the finned tubes; liquid hydrogen boils inside the tubes. Space limitations in the vacuum space dictated the use of two parallel assemblies, which are interconnected on both hydrogen and intermediate fluid sides. The assemblies are installed under a slight angle to maintain liquid level above the finned tubes for maximum heat transfer. Lower rates of heat transfer will be accomplished by lowering the liquid level of the boiling liquid hydrogen.

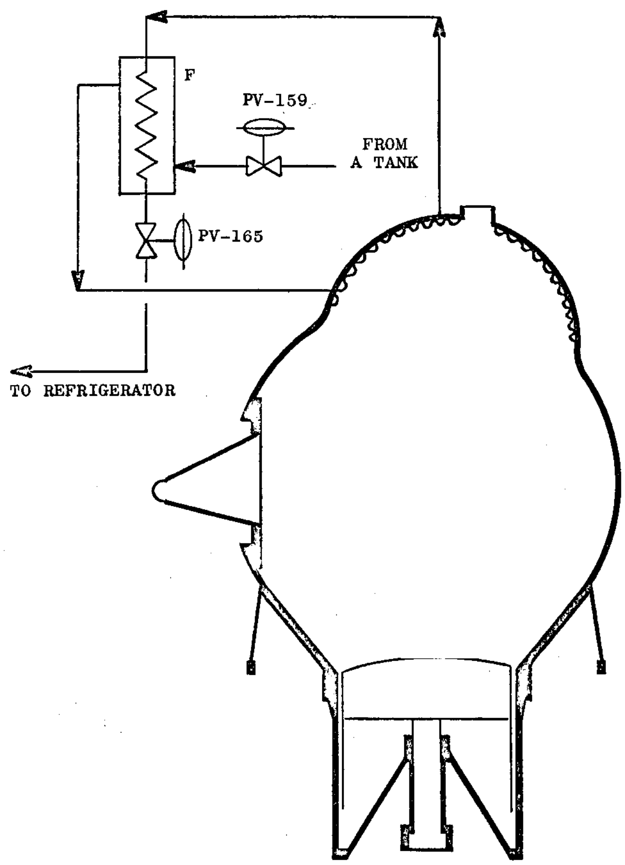
Chamber cooldown is accomplished through the use of the main chamber loop with flow of hydrogen gas directly from the cooldown exchanger F in valve box R. Figure 5 shows the schematic arrangement of the cooldown system. Liquid hydrogen from hydrogen storage tank A flows to heat exchanger F in valve box R, vaporizes, and enters the dimpled plate exchanger in the chamber head. The gas flow leaves the exchanger at the top of the chamber and returns through exchanger F to the hydrogen

FIGURE #4



MAIN HEAT EXCHANGER

FIGURE 5



FLOW SCHEMATIC FOR
CHAMBER COOLDOWN

refrigerator for reliquefaction.

With this arrangement the temperature of the gas entering the dimpled plate heat exchanger automatically adjusts to the temperature of the chamber. The maximum amount of refrigeration supplied to the chamber is determined solely by the rate of liquid flow. Only the heat of vaporization of the liquid is available, independent of chamber temperature.

It should be noted that the main exchanger used during steady state chamber operation provides a parallel path for hydrogen gas flow. Calculations show that the impedance of the main exchanger circuit is large compared to that of the dimpled plate exchanger. Therefore, only a small portion of the cooldown flow will bypass the dimpled plate exchanger.

It should also be noted that during steady state operation of the chamber, the intermediate fluid is separated from hydrogen only through valves PV-159 and PV-165. To provide positive shutoff, extra valves, PV-160 and PV-162, are provided.

By using a flow rate of 128 lbs/hr of liquid hydrogen, the rate of cooling of the chamber is 8.2 KW. At this rate the chamber (approximately 45,000 lbs) cools from 300 °K to 60°K in 48 hours. With this flow rate, the temperature of the wall of the dimpled plate exchanger closely approaches the temperature of the gas flowing through. The total change of temperature of the gas flowing through the dimpled plate exchanger is 45°K. Heat transfer between gas in the chamber and the dimpled plate exchanger is not very efficient, because heat transfer coefficients are low. In order to cool the bottom part of the chamber, heat needs to be transferred twice (from wall to gas and from gas to dimpled plate exchanger). Therefore, during cooldown there will be a large difference of the order of 100°K between the bottom and top of the chamber.

3. Window Cooling Loops

The functions of the window cooling loops are:

a) Intercept the heat leak from the environment before it reaches the chamber fluid.

b) Provide cooling of the window assemblies in a controlled way during cooldown of the chamber.

The flow schematic of the loops is shown in Figure 6. Figure 6 shows that the window cooling loops are arranged in series with the main chamber cooling loop. Liquid hydrogen from the storage tank always flows through the window loop exchanger, then the windows, back through the window loop exchanger to the heat exchanger of the main chamber loop.

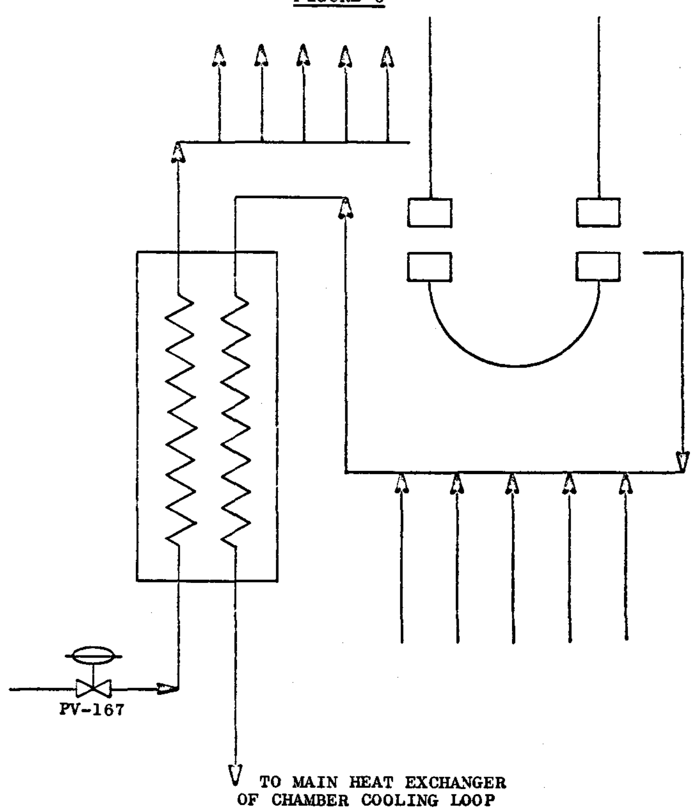
This arrangement makes control of coolant flow through the window loops a function of the requirements of the main chamber cooling loop. During steady state chamber operation, the window loops are cooled through vaporization of some of the liquid hydrogen which flows to the main exchanger. The temperature at which the liquid boils is of no consequence to temperature stability of the chamber liquid at the windows, since the window cooling loops are loosely coupled to the chamber.

During chamber cooldown, windows need to be cooled at the same rate as the head of the chamber and at a rate slow enough to prevent the occurrence of large thermal stresses. To achieve a controlled rate of cooling the window loop heat exchanger serves the same function as exchanger F for chamber cooldown.

The heat transfer coefficients in the cooling channels of the window are relatively low (see calculations). Consequently the windows cool rather uniformly and are never "shocked" by very cold fluid. The six parallel cooling loops to the windows are carefully matched on impedance to flow during installation and rate of cooling of individual windows should be nearly equal. If differences appear in the rate of cooling, the window which cools faster will slow down as soon as it advances by 10-15°K because the difference in temperature between window and gas disappears.

The maximum rate of cooling of the windows will be controlled through control of flow rate. Temperature measurements will be used to

FIGURE 6



FLOW SCHEMATIC OF
WINDOW COOLING LOOPS

control by. Since the chamber is cooled in no less than 48 hours, windows will also be cooled at this rate, unless temperature differences in the window itself dictate a slower rate.

During steady state bubble chamber operation, the window loop always sees liquid hydrogen on its way to the heat exchanger of the main chamber loop. Part of this liquid vaporizes in the window loops and the gas is separated from the liquid in the main chamber loop heat exchanger.

The heat leak of each window from conduction and radiation is approximately 90 W. Approximately 500-600 W are removed during steady state bubble chamber operation. Since the main chamber loop exchanger is sized for removal of 4000 W, the extra liquid hydrogen flow due to window heat interception is 15%. This extra flow can be accommodated easily by the main chamber loop heat exchanger.

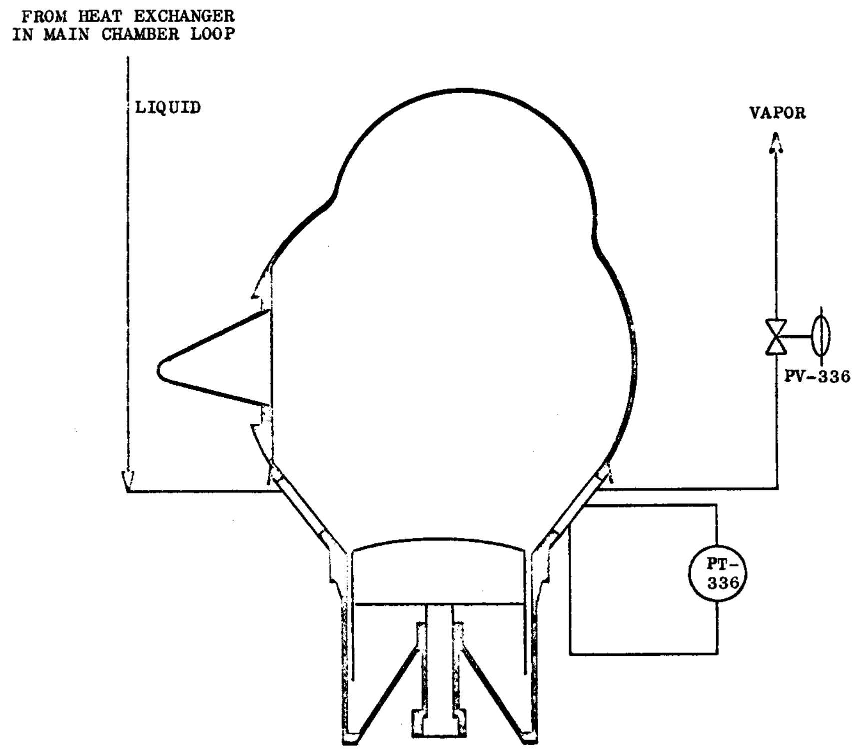
4. Chamber Cone Cooling Loop

Figure 7 shows the schematic arrangement of the chamber cone cooling loop. The function of the chamber cone cooling loop is controversial. The loop has been installed because of experience with the 7 foot chamber at Brookhaven National Laboratory, which shows evidence that cooling in the conical region of the chamber suppresses the formation of gas in the area of the piston rings during pulsing of the chamber.

It is anticipated that the cooling loop provided in the piston ring area will provide a fairly large amount of cooling in that region. If this amount of cooling were to be insufficient or if heat from piston ring friction penetrates into the chamber, cooling of the chamber liquid by means of the cone cooling loop may be helpful.

Because of the controversial nature of the cooling loop, it is not clear how much heat this loop should remove from the chamber. Clearly, if it removes a significant fraction of the total to be removed, the bottom of the chamber will be cold relative to the top. The maximum amount of heat which can be removed is dictated by the physical arrangement of the exchanger and the maximum temperature difference possible.

FIGURE 7



FLOW SCHEMATIC OF
CHAMBER CONE COOLING LOOP

Heat transfer between chamber and exchanger fluid takes place through a one-inch thick, stainless steel plate. Maximum heat transfer takes place when the liquid in the exchanger boils at the lowest possible temperature of 22.8°K and all of the surface of the cone is wetted. A total of 450 watts can be removed in this case when the chamber is filled with liquid hydrogen at 26°K.

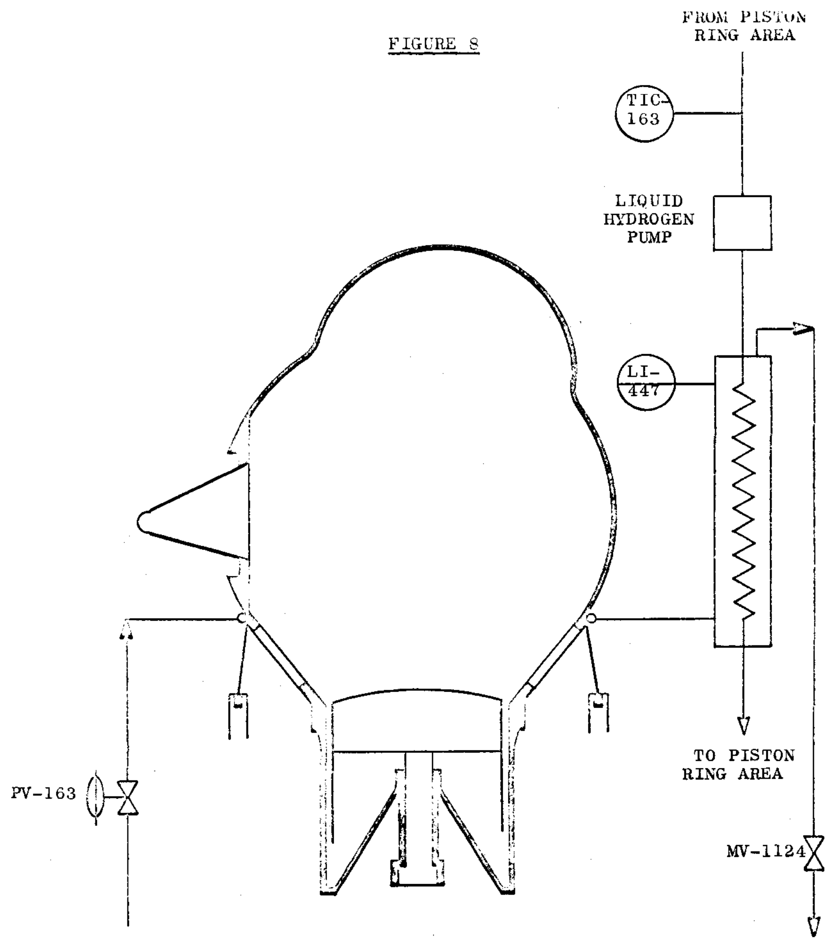
Control of the amount of cooling provided to the chamber is through liquid level of the intermediate fluid in the cone. The desired liquid level is determined by the operator on the basis of chamber requirements. Variation of liquid level is achieved by changing the impedance of the vapor line through valve PV-336. Differential pressure transmitter PT-336 and control station CS-336 allow maintenance of liquid level automatically.

5. Chamber Support Skirt Cooling Loop

Figure 8 shows the schematic arrangement of the chamber support skirt cooling loop. Heat flowing towards the chamber through the support skirt is intercepted by boiling liquid hydrogen in the channel mounted on the skirt. The tube is located at a small distance from the chamber, which provides a loose coupling between chamber and cooling loop temperatures. The total heat leak from ambient temperature to 25°K is 216 watts. The number is constant and independent of the chamber temperature.

Liquid hydrogen is admitted through valve PV-163. Excess liquid flows through the exchanger into the pump loop exchanger. The rate of liquid flow is determined by the requirements of the pump loop. The support skirt cooling loop is only cooled when the pump loop requires liquid. Under normal chamber operation the pump loop operates continuously. Only when the pump loop has problems will the liquid flow to the loop stop. In that case, flow to the chamber support skirt cooling loop will stop and heat leak through the skirt will penetrate into the chamber. This is undesirable, but it is anticipated that the chamber

FIGURE 8



FLOW SCHEMATIC OF
CHAMBER SUPPORT SKIRT COOLING LOOP

will stop pulsing when the pump loop is inoperative. The heat flowing into the chamber is then removed by the main chamber loop.

6. Piston Ring Area Loop

Figure 9 shows a loop employing a liquid hydrogen pump to provide cooling at four places. Following the flow diagram, the pump forces subcooled liquid into two parallel heat exchangers located between the piston rings. The discharge from these two exchangers is piped to an exchanger located above the piston ring and from there, to the space between chamber cylinder and piston skirt below the piston rings. Liquid is taken from the lowest spot in the chamber and returned to the pump suction. Heat is removed in a heat exchanger which contains liquid hydrogen boiling at 22.8°K. Liquid is added to this exchanger through valve PV-163 and the chamber support skirt cooling loop. The vapor from the exchanger is returned to the hydrogen refrigerator through valve MV-1124. The rate of cooling in the exchanger is controlled by variation of the liquid level. Automatic control is provided by a temperature sensor TIC-163 (vapor pressure thermometer) which provides a control signal for operation of PV-163. The pump loop is equipped with two valves, PV-337 and PV-338, which permit closure of the chamber system from the piping system of the cooling loop. The valves are mounted directly on the chamber to prevent drainage of the chamber fluid into the vacuum space in case of a line rupture. The loop is equipped with various temperature indicators and a flow indicator to allow analysis of the amounts of cooling provided to the various exchangers.

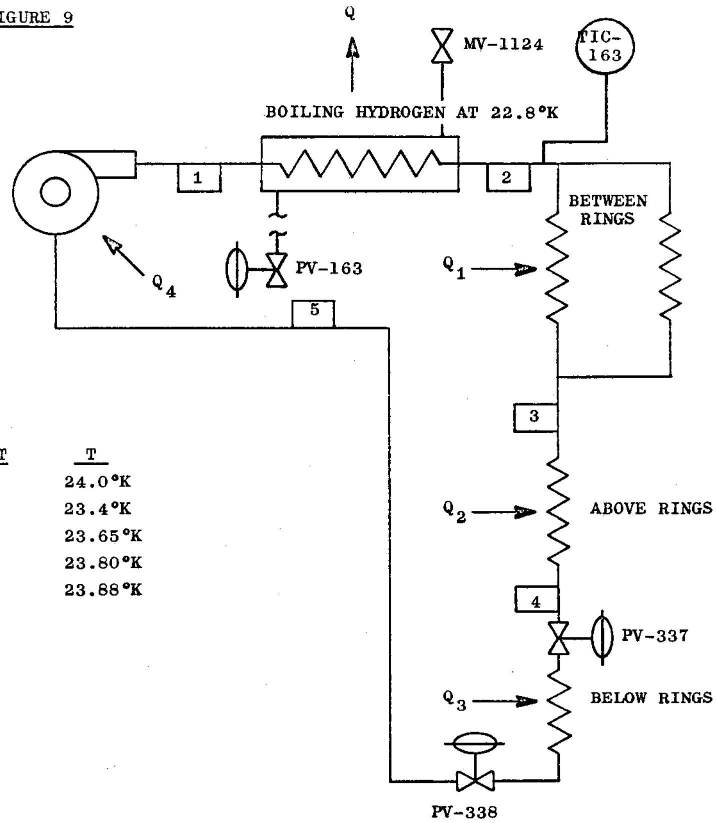
The amount of heat to be removed from the piston ring area is difficult to determine. The two main contributions to the heat load are:

a) Piston ring friction.

b) Irreversible expansion of liquid passing through the piston rings from areas of high to low pressure during chamber expansion.

Piston ring friction can be estimated roughly through assumptions

FIGURE 9



POINT	T
1	24.0°K
2	23.4°K
3	23.65°K
4	23.80°K
5	23.88°K

Flow Rate: 140 g/sec = 32 gallons/minute

$Q = Q_1 + Q_2 + Q_3 + Q_4 = 150 + 450 + 250 + 140 = 990$ W

FLOW SCHEMATIC OF
PISTON RING AREA LOOP

for friction coefficient, pressure differential, stroke and surface area over which the ring rides on the moving surface of the piston.

Of necessity the calculations will only provide a rough answer since tolerances alone for a 70" diameter ring makes bearing surface very difficult to determine. However, assuming a friction coefficient of .1, a total bearing surface area of 27.6 square inch (1/8" wide ring, 70" Dia.) and a pressure differential of 100 psi, the energy dissipated during one pulse with a 4" stroke is of the order of 200-250 Joules. This heat of friction is deposited in the ring and stationary surface over which the ring moves, only in those areas where the ring touches. Typically, liquid or gas leaking through the ring will not pass at these areas and heat of friction will be removed when the warm surface comes in contact with liquid above or below the ring.

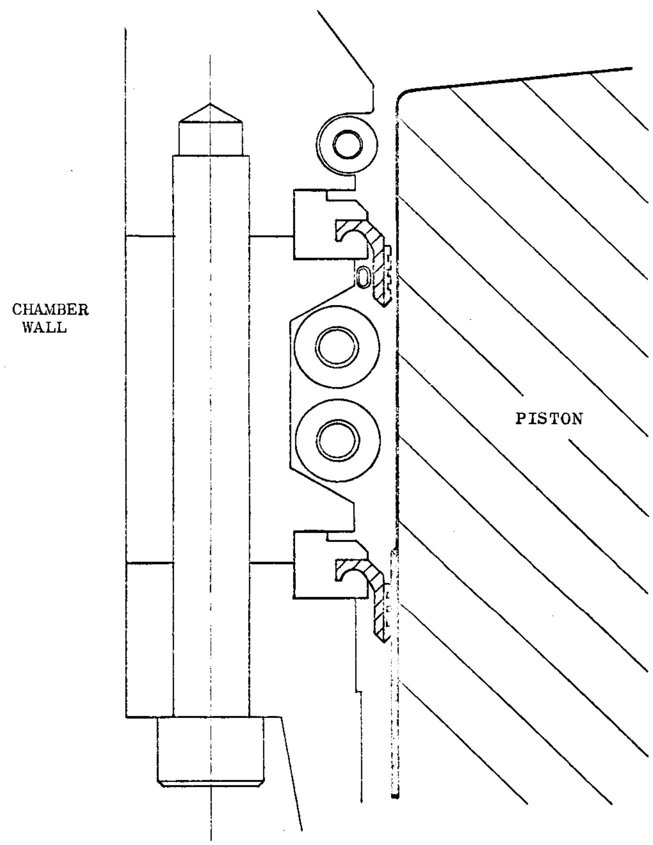
At the end of a pulse the situation is as follows:

Warm spots on the piston from frictional heat are located in the chamber fluid. Heat transfer will take place between chamber liquid and surface and heat will be deposited in the liquid of the chamber. Some frictional heat has been deposited in the piston rings, which will be transferred to the piston before and during the next stroke. Prior to the end of the pulse, some boiling may take place on warm surfaces of the piston at the time when the temperature of the liquid at the piston surface area is above the boiling point.

Prevention of boiling from piston ring friction during a pulse can only be accomplished through reduction of the temperature of the liquid in the vicinity of the rings. This is accomplished through the use of heat exchangers above and in between the piston rings. Figure 10 shows the schematic arrangement of these exchangers.

Some of the heat of friction is deposited in the volume between piston rings. A heat exchanger is located in this volume as is achievable and to remove the deposited heat of friction. The heat of friction of the lower piston ring is deposited above and below the ring. By cool-

FIGURE 10



SCHEMATIC ARRANGEMENT OF
HEAT EXCHANGERS IN THE PISTON RING AREA

ing the liquid on both sides of this ring, the heat of friction is removed.

Leakage of liquid and/or gas through piston rings from areas of high to those of low pressure results in so-called pluming. The design of the piston ring area has been carried out to minimize the leakage into the chamber past the top piston ring during the pulsing of the chamber. In order to lower the pressure below the top piston ring, the piston is equipped with a slight step as shown in Figure 10. Because of this step the volume between rings increases during the pulsing of the chamber. The step chosen provides a slight over-expansion (2%) of the volume between rings relative to the chamber. The choice of over-expansion is arbitrary since little is known about the leakage rate and fit of both piston rings.

During the pulsing of the chamber, the area below the lower piston ring increases in pressure and liquid in the region between piston skirt and cylinder wall is under pressure and does not boil. However, this liquid will leak past the lower ring into the volume between rings. In order to reduce the rate of boiling above the lower piston ring, the temperature of the liquid below the lowest piston ring should be as low as possible.

In summary, the piston ring area loop does the following in the piston ring area:

a) Removes heat of friction before it enters the chamber.
b) Reduces temperature of the liquid above, between and below the piston rings to the lowest possible value.

Figure 9 shows that a liquid pump is used to provide circulation of chamber fluid through the heat exchangers located above and between the piston rings of the chamber. The use of the pump is dictated by severe space limitations between and above the piston rings. The outside surface areas of the exchangers between and above the rings has been enlarged greatly to increase the heat transfer between chamber fluid and the wall of the exchanger. Boiling heat transfer inside the tubes yields a low coefficient of heat transfer. This is because most of the tubes are filled with gas rather than liquid and heat transfer takes primarily place between wall and gas and then from gas to liquid. The combination of these two effects results in a very low coefficient.

In order to improve the heat transfer, subcooled chamber fluid is driven through the tubes. In this case, heat transfer is excellent, but the flow rates need to be high enough to prevent boiling of the liquid anywhere in the pump loop.

The liquid pump is shown in Figure 11. The pump is equipped with submerged electric motor which requires approximately 120-150 W of power. The pump is installed in a dewar located at some distance from the chamber to reduce the magnetic field strength to which the motor is subjected.

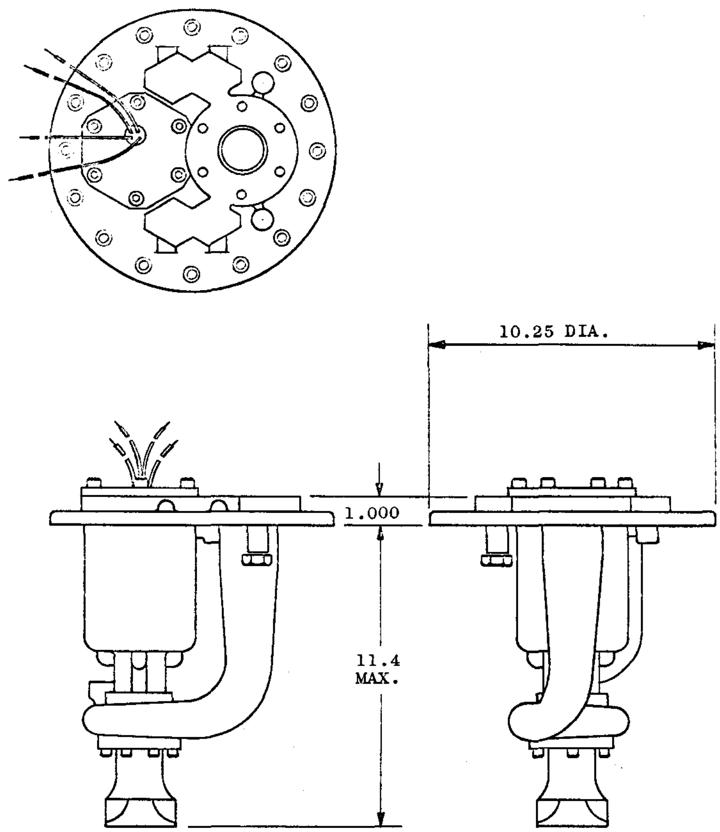
7. Chamber Pressure Control Loop

Figure 12 shows the schematic arrangement of the chamber pressure control loop. The heat exchanger of the loop consists of a dimpled plate welded to the conical section of the chamber. Liquid hydrogen is admitted to the exchanger through valve PV-164. Hydrogen vapor returns to the hydrogen refrigerator through valve MV-1125. The rate at which liquid hydrogen is added to the loop is controlled by a pressure sensor PT-164. The sensor provides a signal which is used for proportional control of the liquid flow through valve PV-164.

The operation of the chamber pressure control loop is rather complicated. During normal chamber operation, a gas bubble exists below the piston and the liquid at the gas-liquid interface is in equilibrium with the vapor. The liquid below the surface down to the bottom of the Z section is subcooled. At the very bottom liquid is removed for use in the piston ring area loop.

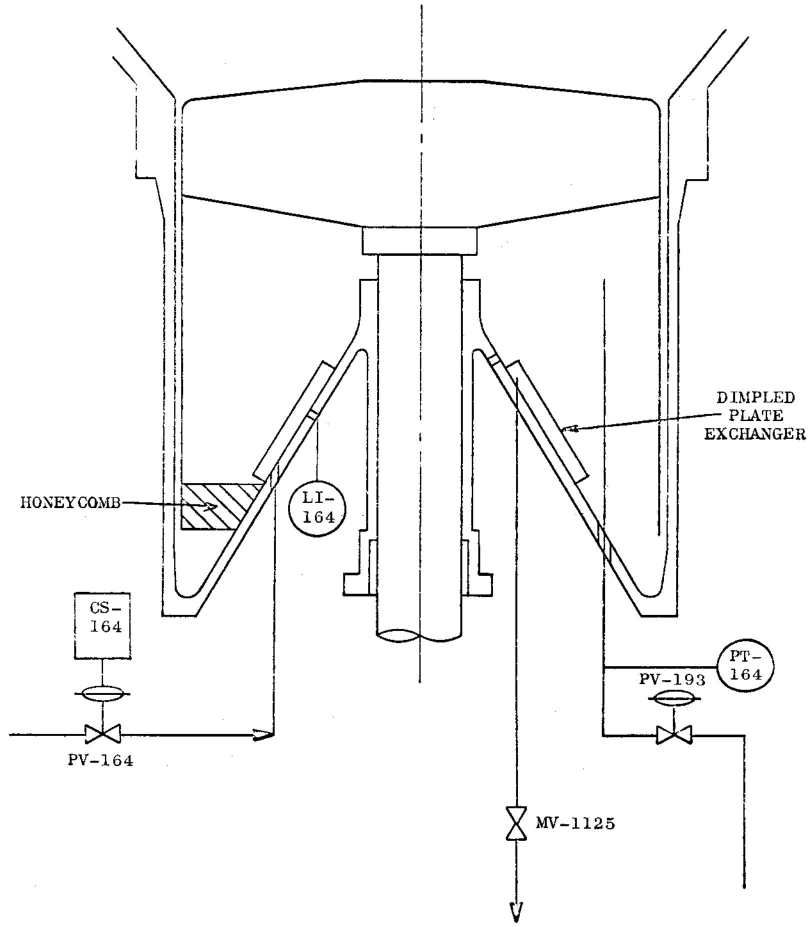
Stratification of liquid is maintained through use of a honeycomb material. The piston skirt separates two regions of different temperature. Outside the skirt liquid is cold; inside the skirt there is gas of a temperature slightly above chamber liquid temperature and stratified

FIGURE 11



LIQUID PUMP

FIGURE 12



FLOW SCHEMATIC OF
CHAMBER PRESSURE CONTROL LOOP

liquid. Heat input from the environment consists of conduction along the piston rod and some radiation through the insulation in the vacuum space. Total heat flux is of the order of 100 watts.

In order for the system to be controllable, the vapor in the Z section needs to be at least as warm as the boiling point of the chamber fluid at chamber pressure. The vapor is cooled through the piston skirt and by the liquid in the dimpled plate exchanger. The vapor is heated through the heat flux of the piston rod. Figure 13 shows the way in which the vapor circulates through the space below the piston with direction of heat flow.

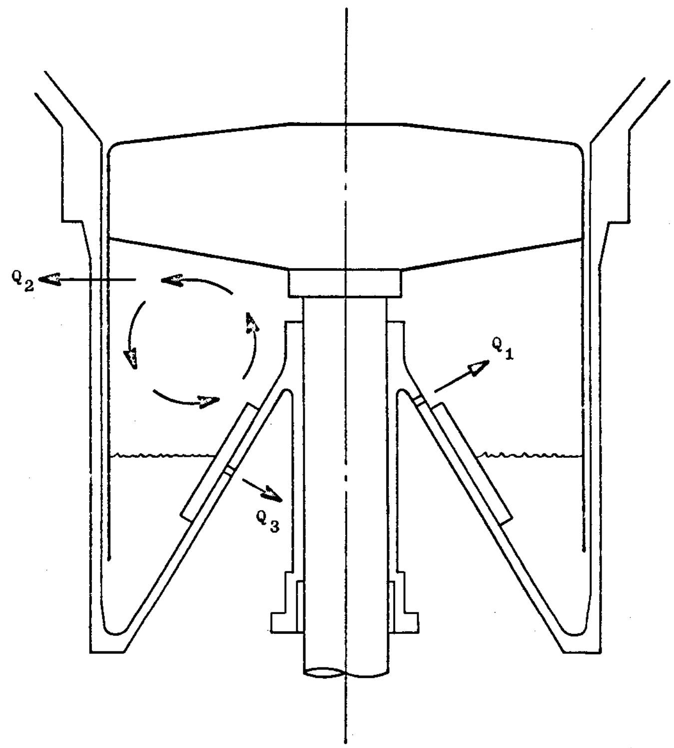
Under steady state conditions of bubble chamber operation some heat is generated through irreversibility of the compression-expansion cycle of the vapor bubble. By varying the liquid level in the dimpled plate exchanger on the cone, more or less condensation of vapor takes place. The system is slow in response and under normal conditions it does not need to respond quickly, since the mass in the Z section (vapor and liquid) represents a large flywheel.

During a chamber pulse the piston skirt moves downward into the liquid of the Z section and provides pumping action. It is necessary to make sure that this pumping action does not result in mixing of warm and cold liquid. Mixing will result in tremendously large amounts of heat being transferred from warm to cold liquid. Control of the pressure in the Z section becomes impossible and the subcooling of the liquid in the pump loop will be destroyed.

With changing conditions in the chamber proper, inventory change below the piston is required. When the chamber warms up, some liquid will be moved into the Z section and vapor may be bled through valve PV-193 to the proper storage dewar.

When the liquid in the chamber cools, vapor may be added from gas storage vessel B of the cryogenic support system. This vapor will be added at a temperature of 80-90°K. The dimpled plate exchanger will

FIGURE 13



HEAT FLUX AND GAS CIRCULATION
IN SPACE BELOW THE PISTON

then be used to condense this vapor. The rate of condensation is a function of liquid level in the Z section. The maximum rate of 600 watts is achieved when the liquid level in the Z section is below the dimpled plate exchanger.

(4) CONTROL OF THE BUBBLE CHAMBER

The following paragraphs outline the method by which the chamber liquid temperature is controlled during steady state operation, cooldown and warmup, and changing of the temperature level of the chamber:

1. Steady State Conditions

1.1 Window cooling loop and chamber support cooling loop are not controlled. The amount of liquid hydrogen vaporized in these loops is a function of the heat entering the loops. The loops always contain excess liquid since other loops are fed through these loops.

1.2 The temperature of the liquid in the chamber is controlled through the use of the bubble condenser loop, the main chamber loop, and the chamber cone loop. The total amount of heat to be removed is fixed and is dependent on the heat leak, irreversibility and pulse rate of the chamber. In order to maintain the chamber full of liquid without vapor bubble, the bubble condenser will operate most likely at full capacity (200-300 W). Control of this loop is by point sensor level which changes the liquid inlet valve PV-168 between two positions. One position supplies too little liquid and the other supplies too much. Pressure of the coolant in the loop will be approximately 30 psia.

The chamber cone loop will be operated by level control of the liquid in the cone (PT-336). It will be the operator's choice to select high, low or medium level.

The balance of the heat generated in or added to the chamber loop. This loop will be controlled by providing enough cooling to maintain the intermediate fluid at a constant selected temperature. PT-167 provides the signal. Since chamber heat input under steady state conditions will vary little, a constant temperature difference between chamber fluid and intermediate fluid is obtained, assuming that the dimpled plate heat exchanger in the chamber is always full. A change of liquid level in the cone will result in a change of liquid level in the dimpled plate exchanger or the main heat exchanger. It may be necessary to either add to or remove liquid from the intermediate fluid system.

1.3 The pressure of the chamber is controlled with the chamber pressure control loop located below the piston. Control is from a pressure signal which manipulates a valve, PV-164, to add more or less liquid hydrogen to the loop. This, in turn, changes the rate of heat transfer to the gas bubble.

1.4 In order to reduce the effect of irreversible heating and pumping of the piston and piston rings, liquid above, in and below the rings is subcooled substantially. The amount of subcooling is controlled through temperature measurement of the circulating liquid (TIC-163). The rate of heat transferred is varied through change of the heat transfer surface area in the pump loop exchanger.

1.5 In all cases, where liquid flow is controlled by temperature or pressure sensors, overflow protection is provided by liquid level sensors. These are LI-167 in the main heat exchanger, LI-447 in the pump loop exchanger, and LI-164 in the piston plenum heat exchanger. Liquid control valves will be shut off when liquid level reaches a predetermined point.

2. Cooldown of Chamber

During chamber cooldown only the dimpled plate exchanger in the chamber and the window heat exchanger are used. All other cooling loops are valved off until the chamber is cold. Control of rate of cooling of the chamber is exercised through variation of liquid flow rate. The use of window heat exchanger and F exchanger in valve box R makes it impossible to shock either chamber or windows with a fluid much different in temperature from that of the chamber or window.

3. Filling of Chamber

When the chamber is at 80°K or a lower temperature, liquid may be added through valve PV-189. At this time the bubble condenser and main chamber loop are used at full capacity to condense the cold vapor present in the chamber. At the same time when the chamber is being filled, the chamber pressure control loop will be started to condense vapor in the area below the piston.

4. Temperature Change of Chamber Liquid

After filling of the chamber, the temperature of the liquid most likely needs to be raised to the desired level. Electric heaters on the conical wall of the chamber with a capacity of 2KW can be used to raise the temperature of the liquid. At the same time excess liquid will move into the area below the piston. Pressure control will be exercised by operation of the chamber pressure control loop. If liquid level below the piston becomes too high, the loop becomes inoperative and gas needs to be vented through valve PV-193. With time, operators will become experienced and will learn to fill the section below the piston with liquid driven from the chamber during warming of the chamber fluid.

5. Shutdown and Liquid Removal from Chamber

When liquid is to be removed from the chamber, the main chamber loop and bubble condenser will stop operation. Gas of 80-90°K may be added to the chamber through valves PV-191 and PV-192 and liquid will be removed through valve PV-189.

6. Warmup of Chamber

The chamber will be warmed by disruption of the insulating vacuum. Electric heaters are located in the vacuum space inside the super-insulation to provide heat to the gas circulating in the vacuum space. The vacuum will be broken with helium gas to prevent condensation of gas on the walls of the chamber.

V. CRYOGENIC SYSTEMS

C. Failure Mode Analysis: HYDROGEN SYSTEM FOR A SINGLE FAILURE

Prepared by

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Cryogenic Consultants, Inc.

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V. C. Failure Mode Analysis: HYDROGEN SYSTEM FOR A SINGLE FAILURE

(1) INTRODUCTION

The safety report of the 30,000 Liter Hydrogen Bubble Chamber at NAL analyzes the various failure modes of the cryogenic system as shown on the flow schematics of NAL drawings 2625.ME-25050, -25051, -25052, -25053, -25054, and -25055 with the exception of that part of the bubble chamber located inside the chamber vacuum shell. The report is organized into the four following sections:

Section (2) contains a discussion of the basic safety hazards associated with the storage and handling of cryogenic liquids. Cryogenic liquids are divided into two groups, consisting of flammable and nonflammable fluids.

Section (3) contains a discussion of the safety criteria which were chosen for the design of the cryogenic system. The discussion shows that the criteria are consistent in dealing with the basic safety hazards and are reasonable from a standpoint of acceptable risk.

Section (4) deals with the most important general safety problems of the system. The fundamental approach taken in solving these problems and reducing the risks to acceptable levels is discussed. The section also deals with some of the important features of the environment of the system.

Section (5) covers the detailed failure mode analysis of the system. The documents used in this section are the engineering flow sheets of the system (NAL drawings 2625.ME-25050, -25051, -25052, -25053, -25054, -25055, and -33424) and drawings and specifications of equipment available at the time when the analysis was carried out.

Sections (2), (3), and (4) of this report can be read as a complete safety report of the system. Section (5) should be read when the reader is interested in the safety problems of a specific item or component of the system. These problems are analyzed and discussed in some detail in this section.

(2) BASIC SAFETY HAZARDS IN STORAGE AND HANDLING OF CRYOGENIC FLUIDS

The bubble chamber cryogenic system will deal with the following cryogenic liquids and gases: hydrogen, deuterium, neon, nitrogen, and helium. Three of these fluids are inert and the safety hazards are those associated with the cryogenic and pressure aspects of the system. Sound cryogenic design practice widely used in industry and laboratories is sufficient to provide a safe system.

A. Potential safety problems of the fluids of the system due to the cryogenic temperatures are:

a. At low temperatures, the ductility and impact resistance of most materials decrease. The exposure of unsatisfactory materials to cryogenic temperatures can lead to structural failures, which in extreme cases may be accompanied by fragmentation.

b. All materials expand or contract to some degree with temperature changes as indicated by their coefficients of expansion. In rigidly confined members or in components comprising several materials with widely different coefficients of expansion, stresses will obviously tend to develop over the broad temperature change from ambient to -423°F. If designs do not consider these factors, structural failures or binding of movable parts may occur.

c. Pliability, elasticity, and surface smoothness of seal and gasket materials can be radically altered as they approach -423°F. Resultant leakage problems may release hydrogen into the atmosphere where it has fuel potential.

d. Liquid hydrogen vessels and lines are carefully insulated to minimize heat leak from their surroundings. This connotes confinement. Since no insulation is perfect, there is always some heat influx into vessels and lines. Imperfections in insulation, such as loss of vacuum or settling or loss of powder, can lead to abnormal heat input. In either case, slowly or rapidly, vaporization and expansion take place.

Since liquid to gas expansion ratio for hydrogen is about 850, a completely confined vessel of liquid at one atmosphere, upon warming to 70°F, could have a pressure in excess of 12,000 pounds per square inch exerted on its walls. If adequate relief devices are not provided wherever liquid can be confined, the possibility of fracture is evident.

e. Liquid and very cold hydrogen gas exist at a temperature lower than the boiling point of air. As a result, should liquid or cold gas be vented through uninsulated lines, air could condense on exposed surfaces. Should this liquid drip or be blown onto adjacent structures not designed to withstand low temperature, structural failures might occur.

B. Hydrogen and deuterium are flammable over a wide percentage range in mixtures with air and oxygen. This fact introduces problems beyond the normal cryogenic problems in the design of the cryogenic system. The magnitude of the problems is a function of the size and physical configuration of the equipment of the system. Potential accidents become large when the system contains large quantities of the flammable fluids. Potential accidents involving hydrogen or deuterium as a flammable fluid may be classified as follows:

a. A leak or spill of liquid or gas without ignition.

b. A leak or spill of liquid or gas with immediate ignition.

c. A leak or spill of liquid or gas with delayed ignition.

d. An ignition of an accumulation of oxygen or air with hydrogen (deuterium) in a vessel or piping system containing hydrogen (deuterium) liquid or gas.

In order to ignite hydrogen (deuterium) it is necessary to combine three elements: air (or oxygen), hydrogen (deuterium), and an ignition source. The absence of any one of the elements makes it impossible to combine hydrogen and oxygen and generate a large quantity of concentrated energy.

The statement above implies that fundamentally it is simple to design a safe system for the storage and handling of hydrogen or deuterium. Inside the system, exclude air (or oxygen) and it is impossible to ignite. Outside the system, prevent leakage of hydrogen and deuterium or ignition sources and it is impossible to ignite. The safety hazard is then reduced to that of any other cryogenic system containing an inert fluid. In actual practice things are not this simple and this leads to the many and varied approaches to safety involving a cryogenic system containing hydrogen.

The classification of potential accidents into four groups is based on practical aspects. It is based on the difference in magnitude of the energy release realized. In general, a spill of hydrogen into the atmosphere without ignition is a rather harmless affair. Hydrogen has a low heat of vaporization and in the gaseous form, low density. Consequently, spilled liquid hydrogen vaporizes rapidly and the gas rises. If allowed to escape, the spilled hydrogen will have disappeared in a matter of a few minutes.

A spill of hydrogen with immediate ignition generally results in a very hot local fire, but not in a damaging pressure wave. Injury to personnel is limited to those in direct contact with the fire. The flame has a very low emissivity and personnel not directly in the fire will not receive burns. Equipment that is some distance from the fire and building walls is not damaged.

A spill of hydrogen with a delayed ignition generally results in a large fireball at the moment of ignition, combined with a pressure wave. The magnitude of the pressure wave is a function of the quantity of the flammable mixture and the geometry and strength of the enclosure in which the delayed ignition occurs. The pressure wave can be strong enough to lift the roof and demolish walls of the building in which the ignition occurs.

An ignition of solid air or oxygen in liquid hydrogen or cold vapor generates a very strong pressure wave. The magnitude of the energy released is a function of the quantity of oxygen involved.

In general, wall of piping and vessels will be ruptured and spillage of contained liquid or gaseous hydrogen follows.

The first three events occur in the air environment of the system; the fourth occurs in the cold parts of the system which normally contain hydrogen only.

When hydrogen leaks from a system, as for instance through a valve packing or the flanges of a liquid hydrogen line coupling, there may be no ignition at all, an immediate ignition, or a delayed ignition. It must be assumed that a delayed ignition may occur, accompanied by a destructive fireball and pressure wave. To limit the effect of a delayed ignition, the acceptable leakage rate is small. To eliminate the hazards after its initiation, the flow of hydrogen should be stopped. Sealing of the leak, especially when cold gas or liquid is escaping, has little chance of success. To stop the flow of hydrogen, the source of hydrogen should be sealed off.

To reduce the chances of the occurrence of a delayed ignition, the environment of the system should not contain ignition sources, such as open flames, sparking devices, or hot surfaces with a temperature of $920^{o}K$ or higher. Nonsparking electrical devices, such as insulated wiring, induction motors, and enclosed electrical systems with an effective inert gas atmosphere, are not sources of ignition.

(3) SAFETY CRITERIA FOR THE DESIGN OF THE CRYOGENIC SYSTEM

A safe cryogenic system is one in which energy generated and released from chemical reactions and/or the cryogenic aspects of the fluids is minimized to sufficiently low levels to prevent injury to personnel and extensive damage to equipment. Large amounts of energy may be generated when hydrogen or deuterium combines with oxygen. Large amounts of potential energy may also be generated when a cryogenic liquid sealed in a closed system receives heat and is not allowed sufficient room for expansion.

The system is designed to prevent the occurrence of an unacceptable accident in case a single failure occurs. Rupture of a system with a large inventory may release large quantities of hydrogen or deuterium into the bubble chamber building or into the atmosphere directly outside the building. To limit the release of energy from ignition of a mixture of hydrogen and oxygen (air) to levels which will not seriously injure personnel or damage equipment, the rate of hydrogen release into the atmosphere must be controlled to acceptable levels.

It should be realized that in practical cases it is impossible to generate a combustion of hydrogen with a release of energy equivalent to the detonation of a stoichiometric mixture. In other words, the combustion of hydrogen in an air atmosphere is inefficient when considered from a standpoint of "yield".

Some experiments have been carried out to determine the magnitude of a pressure wave generated from a certain quantity of spilled liquid hydrogen in an enclosure of fixed volume. Data [2] indicate that a delayed ignition of a quantity of hydrogen gas representing less than 8% of the containment volume results in a pressure wave with a maximum value of .1 psig or less. The bubble chamber building will have a contained volume of some 75,000 to 90,000 cft. Eight percent of this volume is 6,000 to 7,200 cft of hydrogen gas.

It appears reasonable to allow the total leakage into the building to be a small fraction of this number. A total of 1,000 scft of hydrogen leakage into the building was chosen as the maximum quantity which may be vented or spilled in case of a failure. In addition to setting a limit on a total quantity spilled, a continuous tolerable rate of leakage shall be specified. In this case, hydrogen will rise to the ceiling of the building and will be removed at a more or less constant rate through the ventilation system of the building. Since hydrogen or deuterium rises rapidly due to its low density [3,4], accumulation of hydrogen or deuterium in the building does not occur.

It appears reasonable to tolerate a continuous leakage rate of 2 g/sec. (approximately 50 scfm) from potential leaks.

In areas outside the bubble chamber building with extremely good ventilation and essentially no containment, tolerable leakage rates may be higher than in the bubble chamber building. The maximum rate of release of hydrogen or deuterium from a failure will be less than 10 g/sec. (approximately 250 scfm). A total of 15,000 scft in any single failure will be the limit of an instantaneous spill.

In order to determine the required minimum distance between two or more separate storage tanks and the building, an analysis needs to be made of the effects of a spill of liquid hydrogen from one tank on the other tank and on the building. The postulated spill may take one of two forms, as follows:

a. Large instantaneous spill with the duration of the effects equal to the time required to vaporize and remove all spilled liquid.

b. A continuous spill from a pipeline break for the length of time required to remove all stored liquid from the tank through the broken line. Length of time may be as much as one hour.

When the spill occurs, the liquid and gaseous hydrogen may be ignited. Two occurrences need to be evaluated, as follows:

a. Immediate ignition.

b. Delayed ignition.

To establish reasonable criteria for the facility, experimental and theoretical work done by the Arthur D. Little Company in 1958-1959 has been reviewed. The work was done under an Air Force Contract (AF 18/600) - 1687 C-61092) and a considerable portion of the work was reported on in an interim report dated January 15, 1959. [1]

Immediate Ignition

The effects of an immediate ignition from a spill were analyzed and tested and heat transfer to structures was determined. The following are the basic assumptions made for this study:

Radiation effects from a fire are computed for three different occurrences, as follows:

1. A fire resulting from an instantaneous total spill of the contents of a storage tank into a diked area.

2. A fire at a pipeline break midway between two tanks at a point where flow to the line could be shut off.

3. A fire at a pipeline break near a tank where the flames would persist until all liquid contents are consumed.

To calculate the maximum probable effects from these three conditions, the following limiting assumptions were made:

1. The thermal flux density is as determined by experiment and varies with distance according to theory (see Figure 1).

2. The surrounding atmosphere neither absorbs nor emits radiation.

3. There is a 50% exposure of the receiver's surface area to radiation from the flame.

4. Conduction and convection effects of the fire will have a negligible influence on the receiver (experimental evidence suggests that the convection acts to draw cold air toward the fire--not to cause hot air to pass over the tanks).

5. In fires resulting from large spills, the flames are vertical and reach a height of 150 ft (maximum height of flames in 5,000-gal spill tests). The width of the flame is bounded by the walls of the dikes which are spaced equidistant between the tanks.

6. Burning time in large spills is 14 sec/in of pool depth (as estimated from evaporation-rate data).

7. In pipeline breaks, the flame volume is proportional to liquid flow rate. The initial assumption is based on linear consumption rates and maximum flame volume, as determined in 5,000-gal spills. It is further assumed that flame height to flame diameter is in the ratio of 5:1.

8. In a pipeline fire occurring between tanks, shut-off of the

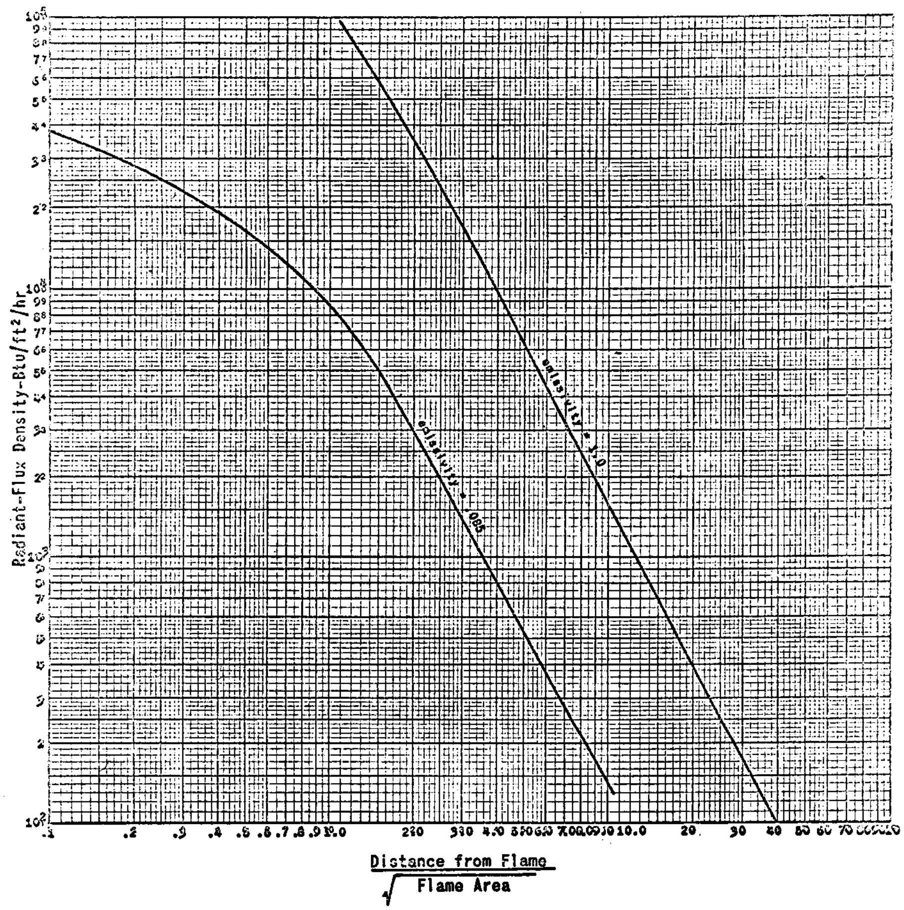

Figure I

RADIANT-FLUX DENSITY OF HYDROGEN FLAME

T_F = 3720 °F

liquid hydrogen flow is accomplished within 5 minutes.

9. In a pipeline fire occurring near a tank where shutoff cannot be achieved, the flow rate of liquid hydrogen feeding the fire is determined by calculation using the following assumptions:

a. Initial tank pressure = 5 psig.

b. Initial ullage = 10%

c. Pressure decrease within the tank during emptying is proportional to increase in tank free volume.

d. Flow rate determined by tank pressure and liquid head with a discharge coefficient of 0.6.

e. A 6-inch diameter pipeline used for 60,000 lb. tank; pipeline sizes for other capacity tanks determined from assumption that line area is proportional to tank volume. (Use of a different pipe size that assumed herein could cause a significant difference in the radiation effects, since both the quantity and duration of the liquid flow would be affected.)

10. Storage tank specifications for a 10,000 lb. capacity are as follows:

a. Shape = spherical.

b. Inner shell diameter = 16.5 ft.

c. Outer shell diameter = 18 ft.

d. Outer shell construction = 3/8-inch thick, low carbon steel.

e. Tank coating = aluminum paint (absorptivity = 0.3).

f. Heat-transfer coefficient across vacuum = .01 Btu-in/ft^2°F-hr (Reference NBS Cryogenic Data Book, 1956).

11. For all type fires, hazards to personnel are estimated on the basis of the following assumptions:

a. The total flux required to produce 2+ median burns (second-degree burns in 50% of exposed persons) can be derived from the following equation:

$$Q_c = 3.56t^{0.196}$$

where Q_c = total flux (cal/cm^2) and t = exposure time (sec).

b. Unprotected personnel within the immediate vicinity of a sudden flare-up can reach a safe distance within 8 sec. (initial discomfort would cause him to leave). Serious injuries will result, therefore, only at distances where the total flux received in 8 sec. is equal to or greater than Q_c.

c. Safe distance for unprotected personnel is that for which the total flux received in 30 sec. is less than Q_c. (Computations based on the above equation and the emission characteristics of the liquid hydrogen flame show that the minimum distance changes only slightly for longer exposure--see Figure 2).

Radiation Effects on Surrounding Storage Tanks

The radiation effects on a 10,000 lb. storage tank from the three occurrences postulated above are shown in Figure 3.

The results indicate that a line break with valve closure limiting the fire to less than 5 min. does not result in a dangerous rise of the temperature of the outer shell of adjacent tanks at a distance of 5 feet. A complete spill of the liquid will also result in a moderate temperature rise of the shell of adjacent tanks at 5 feet of 480°F. Only a line break near the tank, which cannot be sealed off, will result ultimately in exceeding the safe shell temperature of 600°F. The distance of the lines depicting the 5 min. and 84 min. duration suggests that the safe limit of 600°F will be exceeded after a period of some 60 min.

The situation becomes better when the following precautions are taken:

1. Water is sprayed on the tanks in the area of the fire. With water spray it is possible to limit the temperature of the outer shell of the tanks to less than 600°F.

2. A postulated break of a liquid line between the tank and the shutoff valve probably results in a flame directed at the building. In order to protect the building wall, either water or a fire resistant material needs to be used to maintain integrity during the

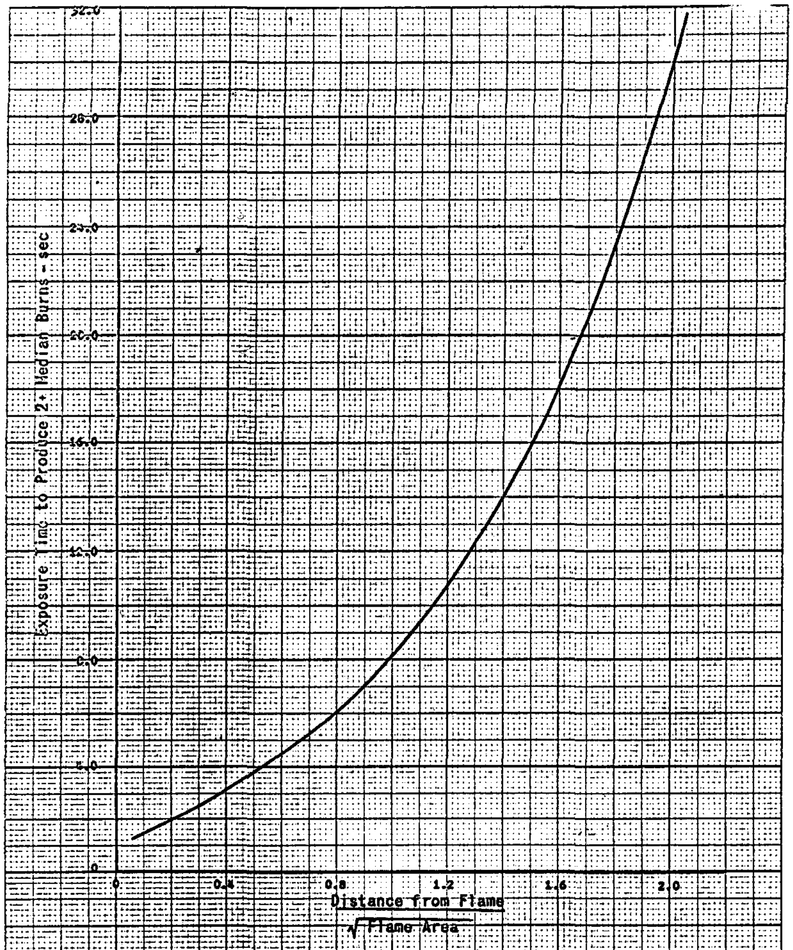

Figure 2

EXPOSURE TIME TO HYDROGEN FLAMES PRODUCING 2+ MEDIAN BURNS

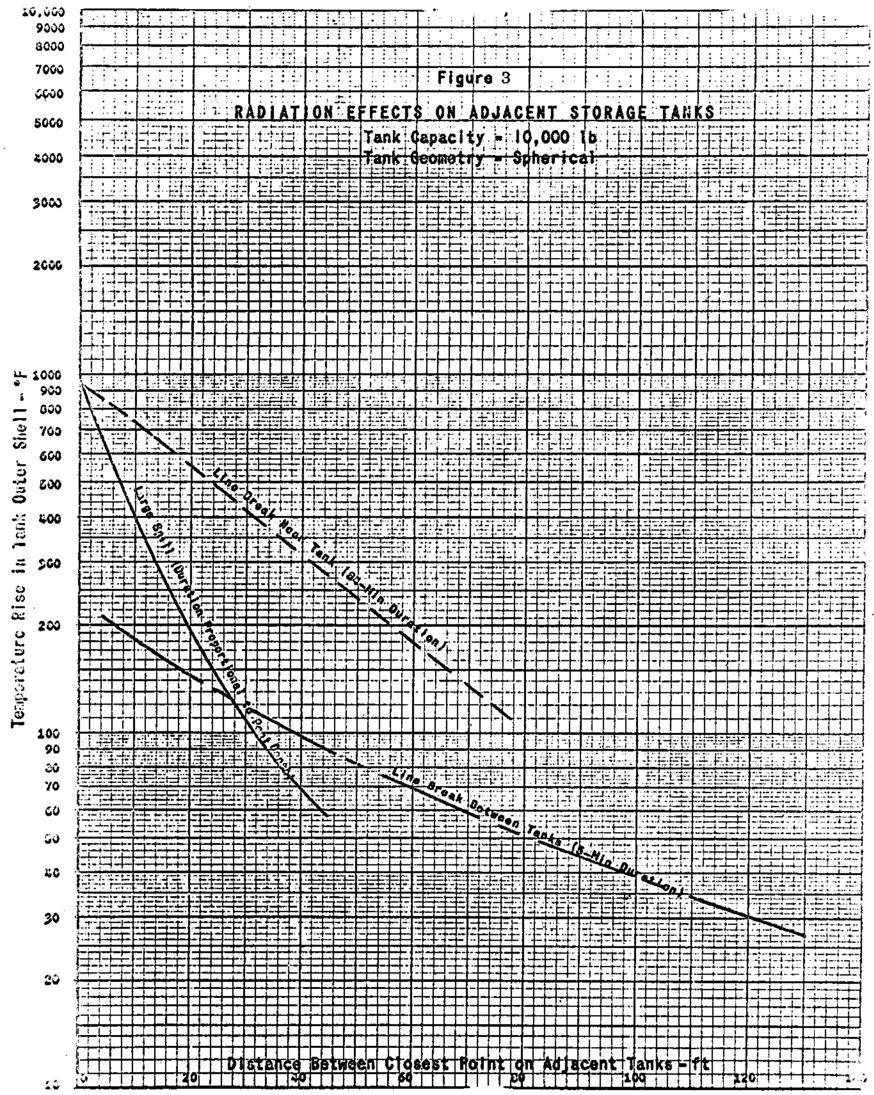
Figure 3
RADIATION EFFECTS ON ADJACENT STORAGE TANKS
Tank Capacity = 10,000 lb
Tank Geometry = Spherical
Temperature Rise in Tank Outer Shell - °F
Distance Between Closest Point on Adjacent Tanks - ft
Line Break Near Tank (30-Min Duration)
Large Spill (Duration Proportional to Pool Dia)
Line Break Between Tanks (5-Min Duration)
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
20
40
60
80
100
120

period of the fire. It is obvious that this type of break will not result in direct flame impingement on adjacent storage tanks since the tanks are shielded by each other.

3. The ground area under the tanks is sloped in a direction away from the building. Since the evaporation rate of liquid is at a velocity of one-inch per 14 sec., the liquid will be consumed quickly after the spill is finished. All equipment in the area is then in the category of short duration fires.

4. The exposed piping area between tank and shutoff valve is only one to one-and-a-half feet long. The probability of a break in this area resulting in a complete severance of the pipe is extremely small. The probability may be made smaller by providing mechanical protection of the piping in this area. Breaking of a pipe downstream of the shutoff valves is in the category of short duration pipeline break, as long as the valves are closed immediately upon a signal of fire detection. All liquid valves are interlocked with the fire detection system.

Delayed Ignition of Spilled Hydrogen

The previous discussion is based on the assumption that the spilled hydrogen is ignited instantaneously. Upon immediate ignition there will not be a significant pressure wave and no damage to the environment from pressure effects.

A delayed ignition is potentially the most serious condition for the storage facility. A considerable quantity of hydrogen in the vapor form may be mixed with air and ignition will result in a pressure wave. The magnitude of the pressure wave will be determined by the configuration of the storage area. The two walls of the building present a semi-confined area and the ignited hydrogen can only expand in three directions. This will generate some pressure. The walls need to be blast walls with an overpressure rating of 3 psig. Mechanical equipment in the area consisting of piping and vessels will take an overpressure of 3 psig.

NASA Quantity-Distance Criteria

NASA Technical Memorandum, NASA TMX 52454, covers the know-how and long experience of the Lewis Research Center in the handling and utilization of hydrogen. The manual is an integral part of the Lewis Safety Program and the contents are used as a guide for other NASA centers. Section 6-c deals with the storage of liquid hydrogen. The following is a direct quote from this section (page 37) and appears applicable to the situation at the NAL 30,000 Liter Bubble Chamber:

> "No quantity-distance relations have been established for operations involving liquid hydrogen alone, such as pump or heat-transfer tests. The work and the conditions under which it is carried out are so variable that no hard-and-fast rules can be set down. Each test setup must be considered separately to determine the possible results of accidents, keeping in mind the likelihood of contamination by liquid air and the danger of detonation if gaseous hydrogen-air mixtures are formed in confined spaces."

Conclusions

The spacing between individual storage tanks of 5 ft. is reasonable, provided the following measures are taken:

1. Mechanically protect liquid piping between tank wall and shutoff valve to make complete severance of pipes impossible.

2. Protect the building wall with a fire-retarding substance for a fire lasting up to one hour.

3. Provide water spray on piping and tanks in the area between building and tanks.

4. Interlock liquid valve closures with detection of fire in the area.

5. Provide a sloping ground below the tanks to move spilled liquid in the shortest possible period of time from the tank area and vaporize it in a region away from equipment and building.

The spacing between building walls and tanks of 13 ft. is reasonable, provided the following measures are taken:

1. Provide the building and walk-way with a wall strong enough to withstand an overpressure of 3 psig.

2. Provide fire protection of these walls.

Other safety criteria to be used are those normally accepted in the design of sound cryogenic systems. They are:

a. Wherever practical, pressure vessels and piping will be designed in accordance with ASME Code for Unfired Pressure Vessels, Section VIII, and ASA Piping Code for Petroleum Refinery Piping, Section B31.3.

b. All cryogenic systems will be equipped with pressure relief systems which are sized to handle the maximum flow rate which may be anticipated from loss of insulation, failure of valves, etc. without exceeding the design limits of vessels and piping.

c. Area classifications will be in accordance with the National Electric Code.

d. Instrumentation and other electrical equipment will be designed in accordance with procedures in effect at other bubble chamber installations.

e. Materials of construction for vessels and piping will be satisfactory for service at low temperatures.

f. Relief valves and discharges from control valves used to vent hydrogen will be manifolded to a vent system (or systems) equipped with weather covers and nitrogen gas purge connections. The hydrogen gas will be vented at an elevation 10 feet above the nearest building.

(4) IMPORTANT SAFETY PROBLEMS OF THE SYSTEM

The previous discussions under Sections (2) and (3), coupled with practical experience gained in the operation of many large-scale liquid hydrogen systems, show the following to be the major safety problems of the system:

Solid air or oxygen accumulation in refrigerator piping and vessels, liquid storage tanks, and vacuum jackets.

Release of hydrogen into the atmosphere from leaking joints or outright breaks in equipment.

The presence of ignition sources of various types which may ignite spilled hydrogen at any time after the spill occurs.

Fire and possible pressure wave from an ignition of hydrogen in air or solid air in hydrogen.

Separation of components of the system containing flammable liquid or gas from components containing air during periods of maintenance or modification.

Generation of excessive pressure in components due to failure of insulation and/or relief devices.

Nonsuitable materials for low temperature service.

Building and site ventilation and purging of equipment containing ignition sources.

Operator training and operating procedures.

A. Accumulation of Solid Air or Oxygen in Refrigerator Piping and Vessels, Liquid Storage Tanks, and Vacuum Jackets

Practical experience with hydrogen liquefiers and refrigerators shows that occasional explosions occur in the low temperature piping, especially in the area around the J-T expansion valve. The occurrence of these explosions normally is associated with fairly frequent plugging of piping and the J-T valve itself. The plugging occurs when adsorbers, used to remove impurities from the high pressure gas stream, break through. The breakthrough is a result of operating the adsorber for too long a period of time before reactivation restores the adsorber bed capacity for impurity removal.

Adsorption of air on an adsorber bed is selective[5]; oxygen is adsorbed preferentially since it has a higher boiling point than nitrogen. As a result of this, the impurities breaking through the bed initially consist primarily of nitrogen. Plugs downstream of the adsorber consisting of nitrogen are not a safety hazard. Also, experience indicates that these plugs can be extruded to some extent and moved along the flow path of the system.

If the adsorber bed is used too long, oxygen finally will break through. Experience indicates that solid oxygen cannot be extruded very easily and that a rupture or break in a solid oxygen plug may provide the ignition source for the initiation of an explosion. In order to remove the possibility of occurrence of this sequence of events, the refrigerator is equipped with a "deoxo" unit in the high pressure hydrogen gas stream to the refrigerator. Oxygen in trace quantities combines with hydrogen and the gas stream becomes completely inert.

To insure the fact that oxygen only occurs in trace quantities, the compressor system is equipped with a bypass or kickback valve between high and low pressure streams which automatically maintains the suction line of the compressor at a pressure above atmospheric. Leakage of air is reduced to diffusion against a positive pressure differential.

The refrigerator is also equipped with a dual set of adsorbers which are sized to be completely reactivated before breakthrough occurs in the on-stream unit. It should be realized that operators need to handle the equipment in accordance with the established operating procedures and not persist in continuation of the operation of the refrigerator when plugs develop.

Reactivation of adsorbers releases the adsorbed impurities. During the reactivation process, flammable mixtures may exist in the adsorber. In order to reduce the possibility and magnitude of an ignition, the adsorber is warmed after high pressure hydrogen gas has been removed from the adsorber. Since the adsorbers are parallel units, the system relies on tight shutoff valves to prevent hydrogen gas leaking into the adsorber during reactivation. The refrigerator is equipped with high-quality shutoff valves.

The accumulation of solids in the storage tank cannot be evaluated during operation of the system. Solid air, nitrogen, or oxygen has no measurable vapor pressure at liquid hydrogen temperature and it is not feasible to obtain representative samples from the liquid hydrogen storage tank. Experience in liquid hydrogen generation plants indicates that accumulation of solids in storage tanks is extremely small when the plant operates smoothly without plugging. The accumulation in the tank is measured after long periods of operation (6 months - 2 years) by emptying the tank, warming the tank while an impurity accumulator is attached to the tank, and analyzing the gas contained in the accumulator. The absence of solids in the liquid tanks of the bubble chamber can only be guaranteed by careful evaluation of the operating experience of the refrigerator and an occasional warming and analyzing of the contents of the hydrogen storage tank. The liquid deuterium and neon tanks are expected to be filled once and then maintained without continuous flowing in and out of the tank. Consequently, it is not expected that impurity levels will build up with time in these tanks.

The accumulation of solid air in vacuum jackets of low temperature lines and vessels occurs when small vacuum leaks exist. Accurate record keeping and recording of vacuum data will indicate at an early stage the occurrence of air leaks. If the equipment is used for short periods of time between warm-ups, accumuation of air is not large and does not present much of a hazard. Careful attention by the operators with an early decision to repair the vacuum leak will prevent the accumulation of large quantities of solid in equipment which is maintained at low temperature for extended periods of time.

B. Release of Hydrogen Into the Atmosphere from Leaking Joints or Outright Breaks in Equipment

The discussion in Section II indicates that the release of hydrogen into the atmosphere is the major hazard of the system. A single failure of many parts of the system results in leakage of hydrogen gas or liquid into the atmosphere. The provision of a double barrier to prevent spilling of hydrogen from a single failure is often impractical and expensive. Also, in many cases the hazard associated with the failure of a single component is not large enough to warrant the expenditure for an additional barrier. For instance, leakage of valve packings is a rather typical occurrence in cryogenic systems. Experience indicates that leaks of this type may burn. Ignition is apparently caused by static charges of particles carried by a high velocity stream. Experience also indicates that packing leaks of low temperature valves increase in magnitude when the packing becomes cold due to relative greater shrinkage of the packing material.

In order to reduce the magnitude of the packing leak, all valves with packings will be installed in such a way that the packing is on the low pressure side of the valve, or in the case of a shutoff valve, downstream of the valve. Also, in case a leak occurs, it is necessary to be able to shut off the flow of hydrogen to the leak. This will be done by either reducing the pressure in the system to near atmospheric, or in a flow system, by closing a valve upstream.

It can be postulated that a major break or leak occurs anywhere in the piping system. Such a leak will release hydrogen into the atmosphere at a high rate. In this case, the flow of hydrogen needs to be stopped in the shortest possible time. An effective way of doing this is by dividing the system into components with large inventories and separating these components by pneumatically-operated valves. For example, the three-inch liquid line between chamber and valves contains a pneumatically-operated shutoff valve at each tank and the chamber. These valves are interlocked with hydrogen detection and will be closed upon a signal of the detector. Location of detectors has been considered carefully. Inside the building, hydrogen will rise in the vicinity of the leak and the detector needs to be located directly above the leak or the leaking gas needs to be ducted by means of a collecting hood. Location of detectors in areas without piping or equipment is useless.

The areas inside and outside the building are separated carefully to prevent leakage of hydrogen into the building and to facilitate venting of hydrogen from the building. The wall of the building separating storage tanks outside and refrigerator inside is a blind wall without penetration to prevent leaking hydrogen from entering the building.

Outside the building air movements can be large. Because of this, hydrogen detection of small leaks often cannot be accomplished. However, large leaks can be detected by strategically located detectors. Fire detection is more important. A number of fire and hydrogen detectors are located above the area between storage tanks and building. In case a fire is detected, a sprinkler system will spray water on piping, tanks, and walls to keep equipment cool. Also, the main shutoff valves at the tanks will be closed through a fire and hydrogen detection alarm interlock signal.

C. Presence of Ignition Sources of Various Types

In order to prevent delayed ignition of a mixture of hydrogen and air, ignition sources of all types are eliminated from the building and the area outside the building where storage tanks are located. Ignition sources are eliminated by:

1. Using equipment approved by the National Electrical Code for service in atmospheres which may occasionally contain hydrogen, or wherever equipment so approved is not available, inert gas (usually nitrogen) purges are applied to equipment enclosures. Monitoring devices are employed to verify purge continuity.

2. Grounding of equipment.

3. Protect materials which are subject to brittle failure from contact with cold hydrogen during a spill. Brittle failure under stress conditions is often accompanied by sparking which in turn may initiate the delayed ignition of a spilled mass of hydrogen.

4. Electrical equipment, in general, will be located at low elevations, while piping carrying hydrogen gas will be at high elevations. The chance of bringing electrical ignition source and leaking hydrogen

together are thus reduced.

D. Fire and Possible Pressure Wave from an Ignition of Hydrogen in Air or Solid Air in Hydrogen

It has been pointed out that a delayed ignition of hydrogen in air is the most dangerous and damaging event which may happen in case of a failure. Immediate ignition of leaking hydrogen is not as bad as long as the rate of leakage is kept reasonably small. Once hydrogen is ignited, it is very difficult to extinguish the flame. Only removal of oxygen or the hydrogen itself will stop the fire. It is also unwise to extinguish the flame since the chance for a delayed ignition of the leaking hydrogen is then introduced.

In case of a leak, with or without fire, main sources of hydrogen supplying gas or liquid to the leak should be closed immediately. Since speed is essential, it is not advisable to have the operator make a judgment of the situation and then take the proper action. For example, the three-inch liquid line between tanks and chamber will be isolated through closure of the shutoff valves to stop flow from or to the tanks. Consequently, the action of closure will be automatic and be interlocked with hydrogen or fire detection. Through experience, it has been found that it is not advisable or necessary to interlock the action of closure with the lowest level of detection of hydrogen. Small leaks, which will show up on the detector as a small fraction of the low flammability limit, are potentially not very dangerous. The operator will in this case use his judgment to decide the course of action to be taken.

The ignition of solid air in liquid or cold gaseous hydrogen quite often is a detonation. Depending on the mass of air involved, the explosion may break through walls of the pipe or vessel and possibly the vacuum jacket of the system. In general, the result will be immediate ignition of the escaping hydrogen. Fire detection will then automatically close valves, preventing massive flow of hydrogen to the leak.

E. Separation of Components of the System Containing Flammable Liquid or Gas from Components Containing Air

It is expected that modifications will, from time to time, be made in the bubble chamber system. At this time, hydrogen and deuterium will be stored in liquid tanks. During normal operation, these tanks are connected through a number of pipes to many components of the system.

It is very dangerous to depend on shutoff valves only for separation of components containing a flammable liquid and components on which personnel may be making modifications. In general, these components will at that time be filled with air.

In order to be completely safe a physical separation in the piping system will be made and blinds will be installed in series with the shutoff valves. In the case of vacuum-jacketed lines, spool pieces will be removed and blinds installed. This is rather common practice and provides a position barrier.

F. Generation of Excessive Pressure in Components Due to Failure of Insulation and/or Relief Devices

Storage tanks are normally protected by relief valves and rupture discs. Sound engineering practice requires that the relief devices are sized to handle the maximum conceivable flow rate which may be generated from any failure of a component of the system. For instance, loss of vacuum through a break in the outer shell which allows condensation of air on the inner vessel of the liquid hydrogen vessel is anticipated and the relief valve and/or rupture disc will handle the resultant flow of vapor without exceeding the design pressure of the vessel. Also, failure to close the liquid valve admitting liquid to the vaporizer of the tank is considered.

Another hypothetical case is the one in which the liquid hydrogen tank is completely full and the high pressure circuit of the refrigerator is connected directly to the tank.

The deuterium and neon liquid storage tanks are not equipped with a rupture disc. In case of a premature failure of this disc, the loss of very expensive neon or deuterium would be very great and it would be very difficult and dangerous to replace the disc with liquid in the tank. These tanks are equipped with a relief valve and a pressure alarm system indicating either a high or low pressure beyond the normal range of pressures.

All cold systems equipped with a shutoff valve on either end are equipped with a relief valve. If the relief valve were to fail, the system would break at its weakest point and leak hydrogen or other cryogenic fluids to the atmosphere. The total quantity of fluid spilled will be small since failure of the relief devices implies a sealed system. The three-inch chamber fill line has a maximum inventory of some 5,000 scft of gas.

G. Nonsuitable Materials for Low Temperature Service

Only ductile materials will be used for low temperature service. In some cases, nonductile materials, such as the carbon steel of the vacuum shells of the storage tanks, will be protected from becoming cold through the application of insulation or shields to keep the cold fluids from touching the shell. A typical example is the vent line of the liquid hydrogen storage tank. When the tank is being filled from a trailer, a rather large amount of vapor may be vented at fairly large rates. A poorly-designed vent system will allow liquid air condensed on the vent pipe to drip on the shell. Cracking of the shell often results.

H. Building and Site Ventilation and Purging of Equipment Containing Ignition Sources

Design of ventilation systems for buildings containing liquid or gaseous hydrogen have generally been based on precedents, rather than sound evaluation of the pertinent circumstances. A typical approach is to install a fan system in the roof structure of the building, capable of moving air at relatively large rates. A magic number is the number of total air changes which the building receives when the fans operate at full speed.

Evaluation of the movement of air in the building with the help of smoke bombs generally shows that the smoke is spread over the entire building and that there is not a pronounced flow from floor level to the exits in the roof at the fan locations.

Analysis of the situation shows that this is a reasonable result. The movement of air generated by the fans is a small perturbation on the thermal movement of air in the building. In winter the air generally moves down along the walls and up in the center after it has been heated. Variations in the location of the heating elements will change the pattern of air flow quite considerably. In summer the air generally moves up along the walls and out through the top of the building.

As pointed out on Page 47, hydrogen gas rises rapidly in air. Even cold hydrogen vapor from a liquid spill quickly warms to a temperature level at which it rises at a velocity much greater than that of air due to thermal currents or fan operation. In consideration of this, a reasonable approach to hydrogen removal is to lower the roof of the building as much as is possible and to open the roof at locations where leaks or spills are likely to occur. The combination of these two factors reduces the total quantity of hydrogen in the building. A fan will not materially increase the speed with which the hydrogen is removed from the building, especially when the fan is located at some distance (in horizontal direction) from the point of spillage.

It also seems reasonable to locate air intakes to the building at the lowest possible elevations and at locations farthest from the liquid storage area.

Equipment containing ignition sources will also be located at low elevations and piping containing hydrogen gas at the highest possible elevations.

I. Operator Training and Operating Procedures

An operator can be a major safety problem of the system. During the design of the system, safety of equipment is evaluated and features are incorporated to make the system tolerate a single failure without generating a major accident. When all this has been done, the operating crew becomes the chief factor in determining whether the operation of the system really will be safe.

In previous discussions it has been pointed out that accumulation of solid air in a cryogenic system is possible and potentially dangerous. Continuation of the operation while evidence of solid accumulation is present may nullify all the efforts put into the design of the system.

The operating procedures of the system have been developed during the design of the system. This has added to the safe design of the system. For instance, purging and elimination of air from equipment is essential before hydrogen is admitted.

The operating crews will be trained to safely operate the system and to recognize the procedures (or lack of) which will generate dangerous situations. It will also be necessary to keep adequate records and to record all unusual events.

(5) DETAILED FAILURE MODE ANALYSIS OF THE SYSTEM

1. Hydrogen Compressor

1.1 Electrical Failure

A failure of the electric motor will stop operation of the compressor. The motor is purged with an inert gas (nitrogen) and an electrical failure accompanied by sparking will not result in an ignition in the motor.

A failure of the purge system resulting in low pressure in the motor will sound an alarm in the bubble chamber control room. Failure of the low pressure alarm may generate a dangerous situation, if continuing for a long period of time. The low pressure alarm will be checked at regular intervals.

With the compressor stopped, check valve NV-1055 will prevent high pressure flow from returning from the cold box. Low pressure flow is controlled by controller CS-227. Flow from A tank will be stopped by this controller. If controller CS-227 is in the manual mode, A tank pressure will be low. In that case, controller CS-101 will maintain a constant pressure in the suction line to the compressor and vent excess gas to the stack.

1.2 Failure of Temperature Indicators on the Compressor

A failure of pressure and temperature indicators does not immediately affect the operation of the compressor. With regular data taken (once every two hours), an instrument failure will be noticed and corrective action may be taken. Gauges may be removed after the shutoff valve has been closed off. Temperature indicators may be removed from wells.

1.3 Failure of Safety Valves SV-1266, SV-1267, SV-1268, and SV-1269

These safety valves protect suction and first, second, and third stages of the compressor. PV-101 is in parallel with valve SV-1269 and is set to control the suction line of the compressor at a low value consistent with compressor operation in case SV-1269 fails.

SV-1268 has four check valves located upstream of the valve. These are the suction and discharge valves of the second and third stages. During operation of the compressor, interstage pressures and temperatures will indicate the tightness of suction and discharge valves. An increase of the discharge pressure of the first stage only becomes a potentially dangerous situation if ignored by the operators. Shutdown of the compressor with full discharge pressure of 1,200 psig only occurs due to a power failure or operator error. This, combined with leaking compressor valves, represents a number of failures. Failure of the safety valve is not postulated under these conditions.

SV-1267 (second stage discharge safety valve) has two check valves located upstream. Reasoning applied to SV-1268 applies also.

SV-1266 (third stage discharge safety valve) has PV-100 located in parallel. PV-100 will open in case SV-1266 does not open.

1.4 Failure of Valves MV-1270, MV-1271, MV-1272, MV-1181, MV-1000, MV-1002, MV-1273, MV-1275, and MV-1274

These valves are normally not used. MV-1273, MV-1274, and MV-1275 are gauge shutoff valves which are always open. Failure to close these valves does not generate a dangerous situation.

Valves MV-1000 and MV-1002 are normally open. The valves are only closed in case the compressor is shut down for maintenance. The refrigerator may contain hydrogen gas at this time. However, a double block and bleed arrangement through closure of valves PV-188 and PV-187, opening of valves MV-1182 and MV-1183, and lowering of the pressure in the refrigerator allows work on the compressor safely.

Valves MV-1270, MV-1271, and MV-1272 are closed during compressor operation. Leakage through the valve seats does not affect safety. Failure of the valves to open requires unloading of the compressor during shutdown through valve PV-100. Failure of the valves to close during compressor startup does not affect safety.

Valve MV-1181 is normally closed and only used during evacuation and purge. The valve is backed by a Figure 8 blind and valve seat leakage does not affect safety.

Valve packings of all the hand valves may leak. All valves are warm valves and packings, when bad, normally leak at a rate less than 50 scfm. The leak rate will increase with time, but slowly, and the hydrogen detector located above the compressor will have signaled the leak long before a dangerous situation has been reached.

1.5 Failure of Controller CS-100 and/or Control Valve PV-100

CS-100 maintains, during compressor operation, the compressor discharge and suction pressures at preset conditions. If valve PV-100 fails to stroke properly upon a signal from CS-100, one of the following may hapen:

a. Compressor discharge pressure increases. SV-1266 will handle the high pressure and is a full flow relief valve capable of handling all the flow from the compressor.

b. Compressor suction pressure becomes too high. CS-101 will control and valve PV-101 will bleed gas to the stack and/or SV-1269 protects the compressor suction.

c. Compressor suction line drops below atmospheric pressure. PA-233 will give a signal on which the operator can act by opening MV-1270 or PV-227 or close PV-101. A failure of the operator to act may draw air into the compressor. Deoxo unit G-G will remove the oxygen.

Instrument air failure will open valve PV-100. The compressor will unload and the excess gas will flow through SV-1269 to the stack. Check valve NV-1055 will prevent backflow from the cold box.

1.6 Failure of Water Cooling System of the Compressor

Water cooling failure will be indicated by a temperature alarm. The operator will shut down the compressor.

1.7 Failure of Pressure Alarm PA-233

A failure of PA-233 implies that the compressor suction line is below atmospheric pressure. Failure of PA-233 prevents the detection of this situation. Air may be drawn into the compressor. If the compressor discharges through the deoxo unit, G-G, oxygen will be removed and accumulation of oxygen will not take place. However, if the manual valves, MV-1000 and MV-1002 are closed, it may be possible to accumulate a flammable mixture in the compressor cylinders and piping. To avoid this situation, a redundant low pressure alarm is used on the compressor suction line.

1.8 Failure of Compressor Piping

a. Break of the compressor suction line. The compressor may pump a mixture of air and hydrogen. Valve PV-101 will close and valve PV-227 will open to maintain suction pressure above atmospheric. The rate of flow of hydrogen gas into the atmosphere is large (of the order of 100 g/sec.). Time required to accumulate 1,000 scft of hydrogen gas in the building is then 25 seconds.

The hydrogen detector in the compressor area will sound an alarm and the interlock between detector and control circuit CS-227 will close valve PV-227. This action will stop flow from the cold box. Valve

PV-100 will open to maintain compressor suction pressures. The compressor will unload itself through open valve PV-100 to the break. For a short period of time air will be pumped by the compressor, together with hydrogen, until all of the hydrogen in the compressor piping has been vented.

<u>b. Break in discharge line of compressor between compressor and drier assembly</u>. The compressor will pump hydrogen gas into the atmosphere of the room at a rate of 275 lbs/hr (35 g/sec or 840 scfm). An accumulation of 1,000 scft will have been reached in a period slightly longer than one minute. The hydrogen detector will close valve PV-227 and the compressor will unload itself through valve PV-100. Since the total inventory in the piping system between valve PV-227 and NV-1055 is less than 1,000 scft, total accumuation in the room through the leak cannot reach 1,000 scft.

<u>c. Break in interstage compressor piping</u>. The flow rate into the atmosphere or water cooling system is a maximum of 275 lbs/hr. If the gas flows into the room hydrogen detection will close PV-227, PV-100 will open, and the case is the same as under 1.8-b.

If the hydrogen gas flows into the water cooling system, the relief valves of the water system will handle the flow rate and the gas will be vented away to the stack. There will not be detection of this leakage by the hydrogen detector. The cooling system will cease to operate properly and also the flow rate to the H_2 refrigerator will drop noticeably. If the J-T valve setting is controlled automatically, valve setting PV-226 will change; if the J-T valve is controlled manually, the compressor discharge pressure will drop.

The operators will notice the unusual behavior of the system and, after analysis, will take action. There is no immediate danger in the situation.

1.9 Failure of Valves MV-1001 and MV-1003

Valves MV-1001 and MV-1003 are used when the chamber is being warmed up. Failure of the valves to open or close under these conditions is not a safety hazard. Flow can be stopped by opening valve PV-100 and closing valve MV-1000.

When the chamber is not being warmed up, valves MV-1001 and MV-1003 are backed by blind flanges. Valve packing leaks allowing hydrogen gas to escape into the room fall in the same category as those described in 1.4.

1.10 Failure of Flow Indicator FI-103 and Pressure Gauge PI-142

Both instruments are used to set the flow rate for warming of the chamber. Safety is not impaired when the instruments are not operating properly. Chamber temperature indicators will be used as redundant instruments to determine a satisfactory flow rate.

1.11 Line Breaks in Lines GH-2000 and GH-2001

With the lines in use, a break may result in a flow rate of 275 lbs/hr or less into the room. Hydrogen detection will close valve PV-227 and valve PV-100 will open to supply the compressor suction with enough gas to maintain a constant suction pressure. The total inventory in the system is smaller than 1,000 scft after valve PV-227 closes. Again, (see 1.8) the compressor may handle a mixture of hydrogen and air.

Operator error may result in closure of valve MV-1003, which in turn could subject heat exchanger F in valve box R and associated piping to high pressures. Full flow relief valve SV-1373 prevents this. Failure of relief valve SV-1373 requires an additional failure before the system is subjected to high pressure.

1.12 Failure of Valves PV-187 and PV-188

Valves PV-187 and PV-188 are normally open. The valves are air operated. Air is supplied by operation of a solenoid valve.

Air failure closes the valves. The compressor bypass valve, PV-100, will open and maintain a positive suction pressure. The compressor will be isolated from the rest of the system. The situation is safe.

Power failure to the solenoid will shut off air to the valves and close the valves.

A packing leak in either valve will generate the situation described in 1.4. When the valves are closed and fail to open, flow to the H_2 cold box cannot be initiated. This is not a safety hazard.

1.13 Failure of Controller CS-101 Circuit Including Valve PV-101

The controller prevents the compressor suction pressure from rising above a preset level. If the controller fails to open valve PV-101 when required, relief valve SV-1269 and relief valve SV-1299 back up the controller.

If the controller fails to close valve PV-101, gas will continue to bleed to the stack. Check valve NV-1005 prevents reverse flow. PA-233 will indicate a low suction pressure at the compressor. Valve PV-227 will continue to supply gas to the compressor suction. If pressure in A tank drops to a low value, the vaporizer will go into action through CS-104 to supply gas.

Operators will read FE-102 at regular times. These data will tell whether substantial leakage takes place through valve PV-101 with the valve in a supposedly closed position.

Air failure closes the valve. In case of valve closure, valve SV-1299 protects line GH-2145.

Packing leaks of valves PV-101, MV-1006, and MV-1007 fall in the category described in 1.4.

1.14 Valves MV-1248 and MV-1004

These valves are normally closed and backed up by blind flanges. Valve MV-1004 is used during evacuation and purging of the piping connecting to the compressor at the same time as valve MV-1181. The discussion on valve MV-1181 applies (1.4). Valve MV-1248 is operated when the neon-deuterium purifier-condenser is used. Failure of the valve to open or close is not a safety hazard. Valve PV-157 backs up valve MV-1248 and can be closed. In case of a compressor line break or break in line GH-2168, gas flow to the atmosphere will be as described in 1.8. With valve PV-227 closed off, the flow to the atmosphere will be at a rate of 50 scfm until valve PV-157 is closed off.

1.15 Failure of Heater C-C in Compressor Suction Line

Heater C-C consists of a water bath with a number of parallel 1/2-inch diameter tubes, through which the hydrogen gas flows. Downstream of the heater is a temperature indicator, TI-244, and a temperature alarm, TA-245. The water is compressor cooling water discharged from the compressor cooling system. An electric immersion heater is part of the water system to maintain a desired water temperature in case the compressor is not used.

Under normal operating conditions, heater C-C takes cold gas from the hydrogen cold box and warms it sufficiently to protect the compressor. The C-C heater is designed to reduce the difference in temperature between incoming hydrogen gas and that of the water by a factor 5. With a water temperature of 80°F and a gas temperature of -120°F entering the heater, the temperature of the gas leaving the exchanger will be 40°F.

Failure of the electric heater to supply heat will result in a gradual decrease of the temperature of the effluent gas since water will act as a heat reservoir. Temperature alarm TA-245 will indicate the situation before a dangerous situation has developed.

Without compressor operating and with gas bleeding through valves PV-227 and PV-101 (from A tank), PV-101 and flow meter FE-102 are protected from low temperature by heater C-C.

Failure of the alarm, TA-245, to indicate while cold gas exists from heater C-C is a double failure and is not considered under the basic safety criteria.

Leakage of hydrogen into the water circuit results in venting of the water system or in water entering the hydrogen system. Water entering the hydrogen system will ultimately result in freezing of the heat exchangers in the refrigerator. This is not a safety problem. Hydrogen gas will vent from the water system to the stack.

1.16 Interlocks

In order to reduce the amount of hydrogen gas leaking to the environment from large leaks, such as pipe breaks, the hydrogen detector is interlocked with the air supply of a number of major shutoff valves. The hydrogen detection system consists of a number of heads which sample the air. These heads are located at high points in areas where piping and valves are concentrated. The detection system is interlocked with the following valves: PV-227, PV-251, and PV-252. When hydrogen is detected and when its concentration in air exceeds a preset number, valves PV-227, PV-251, and PV-252 will be closed. This closure will isolate the large inventory in the liquid hydrogen storage tank from venting into the bubble chamber building in case of a compressor line break.

The probability of line breaks has not been assessed during this failure mode analysis. All piping of 2-inches and smaller in size will be Schedule 40. The compressor suction line will be Schedule 10. Pressure ratings of all this piping is far in excess of the safe design pressures required. Also, the piping is quite strong mechanically and it is difficult to see how a mechanical failure may occur while the system is in operation. The presence of a flammable mixture in the piping at any time during system operation is difficult to conceive. The compressor suction line receives gas from a hydrogen storage dewar. This gas is ultra pure. The compressor discharges gas to a purification system in the refrigerator and contaminants are removed continually. The probability of a line break is extremely small.

2. Drier Assembly E-E and Deoxo Unit G-G

The assembly consists of three bottles of small volume, interconnecting piping with manually-operated valves and local readout instruments, and an electric heater used for reactivation of the off-stream drier bottle. Failures, in general, will consist of leaking valve packings, valves leaking through the seat, line breaks, and instrument and heater failure.

2.1 Valve Packing Leaks

Valves MV-1280, MV-1281, MV-1283, MV-1362, MV-1363, MV-1364, MV-1365, MV-1288, and MV-1282 are 1/4-inch valves to close off pressure gauges or handle small bleed streams. A leaking valve packing will result in a flow rate of less than 50 scfm and will satisfy the safety criteria. H_2 detection will indicate soon that a valve packing leaks. The flow through the unit may then be stopped and the pressure lowered and the packing repaired.

If the valves leak through the seat, a small amount of H_2 gas may leak into the environment when the valve is closed off and the gauge disconnected or the sample point connected. The quantities released are less than 50 scfm and the safety criteria have not been violated.

2.2 Valves MV-1284, MV-1285, MV-1286, MV-1287, MV-1289, MV-1290, MV-1291, and MV-1292

These valves are 1-inch line size valves. They are sized to handle full compressor flow or reactivation nitrogen gas stream. A leaking valve packing will result in a gas leakage rate of less than 50 scfm unless the initial leak is ignored and allowed to increase. A considerable amount of time has to pass before a total accumulation of 1,000 scft has been obtained. Hydrogen detection will indicate the leak. Also, the leak is most likely to occur when the valve is being operated by personnel. Leakage will be reported immediately and action taken. Pressure may be reduced by closing valve PV-188 and opening J-T valve PV-226. Leakage through the valve seat will result in leaking hydrogen with nitrogen to the vent system during reactivation of a drier and may yield some contamination of the hydrogen stream to the refrigerator with nitrogen gas. This does not result in a dangerous situation.

2.3 Valves MV-1360, MV-1361, and NV-1279

These valves are part of the nitrogen reactivation system. Hydrogen gas is prevented from entering the nitrogen system through check valve NV-1279 in case an operator makes an error in valve operation during drier reaction. Safety valve SV-1276 protects the nitrogen circuit from high pressure in case valve NV-1279 leaks high pressure hydrogen gas. SV-1276 is sized to handle the maximum conceivable flow rate through NV-1279 and RO-158.

2.4 Instrument Failures

Instrument failures do not impair safety of the system. Pressure gauges PI-219, PI-246, and PI-247 are useful for operation, but lack of data from these gauges is not a safety hazard.

Temperature indicator TI-220 signals the end of the reactivation cycle. Failure to operate properly is not a safety hazard.

Temperature controller TIC-222 is used to set the temperature of the N_2 gas flowing to the drier to be reactivated. If the temperature of the N_2 gas flowing to the drier is too high, TS-221 will shut off the heater.

2.5 Heater Failure

Heater failure will result in cold nitrogen gas flowing to the drier. Failure of nitrogen gas to flow through the heater may result in a high heater temperature (internally). The heater is protected from overheating and will be turned off on high temperature.

2.6 Failure of Drier Assembly Piping

A high pressure line break will release hydrogen into the atmosphere at a rate of 275 lbs/hr. The total volume of the drier system is small and amounts to less than 5 cft. The gas inventory is some 400 scft. A total of 1,000 scft will have been released in a matter of 40 seconds. The hydrogen detector will have detected the hydrogen and closed valve PV-227. This will stop the supply of hydrogen gas into the room.

The drier assembly and piping may be subjected to 1,200 psig when a temperature of 600°F exists in some of the assembly. All piping, valves, and vessels are rated to withstand this pressure when at this temperature.

2.7 Valves SV-1277 and SV-1278

These are thermal relief valves which protect the bottles from high pressure (in the sealed condition). Since heat cannot be added when the bottles are sealed, it is only possible to heat the bottles in case of an external fire. An external fire implies that another failure has occurred somewhere, and in that case, SV-1277 and SV-1278 will perform satisfactorily.

3. Hydrogen Refrigerator Cold Box

The hydrogen refrigerator cold box is a vacuum-insulated assembly of heat exchangers, piping, instruments, and valves. At the warm end, the assembly is connected to the compressor suction through a 3-inch stainless steel line (GH-2145), and the drier assembly through a 1-inch stainless steel line (GH-2152). This line is equipped with a check valve, NV-1055, located directly at the box. Also, all relief valves from various hydrogen circuits in the box are manifolded together and piped through a stainless steel line to the stack outside the building.

A number of vacuum-insulated cold hydrogen lines connect the cold box with expansion engine G and hydrogen storage vessel A. In addition to this, low pressure cold hydrogen gas returns from the chamber cooling loop through line GH-2002 and low pressure cold hydrogen gas returns from the neon-hydrogen and deuterium tank condensers. The box is located inside the building.

3.1 Leaks Inside the Box

All piping and heat exchangers are located inside the box. Since vacuum insulation is required to realize a reasonably efficient performance of the refrigerator, leaks in piping, valves, and vessels will ruin the insulating vacuum of the box, but will not immediately result in leakage into the room. The vacuum shell of the cold box is constructed to withstand an external pressure differential of 15 psig. This means that the vessel can withstand a pressure up to 30 psig without failing. The box is equipped with a relief valve and rupture disc which are piped to the vent stack of the system. Since the box can withstand pressures up to 30 psig, all leaks in low pressure piping and valves will merely result in loss of insulation and not in venting of gas. High pressure leaks may result in opening of the relief valve of the vacuum box to the vent stack.

In all cases, leaks inside the box will be detected very rapidly through deterioration of performance of the refrigerator. Also, the vacuum gauge indicating insulating vacuum will show the presence of a leak.

3.2 Leaks in High Pressure Lines to the Cold Box

Three warm high pressure hydrogen lines enter the cold box. The line connecting exchanger I is equipped with check valve NV-1055 which will prevent backflow from the cold box in case of a line break. Heat exchangers III and IV are equipped with valves PV-228 and PV-229. These valves are interlocked with the H_2 detection signal and will be closed upon detection of hydrogen in the area of the refrigerator.

Line breaks between the drier assembly and valves NV-1055, PV-228, and PV-229 fall into the category described in 1.8 and the total quantity of hydrogen released will be less than 1,000 scft.

3.3 Valves MV-1314, MV-1358, and MV-1359

Valves MV-1314 and MV-1358 are normally closed valves. Valve MV-1359 is a normally open valve. Failure of these valves under normal conditions will be a packing failure. In all three cases, the packings are subject to a low pressure differential and the leakage rate through the packings will be considerably less than 50 scfm.

3.4 Valves MV-1370, MV-1371, MV-1372, MV-1320, MV-1321, MV-1348

Valves MV-1370 and MV-1371 are gauge shutoff valves and normally open. Packing leaks will be less than 50 scfm and will be detected long before the packings have deteriorated to high flow rates. Valves MV-1348, MV-1320, MV-1321, and MV-1372 are small bleed valves. All of these valves are to be used during reactivation of equipment. Packing leakage will be detected rapidly and shut off of hydrogen flow at valve PV-227 will be accomplished before large quantities of hydrogen gas have been accumulated in the building.

3.5 Safety Valves SV-1295, SV-1296, SV-1297, SV-1300, SV-1301, SV-1302, SV-1303, and SV-1375

There are a number of safety valves, manual purge valves, and manual cooldown valves which connect to the various cold lines in the cold box. Wherever possible, the packing side of the valve has been connected to the low pressure part of the system to reduce the rate of leakage in case of packing failure.

Safety valves SV-1300, SV-1301, SV-1302, SV-1303, SV-1375, SV-1295, SV-1296, and SV-1297 are thermal relief valves piped back to the suction of the compressor. Leakage of these valves does not constitute a safety hazard. If the safety valves fail to relief high pressure, a break in the closed system may occur. Under these conditions the total inventory of the system in question is considerably less than 1,000 scft and the safety criteria have been met.

3.6 Valves MV-1319 and MV-1366

Leakage through the seat of manual valves MV-1319 and MV-1366 does not constitute a safety hazard. Packing leaks will, in due time, trigger the hydrogen detector, which in turn will stop the flow of hydrogen gas to the cold box.

3.7 Valves MV-1304, MV-1305, MV-1306, and MV-1307

Manual valves MV-1304, MV-1305, MV-1306 and MV-1307 are not used under normal conditions and are equipped with a blank on their downstream side. The valves are used when vacuum-jacketed line sections need to be inerted prior to removal. Under these conditions the vacuum-jacketed line is valved off and the inventory of the system is very small. Failure of the valves under those conditions will release very little hydrogen gas into the atmosphere. Packing failures of the valves releasing hydrogen in the atmosphere will be detected and the hydrogen flow to the complete system will be shut off to prevent large accumulation of gas in the room.

3.8 Valves MV-1310, MV-1311, MV-1312, and MV-1313

These high pressure manual cold valves are used frequently to remove an adsorber from the line for reactivation. The valve packings are subject to high pressure. Small packing leaks will soon become large leaks due to the cooling of the packing to nitrogen temperature. The valves are installed in such a way that the packing is on the low pressure side during reactivation of the adsorber.

If the packing leaks badly, the hydrogen detector will close off the hydrogen supply to the cold box and the total accumulated leakage will be less than 1,000 scft. It will be impossible to operate the valves when the packing leaks badly and it is necessary to wait until the pressure has been removed from the system. Failure of the valves to close tightly is not a safety problem since leakage is vented away to the stack system.

3.9 Control Systems CS-224 and CS-225

Level gauges and controllers CS-224 and CS-225 may fail to shut off the liquid nitrogen supply. Too high a liquid nitrogen level will be indicated on TI-234 or TI-235. Finally, TA-254 will alarm and the operator needs to take action. Liquid nitrogen supply may be shut off manually at the liquid nitrogen tank.

Failure of valves PV-224 and PV-225 to open will be an operational problem and is not a safety hazard.

3.10 Control Systems CS-226 and CS-227

Failure of controller CS-227 to open valve PV-227 will stop flow to the compressor suction. Valve PV-100 will open and maintain suction pressure from the compressor discharge. If valve PV-226 is on automatic, flow through the J-T valve will stop. If this valve is on manual, the compressor discharge pressure will decrease rapidly. There is no safety hazard.

Failure of controller CS-227 to close valve PV-227 will potentially supply too much flow to the compressor suction. Pressure will rise and controller CS-101 will let hydrogen gas flow to the vent system. SV-1299 is in parallel with PV-101 and is sized to handle full flow through PV-227 at a pressure of 50 psig in A tank and maintain a compressor suction pressure of 15 psig or less. The operator may close MV-1182 to stop the flow to the hydrogen cold box.

Failure of controller CS-226 to open valve PV-226 will stop flow to A tank. To maintain compressor discharge pressure PV-100 will open. PV-227 will close when CS-227 is on automatic control. If CS-227 is on manual control, compressor suction will go up until PV-101 opens or SV-1299 acts. There is no safety hazard.

Failure of controller CS-226 to close valve PV-226, or opening PV-226 wide, will lower compressor discharge pressure and add hydrogen gas to A tank temporarily at a high rate. The relief system of A tank can handle this flow without exceeding the safe pressure rating of the tank.

3.11 Vacuum Failure

Insulating vacuum failure may occur due to an internal leak in hydrogen or nitrogen piping, or an external leak from the air environment.

Internal leaks of small magnitude will impair the capacity of the refrigerator. The vacuum gauge of the refrigerator will indicate the deterioration of the vacuum. An internal leak is not a safety hazard.

An external leak will result in a slow accumulation of air on the cold surfaces of the refrigerator components. As long as the refrigerator is cold, the air will remain as a solid on the cold surface with very low vapor pressure in the vacuum space. In case of a break in a hydrogen line or component in the cold box, hydrogen will spill in the vacuum space. At this time an explosive mixture exists somewhere in the box. It will take time to generate vapor pressure of air because the solid air needs to be warmed. If ignition does not take place at the time when hydrogen breaks into the box, ignition is not likely to occur at any time thereafter. Immediate action will be taken to stop operation of the refrigerator and purge the system of hydrogen.

It appears that a slow accumulation of air is potentially dangerous, but a considerable amount of time is required before a sufficiently strong interaction may result in case of a hydrogen break into the box. Long before this, action should have been taken to remedy the situation.

3.12 Adsorber Reactivation

During reactivation of adsorbers, the adsorbed impurities are driven off the surface and accumulate in the adsorber until such time that the adsorber is purged with nitrogen gas. With deoxo unit G-G in the system, the ratio of nitrogen to oxygen in the adsorber will be very large. Because of this, a flammable mixture of hydrogen and oxygen will not exist at any time during the reactivation cycle of the adsorber.

3.13 Accumulation of Solids

This may lead to plugging of the J-T valve and piping downstream of the adsorber beds. Essentially this event is an operational error caused by insufficient attention to adsorber reactivation. Since oxygen is preferentially adsorbed at the temperature levels of the adsorber, breakthrough of the adsorber will primarily consist of nitrogen. If plugging occurs, the refrigerator needs to be shut down and warmed to remove the solids. Under no circumstance should the solids be pushed through the system to the A tank.

It appears that the occurrence of plugs does not constitute a safety hazard as long as proper action is taken.

3.14 Expander G Failures

These may be the leakage of valves, loss of insulation, or leakage through packings. Loss of insulation may be due to air leakage or hydrogen leakage. Slow accumulation of air is potentially dangerous. However, if action is taken rapidly, the situation is not dangerous. Leakage through expander inlet and discharge valves is an operational problem and not a safety problem. Leakage through packings into the room will result in the hydrogen detector closing valve PV-227. The amount of gas leakage will be limited.

3.15 Instrumentation

Failure of temperature and pressure gauges of the hydrogen refrigerator will not be a safety problem. Temperature gauges TI-240, TI-234, and TI-235 will be the guide for distributing hydrogen flow over the exchangers. The return hydrogen flow through line GH-2145 flows through exchanger C-C and a low temperature at TI-240 is not a hazard. Failure of valve PV-228 or PV-229 will cool the suction line to the nitrogen vacuum pump F-F to a very low value. Both hydrogen and nitrogen lines are designed to handle low temperatures and will not be overstressed. TA-254 will indicate the low temperature to F-F and the operator will take action to divert the cold nitrogen stream directly to the vent through valve MV-1324 or MV-1325. In that case, check valve NV-1327 or NV-1328 will prevent backflow into the nitrogen liquid reservoirs.

Temperature indicators TI-236, TI-237, TI-238, TI-239, TI-241 and TI-223 are used for operational purposes and failure of these gauges is not a safety hazard.

Pressure gauges PI-230, PV-231, PV-232, PI-248, and PI-249 are used for operational purposes. Failure of these gauges does not affect safety.

4. Compressor D-D

Compressor D-D (either Corblin or nonlubricated recipricating compressor) is used to fill gas storage vessels B and B-B with hydrogen-neon or deuterium gas. The suction line of the compressor is connected to the vaporizer of either A, C, or D tank. The discharge of the compressor may be connected to either B or B-B tank. The connections to suction and discharge lines are made through Figure 8 flanges. After the proper connections have been made, tightness of the flanges is checked before the compressor is put in service. The compressor has a low ultimate discharge pressure of 250 psig and a flow capacity of 10-40 scfm.

The suction line of the compressor is equipped with a temperature indicator (TI-202) and a temperature alarm (TA-203). In case the tank vaporizer does not warm the gas sufficiently, TA-203 will tell the operator to shut down the compressor. Temperature alarm TA-203 is set at a temperature considerably above the safe low temperature limit of the compressor system.

4.1 High Compressor Discharge Temperature

The discharge line of the compressor is equipped with a temperature indicator, TI-201. There is no temperature alarm. The discharge line is capable of withstanding all conceivable temperatures at the rated pressure. A safety valve in the discharge line will recycle gas to the suction of the compressor. If the temperature in the suction line becomes high, TA-203 will alarm.

4.2 Leakage of Gas from the System

Leakage from the compressor system into the room will be detected by the hydrogen detector (except for neon leakage which is not flammable). Leakage rate is always within the tolerated amount when leakage occurs from the discharge side of the compressor. A check valve, NV-1247, prevents backflow from vessel B or B-B in case of a line break upstream of the check valve. Check valve NV-1247 is located in the vicinity of tanks B and B-B. Rate of leakage from a break in the suction line of the compressor will be a function of liquid tank pressure. An interlock acting from hydrogen detection in the building, closing the supply valves PV-104-A, PV-140-B, and PV-150-B, will stop the flow of liquid before a large quantity has been accumulated.

4.3 Safety Valve SV-1245

Failure of safety valve SV-1245 to operate needs to be coupled with a closed hand valve between compressor D-D and vessel B or B-B. With an open circuit to vessel B or B-B, the rate of pressure buildup is slow (at a rate of 2.5 psig/hour or less for B tank and 15 psig/hour for B-B tank). Since the operation of D-D is controlled manually, operator error, only, will cause a failure of piping on the discharge side of the compressor with a failure of SV-1245.

4.4 Valve Packing Leaks

All valves of the compressor system are manual valves. Packing leaks may occur. Because of the small size of the valves, packing leaks are small to start with. At the low pressure suction side of the compressor the packing seals against a low pressure differential and leakage rate will never exceed 50 scfm. On the discharge side of the compressor the leakage rate can never exceed the compressor capacity and will therefore be below 50 scfm.

4.5 Safety Valve SV-1246

Failure of safety valve SV-1246 to operate will bring the suction line of the compressor to the pump discharge pressure with manual valve MV-1238 closed. The system is designed to handle the maximum pressure.

4.6 Low Pressure in Compressor Suction Line

Operation of compressor D-D with suction valve MV-1238 or PV-104-A (PV-140-B or PV-150-B) closed will result in pulling a vacuum in the suction line. The possibility of pulling in air exists. This air will then be mixed with hydrogen or deuterium gas in vessel B or B-B. This, in time, can generate a dangerous situation. PA-255 will indicate the occurrence of a low pressure in the suction line of the compressor. Operator action consisting of shutting the compressor, opening bypass valve MV-1239, or increasing the supply of gas to the compressor will correct the situation before a dangerous condition has been generated.

4.7 Operator Error

Operator error may consist of generating the condition of low suction pressure (4.6), high discharge pressure (4.3), and temperature (4.1). Improper purging of the system prior to use and unsatisfactory coupling of the system through Figure 8 blinds may result in some contamination of the gas in vessels B and B-B or in leaks to the environment. A complete omission of purging of the system prior to use will contaminate vessels B and B-B, but will not result in flammable mixtures in B or B-B.

5. Chamber Fluid Precooler P

The chamber fluid precooler is used when small quantities of chamber fluid need to be added to the chamber. The unit is also used when rapid transfer of liquid from the chamber to the dewars needs to be accomplished. At this time, it is essential that the gas added to the chamber is at a sufficiently low temperature to prevent thermal shock of the glass of the windows. The unit is located outside the building and safety criteria applicable to the area outside the building are governing.

5.1 Insulation Failure

The unit is insulated by perlite. Loss of vacuum will result in an increased boiloff rate of liquid nitrogen. The vent system is sized to handle this increased flow rate. Loss of vacuum may be checked by reading the vacuum of the insulation space. The unit is equipped with a thermocouple gauge.

A leak in hydrogen line GH-2159 in and out of the vessel may result in pressurization of the vacuum space with hydrogen. The vacuum shell of vessel P is equipped with a rupture disc which will safely vent away hydrogen gas leaking into the vacuum space from a break in the hydrogen line.

An external air leak into the vacuum space of vessel P will accumulate air in the insulation. Deterioration of insulation will increase nitrogen boiloff rates. The nitrogen vent system can handle this increased rate. An accumulation of air in the vacuum space with time might result in a high pressure in the vacuum space after the unit is warmed up. The rupture disc will vent this gas to the atmosphere.

5.2 Hydrogen Line Break in Liquid Nitrogen Space

A break in the hydrogen line inside the liquid nitrogen space of the vessel will result in a high flow rate of hydrogen into this space. The vent system of the liquid nitrogen space is large enough to handle the maximum flow rate of hydrogen gas from vessel B without exceeding the safe pressure level of the vessel. The venting gas is a mixture of hydrogen and nitrogen. The flow rate is potentially large (360 lbs/hr) and will exceed the tolerable rate of 250 scfm. By closing valves PV-111 (at B tank), PV-194 and PV-195 at the chamber (valve box J), the flow of hydrogen gas may be stopped by the operator before a total of 15,000 scft has been vented.

5.3 Failure of Level Controller CS-110

Failure of controller to close valve PV-110 will result in liquid nitrogen flowing out of the vent of the vessel. All materials of construction are approved for low temperature service and there is no safety hazard. Failure of the valve to open may result in flowing warm hydrogen gas to the chamber. This may result in breakage of a glass window. Consequences of this will be analyzed during the chamber safety evaluation.

5.4 Check Valve NV-1255 and Safety Valve SV-1376

Failure of check valve NV-1255 to open may lead to over-pressurization of the liquid nitrogen reservoir. A safety valve, SV-1376, in parallel with NV-1255 prevents this. Failure of safety valve SV-1376 is taken care of by a check valve, NV-1255, in parallel with it.

5.5 Vacuum Sensor VI-123

Failure of vacuum sensor VI-123 is not a safety problem. The sensor may be removed and replaced without loss of insulating vacuum.

6. Liquid Hydrogen and Deuterium Piping

The bubble chamber system contains a large amount of vacuum-jacketed piping used for the transfer of liquids and cold gases between:

a. Hydrogen refrigerator and A tank.

b. Hydrogen refrigerator and valve box J.

c. Hydrogen refrigerator and C-D tank condensers.

d. Hydrogen refrigerator and expander.

e. A tank and C-D tank condensers.

f. A, C, and D tanks and valve boxes J and R (liquid lines).

g. A, B, C, and D tanks and valve box J (vapor lines).

All piping is vacuum-jacketed. Joints between individual sections are made up by means of two types of bayonets. Type one is a welded joint with, in all cases, the male bayonet pointing down. Type two is a typical commercially-available bayonet with Marman clamp-type coupling. Male bayonets are also pointing down. The commercially-available type is used where lines need to be made and broken depending on the services required for the bubble chamber.

6.1 Line LH-2004

Line LH-2004 connects the J-T valve in the hydrogen refrigerator with the vapor space of A tank. The line is a single section equipped with a high pressure bayonet on each end. The bayonets are connected through welded joints. The line is rated at a pressure of 1,200 psig, but will under normal operating conditions operate at a maxiumu pressure of 50 psig. The line is protected by a thermal relief valve, SV-1300.

Failure of valve PV-226 (J-T valve) to close may result in a high pressure in the line. The line is built to withstand this pressure. Failure of controller CS-226 or operator error may open valve PV-226 wide and open the refrigerator high pressure circuit to line LH-2004 and the vapor space of A tank. The inventory of the hydrogen refrigerator is small relative to the minimum vapor space of A tank and the tank pressure will not rise above the design level of the tank. The relief system of A tank is sized to handle the full flow of the hydrogen compressor.

Valve PV-252 is a pneumatic valve with air pressure required to open the valve. An air failure will close the valve and subject line LH-2004 to 1,200 psig pressure. The line is designed for this pressure. Failure of valve PV-252 to close is not a safety hazard. Failure of SV-1300 to open when required may make the line fail. At this time, valves PV-226 and PV-252 are closed. The inventory in the line system is small and the total accumulated amount of hydrogen from the break is within the safety criteria. Loss of vacuum by a hydrogen leak will potentially generate a high pressure in the vacuum jacket. The jacket is strong enough to withstand both pressure and cold shock.

Loss of vacuum by an air leak will slowly accumulate solid air in the vacuum space. The loss of vacuum during operation will be noted by loss of performance of the refrigerator. When the line is warmed, the solidified air becomes gas and may generate a high pressure in the vacuum jacket. The outer jacket may rupture or the inner line may collapse. A rupture disc in the outer jacket will prevent this.

A line break at a bayonet coupling may vent large quantities of hydrogen into the atmosphere. Hydrogen detectors located in A tank area, upon detection of hydrogen, close valves PV-226 and PV-252 to block in hydrogen. The total quantity of hydrogen released will be within the safety criteria.

Valve packing leaks of valve PV-252 is small relative to the permissible rate outside the building.

6.2 Line LH-2005

Line LH-2005 connects the vapor space of A tank with the low pressure circuit of the hydrogen refrigerator. The line is a single section equipped with a male bayonet at each end. The bayonets are held in place with Marman couplings. The line is rated at a pressure of 150 psig, and in actual service, will be subjected to a maximum pressure of 50 psig.

The line is equipped with pneumatically-operated shutoff valves (PV-251 and PV-227) at both ends and is protected by a thermal relief valve, SV-1301.

Failure of valve PV-251 to open prevents flow to the refrigerator. This is not a safety hazard. Failure of valve PV-251 to close is not dangerous. Valve PV-227 is in series and may be closed. Failure of valve PV-227 to open or close has the same results as the failure of PV-251 to open or close.

Failure of the thermal relief valve, SV-1300, to operate may result in a line failure. The total inventory leaking to the atmosphere is small.

Loss of insulation by an air leak will slowly accumulate solid air in the vacuum space. A rupture disc in the vacuum jacket protects the line from breaking during the warming process. Loss of insulation through a hydrogen leak does not generate a dangerous situation.

Both lines LH-2004 and GH-2005 are equipped with pumpout valves which may be connected to the utility vacuum header. When the lines are in service, both pumpout connections will be blanked off. Packing leaks through pumpout valves MV-1304 and MV-1305 will be small.

6.3 Line GH-2002 Between Refrigerator and Valve Box R

The line is equipped with eight manual shutoff valves and one remotely controlled valve in parallel in box R and a manual shutoff valve in the refrigerator cold box. Without refrigerator in use, the line will be connected to the vent stack. At valve box R the line is connected through two welded bayonets, and at the hydrogen refrigerator, the line is connected through bayonets with Marman couplings to a common vacuum-jacketed line system located outside the building.

A loss of insulation due to a hydrogen leak into the vacuum space will not generate a hazardous condition. The vacuum jacket is built to withstand the maximum pressure in line GH-2002.

A loss of insulation due to an air leak is not dangerous. The vacuum jacket is equipped with a rupture disc to vent excessive pressure after line warm up.

A leak in the bayonet joints at valve box R will vent hydrogen gas into the area at rates dependent on the size of the leak. It is inconceivable that a complete separation of the weld occurs (stress level is 400 psig max, and under normal operation conditions, 100 psig). The anticipated leakage rate is small and within the criteria set for the design of the system.

At the refrigerator the line is equipped with two commercially-available bayonets with Marman couplings. Leaks through these bayonets may vent gas into the area at fairly high rates. Hydrogen detection will stop flow of liquid hydrogen from A tank to valve box R and hydrogen refrigerator. By closing manual valves in box J, the flow of hydrogen to the environment may be stopped before a large accumulation of gas occurs in the area.

Failure of the thermal relief valves, SV-1260 and SV-1303, will result in line breakage. The line section is isolated under these conditions and the total quantity of fluid spilled into the environment is small.

Failure of manual valves MV-1120 through MV-1127 to open or close does not affect the safety of the system. Failure of valves MV-1309, MV-1307, and MV-1258 to open or close does not affect the safety of the system.

Packing leaks of valves MV-1120 through MV-1127 will be small since leakage has to pass through packing and a set of threads. The leakage rate will be at 50 scfm or less.

Packing leaks of valves MV-1309, MV-1307, and MV-1258 will be small since the packing will be subject to a low pressure differential.

6.4 Line GH-2003 Between Refrigerator and C-D Tank Condensers

The line consists of four shop-fabricated sections equipped with Marman coupling bayonets. The line may be closed off in the refrigerator with manual valve MV-1308, and at the tanks with pneumatically-operated valves PV-140-A and PV-150-A. The line is protected by thermal relief valve SV-1302 and may be purged and evacuated through valve MV-1306.

A loss of insulating vacuum is not a hazard. The vacuum jacket of the line is protected by a rupture disc which will vent accumulated air from an air to vacuum leak after the line warms up. A hydrogen leak from the bayonets into the atmosphere will be at a rate less than 50 scfm since the line under normal use is at a pressure of 5 psig or less. In case of a leak, valves PV-140-A and PV-150-A may be closed off by the operator and valve PV-227 will be closed automatically through hydrogen detection in the refrigerator area.

Failure of valves PV-140-A and PV-150-A to close or open is not a hazardous situation.

Packing leaks of valves MV-1308 and MV-1306 will be small. Failure of these valves to open or close does not affect safety. The leaks may be stopped by closing valves MV-1308, PV-140-A, and PV-150-A.

6.5 Lines Between Refrigerator and Expansion Engine

The high pressure gas inlet line to the engine consists of a single piece, bolted in place with high pressure flanges. The couplings are bayonets with male ends pointing down.

The low pressure line is coupled through Marman couplings and bayonets with male ends pointing down.

Both lines are connected to the piping of the cold box without valves. Both lines operate at the same pressures as the piping in the cold box and are protected by relief valves SV-1375 (high pressure piping) and SV-1298 (low pressure piping).

Vacuum insulation is protected by a rupture disc in case solidified air generates a potential high pressure. Loss of vacuum insulation by a hydrogen leak is not a hazard. The outside jackets of the lines are rated at full pressure.

In case of a bayonet leak, the hydrogen detector will close valve PV-227 and stop flow to the refrigerator. By closing valve MV-1311 (or MV-1313), the flow of high pressure gas to the leak may be stopped altogether.

When the expander is not in use, the lines may be disconnected and removed. The lines will be capped at the refrigerator cold box.

6.6 Liquid Lines LH-2013 and LH-2014 Between A Tank and Condensers in C-D Tanks

The lines consist of single sections equipped with Marman coupling bayonets with male ends pointing in the downward direction. Each line has a pneumatically-operated valve at each end, a thermal relief valve, and a manual purge and evacuation valve. The lines operate at a maximum pressure of 50 psig and normally at a pressure of 15 psig. The lines are located outside.

Failure of valves PV-106 and PV-107 to open is not a safety hazard. Failure of the valves to close is not a hazard, since control valves PV-134 and PV-147 will close. Failure of valves PV-134 and PV-147 to open is not a hazard. Failure of these valves to close may be remedied by closing PV-106 and PV-107.

Valve packing leaks are not serious since the rate of leakage will be within the design criteria. All valve packings are on the downstream side of the valve to realize the lowest pressure differential across the packing.

A failure of the thermal relief valves, SV-1211 and SV-1212 implies a sealed line with small inventory. If the line breaks, total mass of vented gas is within the limit set by the design criteria.

A leaking purge valve packing or seat is not dangerous. The valve under normal conditions is blanked off with a cap and a packing leak is small.

A leaking bayonet or line break permits fairly high flow rates of hydrogen to the environment. Hydrogen or fire detection outside the building closes valves PV-106 and PV-107 to stop liquid flow. PV-134 and PV-147 will also be closed to stop vapor flow to the environment.

6.7 Liquid Lines LH-2011, LH-2126 (LH-2021), and LH-2012 Between A, C, or D Tank and Valve Boxes J and R

Line LH-2011 supplies liquid hydrogen to the cooling loops of the chamber. Line LH-2126 is the major fill and drain line of the chamber, and line LH-2012 is the fill and drain line of the chamber target. Line LH-2126 may be connected to A, C, or D Tank, depending on what fluid is contained in the chamber. In general, the line is connected to one tank only and capped off at the other tank connections. Line LH-2012 may be connected to A or D tank and capped off at the other tank. All three lines are equipped with a thermal relief valve (SV-1208, SV-1209, and SV-1210).

At the tanks the lines are equipped with pneumatically-operated valves, PV-108, PV-109, PV-180, PV-137, PV-143, PV-144, and PV-145. Line LH-2012 is equipped with manual valves MV-1082 and MV-1092 at C and D tank respectively.

In the valve boxes the lines are equipped with pneumatically-operated valves, PV-159, PV-162, PV-163, PV-164, PV-165, PV-166, PV-167, PV-168, PV-189, and PV-196. Also, there are two small manually-operated valves, MV-1127 and MV-1128.

Under normal operating conditions, only line LH-2011 is used continuously. Lines LH-2126 and LH-2012 are only used during filling and draining of the chamber.

Failure of any of the pneumatically-operated valves to open or close is not a hazard. In all cases, a valve in series with the valve may be closed off.

A failure of the thermal relief valve with a closed system may result in a relatively small amount of gas being spilled into the atmosphere within the quantity limit set by the design criteria.

A loss of vacuum due to air leakage is not a safety hazard. The vacuum jacket is protected by a rupture disc in case of overpressure during warming of the line.

A loss of vacuum due to a hydrogen leak is not a safety hazard. The vacuum jacket is designed to withstand the design pressure of the lines.

At valve boxes J and R the lines are connected through welded bayonets with male ends pointing down. The welds are designed to take a stress level equivalent to a pressure of 1,350 psig in the line. Since the maximum pressure in the line will not exceed 150 psig, it is inconceivable that a complete separation of the weld will occur. A leak at these bayonets will spill hydrogen at relatively low rates into the environment. Detection of hydrogen or fire will automatically close valve PV-109 at the A tank. This will stop the flow of coolant to the cooling loops of the chamber.

Lines LH-2126 and LH-2012 are used for an extremely short percentage of time. Operators will close valves PV-108 and PV-180 and chamber valves PV-189 and PV-196 in case of an alarm.

6.8 Vapor Line GH-2018 Between A, B, C, and D Tanks and Valve Box J

Line GH-2018 connects the chamber volume to the vapor space of A, C, or D tank and the gas tank B through vessel P. Only one of the three connections to A, C, or D tank is made dependent on the fluid contained by the chamber. The other two connections are blanked off. The line is equipped with remotely-controlled valves PV-194 and PV-195 at valve box J and PV-105 at A tank (PV-139 at C tank or PV-155 at D tank). At vessel

P the line is valved off by PV-111.

At the valve box the line is connected through welded bayonets with the male end pointing down. At A, B, C, and D tanks the bayonets are coupled with a Marman-type coupling. The Marman couplings are located outside.

The cooling loop systems of the chamber are charged with the proper fluid from line GH-2018 through a set of parallel manual valves, MV-1132 through MV-1144. A single line ties into GH-2018 at the chamber for this particular purpose.

The line is equipped with a thermal relief valve, SV-1221, and a purge connection, MV-1222.

Under normal operating conditions the line is maintained at a constant pressure through control station CS-111. Small amounts of gas may be added to the chamber by opening valve PV-193. Gas may be removed from the chamber through PV-193 and the valve to the liquid tank. The line is also used to add gas from B tank to the top of the chamber at relatively high rates to speed up the transfer of liquid from the chamber.

Failure of valve PV-111 to close will bring the line pressure up to the pressure in tank B. Maximum pressure in tank B will never be more than 150 psig to make sure that the chamber is not exposed to a pressure above its design limit. Also, valve MV-1223, in series with valve PV-111, may be closed. Failure of valve PV-111 to open is not a safety problem.

Failure of relief valve SV-1221 to open occurs when the line system is sealed off. The total inventory of the system is small and a break in the line vents a total quantity of gas smaller than the amount tolerated by the design criteria.

Manual valve MV-1222 is used for evacuation and purging. Valves MV-1197 and MV-1198 are gauge shutoff valves. Packing leaks from these valves are small and within the quantities tolerated by the design criteria. Also, these valves are located outside. Failure of these valves to open or close is not a safety problem.

Under normal operating conditions valves MV-1132 through MV-1144 are closed and the cooling loop systems are sealed off. Each of the loops has a small inventory of liquid. A leak from any of these systems permits a limited quantity of liquid or vapor to enter the chamber building. The total quantity vented from any one of the systems is within the design criteria.

7. Deuterium-Neon Purifier-Condenser

The deuterium-neon purifier-condenser is used to purify and condense gaseous deuterium and neon. After condensation of the pure gas, the liquid is vaporized and transferred to the storage tank (C or D) where the pure cold gas is condensed. The unit is not permanently installed since neon or deuterium will be condensed in batches when the purifier is to be used. It will be placed adjacent to the liquid hydrogen and neon (or deuterium) tank on a temporary basis and removed when the gas has been transferred to the liquid storage tank.

The following connections will be made: A vacuum-jacketed line between hydrogen tank (at filter N) and the hydrogen reservoir of the purifier; a vacuum-jacketed line between neon (or deuterium) tank and the cold vapor discharge of the purifier (line LH-2148); a warm line from heat exchanger discharge to hydrogen compressor suction (line GH-2168); a warm line to the utility vacuum header, UV-2006; and a warm line to the neon or deuterium gas source.

After all line connections have been made, the purifier-condenser will be evacuated, purged with nitrogen gas, reevacuated, and filled with hydrogen and neon (or deuterium) gas in strict accordance with the operating procedures.

7.1 Failure of Valve RV-1061

Regulator RV-1061 reduces trailer pressure to 30 psig. If the regulator fails, relief valve SV-1204 will handle maximum flow through RV-1061 without exceeding the safe pressure of the system.

7.2 Valves MV-1058, MV-1057, MV-1232 MV-1051, MV-1025, and MV-1233

These are manual gauge or sample point shutoff valves. Failure of the valves to open or close does not affect safety. Packing leaks, if occurring, will be small and within the design criteria set for leakage outside the building.

7.3 Manual Valves MV-1059 and MV-1060

These are high pressure shutoff valves to close off gas trailer flow. Failure of the valves to open does not affect safety. Failure of the valves to close requires closure of valves on the gas trailer. Packing leaks will be stopped by closing valves on the trailer and will allow leakage at a rate within the design criteria for areas outside the building.

7.4 Manual Valves MV-1205 and MV-1249

These valves are only used during purge and evacuation of the system. They are closed and backed by a blind flange when the system is in use. Failure of the valves to open or close under these circumstances is not a safety problem. Packing leaks are small and within the tolerances for leakage outside the building.

7.5 Manual Valve MV-1206

This valve is used when the chamber contains deuterium or neon-hydrogen and is prepared for a change of fluid. Failure of the valve to open or close is not a safety problem. Valve packing leaks are small and within the tolerances of the applicable criteria.

7.6 Manual Valves MV-1049 and MV-1050

Failure of either valve to open or close is not a safety problem. To shut off flow, one or the other valve, or valve RV-1061, MV-1059, or MV-1060, may be closed. Packing leaks will be small and within the criteria for leakage outside the building.

7.7 Safety Valves SV-1259 and SV-1261

They are thermal relief valves. If they fail to open, a line may break. Failure of the valve implies a closed system with a limited inventory. The total amount of gas leakage to the atmosphere is within the total quantity permitted by the design criteria.

7.8 Instrument Failures

Neither instrument PI-116, TI-117, FI-170, PI-118, TI-119, PI-121, nor TI-217 performs a critical function.

7.9 Relief Valve SV-1204

Failure of this valve to open at a preset level implies high pressure due to failure of RV-1061 or the operator. The analysis does not assume a secondary failure and failure of SV-1204 by itself does not generate a dangerous situation.

7.10 Valve PV-113

Failure of the valve to close will ultimately cool the gas flowing to the hydrogen compressor suction to a very low temperature. The gas flows through heater C-C and TA-245 ultimately will give an alarm. Valve PV-157 may be closed to stop the flow of cold gas. Failure of the valve to open does not generate a dangerous situation.

7.11 Failure of Controller CS-113

This results in failure of valve PV-113 to react properly. See 7.10. Failure of valves MV-1046, MV-1047, or MV-1048 to open or close does not generate a dangerous situation. Normally the valves are in a fixed position and do not need to be opened or closed. Valve packing leaks will permit leaks small enough to meet the criteria set for leakage outside the building.

7.12 Failure of Controller CS-157

Failure of controller CS-157 will result in valve closure. This is not a dangerous situation. Failure of the valve to close is not a dangerous situation. It may result in freezing of neon. Valve MV-1248 may be closed.

7.13 Vacuum Failure

The vacuum insulation of the purifier-condenser may fail. Failure by leaking hydrogen, deuterium, or neon does not generate a dangerous situation. Relief valves SV-1054 and SV-1259 are sized to handle the situation. Failure by leaking air is potentially dangerous. However, the unit is only used for relatively short period sof time and then again warmed up. The condition of the vacuum insulation of the unit can be ascertained before use (VI-120) and proper action may be taken to prevent the accumulation of air in the vacuum space.

7.14 Failure of Vacuum Indicator VI-120

This does not generate a dangerous situation. It will be noticed quickly and the vacuum sensor may be replaced.

7.15 Failure of Reactivation Heater, Temperature Controller TIC-218, and Flow Meter FI-122

Failure of these components will not generate a dangerous situation. They are used when the unit is isolated from flammable gas and liquid source. A check valve, NV-1373, prevents backflow of deuterium or neon into the nitrogen piping.

7.16 Failure of Piping and Vessels

Failure of piping downstream of regulator RV-1061 limits the flow of gas to less than 250 scfm which is within the rate permissible by criteria set for outside the building. A break in the piping between gas trailer and regulator valve RV-1061 will allow a very large rate of gas flow until the inventory in the trailer has been vented or until a manual valve has been closed. The latter may be difficult. Proper operating procedure requires that no more than 10,000 scft of gas inventory is connected to the purifier-condenser. Leakage of this gas is within the criteria set for total accumulation outside the building.

Failure of liquid hydrogen piping and warm hydrogen vent piping results in large flow rates of hydrogen until valves PV-186 and PV-227 are closed. The valves will be closed before a total accumulation of 15,000 scft has been reached.

8. Gas Storage Vessel B and Associated Piping

Gas storage vessel B is used to store chamber fluid in the gaseous form (hydrogen or deuterium). The gas will be used to add inventory to the chamber when required or to add gas to the chamber during removal of liquid from the chamber. Volume of the vessel is 2,000 cft and it will be filled to a maximum pressure of 150 psig. Associated piping contains shutoff valves, a relief device, and purge and evacuation connections.

8.1 Line Breaks

Vessel B is isolated from the line system through valve MV-1377 at the tank and valves MV-1223 and PV-111 at the building. Any one of these valves may be closed in case of a line break. Valve PV-111 is interlocked with hydrogen detection and will close. The total accumulated leak may be some 20,000 scft if vessel B were to bleed down to atmospheric pressure from full condition. Closure of valves by operators will limit the total leakage to less than the quantity permitted by the design criteria.

8.2 Valves MV-1377, MV-1223, MV-1185, MV-1184 MV-1186, MV-1032, and MV-1033

Failure of any of these valves to open or close does not affect the safety of the system. All of these valves are rarely used. Packing leaks of the valves will be small and may be stopped by closing valve MV-1377 at the tank. All packings are located downstream from this valve.

8.3 Controller CS-111 and Valve PV-111

Failure of controller to open valve PV-111 is not a safety hazard. Failure of the valve to close may bring the bubble chamber to the same pressure as B tank. By limiting the maximum pressure in B tank to 150 psig, the chamber is never pressurized beyond its rated design pressure. Failure of valve PV-111 to open or close does not result in a hazardous condition.

8.4 Valves MV-1222, MV-1197, and MV-1198

Valve MV-1222 is only used for evacuation of lines GH-2159 and GH-2018 and then closed and backed by a blind flange. Valves MV-1197 and MV-1198 are gauge shutoff valves. Packing leaks, if occurring, are small. Leakage through valve seats is not a dangerous situation.

8.5 Safety Valve SV-1221

SV-1221 is a thermal relief valve. Failure may break line GH-2158, GH-2054, or GH-2157. Total leakage will be small from a closed line system and within the design criteria.

8.6 Rupture of Vessel B

If the vessel ruptures, a total of 20,000 cft (max) will vent to the atmosphere. This will occur at some distance from buildings in an isolated area. There will not be damage to other equipment. Personnel may be injured if in the area. Probability is very small since for normal operation personnel does not have to be in the area.

The vessel is protected from overpressure through a rupture disc. During filling of the vessel, relief valve SV-1031 will vent gas at a pressure below the design pressure of the vessel at maximum flow rate.

8.7 Safety Valve SV-1031

Failure of the valve implies operator failure. The B vessel is filled at a very small rate (rate of pressure rise of 2.5 psig/hour). RD-256 will protect the tank in case of failure of SV-1031.

8.8 Operator Error

Through operator error the gas in vessel B-B may become contaminated with some air. Unless gross deviations from the operating procedures are practiced for long periods of time, flammable mixtures of gas in the tank will not be generated.

9. Gas Storage Vessel B-B and Associated Piping

Gas storage vessel B-B is used to store chamber target fluid in the gaseous form (hydrogen or deuterium). The gas will be used to add inventory to the target when required and to add gas to the target for removal of liquid. Volume of the vessel is 150 cft and it will be filled to a maximum pressure of 150 psig. Associated piping contains shutoff valves, relief valves, and purge and evacuation valves and connections.

9.1 Line Breaks

Vessel B-B is isolated from the line system through valve MV-1378 at the tank and valves MV-1225 and PV-112 at the buildings. Any one of these valves may be closed in case of a line break. Valve PV-112 is interlocked with hydrogen detection. The total accumulated leak may be some 1,500 cft if vessel B-B were to bleed down to atmospheric pressure. This is less than the total quantity permitted by the design criteria applicable to areas outside the building.

9.2 Valves MV-1378, MV-1225, MV-1199, MV-1200, MV-1201, MV-1035, and MV-1036

Failure of any of these valves to open or close does not affect the safety of the system. All of the valves are rarely used. Packing leaks of the valves will be small and may be stopped by closing valve MV-1378 at the tank. All packings are located downstream from this valve.

9.3 Controller CS-112 and Valve PV-112

Failure of controller to open valve PV-112 is not a safety hazard. Failure of the valve to close may bring the bubble chamber target to the same pressure as B-B tank. By limiting the maximum pressure in B-B tank to 150 psig, the chamber target is never pressurized beyond the rated design pressure of the chamber. Failure of valve PV-112 to open or close does not result in a hazardous condition.

9.4 Valves MV-1224, MV-1202, and MV-1203

Valve MV-1224 is only used for evacuation of line GH-2019 and then closed and backed by a blind flange. Valves MV-1202 and MV-1203 are gauge shutoff valves. Packing leaks, if occurring, are small. Leakage through valve seats is not a dangerous situation.

9.5 Safety Valve SV-1226

SV-1226 is a thermal relief valve. Failure may break line GH-2019. Total leakage will be small from a closed line system and within the design criteria.

9.6 Rupture of Vessel B-B

If the vessel ruptures, a total of 1,500 cft (max) will vent to the atmosphere. This will occur at some distance from buildings in an isolated area. There will not be damage to other equipment. Personnel may be injured if in the area. Probability is very small since for normal operation personnel does not have to be in the area.

The vessel is protected from overpressure through a rupture disc, RD-257. During filling of the vessel, relief valve SV-1034 will vent gas at a pressure below the design pressure of the vessel at maximum flow rate.

9.7 Safety Valve SV-1034

Failure of the valve implies operator failure. Vessel B-B is filled at a very small rate (rate of pressure rise of 15 psig/hour). RD-257 will protect the tank in case of failure of SV-1034.

9.8 Operator Error

Vessel B-B may become contaminated through operator error. Only persistent misoperation can add significant quantities of air to vessel B-B.

10. Valve Boxes J and R and Associated Equipment

Valve boxes J and R contain piping and valves to control the flow of liquids to and gases from the cooling loops of the chamber. Associated piping contains instrumentation and valves used for the control of flow of fluids to the cooling loops. The valve boxes are fastened to the vacuum container of the chamber. Insulation of the cold components of the valve boxes is provided by the chamber vacuum. Failure of components located inside the valve boxes is considered a part of the failure mode analysis of the chamber. Failure mode analysis of vacuum-jacketed pipes connecting to the valve boxes is covered in previous sections of this report.

10.1 Packing Leaks of Valves of Boxes J and R

Packings are located on the low pressure side of the valve. This means that, in general, the pressure differential across the packing is of the order of 15 psig or less. Leaks initially will be small and will flow gas to the chamber building at rates below those permitted by the design criteria. A leak detection point in the area of the valve boxes will alarm the operators to the existence of the leak. At a moderately high percentage (1-2%) of hydrogen in air, the interlock system of the hydrogen leak detector will close valves on tank A and other components and stop flow of liquid hydrogen to the cooling loops of the chamber. If the leak occurs during chamber cooling or warming, closure of valve PV-227 in the hydrogen refrigerator will deplete the gas inventory of the system and the rate of leakage will diminish.

10.2 Relief Valves SV-1349, SV-1350, SV-1351, SV-1352, SV-1353, SV-1354, and SV-1355

The valves are thermal relief valves of the hydrogen system of the cooling loops. Failure of these valves to open may break lines either inside or outside the chamber vacuum system. Failure implies a closed system with a limited inventory of hydrogen gas or liquid. The total amount injected in the building is within the permissible quantity of the design criteria.

10.3 Valves MV-1120, MV-1121, MV-1122, MV-1123, MV-1124, MV-1125, MV-1126, and MV-1127

Failure of the valves to open or close is not a safety hazard. Failure to open would prevent cooling of some part of the chamber. The chamber is protected to take this loss of cooling without generating a safety hazard.

Failure of the valves to close prevents potential maintenance work. Prevention of flow through the loop can be realized by closing the appropriate liquid inlet valve.

10.4 Relief Valves SV-1131, SV-1133, SV-1135, SV-1137, SV-1139, SV-1141, and SV-1143

The valves are thermal relief valves of the chamber fluid systems of the cooling loops of the chamber. Failure of these valves will release limited quantities of gas into the chamber building or the vacuum space of the chamber. The total amount is within the permissible quantity of the design criteria.

10.5 Valves MV-1132, MV-1134, MV-1136, MV-1138, MV-1140 MV-1142, and MV-1144

The valves are opened and closed during changing of the cooling loop systems. Failure to open or close the valves is not a safety hazard. In the closed position the cooling loop is protected by a relief valve.

Leakage through the valve seat is not a safety problem. The cooling loop systems are rated at the maximum pressure of line GH-2018. Packing leaks of the valves will be small. Also, the packings are on the cooling loop side of the valve and the maximum quantity of gas released is the inventory of the cooling loop.

10.6 Line GH-2079

A break in line GH-2079 permits flow of hydrogen gas from line GH-2018 directly into the bubble chamber building. The flow rate is large (capacity of valve PV-111 at B vessel). Hydrogen detection in the area of the chamber is interlocked with valve PV-111 and closes this valve. The total quantity released into the bubble chamber building will be less than 1,000 cft.

10.7 Lines GH-2072 through GH-2078

These lines (a total of seven) connect the various cooling loops with line GH-2079 through manual valves. A failure of any of these lines under normal operating conditions permits the leakage of all of the cooling loop inventory into the bubble chamber building. With the cooling loop inventories at 1,000 cft or less, the condition is within the design criteria.

10.8 Valves MV-1145 through MV-1158

These valves are transmitter calibration and shutoff valves. Failure of the valves to open or close is not a safety hazard. The calibration valves are capped off when the system is in service and leakage through the seat is not a hazard. The shutoff valves are in the open position and need not be closed. Packing leaks from the valves will be small and within the design criteria of the system.

10.9 Control Stations CS-161 through CS-168

A failure of the instrument closes any one of valves PV-161 through PV-168. This does not generate a hazardous condition.

10.10 Instrument Air Failure

Valves PV-159, PV-160, PV-161, PV-162, PV-163, PV-164, PV-165, PV-166, PV-167, and PV-168 will close. During chamber operation, the cooldown circuit consisting of lines GH-2000 and GH-2001 connecting to piping and heat exchanger F in valve box R is blanked off. This piping system is protected from overpressure by relief valve SV-1373. During chamber warmup, compressor flow enters through line GH-2001 and leaves through line GH-2000. Full flow relief valve SV-1370 protects the line system from over-pressurization. During chamber cooldown, the maximum pressure of the system is that of A tank. The system can tolerate this pressure.

10.11 Valves PV-159 and PV-160

The valves close with instrument air failure. Failure of the valves to open or close is not a safety hazard. During chamber cooldown, unscheduled closure of valves PV-159 and PV-160 leaves the piping system containing exchanger F blocked. Relief valve SV-1373 protects in this case.

A failure of solenoid valve EV-160 may make the valve open or close or remain in the set condition. None of these situations generates a hazardous situation.

10.12 Temperature Indicators TI-169 and TI-182

TI-169 indicates the presence of liquid in line GH-2002. Failure of the gauge does not affect the safety of the system. Failure of TI-182 does not affect safety of the system.

10.13 Failure of Line GH-2019

Under normal operating conditions, line GH-2019 will be closed off at the chamber target (valve PV-197) and at gas storage B-B (valve PV-112). A line break under these conditions results in a small quantity of gas leaking into the building. With valve PV-112 and/or PV-197 open. large quantities of gas may leak upon a line break. Hydrogen detection then will close valves PV-112 and PV-197 to limit the total quantity spilled.

10.14 Failure of Lines GH-2000 and GH-2001

During cooldown of the chamber, lines GH-2000 and GH-2001 are blanked off at the compressor and in open connection with valve box R piping. A leak or break in either line allows cold hydrogen to flow into the building. Liquid is supplied by line LH-2011. Valve PV-109 is interlocked with hydrogen detection and will stop flow of liquid before a total accumulation of 1,000 scft has been vented into the building.

11. Liquid Hydrogen Storage Tank (A)

Liquid hydrogen tank A contains a maximum of 15,000 gallons of liquid at a maximum pressure of 50 psig. The tank is powder insulated. Filling of the tank from a trailer occurs at the front end. All piping connections to the bubble chamber system are located at the other end nearest to the building.

11.1 Loss of Vacuum

Loss of vacuum may be due to leakage of hydrogen from the inner vessel and piping or air through the outer vessel. In the event of loss of vacuum through a hydrogen leak, the heat leak into the inner vessel will be substantially increased. The inner vessel relief valve, SV-1023, is large enough to handle the increased evaporation rate without exceeding the rated pressure of the vessel.

A loss of vacuum through an air leak will cause an increased heat leak. Only a complete rupture of the outer shell will result in a substantial heat leak. Safety valve SV-1023 and rupture disc RD-181 and associated piping are sized to handle the flow rate without exceeding the design pressure of the vessel.

A complete rupture of the outer shell (long crack) may be caused by spillage of liquid air or hydrogen from an external piping leak. Piping has been designed in such a way that the chances for this event to occur are remote.

11.2 Rupture of Inner Shell or Associated Piping

In the event of a substantial failure, the outer shell is protected from a pressure failure through rupture disc RD-127. Powder insulation retards the flow of heat from the vacuum shell. The outer shell rupture disc is set to rupture at 10 psig and will vent hydrogen at a high point on the tank. After rupture, the vacuum shell is not subjected to pressure.

11.3 Liquid Vessel Relief Valve SV-1023 Fails to Operate

The spring-loaded relief valve, SV-1023, is the primary safety device on the liquid vessel. In the event that this relief valve should fail to relieve on exposure to excessive pressures, burst disc RD-181 is provided as a secondary relief device. This burst disc will rupture at a pressure of 75 psi, thereby furnishing adequate protection to the liquid vessel.

11.4 Outer Vessel Relief Device RD-127 Fails to Function

Failure of the outer vessel relief device to function is a secondary failure. Some other form of primary failure, such as vacuum leakage, line rupture, etc., must occur before there is need for this device to operate.

11.5 Liquid Level Gauge LI-126 or LI-129 Line Rupture

In the event that the liquid or gas phase line of the liquid level gauge should break, crack, etc., flow is limited by a restrictive orifice built into the piping connection. The maximum flow rate to the atmosphere is within the maximum rate permitted by the design criteria.

11.6 Valves MV-1018, MV-1019, MV-1020, and MV-1062

These valves are level gauge shutoff valves. Failure to open or close does not generate a hazardous condition. Packing leakage is small. Location of packing is on the gauge side of shutoff valves MV-1018 and MV-1019.

11.7 Failure of Rupture Disc RD-181

A leak in this disc vents the tank to atmospheric pressure and prevents pressure buildup. It is not a safety hazard. Replacement of the disc requires removal of liquid from the tank.

11.8 Valves PV-251, PV-252, PV-105, and PV-104-B

All four valves connect to the vapor space of the tank. Failure of the valves to open or close does not generate a hazardous condition. Valve PV-104-B in the open position vents the tank to atmospheric pressure and initiates operation of the vaporizer inlet valve, PV-104-A. The closed position of PV-104-B is backed by SV-1023 and RD-181.

11.9 Valves MV-1024 and MV-1219

Valve MV-1024 is used only when the tank is prepared for hydrogen service. At that time, failure to open or close does not generate a hazard. When the tank contains liquid, valve MV-1024 is backed by a blind flange. Packing leaks will be small. The packing is located at the Figure 8 side of the valve.

Valve MV-1219 is used to supply gas to the suction of compressor D-D. Failure of the valve to open or close is not a safety hazard. In case of a line break downstream of the valve, the valve is closed. Packing leaks will be small.

11.10 Vaporizer and Associated Equipment

In case of a rupture of the vaporizer piping, a massive spill of hydrogen in the area under the hydrogen tank takes place. Hydrogen detection will close valve PV-104-A and stop the flow of liquid. Vapor may still flow until manual valve MV-1218 is closed.

It is inconceivable that the piping connected to the vaporizer will separate complete. The piping has a rating of 1,300 psig pressure (which is based on a safety factor of 4). The maximum pressure is 50 psig which provides a total safety factor of 100. The total leakage will be within the design criteria. Failure of vaporizer inlet valve PV-104-A to close keeps generating gas. The rate is smaller than the vent capacity of SV-1023.

Failure of valve PV-104-A to open with the refrigerator operating will ultimately result in a low pressure in A tank and the refrigerator. Pressure alarms PA-233 and PA-253 will indicate the condition and operators will stop operation of the refrigerator before a pressure below atmospheric has been reached.

Valves PV-104-A and PV-104-B fail closed. The tank is then protected from overpressure by SV-1023.

Valves MV-1037 and MV-1038 are gauge shutoff valves. Failure to open or close is not a safety hazard. Packing leaks will be small. Packings are located on the transmitter side of the valves.

11.11 Valves PV-106, PV-107, PV-108, and PV-109

The valves are used when liquid is supplied to various cooling loops and the bubble chamber target. Failure of the valves to open or close is not a safety hazard. Every valve is backed by a second valve which may be closed. Packing leaks will be small; packings are located on the downstream side of the valve. The valves fail closed. Instrument air failure or solenoid valve failure closes the valve. This does not generate a safety hazard.

11.12 Trailer Fill Line LH-2008

Failure of valve MV-1043 does not generate a safety hazard. Valve PV-186 may be closed. Valve packings of PV-186 and MV-1043 are on the filter side of the valves. Packing leaks are small. Closure of valves MV-1043 and trailer fill valve will restrict the total leakage of gas to the atmosphere.

Valves MV-1040, MV-1041, and SV-1039 constitute the purge, evacuation, and thermal relief system of line LH-2008. Failure of SV-1039 to open may break the line system. Inventory is small and spilled gas is within the permissible total quantity. Failure of valves MV-1040 and MV-1041 to open or close is not a safety hazard. Valve packing leaks are small.

Failure of line LH-2008 will spill liquid hydrogen at large rates into the environment. Valve PV-186 and trailer valve may be closed to stop the flow of liquid.

11.13 Filter N

The filter is designed to remove dirt and particles greater than 40 microns from the liquid stream entering A tank. The filter is protected from a potential explosion by rupture disc RD-128. In case of an explosion, personnel and equipment will not be injured or damaged since the burning hydrogen will vent straight up from the vessel. The spill may be stopped by closing valve PV-186 and trailer valve.

The filter is protected from overpressure by a thermal relief valve, SV-1207. Valve MV-1042 is a purge valve. Failure of this valve to open or close does not generate a hazardous condition.

A vacuum failure of the filter does not result in a hazardous condition. The filter is used for short periods of time and air leaking in does not lead to large accumulation.

A hydrogen leak into the vacuum space generates more vapor through heat leak. The vent system of A tank is capable of handling this.

11.14 Instrumentation

Failure of vacuum gauges VI-124 and VI-258 does not generate a dangerous situation. The sensors may be replaced without breaking the vacuum of tank or filter.

Failure of CS-104, PI-125, LI-126, and LI-129 does not generate a dangerous situation. All instruments may be replaced with the tank in service.

12. Liquid Neon-Hydrogen Storage Tank (C)

Liquid tank C contains a maximum of 10,500 gallons of liquid at a maximum pressure of 75 psig. The tank is powder insulated. Filling of the tank from a trailer occurs at the front end. All piping connections to the bubble chamber system are located at the other end nearest the building. The tank is equipped with a condenser to maintain a no-loss condition.

12.1 Loss of Vacuum

Loss of vacuum may be due to leakage of fluid from the inner vessel and piping or air through the outer vessel. In the event of loss of vacuum through a hydrogen or neon leak, the heat leak into the inner vessel will be substantially increased. The inner vessel relief valve, SV-1068 or SV-1069, is large enough to handle the increased evaporation rate without exceeding the rated pressure of the vessel.

A loss of vacuum through an air leak will cause an increased heat leak. Only a complete rupture of the outer shell will result in a substantial heat leak. Safety valve SV-1068 or SV-1069 and associated piping is sized to handle the flow rate without exceeding the design pressure of the vessel.

A complete rupture of the outer shell (long crack) may be caused by spillage of liquid air or hydrogen from an external piping leak. Piping has been designed in such a way that the chances for this event to occur are remote.

12.2 Rupture of Inner Shell or Associated Piping

In the event of a substantial failure, the outer shell is protected from a pressure failure through rupture disc RD-136. Powder insulation retards the flow of heat from the vacuum shell. The outer shell rupture disc is set to rupture at 10 psig and will vent gas at a high point on the tank. After rupture, the vacuum shell is not subjected to pressure.

12.3 Liquid Vessel Relief Valve SV-1068 or SV-1069

The relief valves are in parallel. Selector valve MV-1066 may be in one of three positions. Normally both safety valves are in open connection with the tank and failure of one relief valve does not generate a hazardous condition.

12.4 Outer Vessel Relief Device RD-136 Fails to Function

Failure of the outer vessel relief device to function is a secondary failure. Some other form of primary failure, such as vacuum leakage, line rupture, etc., must occur before there is need for this device to operate.

12.5 Liquid Level Gauge LI-130 or LI-131 Line Rupture

In the event that the liquid or gas phase line of the liquid level gauge should break, crack, etc., flow is limited by a restrictive orifice built into the piping connection. The maximum flow rate to the atmosphere is within the maximum rate permitted by the design criteria.

12.6 Valves MV-1084, MV-1085, MV-1086, MV-1087, and MV-1088

These valves are level gauge shutoff valves. Failure to open or close does not generate a hazardous condition. Packing leakage is small. Location of packing is on the gauge side of shutoff valves MV-1084 and MV-1085.

12.7 Valves MV-1065, MV-1229, PV-139, and PV-141

Valve PV-139 is used to connect the vapor space of the tank to line GH-2018. This is the case when the chamber is filled with neon-hydrogen. Failure of the valve to open or close does not generate a hazard. At the chamber, valves PV-194 and PV-195 may be closed. If the chamber were in open connection with C tank through valve PV-139 and at high pressure, excess flow into C tank would be relieved by SV-1068 and/or SV-1069.

When the tank is not in use, valve PV-139 is backed by a blind flange. Leakage through the seat is not a safety problem. A solenoid valve failure (electrical or otherwise) may close the valve or prevent movement of the valve. Valve PV-194 and/or PV-195 may be closed.

Valve MV-1065 is a manual vent valve which is normally not used. It is used during initial preparation of the tank for service. Failure of the valve to open or close is not a safety hazard.

Valves MV-1229 and PV-141 are used to condense gas from vessel B into C tank. Pressure regulator PV-111 is located between valve PV-141 and B tank and makes it impossible to connect B tank at 150 psig directly to C tank. Failure of valves PV-141 and MV-1229 to open or close does not generate a dangerous condition. Leaks through the seat are not a hazard. Normally valve PV-141 is blanked by a blind flange. Packing leaks will be small. Packings are located at the blind flange side of the valves.

12.8 Valves SV-1067 and MV-1227

SV-1067 is a thermal relief valve for the vaporizer. Failure may result in rupture of a small inventory system with limited spillage. Valve MV-1227 is normally open and only closed when some gas is generated to fill either B or B-B tank. Failure of the valve to open or close is not a hazard. Packing leaks will be small.

12.9 Valves MV-1064 and MV-1228

Valve MV-1064 is used only when the tank is prepared for hydrogen or neon service. At that time, failure to open or close does not generate a hazard. When the tank contains liquid, valve MV-1064 is backed by a blind flange. Packing leaks will be small. The packing is located at the Figure 8 side of the valve.

Valve MV-1228 is used to supply gas to the suction of compressor D-D. Failure of the valve to open or close is not a safety hazard. In case of a line break downstream of the valve, the valve is closed. Packing leaks will be small.

12.10 Vaporizer and Associated Equipment

In case of a rupture of the vaporizer piping, a massive spill of neon-hydrogen in the area under the tank takes place. Hydrogen detection will close valve PV-140-B and stop the flow of liquid. Vapor may still flow until manual valve MV-1227 is closed.

It is inconceivable that the piping connected to the vaporizer will separate complete. The piping has a rating of 1,300 psig pressure (which is based on a safety factor of 4). The maximum pressure is 75 psig which provides a total safety factor of 70. The total leakage will be within the design criteria. Failure of vaporizer inlet valve PV-140-B to close keeps generating gas. The rate is smaller than the vent capacity of SV-1068 or SV-1069.

Failure of valve PV-140-B to open with the condenser operating will ultimately result in a pressure in C tank below atmospheric. Pressure alarm PA-260 will indicate the condition and operators will stop operation of the condenser by closing valve PV-140-A.

Valves PV-140-A and PV-140-B fail closed. The tank is then protected from overpressure by SV-1068 or SV-1069.

Valves MV-1080 and MV-1081 are gauge shutoff valves. Failure to open or close is not a safety hazard. Packing leaks will be small. Packings are located on the transmitter side of the valves.

12.11 Valves PV-137 and PV-143

The valves are used when liquid is supplied to the bubble chamber and the bubble chamber target. Failure of the valves to open or close is not a safety hazard. Both valves are backed by a second valve which may be closed. Packing leaks will be small; packings are located on the downstream side of the valve. The valves fail closed. Instrument air failure or solenoid valve failure closes the valve. This does not generate a safety hazard.

12.12 Tank Fill Connection LH-2023

Failure of valve MV-1082 to open does not generate a hazard. The valve is opened and needs to be closed when the tank is connected to purifier-condenser E-E or a trailer. Failure to close under these conditions is not a hazard since a second valve in series may be closed. Packing leaks are small. The packing is located away from the tank.

12.13 Instrumentation

Failure of vacuum gauge VI-135 does not generate a dangerous situation. The sensor may be replaced without breaking the vacuum of the tank.

Failure of CS-140, PI-133, PI-132, LI-130, LI-131, and CS-134 does not generate a dangerous situation. All instruments may be replaced with the tank in service.

12.14 Condenser

The tank contains an internal condenser rated at 50 psig in which liquid hydrogen boils to condense tank fluid. Failure of liquid supply valve PV-134 to close (instrument CS-134 failure) may fill the condenser completely and ultimately vent liquid hydrogen to the stack or through line GH-2000 to the refrigerator. With too much cooling of the vapor space of the tank, controller CS-140 will close PV-140-A and stop flow of vapor. Liquid hydrogen will be returned to the A tank through self-pressurization of the condenser.

Failure of liquid supply valve PV-134 to open will, with time, generate pressure in C tank. Safety valve SV-1068 and/or SV-1069 will protect the tank.

Failure of level controller CS-134 to operate will result in either valve PV-134 closure or opening. Consequences are as discussed before.

Failure of valve PV-140-A to open prevents condensation. Pressure in the condenser will build until no condensation occurs or until relief valve SV-1078 opens. Failure of valve PV-140-A to close may result in a lowering of the vapor pressure in the tank. PV-140-B will open. The amount of vapor generated may not be enough to maintain a constant pressure. At a low pressure, PA-260 will alarm. Operators need to take action to close valve PV-140-A or close liquid valve PV-134.

A reduction of the vapor pressure in C tank is in itself not a dangerous situation. When the tank is not in use, all lines connecting the tank with the environment have double seals consisting of a valve and a blind. Because of the expensive inventory of the tank, all valves backed with a blind are equipped with bleed valves. These valves are used to evaluate the tightness of the valves. Consequently, the operating crew should have a very good idea about the quality of the seals.

For rapid condensation, valves MV-1231 and PV-138 are opened. Failure of these valves to open does not generate a hazard. Failure of one of the valves to close requires closing of the other valve and does not generate a dangerous situation.

Failure of relief valve SV-1078 to open may break the vent line or condenser itself. Time required to reach a dangerous pressure level is long since the condenser is located inside the liquid vessel of C tank and does not receive heat from the environment except through C. A break of the condenser into the C tank does not generate a dangerous condition. A break in the piping outside the tank allows a fixed quantity of gas to vent. The total may be in excess of the quantity tolerated by the criteria, but flow rate will, after an initial burst, be at less than 250 scfm.

12.15 Stack System of C Tank

The stack is equipped with a relief valve, SV-1076, which permits checking of the tightness of several C tank valves. Failure of SV-1076 to open prevents venting of the tank. Rupture disc RD-262 will open at 15 psig and vent the tank without exceeding safe pressure levels.

13. Liquid Deuterium Storage Tank (D)

Liquid tank D contains a maximum of 10,500 gallons of liquid at a maximum pressure of 75 psig. The tank is super insulated. Filling of the tank from a trailer occurs at the front end. All piping connections to the bubble chamber system are located at the other end nearest the building. The tank is equipped with a condenser to maintain a no-loss condition.

13.1 Loss of Vacuum

Loss of vacuum may be due to leakage of fluid from the inner vessel and piping or air through the outer vessel. In the event of loss of vacuum through a deuterium leak, the heat leak into the inner vessel will be substantially increased. The inner vessel relief valve, SV-1112 or SV-1113, is large enough to handle the increased evaporation rate without exceeding the rated pressure of the vessel.

A loss of vacuum through an air leak will cause an increased heat leak. Only a complete rupture of the outer shell will result in a substantial heat leak. Safety valve SV-1112 or SV-1113 and associated piping is sized to handle the flow rate without exceeding the design pressure of the vessel.

A complete rupture of the outer shell (long crack) may be caused by spillage of liquid air or hydrogen from an external piping leak. Piping has been designed in such a way that the chances for this event to occur are remote.

13.2 Rupture of Inner Shell or Associated Piping

In the event of a substantial failure, the outer shell is protected from a pressure failure through rupture disc RD-146. The outer shell rupture disc is set to rupture at 5 psig and will vent gas at a high point on the tank. After rupture, the vacuum shell is not subjected to pressure.

13.3 Liquid Vessel Relief Valve SV-1112 or SV-1113

The relief valves are in parallel. Selector valve MV-1107 may be in one of three positions. Normally both safety valves are in open connection with the tank and failure of one relief valve does not generate a hazardous condition.

13.4 Outer Vessel Relief Device RD-146 Fails to Function

Failure of the outer vessel relief device to function is a secondary failure. Some other form of primary failure, such as vacuum leakage, line rupture, etc., must occur before there is need for this device to operate.

13.5 Liquid Level Gauge LI-151 or LI-152 Line Rupture

In the event that the liquid or gas phase line of the liquid level gauge should break, crack, etc., flow is limited by a restrictive orifice built into the piping connection. The maximum flow rate to the atmosphere is within the maximum rate permitted by the design criteria.

13.6 Valves MV-1096, MV-1097, MV-1098, MV-1099, and MV-1100

These valves are level gauge shutoff valves. Failure to open or close does not generate a hazardous condition. Packing leakage is small. Location of packing is on the gauge side of shutoff valves MV-1096 and MV-1097.

13.7 Valves MV-1111, MV-1237, PV-156, and PV-155

Valve PV-155 is used to connect the vapor space of the tank to line GH-2018. This is the case when the chamber is filled with deuterium. Failure of the valve to open or close does not generate a hazard. At the chamber, valves PV-194 and PV-195 may be closed. If the chamber were in open connection with D tank through valve PV-155 and at high pressure, excess flow into D tank would be relieved by SV-1112 and/or SV-1113.

When the tank is not in use, valve PV-155 is backed by a blind flange. Leakage through the seat is not a safety problem. A solenoid valve failure (electrical or otherwise) may close the valve or prevent movement of the valve. Valve PV-194 and/or PV-195 may be closed.

Valve MV-1111 is a manual vent valve which is normally not used. It is used during initial preparation of the tank for service. Failure of the valve to open or close is not a safety hazard.

Valves MV-1237 and PV-156 are used to condense gas from vessel B into D tank. Pressure regulator PV-111 is located between valve PV-156 and B tank and makes it impossible to connect B tank at 150 psig directly to D tank. Failure of valves PV-156 and MV-1237 to open or close does not generate a dangerous condition. Leaks through the seat are not a hazard. Normally valve PV-156 is blanked by a blind flange. Packing leaks will be small. Packings are located at the blind flange side of the valves.

13.8 Valves SV-1114 and MV-1235

SV-1114 is a thermal relief valve for the vaporizer. Failure may result in rupture of a small inventory system with limited spillage.

Valve MV-1235 is normally open and only closed when some gas is generated to fill either B or B-B tank. Failure of the valve to open or close is not a hazard. Packing leaks will be small.

13.9 Valves MV-1116 and MV-1236

Valve MV-1116 is used only when the tank is prepared for deuterium service. At that time, failure to open or close does not generate a hazard. When the tank contains liquid, valve MV-1116 is backed by a blind flange. Packing leaks will be small. The packing is located at the Figure 8 side of the valve.

Valve MV-1236 is used to supply gas to the suction of compressor D-D. Failure of the valve to open or close is not a safety hazard. In case of a line break downstream of the valve, the valve is closed. Packing leaks will be small.

13.10 Vaporizer and Associated Equipment

In case of a rupture of the vaporizer piping, a massive spill of deuterium in the area under the tank takes place. Hydrogen detection will close valve PV-150-B and stop the flow of liquid. Vapor may still flow until manual valve MV-1235 is closed.

It is inconceivable that the piping connected to the vaporizer will separate complete. The piping has a rating of 1,300 psig pressure (which is based on a safety factor of 4). The maximum pressure is 75 psig which provides a total safety factor of 70. The total leakage will be within the design criteria. Failure of vaporizer inlet valve PV-150-B to close keeps generating gas. The rate is smaller than the vent capacity of SV-1112 or SV-1113.

Failure of valve PV-150-B to open with the condenser operating will ultimately result in a pressure in D tank below atmospheric. Pressure alarm PA-261 will indicate the condition and operators will stop operation of the condenser by closing valve PV-150-A.

Valves PV-150-A and PV-150-B fail closed. The tank is then protected from overpressure by SV-1112 or SV-1113.

Valves MV-1108 and MV-1109 are gauge shutoff valves. Failure to open or close is not a safety hazard. Packing leaks will be small. Packings are located on the transmitter side of the valves.

13.11 Valves PV-145 and PV-144

The valves are used when liquid is supplied to the bubble chamber and the bubble chamber target. Failure of the valves to open or close is not a safety hazard. Both valves are backed by a second valve which may be closed. Packing leaks will be small; packings are located on the downstream side of the valve. The valves fail closed. Instrument air failure or solenoid valve failure closes the valve. This does not generate a safety hazard.

13.12 Tank Fill Connection LH-2025

Failure of valve MV-1092 to open does not generate a hazard. The valve is opened and needs to be closed when the tank is connected to purifier-condenser E-E or a trailer. Failure to close under these conditions is not a hazard since a second valve in series may be closed. Packing leaks are small. The packing is located away from the tank.

13.13 Instrumentation

Failure of vacuum gauge VI-149 does not generate a dangerous situation. The sensor may be replaced without breaking the vacuum of the tank.

Failure of CS-150, PI-148, PI-153, LI-150, LI-151, and CS-147 does not generate a dangerous situation. All instruments may be replaced with the tank in service.

13.14 Condenser

The tank contains an internal condenser rated at 50 psig in which liquid hydrogen boils to condense tank fluid. Failure of liquid supply valve PV-147 to close (instrument CS-147 failure) may fill the condenser completely and ultimately vent liquid hydrogen to the stack or through line GH-2000 to the refrigerator. With too much cooling of the vapor space of the tank, controller CS-150 will close PV-150-A and stop flow of vapor. Liquid hydrogen will be returned to the A tank through self-pressurization of the condenser.

Failure of liquid supply valve PV-147 to open will, with time, generate pressure in D tank. Safety valve SV-1112 and/or SV-1113 will protect the tank.

Failure of level controller CS-147 to operate will result in either valve PV-147 closure or opening. Consequences are as discussed before.

Failure of valve PV-150-A to open prevents condensation. Pressure in the condenser will build until no condensation occurs or until relief valve SV-1119 opens. Failure of valve PV-150-A to close may result in a lowering of the vapor pressure in the tank. PV-150-B will open. The amount of vapor generated may not be enough to maintain a constant pressure. At a low pressure, PA-261 will alarm. Operators need to take action to close valve PV-150-A or close liquid valve PV-147.

A reduction of the vapor pressure in D tank is in itself not a dangerous situation. When the tank is not in use, all lines connecting the tank with the environment have double seals consisting of a valve and a blind. Because of the expensive inventory of the tank, all valves backed with a blind are equipped with bleed valves. These valves are used to evaluate the tightness of the valves. Consequently, the operating crew should have a very good idea about the quality of the seals.

For rapid condensation, valves MV-1234 and PV-154 are opened. Failure of these valves to open does not generate a hazard. Failure of one of the valves to close requires closing of the other valve and does not generate a dangerous situation.

Failure of relief valve SV-1119 to open may break the vent line or condenser itself. Time required to reach a dangerous pressure level is long since the condenser is located inside the liquid vessel of D tank and does not receive heat from the environment except through D. A break of the condenser into the D tank does not generate a dangerous condition. A break in the piping outside the tank allows a fixed quantity of gas to vent. The total may be in excess of the quantity tolerated by the criteria, but flow rate will, after an initial burst, be at less than 250 scfm.

13.15 Stack System of D Tank

The stack is equipped with a relief valve, SV-1115, which permits checking of the tightness of several D tank valves. Failure of SV-1115 to open prevents venting of the tank. Rupture disc RD-263 will open at 15 psig and vent the tank without exceeding safe pressure levels.

14. Chamber Vent System

The chamber vent system consists of a knockout drum (A-A) and vent stack. The knockout drum is connected to the chamber through valve PV-190 and a jacketed line, LH-2070.

The knockout drum has a volume of approximately 6,000 liters and is rated at 150 psig. It is connected to the vent stack through two parallel relief valves, SV-1159 and SV-1160, control valve PV-183, and rupture disc RD-173.

The vessel is equipped with a liner or bucket which prevents the vented liquid from the chamber to come in direct contact with the outer wall of the vessel.

14.1 Valve PV-190

Failure of this valve to close connects A-A with the chamber. This is not a dangerous situation. Opening of valve PV-190 through operator error with vessel A-A at low pressure will result in a wave of liquid hydrogen entering line LH-2070. Vaporization will result in pressurization of vessel A-A to a pressure higher than the chamber. The relief valve, SV-1159 or SV-1160, is capable of handling the instantaneous flow rate without exceeding the design pressure of vessel A-A.

14.2 Failure of Line LH-2070

It is inconceivable that line LH-2070 separates completely. The line is an all-welded structure with a pressure rating of 1,200 psig. A leak will be detected by the hydrogen detector. Valve PV-190 is interlocked with the detection system and closes. Total spillage of hydrogen into the environment is then some 1,000 scft, within the maximum quantity tolerated by the design criteria.

14.3 Failure of Vessel A-A and Associated Piping

The total inventory in the system under normal operating conditions is approximately 2,000 scft. Leakage of all this gas is permissible outside the building.

Vessel A-A will only contain liquid hydrogen (deuterium) under emergency conditions. This implies a failure somewhere else in the system. Criteria do not foresee a failure in A-A under these conditions.

14.4 Valves MV-1129, MV-1130, MV-1190, and MV-1191

These valves are not used under normal operating conditions. Valve MV-1129 is backed by a blind flange. Valves MV-1190 and MV-1191 are gauge shutoff valves. Packing leaks will be small. Failure of the valves to open or close does not generate a dangerous condition.

14.5 Safety Valves SV-1159, SV-1160, and Selector Valve MV-1161

Failure of the valves to open does not generate a dangerous condition. RD-173 is a backup for the safety valves. Valve MV-1161 is a selector valve connecting either SV-1159 or SV-1160 with A-A. Failure to change positions is not a dangerous situation.

14.6 Valve PV-183

Failure of the valve to open or close does not generate a dangerous situation.

14.7 Pressure Indicator PI-184

Failure of the gauge does not lead to a dangerous situation.

14.8 Vent Stack Weather Cover NV-1381

The vent stack is equipped with a weather cover. The cover acts as a check valve to prevent air from entering the vent system. It is conceivable that weather conditions freeze the cover closed. To prevent complete closure of the vent system, the cover is equipped with a rupture disc which will burst at a pressure of 10 psig.

14.9 Vent Stack Nitrogen Purge

Failure of valve EV-171 to open does not generate a dangerous situation. An electrical failure opens the valve and nitrogen gas purges the stack.

15. Storage Tank Vent System

The vent system consists of a 6-inch line equipped with nitrogen gas purge and weather cover to prevent moisture from entering the stack. The stack has a drain valve for moisture removal.

15.1 Weather Cover NV-1256 Failure

The cover may freeze to the stack. A rupture disc built into the weather cover will rupture at a pressure of 10 psig and open the stack.

15.2 Nitrogen Purge Valve EV-200

Failure to open does not generate a dangerous situation. The valve fails open on an electrical failure.

15.3 Drain Valve MV-1257

Failure of the drain valve to open does not generate an immediate hazard. A considerable amount of water may be accumulated before vent connections are plugged. Failure of the valve to close would permit some venting at the bottom of the stack. Rates will be below those permitted by the criteria.

16. Utility Vacuum System

The utility vacuum system consists of two 5 bhp Kinney vacuum pumps connected to a manifold system. All components of the system may be connected through Figure 8 blinds. This permits complete separation when the service is not required. The nitrogen purge system is connected to the header to allow inerting of any part of the system.

16.1 Safety Valve SV-1382

Failure of the valve to operate is a secondary failure. Operator error has to proceed in order to subject the header to a high pressure.

16.2 Failure of a Pump to Operate

Pumps S and T are in parallel and redundant.

16.3 Valve MV-1162

Failure of the valve to open is not a hazard. Failure of the valve to close might leak hydrogen into the nitrogen system. Check valve NV-1383 prevents this.

16.4 Break or Leak in the Line System

This will not generate a dangerous situation. Any time the system is used the ultimate vacuum with a closed system is checked. Leaks will be detected before the system is used.

16.5 Vacuum Gauges VI-174, VI-175, and VI-176

Failure is not a hazard. The gauge element may be replaced without taking the system out of service.

16.6 Valves MV-1162, MV-1163, MV-1164, MV-1165, MV-1166, MV-1167, MV-1187, and MV-1189

Failure of the valves to open or close does not generate a hazard. Leaks will be detected at the time the system is to be used.

(6) CONCLUSIONS

It may be concluded that the cryogenic system, as designed, is a safe system, within the safety criteria assumed for the design of the system. The major safety problem of venting large quantities of hydrogen into the bubble chamber building or outside in the tank area has been taken care of by interlocking valves of major components with a signal from the hydrogen detector. The operator does not have to use judgment in deciding whether to close certain valves.

Small leaks, such as from valve packings, may also be detected by the hydrogen detector. However, the level of detection will be too low for the interlocking action to take place. The probability of the occurrence of the postulated events has been assumed to be one. In some cases, the discussion points out that the probability is zero due to the very large safety factors involved. In that case, the postulated event becomes inconceivable.

The failure mode analysis has been summarized in the appendix. Listing is by major item, such as hydrogen compressor, storage dewars, etc. The major item is also identified by the letter used on the process flow sheets. Under each major item, four columns list the following: Subcomponent, section in which the subcomponent is discussed, page on which the section is found, and category. Under the column "category", numbers 1, 2, or 3 may be found. The meaning of these numbers is as follows:

1. There is no possibility of leakage.

2. Leakage of hydrogen or deuterium gas at small rates may be possible. (Valve packings are in this category.)

3. Leakage of hydrogen or deuterium gas at relatively high rates and up to large total quantities may be possible. (Line breaks or substantial flange leaks are in this category.)

APPENDIX - FAILURE MODE ANALYSIS SUMMARY

Hydrogen Compressor (M)

Item	Section	Page	Category
Safety Valves	1.3	70	1
Manual Valves	1.4	70	2
	1.9	73	2
	1.14	75	2
Control Valves	1.5	71	1
	1.12	74	2
	1.13	75	2
Instruments	1.2	70	1
	1.5	71	1
	1.7	72	1
	1.10	74	1
	1.12	74	2
	1.13	75	2
	1.15	76	1
	1.16	77	1
Electric Motor	1.1	69	1
Water Cooling	1.6	72	1
Piping	1.8	72	3
	1.11	74	3
Heater C-C	1.15	76	1

Drier Assembly (E-E and G-G)

Item	Section	Page	Category
Manual Valves	2.1	78	2
	2.2	78	2
	2.3	79	2
Safety Valves	2.7	80	1

Item	Section	Page	Category
Instruments	2.4	79	1
Piping	2.6	79	3
Heater	2.5	79	1

Hydrogen Refrigerator and Expander (H and G)

Item	Section	Page	Category
Vacuum	3.1	80	1
	3.11	84	1
External Piping	3.2	81	3
Manual Valves	3.3	81	2
	3.4	82	2
	3.6	82	2
	3.7	82	2
	3.8	83	2
Safety Valves	3.5	82	2
Control Loops	3.9	83	1
	3.10	84	1
Instruments	3.9	83	1
	3.10	84	1
	3.15	86	1
Accumulation of Solids	3.13	85	1
Adsorbers	3.12	85	1
Expander	3.14	86	2

Compressor (D-D)

Item	Section	Page	Category
Leakage	4.2	87	2
	4.4	88	2
Relief Valves	4.3	88	1
	4.5	88	1

Item	Section	Page	Category
Instruments	4.1	87	1
	4.6	88	1
	Chamber Fluid Precooler (P)		
Insulation	5.1	89	1
Instruments	5.3	90	1
	5.5	91	1
Leaks	5.2	90	3
Relief Valve	5.4	91	1
	Liquid Piping		
LH-2004	6.1	91	3
LH-2005	6.2	93	2
GH-2002	6.3	93	3
GH-2003	6.4	95	2
Refrigerator to Expander	6.5	95	3
LH-2013	6.6	96	2
LH-2014	6.6	96	2
LH-2011	6.7	97	3
LH-2126	6.7	97	3
LH-2012	6.7	97	3
GH-2018	6.8	98	2
	Deuterium-Neon Purifier-Condenser (E)		
Manual Valves	7.2	101	2
	7.3	101	2
	7.4	101	2
	7.5	101	2

Item	Section	Page	Category
	7.6	101	2
Safety Valves	7.7	102	2
	7.9	102	2
Instruments	7.8	102	1
	7.10	102	1
	7.11	102	1
	7.12	102	1
	7.14	103	1
	7.15	103	1
Insulation	7.13	103	1
Piping	7.16	103	3
Heater	7.15	103	1

Gas Storage Vessel B and Associated Piping

Item	Section	Page	Category
Line Break	8.1	104	3
Manual Valves	8.2	104	2
	8.4	105	2
Instruments	8.3	104	1
Safety Valves	8.5	105	2
	8.7	105	1
Vessel Rupture	8.6	105	3

Gas Storage Vessel B-B and Associated Piping

Item	Section	Page	Category
Line Break	9.1	106	3
Manual Valves	9.2	106	2
	9.4	107	2
Instruments	9.3	106	1
Safety Valves	9.5	107	2
	9.7	107	1

Item	Section	Page	Category
Vessel Rupture	9.6	107	3
	Valve Boxes J and R		
Valve Packings	10.1	108	2
Safety Valves	10.2	108	2
	10.4	109	2
Manual Valves	10.3	109	1
	10.5	109	2
	10.8	110	2
Instruments	10.9	110	1
	10.10	110	1
	10.11	111	1
	10.12	111	1
Lines	10.6	110	3
	10.7	110	3
	10.13	111	3
	10.14	111	3
	Liquid Hydrogen Storage Tank (A)		
Insulation	11.1	112	3
	11.2	112	3
Safety Valves	11.3	113	1
	11.4	113	1
	11.7	113	1
Manual Valves	11.6	113	2
	11.9	114	2
Instrumentation	11.5	113	2
	11.8	114	2
	11.11	115	2

Item	Section	Page	Category
	11.14	116	1
	11.10	114	1
Vaporizer	11.10	114	3
Trailer Fill Line	11.12	115	3
	11.13	116	3

Liquid Neon-Hydrogen Tank (C)

Item	Section	Page	Category
Insulation	12.1	117	3
	12.2	117	3
Manual Valves	12.6	118	1
	12.7	118	1
	12.8	119	2
	12.9	119	2
Safety Valves	12.4	117	1
	12.8	119	1
	12.3	117	1
Vaporizer	12.10	119	3
Instrumentation	12.13	120	1
	12.11	120	1
Trailer Fill Connection	12.12	120	2
Condenser	12.14	121	3
Vent System	12.15	122	1

Liquid Deuterium Storage Tank (D)

Item	Section	Page	Category
Insulation	13.1	122	1
	13.2	123	3
Safety Valves	13.3	123	1
	13.4	123	1
	13.8	124	2

Item	Section	Page	Category
Instruments	13.5	123	2
	13.13	126	1
	13.14	126	1
	13.11	126	2
Manual Valves	13.6	124	2
	13.7	124	2
	13.8	124	2
	13.9	125	2
Vaporizer	13.10	125	3
Condenser	13.14	126	3
Trailer Connection	13.12	126	2
Vent System	13.15	128	1
	Chamber Vent System (A-A)		
Solenoid Operated Valves	14.1	128	1
	14.6	129	1
Manual Valves	14.4	129	2
Safety Valves	14.5	129	1
Vessel Failure	14.3	129	3
Line Failure	14.2	129	3
Instruments	14.7	129	1
Check Valve	14.8	130	1
	Storage Tank Vent System		
Check Valve	15.1	130	1
Valves	15.2	130	1
	15.3	130	1

Utility Vacuum System

Item	Section	Page	Category
Valves	16.3	131	1
	16.6	131	1
Safety Valve	16.1	131	1
Line Break	16.4	131	1
Instruments	16.5	131	1

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IV. EQUIPMENT

D. Failure Mode Analysis: HYDROGEN SYSTEM FOR TWO UNRELATED FAILURES

Prepared by

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IV. EQUIPMENT

D. Failure Mode Analysis: HYDROGEN SYSTEM FOR TWO UNRELATED FAILURES

IV. D. Failure Mode Analysis: HYDROGEN SYSTEM FOR TWO UNRELATED FAILURES

(1) INTRODUCTION

It is the purpose of this report to identify the combinations of two unrelated failures which may lead to accidents resulting in large amounts of damage to the facility. In order to do this in a systematic way, the overall cryogenic system has been divided in sub-systems. The sub-systems are coupled in some instances, but many of the sub-systems are never coupled with each other. Each sub-system is analyzed for two unrelated failures and coupled sub-systems are analyzed for a combination of a single failure in each sub-system.

If two sub-systems are not coupled in any way, a single failure in one system and a single failure in another system will act essentially as two single failures. The effect of single failures has been analyzed in the Bubble Chamber Safety Report.

The effect of a double failure occurring as single failures in uncoupled sub-systems is at worst twice as large as that of a single failure, and there is no magnifying effect such as is possible when two failures occur in a single system.

On the other hand, when two failures occur in a single sub-system or two coupled sub-systems, the effects of the failures may be very large. For instance, a valve failure coupled with a line break in a sub-system may release very large quantities of liquid or gaseous hydrogen into the atmosphere without the means for stopping the flow until the inventory of the system is exhaus

Ignition of the vented hydrogen may lead to extensive damage to the facility.

In Section (4) of this report unrelated double failures have been analyzed in sub-systems and coupled sub-systems. The analysis shows that there are two combinations of unrelated failures which may generate potentially dangerous situations leading to extensive damage. They are:

1) A line rupture coupled with a failure of the hydrogen detector system to pick up leaking gas or liquid will fail to close the various valves in the system and lock up large inventories of the system. Large amounts of liquid or gas may be spilled and only action on the part of the operators will stop the flow of liquid or gas.

2) Failure of one valve to close coupled with a line rupture in some instances leads to an uncontrolled spill of liquid and/or gas.

It is easy to provide a solution for the combination of 1) above by providing two completely independent and fully redundant hydrogen detection systems. When this is done (at modest cost) it is not necessary to evaluate the probability of the occurrence of this failure.

It is considerably more expensive to provide a solution for the double failure of 2) above, and it is advisable to evaluate the probability of the occurrence of this type of failure.

Section (2) of the report deals with the probability of the simultaneous occurrence of a line rupture and a valve failure in a qualitative manner.

Section (3) of the report lists the combination of two unrelated failures which have the potential for generation of large amounts of damage to equipment of the facility in sub-systems and coupled sub-systems.

Section (4) of the report deals with the analysis of all sub-systems and coupled sub-systems.

The arrangement of the report is such that reading of Sections (1), (2), and (3) will give the reader a sufficient insight in the failure mode analysis for two unrelated failures.

(2) PROBABILITY OF THE SIMULTANEOUS OCCURRENCE OF A LINE RUPTURE AND VALVE FAILURE

Before considering the desirability of using extra equipment to safeguard the facility from major damage caused by two unrelated failures, probabilities for the occurrences of various combinations of failures need to be considered.

Line Breaks

There are four ways in which a line may be ruptured and allow a significant flow of liquid or gas to escape. These are:

1) Faulty workmanship during construction of the system. It is possible, that bad welds may be the cause of line breaks.

2) Explosions of a hydrogen-air mixture in the pipe may lead to rupture of the pipe.

3) Mechanical interaction between the pipe and the environment. For instance, a crane hook may pull out a pipe or a forklift truck may push a pipe to the breaking point.

4) Operator error.

Faulty workmanship may be checked in a number of ways and the probability of the line rupture occurring from this cause may be reduced to a very low value. The following has been done:

1) Design all piping with wall thickness substantially in excess of the minimum thickness required by code. All pressure piping is installed in accordance with a piping schedule, which specifies materials and minimum wall thickness as a function of pipe diameter.

2) Pressure test all piping after installation in accordance with ASME code regulations.

3) X-ray weld joints.

Explosions in piping are only possible when flammable mixtures are coupled with an ignition source. Ignition sources can be quite common when pipes are dirty and particles are moved along with the gas. The particles may be charged electrically and generate sparks while discharging.

Clean pipes and strict adherence to operating procedures will reduce the probability of the occurrence of an explosion to a very low value.

Mechanical interaction between cranes, forklift trucks or other vehicles and piping is under control of the operating crew. It is always possible to use heavy equipment in the area of the bubble chamber at times when the chamber system is in operation. However, operating procedures and philosophy must generate strict rules controlling the use of heavy powered equipment and it is possible to reduce the probability of the occurrence of mechanical interaction to a very low value.

Operator error makes it possible to generate dangerous situations. For instance, the desire to reduce downtime caused by some maintenance problem may invite short cuts, which temporarily remove some of the safety features built into the system. Again, it is operating philosophy which will determine whether these situations are encouraged or tolerated.

Valve Failures

Valve failures leading to potentially catastrophic events will be failures to close. Valve leakage after closure is not in this category, unless the maintenance program has been neglected and the valve is allowed to leak very badly.

Under certain conditions valves may fail to close. For instance, a leaking packing coupled with warming and cooling of the valve may cause water to penetrate along the valve stem. With water in the valve, the valve will open since the valve at that time is warm and water is present in the liquid form. Once the valve is cold it may freeze in position and cannot be closed.

Mechanical failures resulting in a failure of the valve stem to move are very rare if the valve is checked out properly during installation. During this time the valve needs to be stroked a number of times. Binding or excessive friction will then be discovered and must then be corrected.

The probability of a double failure, consisting of a line break and a valve failing to close can be reduced to a very low value, when the following is strictly adhered to:

1) Pressure test all piping and check weld joints by X-ray.

2) Keep systems clean.

3) Adhere strictly to operating and maintenance procedures.

4) Check valves for packing leaks and evidence of water accumulation in packing.

5) Stroke valves a number of times during system installation.

(3) COMBINATION OF FAILURES WITH POTENTIAL FOR EXTENSIVE DAMAGE

The following combinations of failures have potential for the generation of extensive damage. The number in parenthesis refers to the item number in Section (4) where the failure is mentioned.

1) Failure of valve PV104A to close coupled with a rupture in the vaporizer piping (3.9). Potentially the complete inventory of the liquid hydrogen storage tank drains into the environment and a fire may exist for the duration of the spill. A delayed ignition may cause a pressure wave which may generate some damage to the corridor connecting bubble chamber building and control room. The total amount of spilled hydrogen may be as much as 15,000 gallons.

2) Failure of valve PV252 to close coupled with a rupture of line LH2004 inside the building (2-a.8), or failure of valve PV251 to close coupled with a rupture of line GH2005 (2-a.8) will vent down the liquid storage tank to atmospheric pressure. If this occurs inside the building, a dangerous situation with potentially large amounts of damage exists for the duration of the occurrence.

3) Rupture of line LH2014 (or LH2013) with valves PV106 (or PV-107) failing to close (3-b.3, 3-b.4, 3-b.5) results in flow of liquid from the A tank to the environment just outside the building. This flow continues until the tank has been drained. Potential damage may be as under 1).

4) Rupture of line LH2011 between valve box R and 10" vacuum jacketed line with valve PV109 failing to close (3-c.2) will vent

liquid into the bubble chamber building in the area of the chamber. Fire with or without delayed ignition may occur. Damage may be severe to chamber instrumentation and building.

5) Rupture of lines LH2012, LH2126, and LH2021 coupled with a valve failure (PV180, PV189, PV196) (3-d.1, 3-d.2) may cause extensive damage through fire and pressure wave.

6) Rupture of line GH2028, GH2029, or GH2135 coupled with a failure of vaporizer inlet valves to close (PV104A, PV140B, PV150B) (4-b.1) may vent large quantities of gas into the building. Fire and explosion may generate large amounts of damage.

7) Rupture of compressor suction or discharge line coupled with a failure of the hydrogen detection system will allow large quantities of hydrogen gas to flow into the building. (1.8, 1-ab.4, 2.6)

8) A high pressure circuit break in the hydrogen refrigerator cold box coupled with operator error in removal of rupture disk RD264 from service through blocking (2.1) may result in rupture of the box. Flying metal and burning hydrogen gas may cause extensive damage in the area of the cold box.

9) Failure of warm piping between compressor and refrigerator coupled with a failure of valve PV188 to close will continue pumping hydrogen gas into the building upon detection of hydrogen (1.9). This gas is vent gas from the condenser in C and D tanks and the cooling loops of the bubble chamber.

10) Failure of a control valve in the cooling loops of the chamber coupled with a line failure in GH2002 (2-b.1) will vent large quantities of hydrogen, possibly in the building. Delayed ignition will cause extensive damage.

11) Gas return line from condensers in C and D tanks coupled with a detector failure will vent large quantities of gas into the building or atmosphere just outside the building (2-c.1, 2-c.2).

12) Failure of the vaporizer inlet valve to close coupled with failure of a single relief valve on either C or D tank will ultimately

(after all liquid hydrogen has been used up in the condenser) pressurize the tank to rupture (4.3).

13) Insulation vacuum failure of C or D tank coupled with a relief valve failure (4.4) may lead to rupture of the liquid tank after all liquid hydrogen is used up.

14) Line break of GH2018 coupled with valve PV111 failing to close may vent gas into the bubble chamber building. Delayed ignition may cause extensive damage (6-ab.4).

15) Line GH2018 rupture, coupled with failure of the hydrogen detector (6-ab.5).

16) Rupture of Corblin compressor suction line coupled with hydrogen detector failure may vent large amounts of gas into the building (6-c.3).

17) Rupture of line GH2019 coupled with hydrogen detector failure (7-b.1) will vent large amounts of gas into the building.

18) Rupture of line GH2019 coupled with failure of valve PV197 to close will vent the target down into the building (7-b.2).

19) Line LH2070 rupture coupled with valve PV191 failing to close will vent large quantities of gas and/or liquid (9-a.1).

20) Line LH2148 rupture coupled with an operator's inability to close valve MV1082 or MV1092 on C or D tank may vent all of the neon or deuterium to the atmosphere (10-cd.1).

(4) ANALYSIS OF SUB-SYSTEMS AND COUPLED SUB-SYSTEMS

The following are the sub-systems of the cryogenic system:

H_2 compressor M with deoxo unit G-G and drier E-E

H_2 refrigerator H

Liquid hydrogen storage tank A with filter N

Liquid neon tank C with condenser

Liquid deuterium tank D with condenser

Gas storage vessel B

Gas storage vessel B-B

Chamber fluid precooler P

Corblin compressor D-D

Valve box R with exchanger F

Valve box J

Chamber with vacuum sphere

Chamber knockout drum A-A with vent system

Deuterium-neon purifier-condenser E

Deuterium trailers L

Utility vacuum system with pumps S and T

The following are coupled sub-systems:

1) H_2 compressor M and deoxo-drier unit EE-GG with:
   - a) H_2 refrigerator H
   - b) Liquid H storage tank A
   - c) Valve Box R
   - d) Deuterium-neon purifier-condenser
   - e) Condenser in C and D tanks
2) Hydrogen Refrigerator H with:
   - a) Liquid hydrogen storage tank A
   - b) Valve box R
   - c) Condensers in C and D tanks
3) Liquid Hydrogen Storage Tank A and Filter N with:
   - a) Chamber fluid precooler P
   - b) Condensers in C and D tanks
   - c) Valve box R
   - d) Valve box J
   - e) Gas storage vessel B
4) Liquid Neon Tank C with:
   - a) Bubble chamber
   - b) Corblin compressor D-D
   - c) Chamber fluid precooler P
   - d) Gas storage vessel B

5) Liquid Deuterium Tank D with:
   a) Bubble chamber
   b) Corblin compressor D-D
   c) Chamber fluid precooler P
   d) Gas storage vessel B
6) Gas Storage Vessel B with:
   a) Chamber fluid precooler P
   b) Chamber through valve box J
   c) Corblin compressor D-D
7) Gas Storage Vessel B-B with:
   a) Corblin compressor D-D
   b) Chamber through valve box J
8) Chamber Fluid Precooler P with:
   a) Chamber through valve box J
9) Chamber System with:
   a) Chamber knockout drum A-A with vent system
10) Deuterium-Neon Purifier-Condenser E with:
   a) Hydrogen Compressor
   b) Liquid hydrogen storage tank A
   c) Neon tank C
   d) Deuterium tank D
   e) Trailers L
11) Utility vacuum system with all other sub-systems

<u>1. Hydrogen Compressor M</u>

1.1 Electrical Failure: Electrical failure will not release hydrogen into the atmosphere. A combination of electrical failure and any other single failure in the system can therefore be treated as a single failure releasing gas or liquid from the system.

1.2 Failure of temperature indicators on the compressor with any other single failure will release hydrogen into the environment as if a single failure has occurred. Effects of a single failure apply.

1.3 Failure of safety valves SV-1266, SV-1267, SV-1268, and SV-1269: A combination of SV-1269 and PV-101 failure may generate a high pressure in the suction line of the compressor. Under normal system operation, SV-1299 will relieve pressure. Only when valve PV-187 is closed, is it possible to generate a high pressure in the compressor suction and potentially break a pipe. The quantity of gas released into the building is limited within the quantity tolerated by the design criteria because the system leaking is a limited inventory system.

Failure of SV-1266, coupled with failure of PV-100, may generate a high discharge pressure of the compressor. The overloaded compressor motor will shut the compressor down before the burst pressure of the piping system is reached.

Failure of interstage relief valves, SV-1267 and SV-1268, coupled with failure of compressor valves, may generate high interstage pressures. Valves PV-227 and PV-252 will be closed to stop gas flow to the environment.

All other combinations of failures of these relief valves and the rest of the system will act as single failures with the consequences as spelled out in the Safety Report.

1.4 Failures of Valves MV-1270, -1271, -1272, -1181, -1000, -1002, -1273, -1275 and -1274: Operation of these valves is very limited and under operator control. Failure to open or close, coupled with any other failure in the system, does not violate the design criteria of the system in any way.

1.5 Failure of Controller CS-100 and/or Control Valve PV-100: Failure of the valve to open, coupled with a failure of SV-1266 to operate, may generate a high compressor discharge pressure. Consequences are as spelled out under 1.3.

Failure of the valve to close, coupled with failure of SV-1269 to open, may generate a high compressor suction pressure. PV-101 will relieve under normal operating conditions. When the compressor is operating as a closed off unit, consequences will be as under 1.3. When the compressor suction line drops below atmospheric pressure and valve PV-101 is open or fails to close, nitrogen will be drawn into the compressor. The rate of nitrogen purge to the stack is fairly large when valve EV-200 is open. Normally this valve is closed. Check valve NV-1256 is a well sealing valve and the amount of air drawn into the compressor suction is small. The low pressure alarm PA-253 is redundant in PA-233 and the operator will be warned of the condition.

1.6 Failure of Water Cooling System of the Compressor: Water cooling failure results in a high discharge gas temperature. A temperature switch, TS-177, will stop compressor operation. Failure of the switch will generate ultimately very high temperatures of the discharge gas and the discharge line may fail. Fire will be the immediate result. With the fire detection system tied into emergency closure of various valves of the system duration of the large scale fire will be of the order of seconds. Potential damage is then slight. Failure of water cooling with any other component will not effect shutdown of the compressor and therefore will act as a single failure.

1.7 Failure of Low Pressure Alarm Switches PA-233 and PA-253: When both pressure switches fail, a double failure has occurred and all other components of the system are functioning properly. This then assures that the suction of the compressor will not be below atmospheric pressure since CS-100 and valve PV-100 will flow gas from the high pressure circuit.

1.8 Failure of Compressor Piping:

1.8.1 Break of the compressor suction line combined with a failure of PV-100 to open: Pressure in the line will be maintained through valve PV-227. Hydrogen detection will close valves of the system and the amount of gas vented to the atmosphere will be small.

Break of the suction line combined with a failure to detect hydrogen will vent potentially large quantities of hydrogen into the building. As long as fire does not occur, the situation is not dangerous. A delayed ignition will generate a large pressure wave and cause substantial damage. If the break in the line is very large, compressor suction may drop to atmospheric pressure and pressure alarms PA-233 and PA-253 will indicate.

1.8.2 Break in discharge line of compressor between drier assembly and compressor: This failure, coupled with a failure of the hydrogen detector, will allow large amounts of hydrogen gas to be vented unnoticed with possible delayed ignition. Flow rates are high.

Failure of valve PV-187 to close with hydrogen detector operating is backed up by closure of valves PV-227 and PV-251. Failure of valve PV-188 to close with hydrogen detector operating is backed by check valve NV-1008.

1.8.3 Break in interstage compressor piping: This failure, coupled with a hydrogen detector failure, will yield the same effects as described under 1.8.2. Gas flow may be stopped through closure of valves

PV-187 and PV-188.

1.9 Failure of valves PV-187 and PV-188 to operate, coupled with a line break in the compressor system, will result in hydrogen detection and closure of valves at the liquid hydrogen storage tank. The flow of gas to the environment is limited to the flow returning from the chamber cooling loops. This flow rate may be of the order of 12.5 g/sec. (300 scfm). The total mass vented to the atmosphere is a function of the inventory of the cooling loops. This quantity is not known at the present time.

Failure of valves PV-187 and PV-188 with a failure of other valves does not release hydrogen into the atmosphere. The situation does not generate a dangerous situation.

1.10 Failure of controller CS-101 or valve PV-101 to open, coupled with a failure of SV-1269, may subject the compressor suction line to a high pressure. The line system is built for the pressures that may be generated under these conditions. Failure of controller CS-101 or valve PV-101 to close, coupled with a closure of valve PV-227, will pull nitrogen from the vent system into the compressor. The vent system will pull a slight vacuum, but NV-1256 will provide a reasonably good seal. PV-100 will open and maintain compressor suction. The system will blow down and PA-233 and PA-253 will warn of low pressure. A dangerous situation is not generated.

Failure of valve PV-101 to close, coupled with a failure of TA-245, will cool the suction line of the compressor to a low level. If the gas is very cold, the compressor motor becomes overloaded and will shut the compressor down. All suction piping of the compressor is stainless steel and can handle low temperatures below -20°F.

1.11 Failure of Heater C-C: Failure of this heater, coupled with a failure of temperature alarm TA-245, may result in low temperature gas flowing to the compressor. The system can take this. Compressor motor overloading will finally shut down the compressor. This situation is safe.

Failure of the heater with failure of valve PV-101 to close will vent cold gas to the stack. Temperature alarm TA-245 will indicate and the operator will act before a long period of time has passed.

1-ab. Hydrogen Compressor Coupled with Hydrogen Refrigerator H and Liquid Storage Tank A

The compressor is coupled with the refrigerator through a high pressure line GH-2152 and a low pressure line GH-2145. Single failures of components in the refrigerator coupled with single failures in components of the compressor in all but a few cases will act as the sum of two independent failures. The extent of potential damage is small. In the following cases a potentially serious situation may develop.

1-ab.1 Failure of valve PV-227 or controller CS-227 resulting in valve closure coupled with a failure of valve PV-100 to open will result in a low suction pressure to the compressor. Pressure alarms PA-233 and PA-253 will indicate the situation and operators need to take action.

1-ab.2 Failure of valve PV-227 to close after a line break occurs in line GH-2145. The hydrogen detection system will attempt to close the valve PV-227 and also closes valve PV-251 to stop flow from the hydrogen storage tank to the broken line. The flow into the building is limited.

1-ab.3 Failure of valve PV-227 to control will increase the suction pressure of the compressor to nearly full tank A pressure in case of valve PV-101 failing to operate. The compressor becomes overloaded and will be shut down by the thermal protection system of the compressor motor.

1-ab.4 Rupture of lines GH-2152 or GH-2145 coupled with a failure of hydrogen detection will result in venting of large quantities of hydrogen into the building.

1-c. Hydrogen Compressor Coupled with Valve Box R

1-c.1 Failure of valves MV-1001 and MV-1003: Failure of these valves to close, coupled with a line break, will result in hydrogen detection and blockage of the large inventories of the system.

Plugging of the line downstream of valve MV-1001 with a failure of valve MV-1001 to close will vent gas through SV-1373 to compressor suction.

1-c.2 Closing of valve MV-1003 with valve MV-1001 open and SV-1373 failing to open will subject lines GH-2001 and GH-2000 and valve box J piping to high pressures. All the equipment in the valve box and chamber will vent to the chamber and valve box vacuum system. These systems can handle the flow rate and pressure through RD-267 and chamber vacuum system relief valve. It is most likely that the heat exchanger F will break since a relatively thin wall, large diameter vessel is exposed to high pressure. All piping is Schedule 10 and rated at full pressure. If pressure gauge PI-142 breaks, hydrogen detectors will close valves and stop compressor operation and stop flow of hydrogen gas to the atmosphere.

1-d. Hydrogen Compressor Coupled with Deuterium-neon Purifier-Condenser

Failure of valves MV-1248 and MV-1004 only occurs in opening or closing the valves. The operation of valve MV-1004 only occurs when the compressor is non-operative. Failure of valve MV-1248 to open uncouples deuterium purifier-condenser from the compressor. This failure, coupled with any other single failure, acts as a single failure of the system.

Failure of valve MV-1248 to close occurs at a time when the deuterium purifier-condenser is being shut down. This failure, coupled with a line break in line GH-2168, allows gas to flow from the compressor suction line to flow to the environment. Detection of hydrogen will close valves and limit the amount of vented hydrogen.

1-e. Hydrogen Compressor Coupled with Condenser in C and D Tanks

The compressor is coupled through the refrigerator H and failures in the coupling will be covered under the discussion on the hydrogen refrigerator.

2. Hydrogen Refrigerator H

The hydrogen refrigerator H is located inside the building next to the hydrogen compressor M. When in use, it is always coupled to the compressor M and the storage tank A. It may also be coupled to the vent system of the condensers in C and D tanks and the vent system of the cooling loops of the bubble chamber.

The refrigerator is designed to contain at all times a small inventory of hydrogen gas. It does not contain any liquid hydrogen inventory. The design of the cold box is not firm at this time, but it is anticipated that equipment consisting of heat exchangers and adsorbers will be located in a vacuum-jacketed box. The box will be equipped with a relief device capable of handling the maximum flow rates of compressor without exceeding the safe pressure of the box.

2.1 Failure of a high pressure line inside the box coupled with a failure of the relief device RD-264: The box will pressurize to compressor discharge pressure (1190 psia) or until a component of the box yields. If the box flies apart, damage will be extensive from flying debris and fire. The failure of the rupture disc may actually be an operator error. During checking of the box the relief device may be temporarily removed or blocked by a solid plate. If this situation is left, the box will not be effectively protected.

2.2 Failure of valve PV-228 or PV-229 coupled with a failure of TA-254 to indicate low temperature: The suction of vacuum pump F-F will become very cold. The situation is not dangerous; a break in the F-F system will pull air into the vacuum pump. No flammable mixture will vent into the building.

2.3 Operator error in balancing heat exchangers coupled with failure of heater C-C: Compressor suction or flow venting through PV-101 will become quite cold. The piping is constructed of stainless steel and can handle the situation. A low temperature alarm TA-245 will warn of the condition and corrective action may be taken.

2.4 Rupture of low pressure piping in the box coupled with a failure of the rupture disc RD-264: The box will most likely be capable of withstanding the pressure present in the low pressure piping system. If not, the situation may be identical to the one described under 2.1 above.

2.5 Adsorber breakthrough coupled with a failure of the deoxo unit in removing oxygen: Potentially a considerable amount of oxygen may be present in the bed. Breakthrough resulting in plugging of the high pressure circuit will most likely be nitrogen because of preferential adsorption of oxygen on the bed. Desorption of the impurities in the bed will lead to generation of a flammable mixture and potentially an explosion may take place in the adsorber circuit. This will result in a break into the vacuum space of the box. At the time of the break the adsorber will be valved off from the rest of the system and the vacuum box will contain the effects of the explosion.

2.6 Failure of warm piping outside the cold box coupled with a failure of the hydrogen detection system to close valves: In this case flow rates of flammable gas into the building are large. A delayed ignition will generate a large amount of damage.

2.7 Failure of warm piping coupled with a failure of valve PV-188 to close: The compressor continues pumping hydrogen gas into the room. A potentially very dangerous situation occurs until the compressor is shut down by the operators.

2.8 Failure of warm low pressure piping coupled with a failure of valve PV-227 to close: After the hydrogen detector signals valve closure, valve PV-227 fails to close, valve PV-251 closes and stops gas flow from A tank.

2.9 Failure of instruments of the refrigerator: Any combination of two failures does not affect the safety of the system. Pressure and temperature indicators are used to check the proper functioning of exchangers and adsorbers. Level controllers do not affect safety. Misoperation or misfunctioning of the J-T valve (control station CS-226) may subject line LH-2004 to high pressure as discussed below.
Misoperation or misfunctioning of valve PV-227 (control station CS-227) may subject compressor suction line and low pressure system to full A tank pressure. The system is designed to withstand this pressure.

2.10 Failure of CS-226 coupled with relief valve SV-1300 failing to open: The set of conditions will subject line LH-2004 to compressor discharge pressure when valve PV-252 is closed. The line is only rated at 150 psig. The piping will take the pressure, but the bayonet couplings probably will let go. In that case the line may blow out and high pressure gas will escape either in the building or area adjacent to the liquid hydrogen storage tank. Hydrogen detection will close valve PV-188 and the quantity of gas vented to the atmosphere will be limited to the inventory of the high pressure gas system of the refrigerator.

2-a. Hydrogen Refrigerator Coupled with Liquid Hydrogen Storage Tank

The refrigerator is coupled through two vacuum-jacketed lines, LH-2004 and GH-2005. The following double failures may occur.

2-a.1 Failure of valve PV-226 by opening wide coupled with a closed valve, PV-252: The situation is discussed under 2.10.

2-a.2 Valve PV-227 opens wide coupled with valve PV-104-A opening wide: The low pressure system of the refrigerator up to the suction of the compressor will be pressurized and valve PV-101 will open. The compressor motor will be overloaded and in time the compressor will shut down. The situation is not immediately dangerous since the system is designed to handle maximum tank A pressure. Operators will be aware of the system and valve PV-251 may be closed to stop flow from A tank. Vaporizer flow may be stopped by closing valve MV-1218.

2-a.3 Valve PV-251 fails closed coupled with valve PV-100 failing closed: The compressor starts pulling a vacuum. Pressure alarms PA-233 and PA-253 indicate the condition and the operator may open the failing valves or shut off the compressor. The situation is not dangerous.

2-a.4 Failure of valve PV-226 to close coupled with a rupture of line LH-2005: Hydrogen liquid and gas will vent into the building or just outside the building in the area of the hydrogen tank. Hydrogen detection will close valves PV-252, PV-251, PV-188, PV-187 and PV-227. The inventory of gas between valves PV-188 and PV-226 will vent out. The situation is dangerous for a short period of time. Total inventory vented into the building is larger than tolerated by the design criteria of the system. Delayed ignition will do some damage, but only with a spill inside the building.

2-a.5 Failure of valves PV-252 and PV-226 to close connects the high pressure circuit of the refrigerator to the vapor space of the tank. The tank vent system is capable of handling the maximum flow rate.

2-a.6 Failure of valves PV-251 and PV-227 to close connects the tank vapor space with compressor M suction line through the heat exchangers. This brings the compressor suction line to full tank pressure. Valve PV-101 will open and vent vapor to the stack. The compressor motor will be overloaded and stop the compressor after some period of time. The situation does not generate an immediate danger and operators will be aware of the situation. Valve PV-187 may be closed to maintain compressor suction at a low value. A tank pressure may be reduced by venting to the stack. The situation is not dangerous.

2-a.7 The combination of a failure to close off one valve in line LH-2004 and one in line GH-2005 does not affect safety. Closure of the lines may be achieved by closing the other valves.

2-a.8 A failure of valve PV-251 or PV-252 to close coupled with a rupture of the line GH-2005, or LH-2004, will vent hydrogen gas into the environment. If the rupture occurs outside, gas will vent from an elevation of 10-12 feet above ground. The situation is not very dangerous since even a delayed ignition takes place in an unconfined area. At the same time air will be pulled by the compressor into the shell side of the exchangers of the cold box. Air will be liquefied and a flammable mixture will exist in the cold box. Compressor suction will tend to drop below atmospheric pressures and valve PV-100 will open and unload the compressor. Flow to the refrigerator cold box will be stopped.

With the line breaking inside the building, hydrogen gas will be vented in the building. The hydrogen detection system will close valves PV-227, PV-226, PV-252, PV-140-A, and PV-150-A and stop all flow in the system with the exception of that from the ruptured pipe.

The situation is dangerous since large quantities of hydrogen gas are mixed with air in the building. Ignition leads to severe damage to building and equipment.

2-b. Hydrogen Refrigerator Coupled with Valve Box R

The hydrogen refrigerator is coupled with the valve box R through vacuum jacketed line GH-2002. Line GH-2002 consists of two vacuum jacketed spool pieces and a section of line located in a 10" vacuum jacket.

2-b.1 Failure of any of the valves or controllers in the valve box may force a mixture of liquid and gaseous hydrogen to flow to the refrigerator through line GH-2002. A rupture in line GH-2002 will permit a large flow rate of liquid and gas into the building. Hydrogen detection will close valve PV-109 and stop flow of liquid to the cooling loop in the valve box. A delayed ignition of the vented hydrogen may cause extensive damage. Inventory of the system venting to the atmosphere is not known as yet, since cooling loop designs are not finalized.

2-b.2 Any combination of failures in the valve box R and refrigerator H will not generate a dangerous situation.

2-c. Hydrogen Refrigerator Coupled with Condensers in C and D Tanks

The refrigerator is coupled with the vents of the condensers through line GH-2219 and GH-2203.

2-c.1 Line rupture coupled with a failure of the hydrogen detection system will allow a large flow rate of hydrogen gas into the environment outside the building or inside the building without automatic closure of valves.

2-c.2 Line rupture coupled with a failure of valve PV-140-A or PV-150-A will permit flow of hydrogen gas into the environment outside or inside the building. The results are the same as for the occurrence of 2-c.1 until the liquid inventory in the condenser is depleted.

2-c.3 Failure of valve PV-134 and PV-140-A to close will send a large flow rate of liquid and gas to the refrigerator. The system can handle this without generating a dangerous situation.

3. Liquid Hydrogen Storage Tank A and Filter N

3.1 Loss of vacuum coupled with a failure of relief valve SV-1023 to open: The tank is protected from over-pressure through rupture disc RD-181.

3.2 Loss of vacuum from an internal pipe failure coupled with a failure of the carbon steel outer shell: Depending on the construction of the internal parts of the vessel, it may be debated whether these failures are unrelated.

If the combination occurs, gas will vent from the cracked outer shell into the environment. A crack, once developed, tends to become longer unless the area around the crack is kept warm. The rate of flow to the environment can be reduced by using the normal vent system of the tank. By opening valve PV-104-B wide, tank pressure may be maintained at a value near atmospheric. Water spray on the wall of the tank will keep the outer shell reasonably warm.

It is expected that the event will not generate a dangerous situation, especially since it is probable that the outer shell will not become cold immediately and the loss of vacuum will be noticed shortly after it occurs. The probability of a line break occurring inside the tank vacuum shell is remote and is inconceivable when the tank is not in use and all piping in the vacuum space is warm with the possible exception of the vent line. A significant break in a line can only occur from an internal explosion which requires a substantial charge (one ounce or more) of solid air. Because piping in general is warm during non-use of the tank, the pipes will be free of air or oxygen during periods of standby.

If the rupture of internal piping were to occur during use of the tank with tank pressure somewhere between 0-50 psig, the outer shell will fail at the rupture disc RD-127. If this disc were to remain intact, outer shell pressure will go up to tank pressure. In first instance, the outer shell will remain intact and the vent system of the tank will start operating. In this sequence of events it is important that the tank pressure will be reduced quickly to prevent rupture of the outer shell when under pressure.

The probability of a rupture disc not failing is very remote and the outer shell will be protected from rupture while under pressure. The rupture disc is located at the end of the tank farthest away from the building at a high point. Confinement of the vented gas is zero.

3.3 Failure of fill line valves MV-1043 and PV-186 to operate: Normal sequence of events in filling or draining the tank is to couple the trailer and tank before opening any liquid valves. Failure of the valves to open will not result in a dangerous situation. Failure of the valves to close is not dangerous since the trailer-tank system is a closed system.

Failure of the liquid line between valves MV-1043 and PV-186 results in spillage of the liquid from the tank A until drained. It is unlikely that manual valve MV-1043 can be closed under these conditions. The probability of a line break between valves MV-1043 and PV-186 is very small since the line section is less than one foot long and mechanically quite strong (two Schedule 10 pipes, 1-1/2" and 3" IPS).

Liquid spilling in the area of valves MV-1043 and PV-186 will not cause major damage even in case of a delayed ignition since spilling occurs in an unconfined area and a pressure wave will not be generated.

Failure of valve MV-1043 and purge piping between valves MV-1043 and PV-186 may result in venting of liquid to the atmosphere in the area of the head of the tank. Piping is 1/2" Schedule 10 stainless steel with a pressure rating of 2,800 psig. The probability of an outright break in this piping is quite small.

3.4 Failure of filter N coupled with the failure of valve PV-186 to close: A loss of vacuum does not result in spillage of liquid. An explosion in the filter without failure of rupture disc RD-128 implies internal failure of the filter piping or a very small explosion. The vacuum vessel of the filter will contain the vapor and liquid.

In all cases of filter failure liquid and/or gas will not spill in an uncontrolled manner to the environment.

A badly leaking bayonet coupling between filter N and the tank coupled with failure of valve PV-186 to close will vent gas to the environment at relatively low rates. No major danger is generated.

Filter N is not coupled with any other component of A tank outside the fill and drain line. The filter is only in use during transfer operations between trailer and tank.

3.5 Instrument failures coupled with other instrument failures: Safe operation of the tank does not depend on proper operation of the instruments. Level, pressure and vacuum gauges may all be inoperative and not affect safety of the tank.

3.6 Failure of vent stack check valve NV-1256 to open coupled with a failure of valve PV-104-A to close: In this case the vaporizer continues to operate and pressure rises. The relief system is blocked (ice). In order to prevent rupture of any component of the system, a rupture disc in the stack (RD-276) will yield at a pressure of 15 psig.

3.7 Failure of EV-200 (nitrogen purge to the stack) coupled with any other failure does not affect the safety of the system. A stack explosion may occur without causing damage to the facility.

3.8 Rupture of vent piping with a failure of valve PV-104-A or -B to close will result in venting of gas to the environment in the area between building and A tank. A rupture of vent piping is very unlikely. The piping is constructed of stainless steel and is rated at pressures in excess of 500 psig. The vented gas is pure hydrogen. If a mixture of air and hydrogen were present, a stack explosion could occur. The vent pipe will contain this explosion. If not contained, the most likely locations of rupture will be at the capped ends of the 4-inch IPS Schedule 10 vent header located between tanks and building. A fire would either be pointed vertically from the end closest to the building or horizontally towards the gas storage facility.

3.9 Failure of valve PV-104-A to close coupled with a rupture of the vaporizer circuit will spill liquid hydrogen into the environment below the liquid hydrogen tank. The pressure in the tank and the valve flow coefficient determine the maximum flow rate. With C_V = 15, a tank pressure of 45 psig will yield a flow rate of the order of 2,000 to 3,000 lbs./hr. The flow rate will be strongly dependent on the

temperature of the liquid in the tank and the length and diameter of line between the tank and the rupture.
The rate will be reduced by venting the vapor space of the tank through the same rupture. A delayed ignition of the spill will result in a strong pressure wave and may lift the liquid hydrogen tank off its support.
An immediate ignition of the spilled hydrogen will result in a large fire, which will decay to a small fire over a period of 15-45 minutes, dependent on initial tank conditions.
The probability of a rupture in the piping of the vaporizer is very small. All piping is stainless steel Schedule 10 with pressure ratings in excess of 500 psig. Only gross negligence resulting in accumulation of large quantities of liquid air in the tank over a period of time will increase the probability of a rupture of the vaporizer circuit in the liquid piping.

3-a. Liquid Hydrogen Storage Tank A Coupled with Vessel P

The tank is coupled through line GH-2018. The purpose of the coupling is to remove hydrogen from the bubble chamber and store it in A tank. Under these conditions valve PV-111 at B tank is closed.

Line GH-2018 is used rarely and when used only for short periods of time. When the line is not in use valve PV-105 at A tank is closed and A tank is not coupled with P vessel or the chamber.

3-a.1 Failure of valve PV-105 to close coupled with a failure of valve PV-111 to close will vent B vessel down into the A tank. Excess pressure is relieved through the A tank vent system.

3-a.2 Failure of valve PV-105 to close with a failure of chamber valves PV-194 or PV-195 to close is of no consequence since valves PV-193 and PV-191 are redundant.

3-a.3 Failure of valve PV-105 to close with a line GH-2018 rupture may lead to venting of gas into the atmosphere. Line GH-2018 is located in a large 10-inch diameter jacket. Failure of the line in this jacket does not lead to hydrogen venting. A short spool piece connects A tank with this line. The coupling may leak. The rate of venting will be low under these conditions and will not create a dangerous condition. If the spool piece is not fastened properly, it may blow out under pressure. In this case the hydrogen will be vented straight up along the building wall. No danger will be created. The flow of gas may be slowed and stopped by removing pressure from A tank and closing valves at B tank and the chamber.

3-b. Liquid Hydrogen Storage Tank with Condensers in C and D Tanks

The liquid space of the tank is connected with the condensers in C and D tanks through lines LH-2013 and LH-2014 with valves PV-106, PV-107, PV-134, and PV-147. All valves are located at relatively high elevations on the heads of the tanks. The lines are relatively short spool pieces of single construction put in position through bayonet couplings.

3-b.1 Failure of two valves in series to close either in line LH-2013 or LH-2014: Liquid hydrogen will continue to flow into the condensers until the vent valves of the condensers close upon a signal from the pressure controller of the storage tank (CS-140 and CS-150). This will stop flow of the liquid to the condensers. The situation is not dangerous.

3-b.2 Failure of valve PV-134 to close coupled with a rupture of line LH-2014 somewhere between valves PV-134 and PV-106 will result in venting of gas to the atmosphere. Hydrogen detection will close valve PV-106 and stop flow from A tank. The condenser inventory will vent until all liquid in the condenser has been evaporated. The situation is not extremely dangerous and ignition of the vented gas will not lead to extensive damage.

3-b.3 Failure of valve PV-106 to close coupled with a rupture of the line between the valves will vent liquid to the atmosphere. Hydrogen detection will close valve PV-137 and stop flow from the condenser. Flow from A tank will continue until the pressure in A tank is depleted. This does not happen automatically since valve PV-104-B fails in the closed position. Flow into the atmosphere continues for a long period of time and the rate of flow is large (large C_V and line size). A delayed ignition and fire may do some damage dependent on the direction of the fire.

3-b.4 A failure of the valve PV-106 to close with a line failure between valve PV-106 and tank A is in the same category as the failure described under 3-b.3 above.

3-b.5 A failure of the valve PV-134 to close with a rupture of the line between valve PV-134 and the condenser is in the same category as the failure described under 3-b.2 above.

The probability of the important failures described under 3-b.3 and 3-b.4 above is low. The line is permanently installed and is mechanically well protected. Between tanks the line crosses the open area between tanks at an elevation of 12'-4" above ground. Only a powered vehicle with this height above ground may break the line. The vacuum jacket consists of a 2-1/2" Schedule 5 pipe and is quite strong.

3-c. Liquid Hydrogen Storage Tank with Valve Box R

The tank is coupled with the valve box through line LH-2011. Valve PV-109 is located at the tank and a number of parallel valves in the valve box close the line in the box (PV-159, MV-1127, PV-162, PV-163, PV-164, PV-165, PV-166, PV-167, and PV-168). The line is in constant use when the chamber is operating. The actual liquid carrying line is located with four other lines in a 10-inch vacuum jacket. Two short spool pieces connect this part of the line with the tank and the valve box R.

A mechanical failure of the line inside the 10-inch jacket does not release hydrogen to the atmosphere. Mechanical failure of the 10-inch jacket is extremely improbable.

3-c.1 Failure of valve PV-109 to close coupled with any of the valves in the valve box failing to close continues flow through the particular valve to the cooling loop system or the cooldown system of the chamber. This failure may occur upon a signal from the hydrogen detector. Hydrogen will not be vented to the atmosphere.

3-c.2 Failure of valve PV-109 to close coupled with a line failure outside the building will flow liquid to the atmosphere. The line failure will occur in the spool piece connecting valve PV-109 with the liquid line in the 10-inch jacket. The spool piece is located at an elevation of 12-feet above the ground.

A delayed ignition of the spilled hydrogen will generate a pressure wave. Damage anticipated from this will be small. A line failure may also occur at the valve box R. A short spool piece connects the 10-inch jacket with the valve box. This spool piece is welded in place through special bayonets.

It is inconceivable that the line breaks wide open since a complete weld made between two 3-inch Schedule 10 stainless steel pipes has to break. The cross-section of the welded area is 1.3 sq. in. and the maximum pressure force to which the weld is subjected is 1,300 lbs. Normally the operating pressure force is not in excess of 400 lbs. Therefore, at worst the line may leak badly. Consequences of the leak may be quite serious since a flammable mixture occurs inside the building. A delayed ignition will result in a pressure wave in the area of the chamber. The resultant fire cannot be stopped until the pressure in A tank has been reduced to atmospheric through venting.

3-d. Liquid Hydrogen Storage Tank with Valve Box J

The tank is coupled with the valve box through liquid lines LH-2021 and LH-2012. Both lines connect the chamber and chamber target respectively with the liquid storage tank. The lines are located inside the 10-inch vacuum jacket. Connections between tank A and 10-inch jacket are spool pieces located at an elevation of 12-feet above ground levels. At valve box J the spool pieces are welded in place through special bayonets.

3-d.1 The analysis of these two lines is essentially the same as for line LH-2011 (see 3-c). A valve failure at A tank (PV-180) coupled with a line break can spill liquid at a high rate into the atmosphere just outside the building or inside the bubble chamber building in the area of valve box J.

A valve failure at the bubble chamber (PV-189 or PV-196) coupled with a line break may result in spillage of all the chamber or chamber target liquid into the environment.

3-d.2 The storage tank A is also coupled with the valve box J through vacuum jacketed line GH-2018. This coupling only exists when the chamber operates on liquid hydrogen. At that time vessel B is also connected to the line. At valve box J the line is closed off through valve PV-194 and PV-195 (in parallel) and valves PV-192, PV-193 and PV-191 at the chamber.

A rupture of the line coupled with valves failing to close is similar to the discussion under 4-a.3.

3-e. Liquid Hydrogen Storage Tank with Gas Storage Vessel B

Liquid hydrogen storage tank A is coupled with gas storage vessel B through line GH-2018 and GH-2159. The coupling only exists when the chamber operates with liquid hydrogen.

3-e.1 Valves PV-111 and PV-105 fail in the open position. Vessel B is now in open connection with the liquid storage tank and gas will transfer to A tank. The vent system of the A tank is capable of handling the flow rate without exceeding the safe pressure level of A tank.

3-e.2 Rupture of line GH-2018 or GH-2159 with a failure of valve PV-105 or PV-111 to close will blow down either A tank or B tank. The lines are located outside and the venting of gas without ignition is not unsafe. Delayed ignition will generate a pressure wave, which probably will cause only slight damage.

4. Liquid Neon Tank C

Liquid neon tank C contains the neon of the system. If the tank is filled with neon only, safety problems resulting from flammability are nonexistent. Most likely the tank will be filled with mixtures of liquid hydrogen and neon. When the mixture is not used in the chamber, it is stored in C tank and the tank is only coupled with the rest of the system through line LH-2014 with the liquid hydrogen storage tank and the vent line GH-2068 to the vent system of the facility.

When the neon-hydrogen mixture is to be used in the chamber, the tank will be coupled with the chamber through lines LH-2021 and GH-2018, with vessels B and P through line GH-2018 and with Corblin compressor D-D through line GH-2029.

Liquid neon tank in isolated storage condition:

4.1 All liquid valves (PV-137, PV-143, and MV-1082) are backed by blanks. To open the tank to the atmosphere through any of these valves, operator error, valve failure (to close) and line leak have to be combined. This combination constitutes three independent failures. A double failure consisting of valve failure and operator error will not release liquid to the environment.

4.2 Failure of valve PV-140-B to close coupled with failure of valve PV-134 to open: This combination generates pressure in the vessel. This pressure is relieved through safety valves SV-1068 and SV-1069.

4.3 Failure of valve PV-140-B to close coupled with a failure of one relief valve, SV-1068 or SV-1069: Safety valves SV-1068 and SV-1069 may be closed off from the tank through selector valve MV-1066. The arrangement is such that only one of the two safety valves is closed off at any one time. Valve PV-140-A will open and the condenser will maintain tank pressure at a safe value until liquid hydrogen runs out in A tank. After that the pressure in C tank will rise and the tank will rupture at some point.

The probability of the occurrence of this sequence of events is not large. Normally C tank is protected by 2 parallel relief valves, both open to the tank. Operator error or removal of one of the safety valves is required to have only one safety valve available. On a time basis the probability of one safety valve being in place is very small.

4.4 Insulation vacuum failure coupled with a single relief valve failure: The condenser will provide enough refrigeration unless vacuum fails from a line rupture. The situation potentially is the same as under 4.3 above.

4.5 Rupture of line in vacuum insulation space coupled with any other failure will release gas to the atmosphere through RD-136. This rupture disc is located at the end of the tank farthest from the building. No major damage is anticipated. If the rupture disc RD-136 fails to operate, tank pressure

will rise until safety valve SV-1068 or SV-1069 operates. It is also possible that the carbon steel outer shell of the tank ruptures before the relief valve operates. Leakage then occurs at the cracked shell. Flow rates will be high.
The probability of a line failure in the insulation space of the tank with the tank in the sealed condition is very small. All lines are warm when not in use and do not contain any flammable mixtures.

4.6 Failure of SV-1068 and NV-1076: In this condition, when the other safety relief valve, SV-1069, is not in the system or valved off, the tank cannot vent. The condition develops slowly since the tank has a good insulating vacuum and builds pressure slowly. Operators will be aware of the situation before a dangerous situation develops. Normal operating conditions will not bring about this condition at any time since the condenser will be operated at regular intervals.

4.7 Failure of SV-1068 coupled with a failure of SV-1069 to function: Under these conditions the tank does not have protective devices. In order for this condition to occur, misoperation is required. The tank pressure will build slowly and operators have plenty of time to open a manual valve, MV-1065, to relieve tank pressure.

4.8 Valves PV-134 and PV-140-A fail to close: Under these conditions the condenser continues to operate and the tank pressure will drop below atmospheric. This will be indicated by PA-260. Operators can then close valve PV-106 at A tank to stop liquid flow. Also PV-140-B normally will open to maintain pressure in the tank. Instrument failure of CS-140 though may prevent proper operation of both valves PV-140-A and PV-140-B.

4.9 Failure of valves PV-141, PV-139, and MV-1068 to operate combined with any other failure does not affect the safety of the system. All three valves are backed by a blank and the valves are not operated for any reason. Failure of valves to open or close is immaterial. If the blanks were missing and a valve fails to close, vapor will flow to the atmosphere. The rate will be low and the situation is not dangerous.

4.10 Failure of instrumentation combined with any other failure: Level and pressure instrumentation failure has no effect on the safety of the system. Failure of controllers CS-140 and CS-134 affects valve operation which is covered elsewhere.

4.11 Failure of thermal relief valves may result in line failure. The failure implies a closed system with low inventory (piping). This failure combined with other failures does not affect the system differently than do two single failures as discussed in the bubble chamber system safety report.

4-a. Liquid Neon Tank Coupled with The Chamber

The neon tank will be connected to the bubble chamber prior to cooling and filling of the chamber. When the connections are made, blanks will be removed and various vacuum-jacketed spool pieces installed. Also, some Figure 8 blinds located in warm lines will be changed from the blind position to the open position. All these changes will be made when C tank is at low pressure and all valves are closed. The tightness of each valve may be checked before the blanks are removed. After the tank has been connected, the tightness of the various lines is checked during evacuation and purging.

4-a.1 Failure of valve PV-137 to close couples with a line rupture of LH-2021: The situation is the same as described under the A tank analysis (3-d.1). The line rupture may take place outside the building in a spool piece connecting C tank with the 10-inch vacuum-jacketed line or inside the bubble chamber at valve box J.

4-a.2 Failure of valve PV-139 to close coupled with a rupture in line GH-2018 or GH-2033: The flow of liquid from the chamber will be valved off at the chamber (valves PV-194 and PV-195). The flow from the C tank will be gas and will decrease when the tank pressure decays to atmospheric. The total quantity of gas vented will be small and the condition is not anticipated to generate a large amount of damage.

4-a.3 Rupture of line GH-2018 at valve box J coupled with a failure of valves PV-194 or PV-195 to close: Hydrogen detection will close all valves with the exception of PV-194 or PV-195. Under normal chamber operation valves PV-193, PV-192 and PV-191 are closed and the amount of vented liquid and gas is small. With one of these valves open, the chamber starts to vent down. The operator needs to close these valves since they are not interlocked with hydrogen detection.

4-b. Liquid Neon Tank Coupled with Corblin Compressor D-D

Line GH-2029 connects the Corblin compressor suction line with the vaporizer of the neon tank through manual valve MV-1228. The compressor generates medium pressure gas to be stored in vessel B for use in the bubble chamber.

4-b.1 Rupture of line GH-2029 coupled with a failure of valve PV-140-B to close: Vapor will flow into the atmosphere, either inside or outside the building. Hydrogen detection inside the building will attempt closure of valve PV-140-B which was postulated to fail. Delayed ignition will cause a large amount of damage. If the line break occurs outside, damage will be light, but a fire will burn until the flow of gas is stopped.

The probability of a line rupture is slight. The line is rated at a pressure of 2,200 psig and does not contain a flammable mixture unless not evacuated. Then the mixture only exists for a period of a few seconds. The line is mechanically well protected and is made of stainless steel.

4-b.2 Controller CS-140 fails to close valve PV-140-B and temperature alarm TA-203 fails to indicate low temperature: Under these conditions it is conceivable that parts of compressor D-D may become quite cold with time. The situation does not develop quickly and since the operation of gas generation is manually controlled, it is anticipated that operator action will prevent the occurrence of low compressor temperature.

4-b.3 Pressure alarm PA-255 fails to alarm at low pressure and controller CS-140 fails to activate valve PV-140-B: Under this set of conditions, the compressor may pull a vacuum. Again the rate of pressure decrease will be slow and it is anticipated that the operator will take corrective action before long. The situation is not immediately dangerous since a reasonable tight system will allow only small amounts of air to enter the system and a flammable mixture will not be formed.

4-b.4 Failure of relief valve SV-1246 to operate coupled with a failure of valve PV-140-B to close: The line system and compressor D-D is built to withstand the maximum pressure of C tank.

4-b.5 Operator error combined with failure of D-D compressor may put tank B in open connection with C tank through the vaporizer. Warm gas flows backward through the vaporizer into the liquid of C tank. When tank pressure increases, valve PV-140-B will close and stop flow. If CS-140 is operated in the manual mode, flow will continue and pressure will rise rapidly until the safety valve SV-1068 and/or SV-1069 functions. There is no safety hazard since the safety relief valves are capable of handling the anticipated flow rates.

4-cd. Liquid Neon Tank Coupled with P Vessel and Gas Storage Vessel B

This coupling exists when C tank is used in chamber operation. The coupling is made through line GH-2018. Under normal operating conditions, valve PV-139 at C tank is closed and line GH-2018 is open to P vessel and B tank through valve PV-111. Valve PV-139 is opened when chamber fluid is drained to the storage tank through line GH-2018. Under those conditions valve PV-111 is closed before valve PV-139 is opened.

4-cd.1 Failure of the operator to close valve PV-111 before valve PV-137 is opened puts vessel B in open connection with C Tank through vessel P. Cold gas (-300°F) flows into the vapor space of the C tank and safety relief valves SV-1068 and SV-1069 will function until the operator corrects the situation by closing valve PV-111.

5. Liquid Deuterium Tank D

The analysis of failures of the D tank is the same as for C tank. D tank in all respects is used in an identical manner as C tank.

6-ab. Gas Storage Vessel B with Chamber Fluid Precooler P

The two systems are coupled through line GH-2159. This line contains 3 shut off valves; MV-1377 at B vessel, MV-1223 and PV-111 at rack JJ located in front of the liquid nitrogen storage tank. Normally the coupling with chamber precooler P means also coupling with the valve box J of the chamber. In valve box J dual shut off valves PV-194 and PV-195 are backed by a set of valves at the chamber (PV-191, PV-192, PV-193). Line GH-2018 connects vessel P with valve box J and the appropriate dewar (A, D or D).

6-ab.1 Rupture of line GH-2159 between valve PV-111 and B vessel coupled with a failure to detect hydrogen: Vessel B will blow down. The venting hydrogen may be ignited. No serious amount of damage will be done either in the burning or nonburning case.

Operators will be made aware of the reduction of pressure by reading PI-114. Valve PV-111 will open wide to maintain pressure in line GH-2018. In case the chamber is open to GH-2018 through valves PV-193 and PV-195, the situation will be noticed immediately from faulty bubble chamber operation. Operators may close PV-111, PV-193 and PV-195 to stop flow to the atmosphere. Dependent on when the line break has occurred valve MV-1377 may or may not be closed.

6-ab.2 Valve PV-111 fails wide open with valve PV-105 (or PV-139 or PV-155) open: B vessel is in open connection with the storage dewar. In the case of A tank (liquid hydrogen) the tank will vent gas to the vent system without over-pressurization of the tank. In the case of C and D tanks the tanks are protected by the safety valves.

6-ab.3 Valve PV-111 fails wide open with the chamber valves open to GH-2018: In this case B tank is in open connection with the chamber. The chamber is rated for the maximum pressure of B tank.

6-ab.4 A line break in GH-2018 coupled with valve PV-111 failing to close may vent hydrogen into the bubble chamber building. This case is almost identical to the one discussed under 3-d.2 and 4-a.3. Upon the detection in the building valves PV-194 and PV-195 close, but gas continues to flow from B vessel. The situation is potentially dangerous since hydrogen will vent at a high rate for some time inside the building. Delayed ignition will cause substantial damage.

6-ab.5 A line break in GH-2018 coupled with a failure of the hydrogen detection system will vent gas from vessel B and possibly from the chamber through valves PV-193 and PV-195. The situation is dangerous, and may be cause for extensive damage in case of a delayed ignition.

6-ab.6 A break in the heat exchanger of P vessel coupled with a failure of valve PV-111 to close will blow down vessel B through the nitrogen reservoir of vessel P. The relief system of the nitrogen reservoir can handle this flow rate without exceeding the safe pressure of the nitrogen reservoir. If the hydrogen detector picks up the hydrogen gas, valves PV-111, PV-194, and PV-195 will close.

6-c. Gas Storage Vessel B Coupled with Corblin Compressor D-D

When gas storage vessel B is depleted gas may be added through the Corblin compressor. This compressor may, during normal chamber operation, be tied into B vessel and any one of the three storage vessels A, C or D. Operation of the Corblin compressor is controlled manually under supervision of an operator.

6-c.1 Rupture of compressor D-D piping at discharge side inside the building coupled with H_2 detector failure: Check valve NV-1247 prevents back flow of gas from vessel B into the building. The rate of gas flow from the leak into the building is the pump D-D capacity. By stopping D-D or closing valve PV-140-B (PV-150-B or PV-104-A) flow may be stopped. The total quantity of gas vented is small.

6-c.2 Rupture of compressor D-D discharge piping outside the building between check valve NV-1247 and vessel B coupled with hydrogen detector failure: Gas is flowing to the atmosphere. Total quantity vented is the inventory of B vessel. Flow rate after B vessel is depleted is that of compressor D-D. The situation is not extremely dangerous.

6-c.3 Rupture of the Corblin compressor suction line inside the building coupled with a failure of the hydrogen detector system: Gas from the storage tank will vent into the building. Vaporizer shut off valves PV-104-A, PV-140-B or PV-150-B need to be closed by the operator. The situation is potentially dangerous.

The probability of line rupture is not large. All lines of 2" or smaller size are Schedule 40 and will withstand very high pressures. The possibility of a flammable mixture occurring in the Corblin compressor suction or discharge piping is very small.

7-a. Gas Storage Vessel B-B with Corblin Compressor D-D

This situation is analogous to the item discussed under 6-c.

7-b. Gas Storage Vessel B-B with Chamber Target through Valve Box J

Vessel B-B is connected with the valve box J through line GH-2019. At vessel B-B valve MV-1378 will isolate the vessel B-B from the line. At rack J-J manual valve MV-1225 and control valve PV-112 are in series. The chamber target has a single shut off valve PV-197.

7-b.1 Rupture of the line inside the building coupled with a failure of the hydrogen detection system will vent the contents of vessel B-B into the building. The situation is potentially dangerous for a short period of time. Normally the target valve PV-197 is closed. This valve is only opened when some liquid needs to be removed from the target or gas added to the target. If valve PV-197 is open at the time of line rupture the total quantity of vapor vented into the building is large.

7-b.2 Rupture of line GH-2019 coupled with a failure of valve PV-197 to close will yield similar conditions as under 7-b.1.

7-b.3 Rupture of the line outside the building may not be detected through hydrogen detection. The gas vents into the atmosphere and damage from fire or delayed ignition will be slight. In case the target valve PV-197 is open, chamber operation will indicate the problem in a short period of time.

7-b.4 Rupture of the line GH-2019 coupled with a failure of valve PV-111 to close will vent down vessel B-B and the chamber target in case valve PV-197 is open.

7-b.5 Failure of valves PV-111 and PV-197 to close. Vessel B-B is in open connection with the target. The target may not be able to withstand the pressure differential between chamber and target and break. This is not a dangerous situation, since the bubble chamber is capable of taking full vessel B-B pressure.

8. Chamber Fluid Precooler P

The hydrogen circuit of the chamber fluid precooler P is connected through line GH-2018 to the valve box J. Essentially the precooler circuit is an extension of the hydrogen piping. All previous discussions under section 6-ab apply.

9-a. Chamber System with Chamber Knockout Drum A-A with Vent System

The chamber is connected to knockout drum A-A through line LH-2070. Valve PV-190 at the chamber separates A-A from the chamber. Vessel A-A is equipped with a rupture disc RD-173, two parallel relief valves SV-1159 and SV-1160 and a control valve PV-183, all located in parallel.

9-a.1 Rupture of line LH-2070 coupled with valve PV-191 failing in the open position will vent large quantities of liquid and gas into the environment. The break may occur inside, and results in a very dangerous situation. If the break in the line occurs outside the situation is obviously less dangerous.

9-a.2 Rupture of line LH-2070 coupled with a failure of the hydrogen detector to analyze hydrogen. Under normal operating conditions the chamber valve PV-190 is closed. A limited inventory of vessel A-A leaks out.
A limited quantity of gas (1100 scft) leaks out. The amount will be noticed by observing pressure gauge PI-184.

9-a.3 Valve PV-190 fails in the open position coupled with a failure of one of the relief valves SV-1159 or SV-1160 to function. The system is protected by a rupture disk RD-173

9-a.4 Since there are three parallel devices for relieving pressure from vessel A-A, a combination of any two failing devices will leave A-A protected by the third device.

9-a.5 Failure of check valve NV-1381 to open coupled with a vacuum failure of the bubble chamber: In this case rupture disk RD-291 will yield and relieve pressure from the system.

10. Deuterium-Neon Purifier Condenser

The condenser will be used to fill C and D tank with neon and deuterium respectively. It may also be used to remove deuterium gas from the chamber after a deuterium run. When the condenser is used, it is always coupled with liquid hydrogen storage tank A, and C or D tank. If the refrigerator is in operating condition, it may be connected to the suction of the hydrogen compressor. The condenser is only coupled with gas trailers for the initial condensation of neon or deuterium.

10.1 Failure of RV-1061 to control downstream pressure coupled with a relief valve failure (SV-1204) may subject the deuterium circuit to high pressure. If piping fails, a limited quantity of gas from the gas trailers L will vent into the atmosphere. Damage from ignition and fire will be limited.

10.2 A line failure in the deuterium circuit will allow gas flow to the environment or the hydrogen circuit at a rate governed by the pressure reducer control valve RV-1061. In case of flow to the atmosphere the rate of leakage is within the tolerated quantity. In case of flow to the hydrogen circuit, gas will be handled like hydrogen gas without venting to the atmosphere.

10.3 Failure of SV-1054 coupled with PV-157 failing in the closed position: Hydrogen now flows back to the hydrogen storage tank. In case valve PV-113 is closed the hydrogen circuit will rupture. The inventory is limited and the total quantity vented to the atmosphere is within design criteria.

10.4 Failure of valve PV-113 to close coupled with a hydrogen line failure will vent hydrogen to the atmosphere. Operators can close valve PV-186 on A tank to stop flow of liquid to the environment.

10.5 Failure of valve RV-1061 coupled with a closed valve PV-113 will flow warm gas to C or D tank. Relief valves of these tanks will handle the maximum flow rates.

10-a. Deuterium-Neon Purifier-Condenser Coupled with Compressor M

The coupling is achieved through line GH-2168.

10-a.1 Line GH-2168 rupture coupled with valve PV-113 failing to close may vent large quantities of gas into the bubble chamber building. Rate is determined by the flow coefficient of valve PV-187.

Hydrogen detection will automatically close valve PV-187.

10-a.2 Any other combination of a purifier-condenser failure with a compressor failure does not release hydrogen into the atmosphere and does not result in a hazardous situation.

10-b. Deuterium-Neon Purifier-Condenser Coupled with Liquid Hydrogen Storage Tank

10-b.1 Rupture of the liquid line coupled with a failure of valve PV-186 to close will drain the total inventory of the liquid tank. This occurs on the side of the tank farthest from the building. Ignition will not result in a large amount of damage.

10-b.2 Any other combination of failure of A tank components with failure of purifier condenser components does not lead to an uncontrolled spill of liquid or gas.

10-cd. Deuterium-Neon Purifier-Condenser Coupled with C-D Tanks

10-cd.1 Line rupture with an operator's inability to close valve MV-1082 or MV-1092 will vent all of the C or D tank contents into the atmosphere.

10-cd.2 Any other combination of component failure of the purifier-condenser and C-D tank does not lead to an uncontrolled spill of expensive fluid to the atmosphere.

10-e. Deuterium-Neon Purifier-Condenser Coupled with Deuterium Trailers L

A line rupture may lead to venting of all of the gas in the trailer. Adherence to operating instructions will limit the quantity of spilled gas, since at most a few tubes of the trailer are in open connection with the purifier-condenser.

11. Utility Vacuum System

The utility vacuum system is made up of five parallel vacuum pumps and a 2-1/2" IPS Schedule 10 stainless steel header UV-2006 which reaches various components of the cryogenic system.

The utility vacuum header is coupled with components of the system through a manual valve and a Figure 8 blind. In all cases, the valve is located at the component side of the Figure 8 blind. When components are not evacuated frequently, the Figure 8 blind is installed in the blank off position and it is impossible to connect the utility vacuum header to the component by merely opening a valve. For instance, the liquid hydrogen storage tank A will only be connected to the header when the tank is being prepared for hydrogen service. Once the tank is in service the blank will be installed and not removed until the tank needs to be evacuated again.

This design approach assures that the utility vacuum system will not be directly connected to the large inventories of the system. It may be connected through a transfer line or other component such as the refrigerator.

In order to connect the utility header to a system containing a large inventory of liquid or gas, operators have to deviate from the operating procedures. This in all cases will constitute a failure. If the utility header is used and it ruptures while containing hydrogen, hydrogen detection will close all the valves on components containing large quantities of liquid or gas. The total amount of gas venting to the atmosphere (inside or outside the building) will be a relatively small amount.

V. CRYOGENIC SYSTEMS

E. Helium Liquefaction System

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V. E. HELIUM LIQUEFACTION SYSTEM

The magnet system will be maintained in the cold steady state condition through a supply of liquid helium from a commercially obtained 100 liter per hour liquefier. It has been calculated that the magnet requires a supply of 50 liters per hour of liquid helium. All of this helium will be vaporized in the magnet reservoir and the cold vapor will be used to intercept heat in three magnet support legs, two electrical leads, and two stainless steel pipes through which leads, instrumentation, and lines enter the magnet reservoir.

Liquid helium will be stored in a 10,000 liter gas shielded dewar from which liquid helium at a pressure of approximately 4 psig will be transferred to the magnet reservoir through a liquid nitrogen shielded transfer line. Magnet reservoir pressure will be of the order of 1-2 psig.

The liquefaction system will operate as a closed system with liquid and gas inventory. When excess capacity of the system is available, gas inventory will be changed into liquid inventory; and with insufficient capacity, liquid inventory will be changed into gas inventory.

Purification equipment in the liquefier makes it possible to remove up to 40 ppm of impurities in the compressor stream (or 500 ppm in a raw feed gas supply stream to the system).

The liquefier can provide a cold helium gas stream for magnet cooling with a refrigeration capacity of 2 KW at 50°K and 1 KW at 20°K. (Temperatures indicate return gas temperature at the liquefier.) A complete flow sheet is shown in Figure 1.

<u>Magnet Cooldown</u>

The mass to be cooled from ambient temperature to 4.5°K is of the order of 200,000 lbs. In order to reduce cost and time, liquid nitrogen and liquid hydrogen will be used to reduce the magnet temperature to approximately 120°K and 40°K respectively. The time required to reach

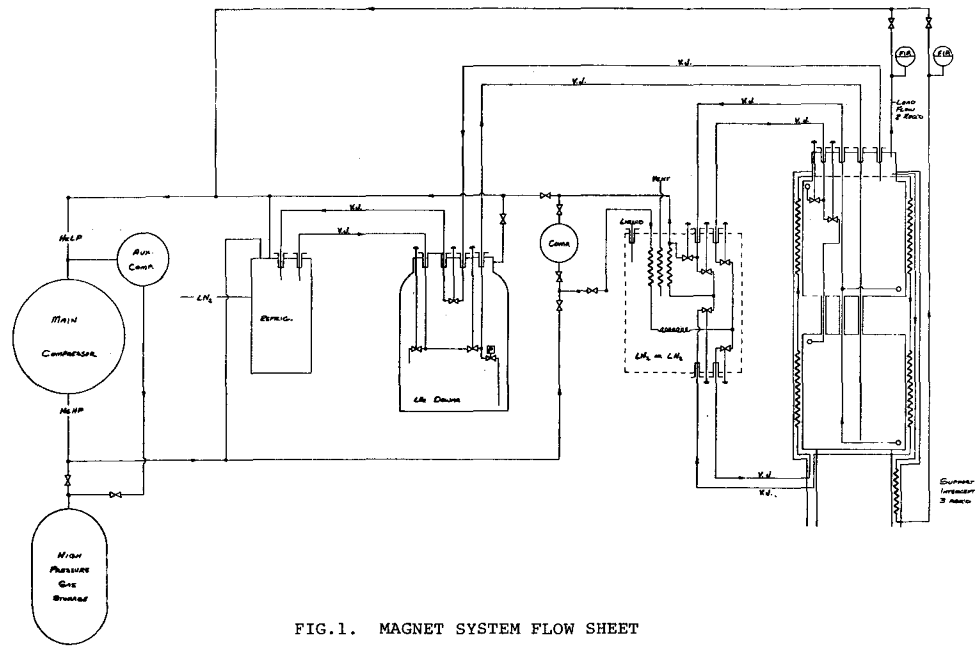

FIG.1. MAGNET SYSTEM FLOW SHEET

40°K will be of the order of seven days. Consumption of liquid nitrogen and hydrogen will be 29,000 and 11,000 liters respectively.

In order to transport refrigeration obtained from vaporization of liquid nitrogen or hydrogen, the helium compressor of the helium liquefier will be used to drive helium gas through the cooldown exchanger (in which nitrogen or hydrogen are vaporized) into the magnet reservoir. Uniform cooling of the pancakes in both reservoirs is achieved through the generation of convection currents. The cold helium gas is added through a distributor in the top of the pancake reservoirs, while warm helium gas is removed through collectors in the bottom of each reservoir.

Non-uniform cooling is permitted as soon as all of the magnet assembly has been cooled to 100°K. When the cooling rate by helium gas flow (cooled by liquid hydrogen evaporation) reduces to the rate at which the liquefier can cool the magnet assembly, the method of cooling will be changed.

The liquefier will now be used and cold helium gas discharged by the expansion engines will be sent directly to the bottom magnet reservoir. The cold gas will rise through the magnet reservoirs and gas of the same temperature as that of the magnet will return to the liquefier.

The magnet will be cooled to 10°K using this method. The final stage of magnet cooldown will be accomplished through transfer of liquid helium from the storage dewar to the bottom of the magnet. The liquid will vaporize partially and fill the magnet at the same time. The rate of liquid transfer will exceed the capacity of the liquefier to reliquefy the vaporized liquid and excess gas will be warmed in the liquefier and temporarily stored in the gas storage facility of the system.

Approximately 1500 liters of liquid helium will be evaporated in cooling the magnet from 10°K to 4.5°K. In addition to this, some 5,200 liters are required to fill the magnet reservoir.

Figure 2 shows the anticipated rate of cooling of the magnet with magnet heat capacity shown in Figure 3.

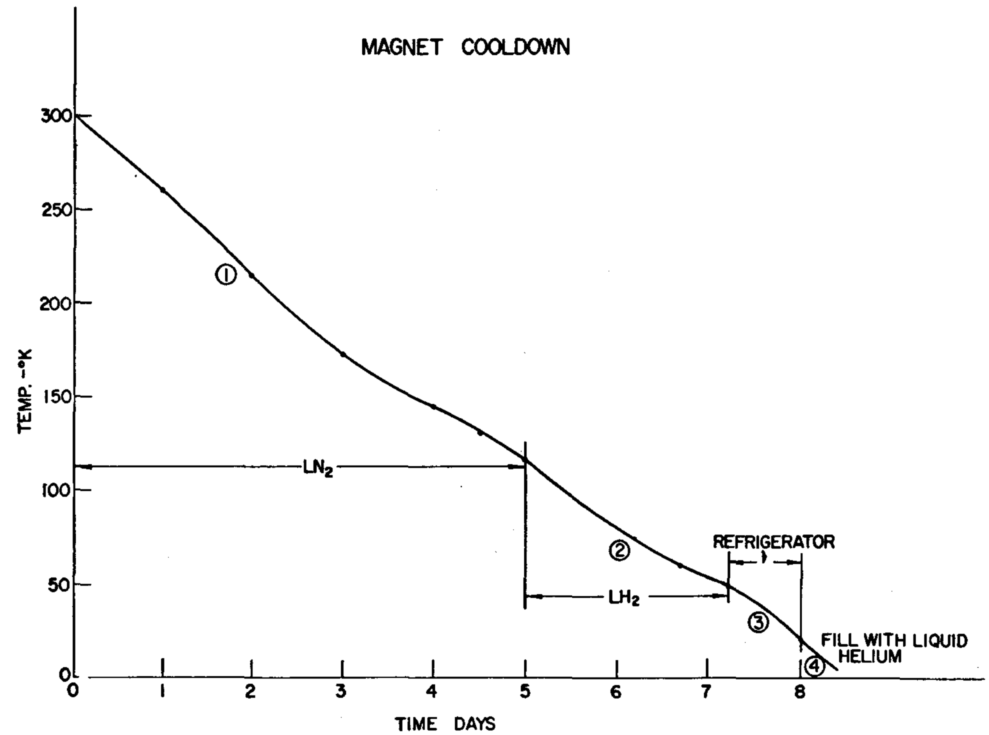

FIG.2. MAGNET COOLDOWN

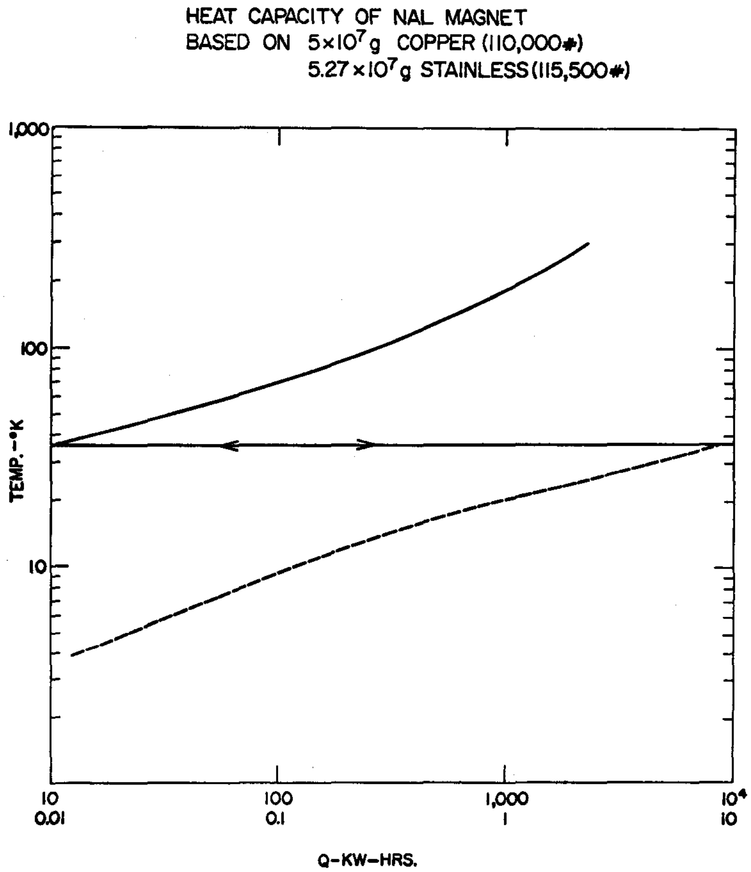

FIG.3. HEAT CAPACITY OF NAL MAGNET BASED ON $5x10^7$g COPPER (110,000#) $5.27x10^7$g STAINLESS (115,500#)

V. CRYOGENIC SYSTEMS

F. Failure Mode Analysis: HELIUM SYSTEM

Prepared by

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V. F. Failure Mode Analysis: HELIUM SYSTEM

Introduction

The first part of this Section contains a discussion of the basic safety hazards associated with the storage and handling of cryogenic fluids. Liquid hydrogen is used during cooldown of the magnet for a brief period of time. With the exception of this period, only inert fluids are handled in the helium system.

The second part of this Section contains the failure mode analysis of the helium system. Documents used for this Section are engineering flow sheets of the system (NAL Drawings 2625.ME-33424, -33425, -33426, and -33427), and drawings and equipment specifications of the hardware of the system.

(1) BASIC SAFETY HAZARDS IN STORAGE AND HANDLING OF CRYOGENIC FLUIDS

The bubble chamber cryogenic system will deal with the following cryogenic liquids and gases: hydrogen, deuterium, neon, nitrogen, and helium. Three of these fluids are inert and the safety hazards are those associated with the cryogenic and pressure aspects of the system. Sound cryogenic design practice widely used in industry and laboratories is sufficient to provide a safe system.

A. Potential safety problems of the fluids of the system due to the cryogenic temperatures are:

a) At low temperatures, the ductility and impact resistance of most materials decrease. The exposure of unsatisfactory materials to cryogenic temperatures can lead to structural failures, which in extreme cases may be accompanied by fragmentation.

b) All materials expand or contract to some degree with temperature changes as indicated by their coefficients of expansion. In rigidly confined members or in components comprising several materials with widely different coefficients of expansion, stresses will obviously tend to develop over the broad temperature change from ambient to -423°F. If designs do not consider these factors, structural failures or binding of movable parts may occur.

c) Pliability, elasticity, and surface smoothness of seal and gasket materials can be radically altered as they approach -423°F. Resultant leakage problems may release hydrogen into the atmosphere where it has fuel potential.

d) Liquid vessels and lines are carefully insulated to minimize heat leak from their surroundings. This connotes confinement. Since no insulation is perfect, there is always some heat influx into vessels and lines. Imperfections in insulation, such as loss of vacuum or settling or loss of powder, can lead to abnormal heat input. In either case, slowly or rapidly, vaporization and expansion take place. Since liquid to gas expansion ratio for hydrogen or helium is about 850, a completely confined vessel of liquid at one atmosphere, upon warming to 70°F, could have a pressure in excess of 12,000 pounds per square inch exerted on its walls. If adequate relief devices are not provided wherever liquid can be confined, the possibility of fracture is evident.

e) Liquid and very cold hydrogen or helium gas exist at a temperature lower than the boiling point of air. As a result, should liquid or cold gas be vented through uninsulated lines, air could condense on exposed surfaces. Should this liquid drip or be blown onto adjacent structures not designed to withstand low temperature, structural failures might occur.

B. With regard to the possibility of leaking hydrogen gas or liquid into the atmosphere during the period when the magnet reservoir is being cooled, the discussion in Section V.- C. applies.

(2) FAILURE MODE ANALYSIS OF THE HELIUM SYSTEM

All of the helium system, with the exception of the cooldown exchanger, is filled with an inert cryogenic fluid (helium or nitrogen). This immediately eliminates the need for consideration of flammable mixtures to be formed either inside the equipment or in the environment of the system. As a result of this, it is not necessary to consider individual components of the system as was done in the failure mode analysis of the hydrogen system. The general type of failures which present a safety problem is failure of a vessel or pipe under pressure or the spillage of large quantities of cold gas or liquid, resulting in freezing of tissue or failure of adjacent components or equipment.

1.0 Failure Due to Pressure

Every component of the helium system which may be valved off is equipped with a safety relief device which will maintain the pressure in the component at a level below the design level. The system is designed to handle a single failure. Actions resulting in potential overpressurization of a vessel or pipe constitute the failure; by definition the safety relief device will be functional and will protect the vessel or pipe from overpressure.

1.1 Helium liquefier compressor. -Safety valve SV-1464 protects the compressor and its discharge pressure from overpressure. The discharge of the valve feeds back to the suction of the machine.

1.2 Compressors X_1 and X_2 are protected by safety valves SV-1428 and SV-1471. The valves feed back into the suction of the compressors. Heat of compression has been taken out in the aftercoolers of the compressor.

1.3 Shield compressor is protected by safety valve SV-1509. Gas is returned to the suction of the compressor after heat of compression has been taken out in the aftercooler.

1.4 The helium liquefier cold box piping is protected from overpressure by the following relief valves: SV-1472, SV-1473, SV-1484, SV-1485, SV-1501, SV-1500, SV-1494, SV-1493, SV-1635, and SV-1597. These valves cover every vessel and pipe of the helium cold box.

1.5 The vacuum shell of the helium cold box is protected from overpressure by NV-1487.

1.6 The liquid helium dewar is protected by SV-1422 and RD-320 from overpressure. These devices can handle the maximum anticipated flow rate caused by a loss of vacuum of the insulation space.

1.7 Vacuum-jacketed transfer lines are protected from overpressure by relief valves of components in open connection with the lines.

1.8 The magnet reservoir is protected from overpressure through relief valve SV-1441 and rupture disc RD-403. The rupture disc will handle the large flow rate in case of loss of superconductivity or insulating vacuum.

1.9 Cooldown exchanger high and low pressure helium piping is protected by relief valves SV-1448 and SV-1635. The liquid nitrogen (or hydrogen) reservoir is protected by relief valve SV-1510.

.0 <u>Failure Due to Low Temperature</u>

2.1 Failure of controller TC-467 would continue feeding liquid nitrogen to the warm exchanger of the liquefier. This, in turn, may reduce the temperature of the gas flowing to the suction of the compressor. All piping is stainless steel, but the compressor is not protected from low temperature, except by operator vigilance.

2.2 Failure of controller LIC-454 on the liquid helium tank. The liquid nitrogen tank of the shield of the helium dewar will be over-filled and liquid nitrogen will be spraying out of the vent.

2.3 Failure of controller LIC-327 of the cooldown exchanger. Liquid nitrogen or hydrogen will flow into the vent system. Piping is all stainless steel and excess liquid will not spray inside the building. The arrangement of the heat exchangers in the cooldown exchanger is such that the helium gas flowing to the suction of the shield compressor or main helium compressor will not get cold.

2.4 Failure of controller CS-270. The magnet may be overfilled. If all gas flows through the heat intercepts, pressure in the magnet will increase and slow down the rate of transfer from the dewar. Some frost will appear on all vents, but main compressor suction will not get very cold, until it has become evident that excess liquid helium is being used in the system.

3.0 Hydrogen Operation of the Cooldown Exchanger

Liquid hydrogen will be maintained in the vessel. The quantity present is 4,500 scft, when the reservoir is completely full. Under normal operating conditions, the reservoir will hold the equivalent of 2,700 scft of hydrogen. Relief valve SV-1510 is set at 100 psig and has a capacity of 1,370 scfm of hydrogen gas at 60°F. At full helium compressor flow rate, 450 scfm of hydrogen are venting from the liquid reservoir. The rate of venting is proportional to the helium flow rate through the exchanger.

3.1 Closure of valve MV-1511 during operation of the cooldown exchanger is an operator error. In that case, relief SV-1510 will handle the required flow rate.

3.2 Vent stack may freeze shut under certain weather conditions. The vent stack is equipped with a rupture disc set at 12-20 psig. This disc will open the vent stack to the atmosphere.

3.3 Loss of vacuum insulation when maximum helium flow takes place. Under these conditions the manual vent valve MV-1511 is in the open position and the piping connecting the cooldown exchanger and vent stack is large enough to handle the maximum flow rate without generating a pressure of 100 psig in the vessel.

3.4 Liquid supply valve PV-327 hangs open. The maximum flow rate with A tank at 150 psig and the cooldown exchanger vessel at 100 psig is some 1,500 lbs/hr. This is beyond the capacity of relief valve SV-1510, and unless valve MV-1511 is open, the pressure in the cooldown exchanger will approach that of A tank within 10-15 psig. Valve MV-1511 is normally open and A tank pressure is not required to be at 150 psig during cooldown of the magnet. Only two or more independent failures, of which PV-327 sticking open is one, will drive the cooldown liquid hydrogen reservoir pressure to a dangerous level.

3.5 A tank vaporizer control fails and A tank pressurizes to 150 psig. All of the transfer piping up to control valve PV-327 is rated at 150 psig. Valve PV-327 will maintain the required flow rate into the cooldown exchanger reservoir.

3.6 Insulating vacuum fails through a large air leak. The rate of liquid hydrogen consumption will increase by as much as 300 lbs/hr (air condensing on the liquid hydrogen vessel). The vent system of the cooldown exchanger will handle this flow rate without exceeding the design pressure of the vessel.

3.7 Insulating vacuum fails through a large hydrogen leak. The vacuum space of the exchanger will be pressurized to the pressure of the liquid vessel. Check valve NV-1682 (3/4" pipe size) will relieve at a pressure of 1 psig to the stack. The vacuum shell of the exchanger is equipped with a number of stainless steel corrugated hoses. In the unrestrained condition the pressure rating is 12 psig. The sections are short (less than 5 inches long) and are restrained at both ends and surround a valve stem. The burst pressure of the hoses is not known. With valve MV-1511 open and valve PV-327 controlling, the pressure in the liquid vessel will not exceed 20 psig and a rupture of the bellows in the vacuum shell is not anticipated.

3.8 Liquid hydrogen line break in the vacuum space of the cooldown exchanger. Gas and liquid will vent through NV-1682. Maximum flow rate of this system is 140 lbs/hr with a pressure of 20 psig in the vacuum space. Pressure in the vacuum space will reach that of A tank. During transfer of liquid hydrogen to the cooldown exchanger, a pressure switch monitoring the pressure in A tank is interlocked with valve PV-109. When the pressure in A tank exceeds 30 psig, the interlock prevents PV-109 from opening. The liquid hydrogen line break will result in a pressure in the vacuum space of no more than 30 psig.

V. EQUIPMENT

G. Chamber Vent System

Prepared by

P. C. Vander Arend

V. G. CHAMBER VENT SYSTEM

Reference drawings 2625.ME-25079 and 2625.ME-25055 and spool sheet SP-210-B. Liquid may be removed from the chamber in a number of ways, as follows:

a) Through valves PV-189 and PV-180 of A tank.

b) Through valves PV-191 (PV-192), PV-194 (PV-195), and PV-105 of A tank.

c) Through valves PV-193, PV-194 (PV-195), and PV-105 of A tank.

Any of these three ways allows liquid flow into A tank and venting of excess flow takes place through the vent stack of A tank.

A further method is available to vent liquid and gas directly from the chamber to the environment. Valve PV-190 connects the top of the chamber through a jacketed line to vessel A-A. This vessel, in turn, is connected to the chamber stack through:

a) Two parallel relief valves, one of which is always in open connection with vessel A-A.

b) A manual valve with an air-operated diaphragm which may be operated from the bubble chamber control room.

c) A rupture disc.

Vessel A-A is equipped with a liner which provides nominal insulation between environment and the liquid reservoir. When liquid hydrogen is dumped into vessel A-A, the rate of vaporization will be such that all of the hydrogen in vessel A-A will vaporize over a period of $1\frac{1}{2}$-2 minutes. Once the first surge of liquid has been released from the chamber, only gas will be venting at the rate at which it is generated.

The chamber stack is a stainless steel pipe (6 inch IPS, Schedule 10), equipped with check valve, rain hat, rupture disc, and nitrogen purge. The stack protrudes 10 feet above the building.

The rupture disc is provided in case the rain hat and/or check valve fail to provide an open path to the environment.

A drain valve in the bottom of the stack allows removal of water in case it leaks through rain hat and check valve.

V. EQUIPMENT

H. Chamber Warmup

Prepared by

P. C. Vander Arend

V. H. CHAMBER WARMUP

After liquid has been removed from the chamber, warmup may be carried out to prepare for a change of fluids, maintenance, or modification work.

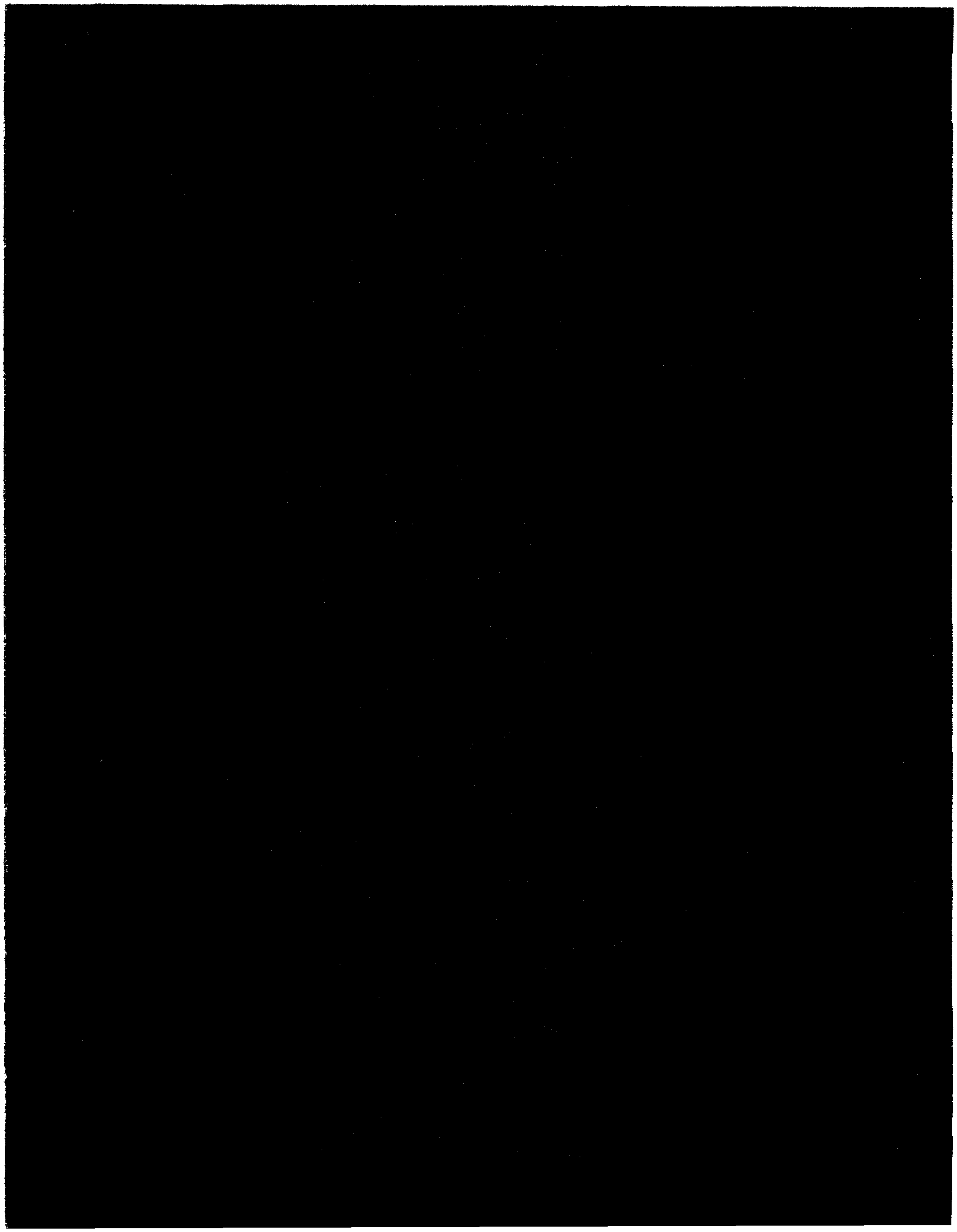
Because the chamber is effectively separated into two regions without communication, a simple flow-through with warm hydrogen gas cannot be used to warm the chamber uniformly. The direct application of electrical heat to the walls of the chamber will not result in uniform heating unless heating is accomplished with a large number of small heaters.

Electric heat may be supplied by a few relatively large heaters located in the vacuum space. By breaking the vacuum with hydrogen or nitrogen gas, heat will be transferred by convection from the electric heaters to the gas, and from the gas to the wall of the chamber. The heaters are located in the bottom of the vacuum space to generate convection currents in the gas.

The amount of heat required to warm the chamber vessel from 20°K to 300°K is of the order of 1.4×10^9 Joules. Warming the chamber in 48 hours requires a supply of 8 KW of heat. The heat flux per unit surface area of the heaters is low to prevent overheating and burn-out of the heaters.

In order to warm the windows at approximately the same rate as the chamber, each window is equipped with an electric heater. The rate at which temperatures of chamber, vessel, and windows rise is monitored. Adjustments in rate of heating are made by adjustments in electric heat and/or gas pressure in the vacuum space of the chamber. During warmup of the chamber, a low pressure with hydrogen gas will be maintained in the chamber volume.

Excess hydrogen gas will be vented either to the stack system or to the liquid hydrogen storage tank for recondensation. When the chamber system reaches a temperature in excess of 80°K, the hydrogen gas will be removed by evacuation and replaced by nitrogen gas.



VI. INSTRUMENTATION

Prepared by

G. T. Mulholland

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VI. INSTRUMENTATION

VI. A. SOURCE FAILURE PROVISIONS - PNEUMATIC, ELECTRICAL

(1) PNEUMATIC POWER

The prime movers of the pneumatic power source are a pair of 200 CFMD (100 ICFM @ 140 psig maximum) standard design, vertical, lubricated, 514 RPM, 30 HP, Worthington 8x7 air compressors. The configuration is the alternate on-line/stand-by accomplished electrically, by suction valve loading at 120 psig and 110 psig respectively. The power source is derived from the emergency MCC with local restart capability.

Monitoring of the proper functioning of the air compressors is accomplished by shift logs, summarized by a remote monitoring panel located in the H_2 compressor and by appropriate alarms in the Control Room (see interlocks). Administrative control is especially important here because of the location of air compressors outside the high traffic areas of the bubble chamber.

Emergency pneumatic power is supplied by two high pressure tubes of the neon high pressure storage system (the railroad cars) pumped with dry N_2 to 2000 psig. This 16,000 SCF will automatically be cut into the air manifold at 90 psig by a reducing regulator, check valve arrangement to supply air at the nominal 100 CFM rate for about 2-1/2 hours. The emergency air supply will be alarmed at 1800 psig to assure its continuous availability, and 500 psig to warn of pending exhaustion.

The entire pneumatic system has, valve by valve, controller by controller, been designed to fail safe. Fail safe is not, however, always fail convenient. The 2-1/2 hour period provided by the stored energy in the emergency pneumatic source allows convenient shutdown preparations to be made.

(2) ELECTRICAL POWER

Power to the site is provided by a Commonwealth Edison 345 KV high line. The site substation (located opposite N-1 on Road A) distributes 13.8 KV to the 15-foot bubble chamber substations NL-10, NL-11, (located southwest of the bubble chamber high bay), which in turn distributes 480V to one of three panels in Building B; the Kinney switchboard, the Motor Control Center (MCC), and the Emergency Control Center (EMCC). Note here that with the exception of the EMCC powered Control Room, all power to Building A is provided by a separate 13.8 KV feeder to the NL-12 substation.

In the event of a Commonwealth Edison power failure an automatic transfer switch throws the load over to a 250 KW emergency generator. This generator is, by the first of the year, to take the form of a natural gas turbine similar to the one used to provide emergency power for the high rise building fire protection water pumps. Until that installation is complete a portable, automatic start,Caterpillar 250 KW diesel will serve this function.

All hydrogen system, main, magnet and window vacuum systems piloting solenoids and panel indicators are provided with diode coupled 24V auto storage batteries to provide power through the transfer time (~15 sec) from commercial to emergency power. Sufficient storage is provided to supply power for about 4 hours in the event the emergency power fails to assume the load. In that event, and after 4 hours, the solenoids will fail in the safe process position, as described elsewhere in this report.

The fact that concurrent motor starting loads can easily prevent the emergency generator from picking up the load requires the usual start-stop motor started configuration; i.e., the motor loads on the EMCC must be manually restarted. This in turn requires, for instance, vacuum pump shut-off valves interlocked to vacuum pump power and a manual reopen arrangement on the shut-off valves in general.

This changeover process takes about 15 minutes with preference given to the main, magnet and window vacuum systems; i.e., in the order of (expected) decreasing pumping loads. The cooling tower fans and pump motors are chosen not to require manual restart, and are breakers rather than motor starters, for obvious reasons.

The Commonwealth Edison line is more reliable than most, typical outages are of short duration and usually only one or two per year, requiring infrequent use of this provision.

VI. B. DEVICE INSTRUMENTATION

Device instruments are those deriving information directly from the chamber or magnet and thus penetrate the vacuum shell at either the chamber electrical or tube, or the magnet lead or instrumentation feed throughs. This class of instrumentation does not bare directly on the safety question, except to the extent the instrumentation itself presents a safety hazard.

A complete list of all instrumentation is available in the Valve and Instrument Summary. The following device list is extracted to demonstrate, generically, the non-hazard aspect:

- Thermocouples
- Vapor Pressure Bulbs
- Dynamic (electrical) Pressure Transducers
- Carbon Resistor Level Gauges
- Pneumatic Differential and Pressure Transducers
- Diagnostic Seal Pump Outs
- Bellows Pressurization (and Sensing) Lines
- Heaters, Z Section and Shaft Seal
- Chamber Fluid Sample Lines
- Superconducting Level Gauges
- Strain Gauges Thermometers
- Carbon Resistor Thermometers

Only four items, the Dynamic Pressure Transducers, the Carbon Resistor and Superconducting Level Gauges and the Heaters are other than intrinsically safe for use in a hydrogen area. All are non-sparking devices and operate in environments normally free of hazard considerations; i.e., the chamber fluid, the magnet helium and the vacuum tank.

VI. C. PROCESS INSTRUMENTATION

Process instruments are those located, in general, in Class I, Division 2 (Article 500, NEC Code) areas and are concerned with the proper operation of the bubble chamber support and ancillary equipment;i.e., the hydrogen and helium refrigerator, the vacuum, the camera, the expansion and the liquid and gas storage systems. In general the functions are linear, operate over a well defined range and depend on relief valves, pressure, temperature, displacement, speed and logical interlocks for upset or abnormal process and equipment protection. The latter are safety and interlocked instrumentation collected, in this report, under that title.

The process instruments are listed in the Valve and Instrument Summary with the following letter designations:

DPT - Differential Pressure Transmitter

EV - Electrical Valve (solenoid)

FE - Flow Element (orifice)

FI - Flow Indicator

IG - Ion Gauge

LI - Level Indicator

LIC - Level Indicator Controller

ML - Manual Loader

PI - Pressure Indicator

PIC - Pressure Indicator Controller

PT - Pressure Transmitter (pneumatic)

PV - Pressure Valve

PX - Pressure Transmitter (electrical)

RS - Recording Station (integrating flow meter)

RV - Reducing Valve (regulator)

SI - Speed Indicator

SC - Speed Controller

SW - Switch (electrical, process)

TG - Thermocouple Gauge

TI - Temperature Indicator (bulb, dial type)

VI - Vacuum Indicator

All but EV, IG, some electrical LIC, PX, SI, SC, SW, TG and VI are pneumatic instruments and therefore intrinsically safe.

The (EV) electrical valves (solenoids) are non-sparking devices, consistent with the applicable code, and on this chamber have high temperature coils wherever possible to significantly reduce coil failure rates. All solenoids fail safe on power failure as indicated by the continuous line through the solenoid on the schematic drawings.

The (IG) Ion gauges are cold cathode gauges with con-flat flanges rated at 150 psig internal pressure and provided with a protective sheath in the area of the high voltage connection.

The electrical LIC (process) are of the carbon resistance type and function in liquid N_2 or H_2 environments.

The (PX) electrical pressure transducers are capacitive, strain gauge or LVDT type consistent with the accepted practice at other chambers.

There is one (SI) speed indicator (a DC generator tachometer), one (SC) speed controller (electronic) and an alternator and resistor load bank (no schematic letter designation), all part of the helium system. The helium refrigeration system is located in a Class I, Division 2 area and thus suffers the same constraints as the hydrogen refrigeration system. All the electrical controls are either collected in a large (alarmed) N_2 purged box behind the cold box panel or connected by means of approved intrinsically safe contact monitors called "Safe Paks" with the exception of the speed indicator, alternator and resistor load bank mentioned above. The first two are sparking devices and are, therefore, provided with N_2 (alarmed) purge provisions. The resistor load bank is a non-sparking device, suitably mechanically protected.

The (SW) electrical (process) switches are used to turn on heaters in the adsorbers, driers, etc. The switches are approved for Class I, Division 2, Group B use.

The thermocouple gauges (TG) are Haystings Raydist DV-36 and DV-34 on all lines relieved above 50 psig and below 150 psig. There are no thermocouple gauges on lines rated, and thus relieved, above 150 psig. The electrical connections are similar to those of the DV-6 and DV-4 in common low pressure use at this and other bubble chambers.

The (VI) vacuum indicators are an old designation currently being replaced with (TG) thermocouple and (IG) Ion gauge, as time allows, to afford more information to the operator.

VI. D. INTERLOCKED INSTRUMENTATION

Interlocked instruments are those that do something in response to out-of-limit conditions in the system. The organization is by sub-system, expansion, H_2 refrigerator, etc., includes all temperature switches (TS), pressure switches (PS), temperature alarms (TA), pressure alarms (PA) and other alarms and interlocks without a letter designation for the moment, but does not, for reasons of manageability include the safety valves (SV) or figure "8" blinds (SB). The latter are thought to be self explanatory by reason of their location on the engineering flow diagrams and, in the case of the figure "8" blinds, by discussion in the text of the various operating instructions.

<u>Expansion System - Interlocks and Alarms</u>

High level H_2 detection (any where)	Interlock	Stop pulsing
Warning level H_2 dector (in shaft area)	Interlock	Stop pulsing
Drive piston return (Δz = .100", fixed)	Interlock	Stop pulsing
Drive piston stroke (high, adj.)	Interlock	Stop pulsing
Drive piston radial motion (high, adj.)	Interlock	Stop pulsing
Oil supply pressure PS753A,B (high, sel, adj.)	Interlock	Stop pulsing
Recompression oil pressure PS754A,B (high, low, adj.)	Interlock	Stop pulsing
Latch oil pressure PS779 (high, low, adj.)	Interlock	Stop pulsing
Return oil pressure PS781 (high, adj.)	Interlock	Stop pulsing
Ross valve gas pressure PS807A,B (low, adj.)	Interlock	Stop pulsing
Drive gas pressure PS859 (high, low, adj.)	Interlock	Stop pulsing

Bouncer gas pressure PS866 (high, low, adj.)	Interlock	Stop pulsing
Excessive vibration (high, adj.)	Interlock	Stop pulsing
Manual panic shutdown (various locations; pit, pump area)	Interlock	Stop pulsing
HP pump low suction pressure (<140 psig)	Interlock	HP pumps stop
Sump level, rate of fail (high, adj.)	Interlock	Stop pulsing
Sump level (low, fixed)	Interlock	Stop pulsing, stop booster pump
N_2 compressor excessive vibration (high)	Interlock	Alarm/stop N_2 Comp.
N_2 compressor lub oil pressure (low)	Interlock	Alarm/stop N_2 Comp.
N_2 compressor oil pressure (low)	Interlock	Alarm/stop N_2 Comp.
N_2 compressor high discharge pressure (high)	Interlock	Alarm/stop N_2 Comp.
N_2 compressor high gas temperature (I, II)	Interlock	Alarm/stop N_2 Comp.
HP N_2 compressor oil level (low)	Interlock	Stop HP N_2 Comp.
HP N_2 compressor discharge pressure (low)	Interlock	Start HP N_2 Comp.
HP N_2 compressor discharge pressure (high)	Interlock	Stop HP N_2 Comp.
HP pump start (logical)	Interlock	Booster pump on
Chamber piston shaft seal temperature (high, low)	Interlock	Stop pulsing
Bouncer water pressure (low)	CR alarm	
Sump level, rate of fall (high)	CR alarm	
Ross valve gas pressure (low)	CR alarm	
Sump oil temperature (high)	CR alarm	

Hydrogen Refrigerator - Interlocks and Alarms

H_2 detection, high level (any >1% H_2 in air)	Interlock	Sound warning horn & see table below
H_2 detector, low level (any >0.3% H_2 in air)	CR alarm	

H_2 Detector Interlock Table

"A" Tank liquid withdrawal valves (fail closed on source failure)

Close PV104A via EV104A,B	Air supply cutoff
Close PV106 via EV106	Pilot air cutoff
Close PV107 via EV107	Pilot air cutoff
Close PV108 via EV108	Pilot air cutoff
Close PV109 via EV109	Pilot air cutoff
Close PV180 via EV180	Pilot air cutoff

"A" Tank gas phase lines (fail closed on source failure)

Close PV104B via EV104A,B	Air supply cutoff
Close PV105 via EV105	Air supply cutoff
Close PV251 via EV251	Pilot air cutoff
Close PV252 via EV252	Pilot air cutoff

Compressor discharge

Close PV188 via EV188	Pilot air cutoff

Chamber valves

Close PV189 via EV189	Pilot air cutoff
Close PV194 via EV194	Pilot air cutoff
Close PV195 via EV195	Pilot air cutoff

Open compressor room, high bay louvers
(open on air, power failure)

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Location of H_2 Detectors - Chamber High Bay

Above the valve boxes at the vacuum flange

Above the H_2 pump dewar

In the neck of the bottom vacuum tank cover plate

South boom 10 feet above southern end camera wells

North boom 10 feet above northern end camera wells

Location of H_2 Detectors - Refrigeration System

High above the cold box

Above cold box panel

Above east end of rack SS

Above west end of rack SS

Above H_2 compressor first stage

Above H_2 compressor second, third stage

Above withdrawal end of "A" tank

Above fill end of "A" tank

H_2 compressor panic stop (two, compressor room and hallway)	Interlock	Stop H_2 Comp.
H_2 compressor discharge gas temperature first stage (high)	Interlock	Stop H_2 Comp.
H_2 compressor discharge gas temperature second stage (high)	Interlock	Stop H_2 Comp.
H_2 compressor discharge gas temperature third stage (high)	Interlock	Stop H_2 Comp.
H_2 compressor water pressure (low)	Interlock	Stop H_2 Comp.
H_2 compressor suction pressure (<7 psig)	Interlock	Stop H_2 Comp.
H_2 compressor vibration (excessive)	Interlock	Stop H_2 Comp.
H_2 compressor oil pressure (low)	Interlock	Stop H_2 Comp.
N_2 vacuum booster pump suction pressure >75 mm	Interlock	Stop booster
N_2 vacuum booster pump temperature >325°F	Interlock	Stop booster
Utility vacuum pumps water pressure (low)	Interlock	Stop pumps
N_2 vacuum pump inlet temperature PA255 (<50°F)	Alarm	
H_2 compressor suction pressure (high)	Alarm	

H_2 compressor room purge manifold <25 psi	Alarm	
Instrument air pressure <90 psig	CR alarm	
H_2 compressor suction temperature TA245, <50°F	CR alarm	

<u>Helium Refrigerator - Interlocks and Alarms</u>

He compressor discharge gas temperature first stage (high)	Interlock	Stop He compressor
He compressor discharge gas temperature second stage (high)	Interlock	Stop He compressor
He compressor discharge gas temperature third stage (high)	Interlock	Stop He compressor
He compressor high suction pressure >2 psig	Interlock	Pump to low pressure storage
He compressor discharge pressure >270 psig	Interlock	Stop He compressor
Engine over speed (high, adj.)	Interlock	Close engine inlet valves
Speed control power (logical)	Interlock	Power failure closes engine inlet valves
Low pressure storage alarm >150 psig	CR alarm	
He compressor suction temperature <32°F	CR alarm	
Engine under speed (low, adj.)	CR alarm	
He recovery compressor water pressure (2) (low)	Interlock	Stop He recovery compressor
He recovery compressor oil pressure (low)	Interlock	Stop He recovery compressor
He recovery compressor auto operation (suction pressure high, adj.)	Interlock	Start He recovery compressor
He recovery compressor auto operation (suction pressure low, adj.)	Interlock	Stop He recovery compressor
He recovery oil pressure loader (hydraulic, pressure >10 psig)	Interlock	Load He recovery compressor, unload on oil pressure failure
He cold box electrical panel N_2 purge (on)	CR alarm	

He refrigerator alternator N_2 purge (on)	CR alarm	
He refrigerator tachometer N_2 purge (on)	CR alarm	

Magnet - Interlocks and Alarms

Magnet power supply transformer temperature (>175°F)	Interlock	PS shutdown
Magnet power supply diode temperature (>135°F)	Interlock	PS shutdown
Magnet power supply current (high, adj.)	Interlock	PS shutdown
Magnet power supply voltage (high, adj.)	Interlock	PS shutdown
Magnet power supply cooling water (<2 gpm)	Interlock	PS shutdown
Magnet power supply amplifier active (logical)	Interlock	PS shutdown
Magnet power supply shorting switch open (logical)	Interlock	PS shutdown
Magnet intercept lead flow (low, fixed)	CR alarm	
Magnet intercept leg flow (3) (low, fixed)	CR alarm	
Magnet shield flow (low, fixed)	CR alarm	
Magnet cooldown exchanger level (low, fixed)	CR alarm	
Magnet dewar level (low, fixed)	CR alarm	
Magnet dump resistor water level (low, fixed)	CR alarm	

Instrument Air - Interlocks and Alarms

Air compressor discharge temperature (2) (>350°F)	Interlock	Stop (each) air compressor
Air compressor water temperature (2) (>100°F)	Interlock	Stop (each) air compressor
Air compressor oil pressure (2) (<15°F)	Interlock	Stop (each) air compressor

Low receiver pressure (<125 psig)	Control	Selected on-line compressor on
Low receiver pressure (<115 psig)	Control	Standby compressor on
Low receiver pressure (<105 psig)	CR alarm	Low pressure
Air compressor 1 off	CR alarm	
Air compressor 2 off	CR alarm	
Emergency air pressure (low, <1800 psig)	CR alarm	
Emergency air pressure (near exhaustion, <500 psig)	CR alarm	

<u>Main Vacuum System</u>

Vacuum tank positive pressure (PA900, >10 psi)	Interlock	Close PV901,PV902
Vacuum tank pressure (>100 mm)	Interlock	Close PV337,338,189, 190,191,192,193
MV fore pump power (logical)	Interlock	Close PV904
PV904 reopen (logical)	Interlock	Manual reopen only
MV fore pump power (logical)	Interlock	Manual restart
MV blower pump power (logical)	Interlock	Manual restart
MV diffusion pump power (logical)	Interlock	Manual restart
MV diffusion pump current (low)	CR alarm	Heater burn out
MV diffusion pump termperature (high)	CR alarm	
MV diffusion pump water pressure (low)	CR alarm	
MV diffusion pump heater purge (off)	CR alarm	
MV mm thermocouple gauge (TG904, high, adj.)	CR alarm	
MV mm thermocouple gauge (TG902A, high, adj.)	CR alarm	

MV μ thermocouple gauge (TG902B, high, adj.)	CR alarm	
MV Ion gauge (IG902, high, adj.)	CR alarm	

Magnet Vacuum System

Magnet vacuum positive pressure (PA910, >10 psig)	Interlock	Close PV916,PV917
Magnet vacuum fore pump power (logical	Interlock	Close PV957
PV919 reopen (logical)	Interlock	Manual reopen only
Magnet vacuum fore pump power (logical)	Interlock	Manual restart
Magnet vacuum diffusion pump power (logical)	Interlock	Manual restart
Magnet vacuum diffusion pump current (low)	CR alarm	
Magnet vacuum diffusion pump temperature (high)	CR alarm	
Magnet vacuum diffusion pump water pressure (low)	CR alarm	
Magnet vacuum diffusion pump purge (off)	CR alarm	
Magnet vacuum mm thermocouple gauge (TG918, high, adj.)	CR alarm	
Magnet vacuum mm thermocouple gauge (TG916A, high, adj.)	CR alarm	
Magnet vacuum μ thermocouple gauge (TG916B, high, adj.)	CR alarm	
Magnet vacuum Ion gauge (IG916, high, adj.)	CR alarm	

Window Vacuum System

Window vacuum space one (6) TC971-876 individually, 750μ fixed	Interlock	Close associated valve(s) PV941-946, PV931-936
Window vacuum space two (6) TC981-986 individually, >50μ fixed	Interlock	Close associated valve(s) PV951-956, PV961-966

Window vacuum manifold "A" (IG manifold "A", >5x10^{-5}, fixed)	Interlock	Close PV931-936
Window vacuum manifold "B" (IG manifold "B", >5x10^{-5}, fixed)	Interlock	Close PV961-966
Window vacuum manifold "C" (IG manifold "C", >5x10^{-5}, fixed)	Interlock	Close PV941-946, PV951-956
Window vacuum manifold "A" (TG manifold "A" >500μ, fixed)	Interlock	Close all valves
Window vacuum manifold "B" (TG manifold "B" >500μ, fixed)	Interlock	Close all valves
Window vacuum manifold "C" (TG manifold "C" >500μ, fixed)	Interlock	Close all valves
Window vacuum manifold "A" (>5x15^{-6}, fixed)	CR alarm	
Window vacuum manifold "B" (>5x15^{-6}, fixed)	CR alarm	
Window vacuum manifold "C" (>5x15^{-6}, fixed)	CR alarm	
Window vacuum space one (6) (TC971-976, >10μ, individual)	CR alarm	
Window vacuum space two (6) (TC981-986, >10μ, individual)	CR alarm	
Turbo "C" rough pump power (logical)	Interlock	Closes PV940 Manual reopen
Turbo "D" rough pump power (logical)		Closes PV950 Manual reopen
Turbo "C" purge (off)	CR alarm	
Turbo "D" purge (off)	CR alarm	
Turbo pump "C" current (off)	CR alarm	
Turbo pump "D" current (off)	CR alarm	
Window vacuum manifold "A" (>500μ)	CR alarm	
Window vacuum manifold "B" (>500μ)	CR alarm	
Window vacuum manifold "C" (>500μ)	CR alarm	

VII. MISCELLANEOUS

A. Tests

Prepared by

National Accelerator Laboratory

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VII. MISCELLANEOUS

A. Tests

VII. A. 1. VACUUM TANK

On Saturday, May 13, the vacuum tank for the 15-foot bubble chamber was penumatically pressure-tested to 60 psig. Prior to the test all penetrations were recalculated in the logbook to verify their integrity. The area (B Building and inside of the fence) during the test was cleared of people except for those necessary for the test (at least two). The personnel involved with the test were stationed in the hydraulics room with the firedoors closed during the period when the pressure was above 10 psig and increasing.

Instrumentation for the test was as follows:

1. Two pressure gauges, one of which was remoted by television to the hydraulics room.
2. Two dial indicators (.001 inch), one on the main flange and one on an optics port blank-off.
3. Eight strain gauges, four on the beam window and four on the narrow 1/2 inch thick ligament between optics nozzles.

Figure 1 is a plot of pressure versus time. At twenty hours, twenty minutes we stopped and reduced the pressure from 35.5 psig to 33.5 psig to check visually the tank and to measure the separation of the main flange. The reason for checking the main flange was that the dial indicator indicated 3.5 mil separation, however, when we checked the flange this was not true. At 55 psig the flange separation was between 2 and 4 mils (measured with feeler gauge). This means that the bolts set somewhat since the expected stretch of the bolts is only 1 mil. It appears that the mounting of the dial indicator must have put a multiplying factor into the reading.

Figures 2-5 show the results from the strain gauges. Table I is a comparison of calculated stress and strain gauge measurements.

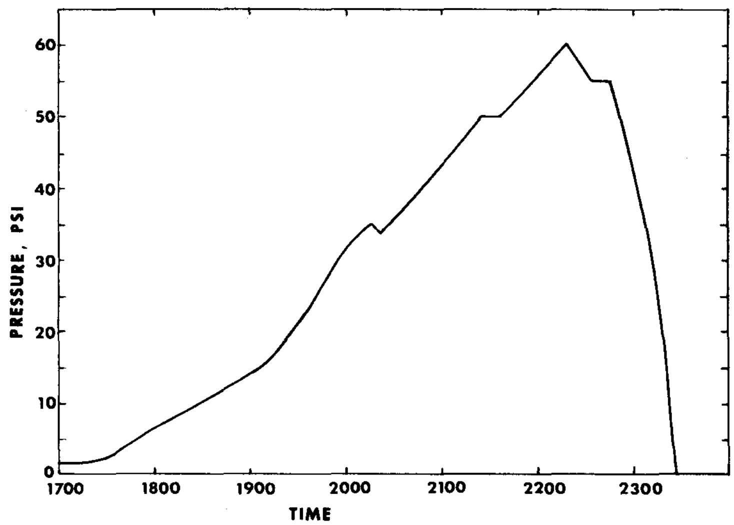


Figure 1. Pressure in Vacuum Tank as a Function of Time.

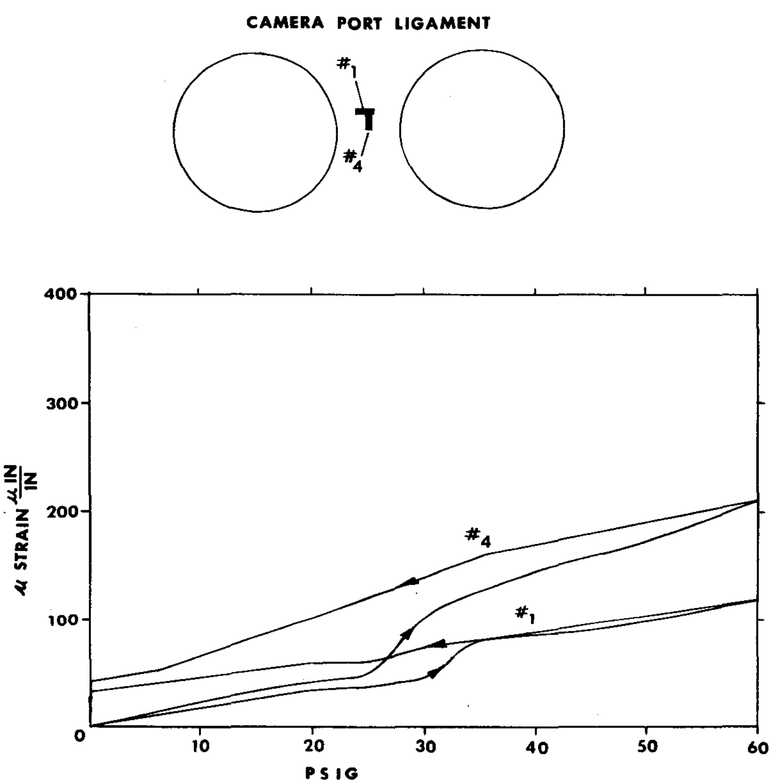


Figure 2. Strain Gauges on Optics Port Ligament.

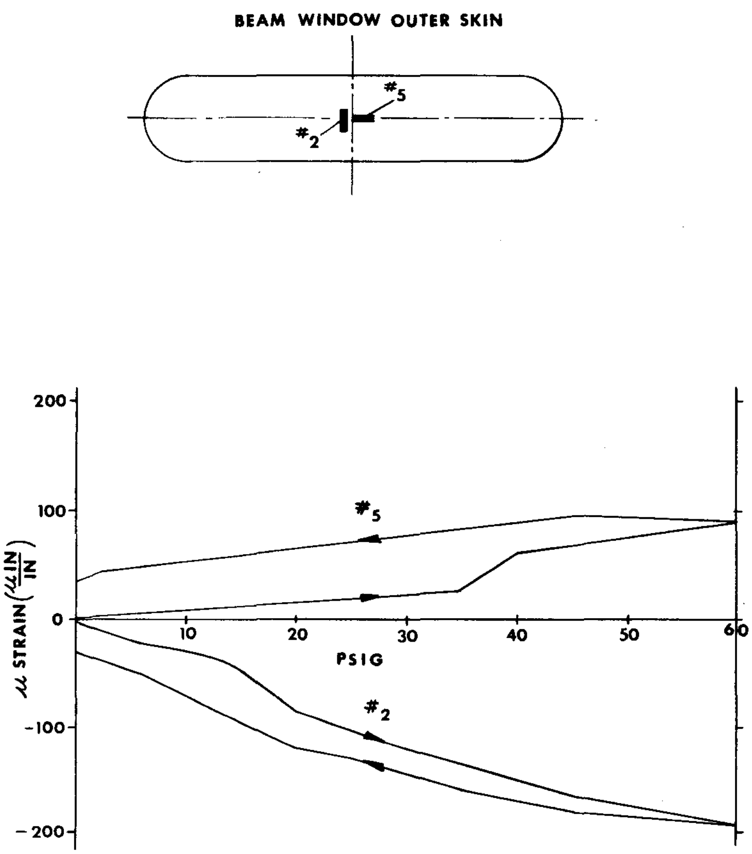


Figure 3. Strain Gauges on Optics Port Ligament.

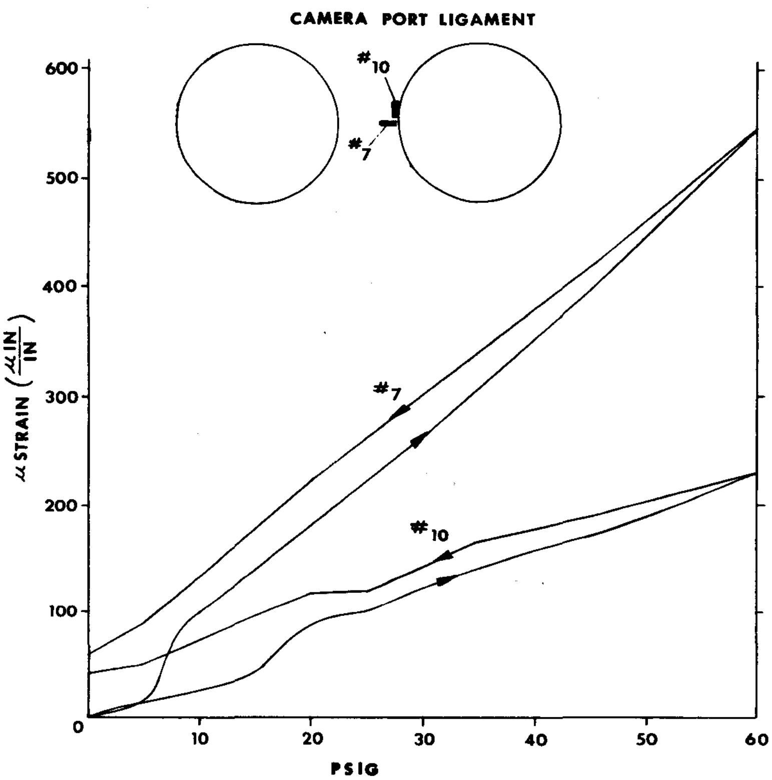


Figure 4. Strain Gauges on Optics Port Ligament.

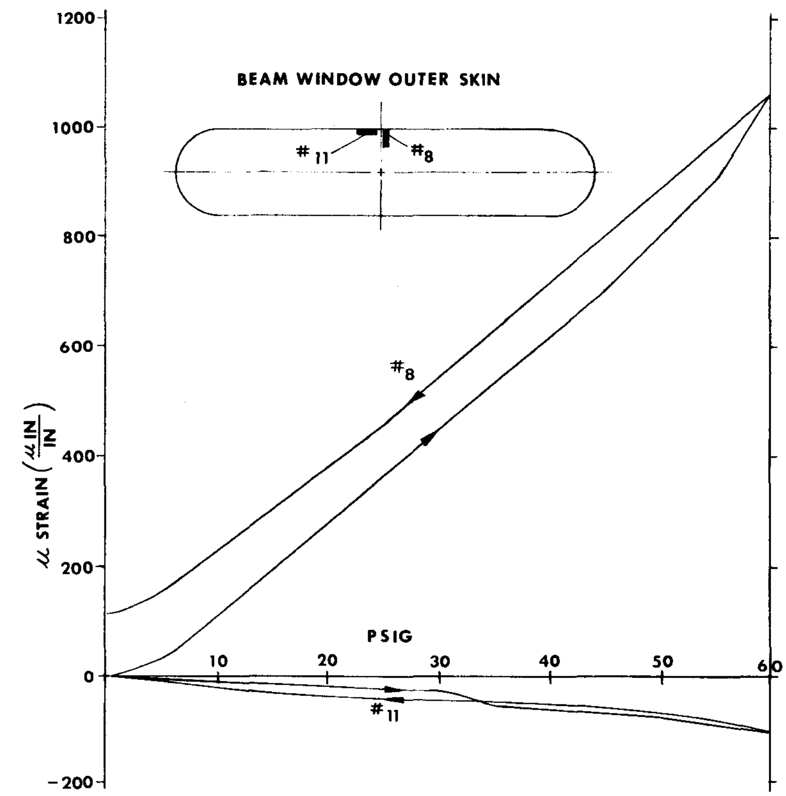


Figure 5. Strain Gauges on Optics Port Ligament.

TABLE I

	POSITION	STRAIN GAUGE	CALCULATED
# 1	Camera Port Ligament	3.0	
# 4	Camera Port Ligament	6.03	Limit <1.5 yield
# 7	Camera Port Ligament	16.5	<45,000 psi
#10	Camera Port Ligament	6.6	
# 2	Beam Window Center	+5.0	7.75
# 5	Beam Window Center	-2.7	-8.7
# 8	Beam Window Top	30.2	54
#11	Beam Window Top	-3.0	54

The stresses in the camera port ligament are limited to 1.5 times yield or 45,000 psia (see design report). Thus, the stresses are very much below the limit. The stresses in the beam window agree well for the following reasons: #5 is different from calculated since calculated assumes a perfect cylinder for the window; #8 and #11 are different from calculated since the strain gauges were not exactly at the joint of the 1/8 inch window and beam.

VII. A. 2. CHAMBER

The hydrostatic test of the bubble chamber vessel and cylinder will be done in accordance with the following letter:

October 8, 1971, from Milton Vagins, Battelle Institute, to Dr. William Fowler, National Accelerator Laboratory:

Dear Dr. Fowler:

This letter deals with the establishment of the magnitude of the hydrostatic test pressures for the bubble chamber.

Main Chamber

The main chamber of the bubble chamber is all of the vessel above the chamber "Z" section flange intersection. There are 3 pressure containing volumes in this region; the dimple-jacket cooling volume in the beanie; the lower cooling volume contained by the double walled cone; and the main volume containing the pressurizing fluid. The highest design pressures that these volumes will see will occur during the neon cycle operation. The various combinations of pressures in these volumes that could occur during normal operation are as follows.

(1) 150 psia in all volumes with vacuum on the outside of the vessel.

(2) 150 psia in the main chamber, atmospheric pressure in either or both the dimple jacket volume and/or the lower cooling volume with vacuum on the outside of the vessel.

(3) 150 psia in either or both the dimple jacket volume and the lower cooling volume, atmospheric pressure in the main chamber and vacuum outside of the vessel.

In order to properly hydrostatically test the main chamber the following procedure is recommended.

(1) Fill all volumes with water pressurized to 187.5 psig with the outside of the vessel at atmospheric pressure.

(2) Fill the main chamber with water pressurized to 187.5 psig with the dimple-jacket volume, the lower cooling volume and the outside of the vessel at atmospheric pressure.

(3) Fill the dimple jacket and lower cooling volumes with water or gaseous helium at 187.5 psig with the main chamber and the outside of the chamber at atmospheric pressure.

(Note: In all cases, the dimple jacket and lower cooling volumes may be pressurized with a gaseous inert medium such as helium).

"Z" Section

The "Z" Section or buffer volume lying below the piston will see a maximum of 200 psia while a vacuum exists outside this vessel. Thus to properly test this structure it should be filled with water at 250 psig with the outside of the vessel at atmospheric pressure.

In all cases the procedure described above should be carried out in accordance with the provisions of Article T-3, "Hydrostatic Tests", of the 1971 edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels, Division 2 - Alternative Rules.

If you have any questions regarding the procedure described, please call me.

Sincerely,

Signed: Milt Vagins

VII. A. 3. MAGNET VACUUM

Magnet Outer Shell

This vessel surrounding the magnet was tested only after final installation with all attachments included. Those are basically: The power penetration on top with superinsulation and the bellows' enclosure, the cooling penetration on top, likewise, the whole shield assembly inside, the three support legs, including the intercept lines, and the magnet pumping system up to the roughing pump.

On the outer skin of the vessel two openings are provided for pressure relief. The positive relief valve was left in place, while the negative relief was blanked off with a steel plate and a flat rubber gasket.

As a pressure test one might consider a fill of gaseous nitrogen up to 3 psig in an attempt to locate big leaks with soap solution. This test went well and showed several leaks.

The vacuum test was accomplished by using the magnet fore-pump only. The helium leak detector was mounted close to the fore-pump and showed excellent sensitivity.

After elimination of several leaks in the pumping system a through leak test of the whole magnet outer skin was performed with no indication of a leak.

A final vacuum of 75 microns Hg was reached after approximately 48 hours of pumping. This vacuum test will be repeated with the oil diffusion pump on after all the leaky spots found are permanently sealed by welding. During all tests, the rate of pressure change was carefully monitored going up and down in pressure to prevent damage to the superinsulation blankets.

VII. A. 4. MAGNET CRYOSTAT

Magnet Inner Shell

This vessel was assembled from basically three prefabricated parts; the bottom can, the top can, and the bridge center piece, welded all around the circumference with a total of four field-welds. At the top of the shell there are two short 1-foot diameter pipes and on the bottom,three little 1/2" diameter intercept lines. Those are all the openings.

For the pressure test all lines were closed. The top with steel plates and flat rubber gaskets held down by eight 1/2"-13 screws each, welded temporarily to the vessel. Gaseous nitrogen was used from gas bottles with a regulator and a 6" diameter test pressure gauge; 0 to 100 psig for read-out.

After several attempts to improve the flat rubber gasket seal until it stopped leaking a maximum pressure of 62 psig was reached and held for approximately 30 minutes. The test went well.

A vacuum test was performed shortly after with a relatively sensitive helium leak detector. The high moisture content in the phenolic used throughout the coil assembly prevented us from reaching vacuum better than 200 microns Hg. A big liquid nitrogen cold trap proved very helpful. After mounting a "plastic tent" over the whole vessel, helium was used from a whole gas bottle with no leak indications. The test was successful.

VII. A. 5. OPTICS

The first complete assembly of the three fisheye windows mounted on their Invar flanges was finished in June 1972. This assembly and its individual windows have been subjected to a number of tests which were intended to uncover any major problem before actual operation of the 15-foot bubble chamber.

(1) The assembly was cooled from room temperature (297°K) to liquid nitrogen temperature (77.37°K) in a test vessel in 44 hours with no major problems. During cooldown temperatures were monitored by 25 thermocouples, including 15 mounted on the glass or Invar, and recorded every 1/2 hour. Temperature differences on the large window (BK7 glass) were less than half the allowed local temperature difference given by Figure 10, Volume II in Section IV. I. As a result of this cooldown test, there will be no problems in cooling down the windows mounted in the 15-foot chamber in 48 hours provided the following restrictions are observed:

a. The rate of temperature drop of the #2 Invar flange (medium window mounting flange) as measured by the average of the two thermocouples mounted in holes in this flange, does not exceed the following values:

Temperature	Rate
300 - 280°K	4.0°K/hr
280 - 250	5.0
250 - 200	5.5
200 - 175	6.0
175 - 150	6.5
150 - 125	7.0
125 - 100	7.5
100 - 75	8.0
75 - 25	8.5

b. The vacuum space between the large and medium window is filled with one atm of dry N_2 gas before starting cooldown, and is pumped to high vacuum when the temperature of the lower of the two medium window flange thermocouples reaches 100°K. (He gas was used for the test but it proved to be exceedingly hard to pump out to a high vacuum and it would complicate any later mass spectrometer leak checking.)

c. The chamber wall temperature near the fisheyes does not differ by more than 30°K from the medium flange temperature.

As an aid to insure that condition a. is obyed an additional thermocouple should be put on the optics cooling loop inlet. Changes here lead changes at the medium flange by about an hour.

The windows could probably be cooled down in less than 48 hours, but before this is done additional cooldown tests would be required and additional thermocouples installed. The data taken during the cooldown test are on file at the bubble chamber.

Two minor problems concerning seals should be mentioned. The inflatable gasket (which seals between the hydrogen vessel and main vacuum space) was at 60 psig internal pressure when cooldown started. This pressure was raised to 300 psig in several steps as minor leaks developed; these leaks being observed as a rise in pressure in the pump-out space between the seals. The gasket sealed and remained sealed with 305 psig at liquid nitrogen temperature. For operation in the chamber, these seals should be pressurized to 300 psig before cooldown. Secondly, the seals on the retaining flange of the large window leaked below 210°K, this seal serves only as a back up for the glass-Invar epoxy joint of the large window and its leaking is not considered serious.

(2) The large window was pressure tested warm with 191 psig (average of two pressure gauges; one read 190, one 192) dry N_2 gas on the chamber side and high vacuum on the other. No leaks to high vacuum or damage observed.

(3) The medium window-Invar epoxy joint was tested for 24 hours with 15 psig gas on the concave side, atmosphere on the convex side. No leaks or movement observed. This pressure difference could occur if optics vacuum space #1 is pumped to high vacuum while optics vacuum space #2 is at atmospheric pressure.

(4) The small window-Invar epoxy joint was tested for a total of 128 hours with 22 psig gas on the concave side, atmosphere on the convex side. No leaks or movement observed. A pressure difference of 15 psi is the normal operating condition for this window.

(5) All epoxy joints, Invar welds, and seals are routinely leak-checked with a mass spectrometer as they are made.

It is expected that the tests (3) and (4) will be repeated for each set of windows, except they will be run for only a few minutes. Leak test (5) will be done for all assemblies.

VII. A. 6. PISTON

The piston will have a series of three tests.

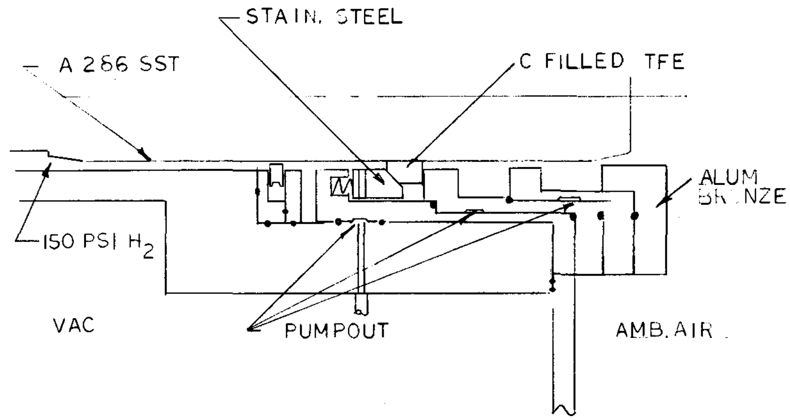
(1) Pressure test the complete piston in the cylinder to 250 psig. Care will be taken to not change the pressure faster than 25 psi per minute to avoid large pressure differences across the fiberglass covering the head of the piston (the time constant for pressure in the head is three minutes to change Δp by 1/2).

(2) Test the rod and head of the piston by putting 150 psig under the piston. To do this the piston must be sealed at the lip seal. The piston will be held in place by the piston clamp attached between the rod fitting and cylinder hub. During this test deflections of the piston head will be measured.

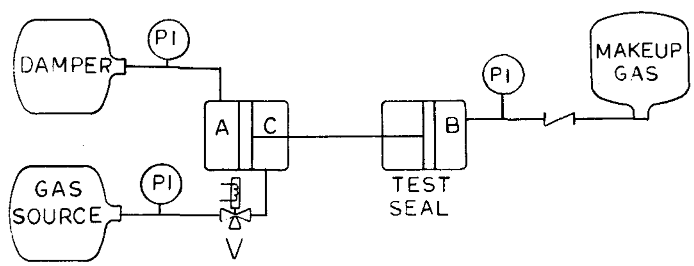
(3) Cool the piston down to liquid nitrogen temperature. This will be done with the piston in the cylinder and the lip seals in place. The most important measurement to be made is the clearance between the lip seal and the piston.

VII. A. 7. PISTON SEALS

As recommended by the Safety Committee and in accordance with our previous plans, the piston seal gland shown below which isolates the lower Z section chamber/fluid inventory from ambient was tested for leakage and performance.



The enclosed schematic represents the test setup as tested. The 3-way solenoid valve V was a high flow Ross valve actuated by limit switches on the shaft connecting the pneumatic cylinder to the seal test piston. Volume A is a stored energy source of a large volume to supply recompression of volume B when volume C is exhausted.



Pressures of the various volumes are as tabulated below:

Seal Test Piston	Vol. A	Vol. B	Vol. C
Fully compressed	105	90	0
Relieved	110	60	110

While these values are not those simulating the worst possible chamber conditions they were the maximum practically attainable values under the test conditions at the time.

The objective of the test was twofold; to ascertain leakage rates, if any, and to get some feel for the wear rate. As often happens in tests such as these some objectives are not attained conclusively, and other problems appear which were not anticipated. In the instance at hand, one of the most critical objectives, that of leakage rate, was not conclusively ascertained because it was so low as to be unmeasurable in a reasonable period of time. The wear rate was shown to be very low, (.015 max.ring reduction in 80,000 cycles).

The most critical aspect of any seal system associated with hydrogen is leakage. As mentioned before, the seal performed very well. Referring back to the schematic, volume B was a closed volume with an isolatable gas source. If leakage had been high, gas consumption would have been measurable. It was not. As it happened, the gas source was isolated from the system and no recordable pressure change occurred in volume B in a 36-hour period during the reciprocating portion of the test. Further, flow meters with a range of .2 to 2 SCFH were placed on the pumpout regions of the seal to measure leakage past the rings. Again no measurable leakage was detected which indicates a leakage of less than 4.8 standard cubic feet per day maximum.

The problem not foreseen until assembly began was friction produced heat buildup. While the phenomenon is not unknown it was not anticipated that the seal would experience this problem because the seal design is quite common to high speed reciprocating piston rod packings on compressors. Further, the seal manufacturer claims the problem is not common in those instances. The manufacturer anticipated an actuation force of approximately 300 pounds which gives a heat input due to friction of roughly 340 watts. The seals in comparable service on compressors normally run 200°F with a maximum of 285°F. Our seal system was running nearly 100°F higher than the normal maximum on the sealing surface so the seals themselves were running considerably hotter.

This problem is currently being investigated with possible solutions such as water cooling the seal region, reduction of seal spring loading, and possible redesign if necessary.

Summarizing, we are confident the seal is leak tight, that wear rate is reasonably low, and that the basic concept of the seal is good. The high operating temperatures are not high enough to cause a H_2 ignition and further, the seal is leak tight which is our primary safety consideration.

VII. A. 8. LIQUID H_2 PUMP

A test program is being conducted to determine the operating characteristics and reliability of the liquid H_2 pump.

The test loop consists of the following:

a) A 1,800 gallon liquid N_2 trailer equipped with an automatic pressure control will serve as the supply and return reservoir for the test loop.

b) A vacuum-jacketed pump cavity equipped with temperature, pressure and liquid level instrumentation in which the pump is submerged.

c) Transfer lines equipped with a flow measuring section.

d) The required power supply, instrumentation and safety devices required for operation of the pump test loop.

After the test loop is assembled and checked out, a test program will be conducted to determine the following:

1. Operating at the manufacturer's recommended speed for liquid N_2, the pump will be tested to determine capacity and head.
2. The pump will be operated continuously for a minimum of 100 hours to determine any operating problems.
3. Careful examination will be made of the pump and drive following the continuous operations to determine any signs of wear.

The above program will be carried out for both pumps prior to instrumentation in the bubble chamber system.

VII. A. 9. a. EXPANSION SYSTEM/PIPING PRESSURE TESTING

The oil piping components associated with the NAL 30,000 Liter Bubble Chamber (30KLBC) have been tested hydrostatically to 1.5 x maximum recommended pipe working pressure; i.e., 3000 psig. The tests have been accomplished on an individual and/or an assembled system basis. Major assemblies tested are as follows:

1. Oil Supply to 717'6" Level

The oil supply piping from the 730' Pump Room to the 717'6" Expansion Pit shut-off valves was tested as an assembly by the Contractor.

2. Oil System Panel

The 730' Pump Room Oil System Panel has been tested as an assembly by the Contractor.

3. Supply and Recompression

The supply and recompression piping and components in the 717'6" Expansion System Pit have been tested as an assembly by NAL personnel.

4. Oil Return

The oil return piping and components in the 717'6" Expansion System Pit from the actuator to the downstream pressure reducing valves have been checked on an individual component basis by the Contractor.

It should be noted that all oil piping components were isolated from the actuator "proper" for the above mentioned tests.

The gas piping components associated with the 30KLBC have not been tested beyond pressures encountered during the initial 250,000 pulse test. Prior to further operations, all connections will be checked and made following the procedure as employed by the SLAC Bubble Chamber Group, and then pneumatically checked to 1.25 x maximum anticipated operating pressure; i.e., 3000 psig.

It should be noted that the care taken initially to rigidly tie down the system piping has resulted in a stable system capable of withstanding pulses from accumulator failures, operator error, etc. Overall vibration observed during tests was minimal in nature and areas having noticeable vibration will be reworked prior to further operations.

VII. A. 9. b. PIPING PRESSURE TESTING

Cryogenic Piping Systems

The site fabricated and equipment supplied piping, and piping components of the cryogenic systems were fabricated to, and pneumatically pressure tested in accordance with the Petroleum Refinery Piping Code; ASA B31.2 - 1966 and Steel Pipe Flanges and Flanged Fittings, USAS B16.5 - 1968 to 125% of the system piping standard. The last letter of each line number is the system piping code letter for the applicable standard. The pressure requirements for the coded piping standards are as follows:

Piping Standard	Pressure
A, B, C, D, G and H	150 psig
J	275 psig
E and F	1300 psig

The line numbers label each line of the Engineering Flow Diagrams and are numerically ordered in the Line Summary. The complete piping standards are available in the Installation Specifications C, D, E, and G.

All pressure vessels purchased new for this installation have been fabricated and tested according to the ASME Pressure Vessel Code Section VIII Division 1 and bear the manufacturer's code stamp.

VII. A. 10. HIGH PRESSURE GAS STORAGE

On May 30, 1972, 0845 to 2000 hours, a high pressure pneumatic test of the proposed neon storage was conducted.

Persons present during the test were as follows:

M. W. Morgan	NAL/BC	Full time
C. E. Barnes	NAL/BC	Full time
W. B. Fowler	NAL/BC	2000 psi to completion
R. Brown	NAL/Safety	Most of the day
H. Allen	NAL/Safety	2700 psi to completion
W. L. Kefauver	Nitrogen Service Co.	Full time
L. McVey	Nitrogen Service Co.	Full time

In addition to the above, several NAL Site Patrol people were stationed at various locations to assist in traffic control.

Prior to the date of the test the manifold tubing and pipe to the tube banks had been tested to 3200 psig and all leaks repaired in preparation for the test.

Prior to testing, certain conditions of the performance during the test were agreed upon. The restrictions were observed and are listed below:

1. "K" Road was closed to traffic and guard posted.
2. TV monitor of pressure was installed and observed remotely.
3. At 2000 psi W. B. Fowler was notified.
4. At 2000 psi Lab B and the corridor were evacuated.
5. At 2400 psi no further access to the immediate storage area was allowed until 3000 psi was reached and held 15 minutes.
6. No attempt to tighten bolts or repair leaks would be made above 2400 psi.

In all, the test went fairly well. We found and carefully repaired many leaks where no breach of safety was involved. All tubes remained intact and all main flanges were found to be leak tight.

At 1850 hours, 2975 psi was reached and due to a lagging tube tank, the pumping rate was reduced and a slow rate was used until 3000 psi registered on the monitored gauge. At this point the pump was disconnected and the banks were allowed to stand for roughly 15 minutes.

It was evident that at 3000 psi there were many leaks. Most leaks were in the rupture disc retainer flange region, at the pig-tail connections and at valve retainer flanges. The vast majority of leaks were in the rupture disc region of the cars, valve and manifold ends were unusually good.

After 15 minutes at 3000 psig access to the area was resumed. A walk through leak test of manifold ends (at a respectable distance) was made and then a gauge bleed valve was opened on each car to allow them to bleed to 2650 psig.

At approximately 1920 hours while at 2900 psig an incident occurred. A burst disc retainer (one which was known to have been leaking) stripped its threads and vented the entire volume of one tube on Car MHAX 1013. No one was in the immediate area at the time and consequently no injuries were suffered. (See attached analysis of this failure and recommendation.) The subject tube was isolated and allowed to vent completely. At this point all access to this end of the cars was terminated until 2650 psi was reached.

At 2650 psig access to the rupture disc end of the cars was carefully resumed and audile and sensible leaks were marked with spray paint. No attempt to stop leaks was made.

At 2030 hours, cleanup was complete. All tubes were isolated from the manifold and the crew departed.

As stated before, the test went very well and the suggestions of the safety people were very helpful and appreciated. An analysis of the problem of the rupture disc retainer (which was later found 140 yards into the field east of the cars) is attached as well as suggested solution and procedure to insure no reoccurrence.

APPENDIX 1

RUPTURE DISC RETAINER FAILURE ANALYSIS

During a pneumatic test of five rail cars purchased from the Bureau of Mines, we experienced a failure of the Helium Manifold Safety Device (Figure 1.).

The failure was in the rupture disc retainer plug and involved stripping of the threads on this plug and ejection of both the plug and the blank off disc 140 yards into a nearby field. This analysis is intended to explain, as well as possible, the mechanics of the failure and propose both an inspection procedure and replacement criteria to insure that the final gas storage facility is both safe and reliable.

Background

The five cars were purchased from the Bureau of Mines in May, 1971 to be used for storage of processed neon and neon mixtures for the 30 KLBC system. They have been the subject of much debate regarding the safety aspects of their use. The discussions regarding the cars resulted in a set of criteria regarding the use, pressure rating and testing of the cars which all involved agreed would give the laboratory a safe storage facility. The points are as follows:

1. All cars were to be tested to 3000 psig (pneumatically).
2. Ratings of safety relief devices on the tube were not to exceed 3000 psig (set at 2850 psig).
3. The tubes were to be operated at 2160 psig.
4. Feed gas system safety devices were set at 2160 psig to further prevent overpressurization.
5. Each car was to have representative tubes ultrasonically tested for wall thickness.
6. Each tube was to be visually inspected internally and externally for excessive scale on the vessel surfaces.

In addition to the above, the bubble chamber group carried out the

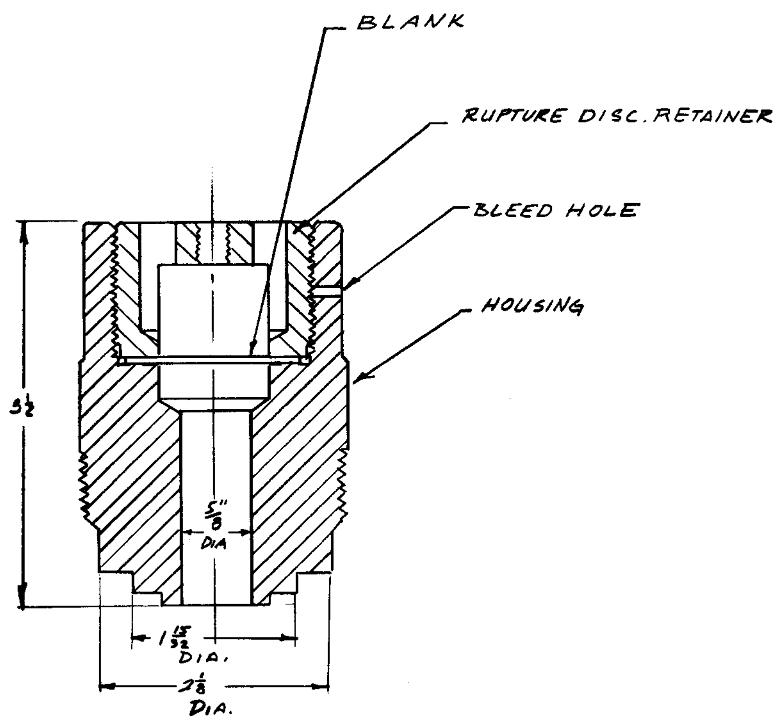


FIGURE 1. HELIUM MANIFOLD SAFETY DEVICE

the following modifications:

1. Complete disassembly of main end flanges and components. (Figure 2.)
2. Installation of new cylinder valves.
3. Removal by vacuum cleaner of loose scale inside tubes.
4. Installation of lead gaskets over copper gaskets to insure leak tight joints.
5. Modification of manifolding to eliminate excess valving.
6. Installation of stainless steel piping to and from car manifolds.

Analysis

Inspection of the plug which failed showed the threads had been stripped axially and probably not by overtightening. The thread region (Figure 3.) also shows evidence that the male thread was badly worn and/or undersized. Plug material is brass as is the safety disc housing.

The rupture disc retainer plug thread is a 1-3/4 - 18 NS-2. According to published data the dimensional information in Table I shows the tolerances for the threads.

TABLE I

1-3/4-18 NS-2				
TYPE	Pitch Dia. Max/Min	Major Dia. Max/Min	Minor Dia. Max/Min	Thread Engagement Max/Min
MALE	1.7139 / 1.7067	1.7485 / 1.7398	NA	.0585
FEMALE	1.7205 / 1.7139	NA	1.703 / 1.690	.0368

This shows a minimum thread engagement of .0368". On the plug and housing that failed, (worst case,after the failure) the diameters were as follows:

Major Diameter	Minor Diameter
1.6968	1.694

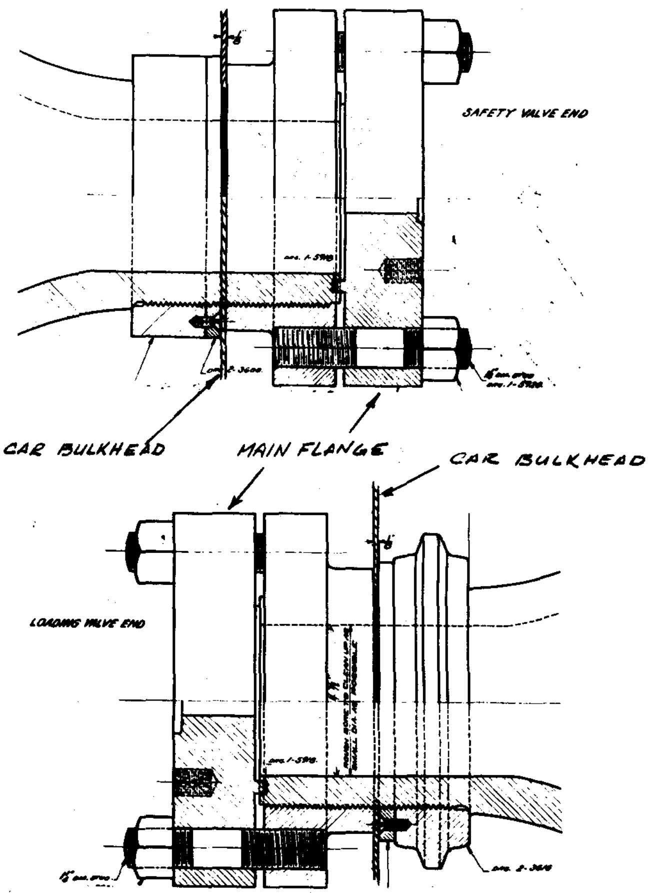


FIGURE 2. HIGH PRESSURE TUBE ENDS

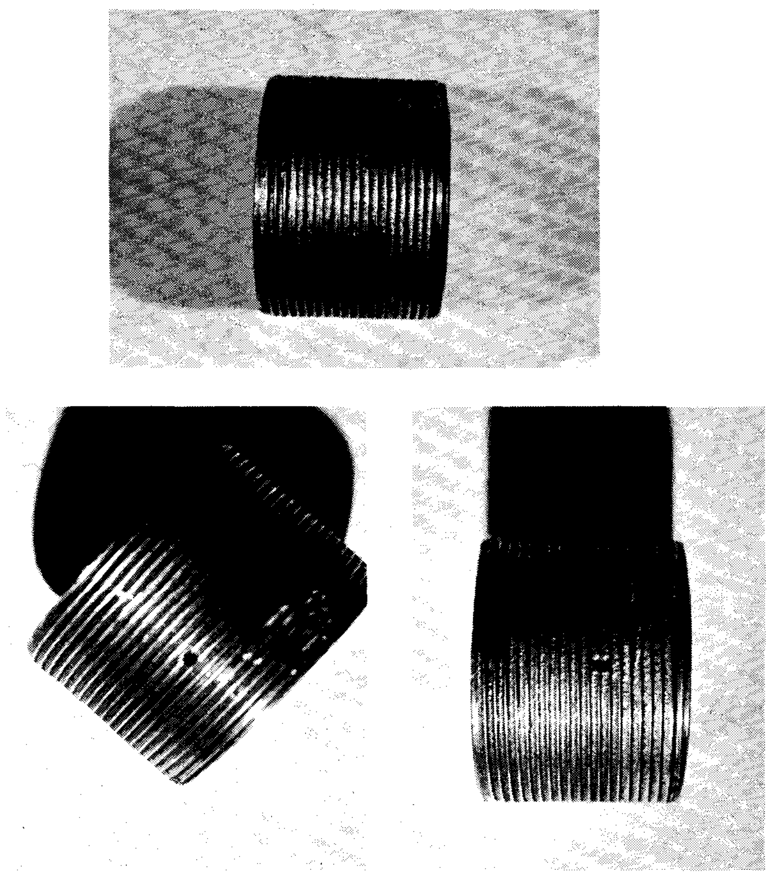


FIGURE 3. MAGNET THREAD

which gave .0028" thread engagement or roughly 5% of that required. Again, it should be noted that this is after the failure and hence that it cannot be accurately said that there was only .0028 prior to failure. However, it is quite evident that there was inadequate thread engagement.

In the safety disc housing, there exist bleed holes at the midpoint of the thread region. The unit which failed (as well as some others) exhibited excessive leakage through this bleed hole prior to failure (Path 1 - Figure 4.) while others leaked around the blank and out the vent ports (Path 2 - Figure 4.). Apparently the bleed hole is in the housing to warn of loose and badly worn threads because Path 1 should be much more restrictive than Path 2 if the threads are close fitting.

The purpose and existence of this bleed hole was unknown to the people at the Bureau of Mines. I spoke to Mr. Summer who is very familiar with the cars, and he stated the holes do not appear on the current drawings. It should be remembered that these cars are 1932 vintage and consequently much has been lost over the years. On the cars we have, it is easy to see why the existence is unknown. Only close inspection or excessive leakage reveals they exist at all due to the 30 or so coats of paint which cover them.

What perturbation actually caused the retainer to go will never be known but it is clear that the following steps should be taken to prevent a recurrence:

1. Inspection of all make threads both visually and with a GO-NO-GO gauge specifically designed for the purpose.
2. Inspection of all female threads both visually and with a GO-NO-GO gauge specifically designed for the purpose.
3. Replacement of any component not conforming to the above gauging.
4. Particular attention will be shown to the devices which exhibit leakage through the bleed hole.

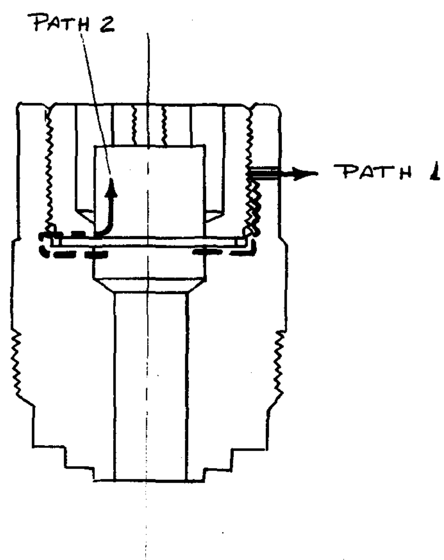


FIGURE 4. HELIUM MANIFOLD SAFETY DEVICE

ADDENDUM

Pneumatic Test of High Pressure Tube Banks at NAL Bubble Chamber Site

Inspection of the rupture disc fittings as proposed in the failure analysis was performed. The male threads were checked with a pitch micrometer and all tested units to date (30 total) were found to be in tolerance. Thirty percent of the female threads, on the other hand, were found to be oversized when checked with a GO-NO-GO gauge.

When this fact was discovered, the decision was made to replace all such fittings with comparable units using stainless steel female fittings with redesigned brass rupture disc retainers.

The replacement of these parts is currently underway and upon preliminary leak testing, neon will be pumped into these completed banks.

VII. A. 11. LOW PRESSURE GAS STORAGE

During a period of two weeks in July 1972, five low pressure storage tanks were hydrostatically tested. These tests were performed and witnessed by Carl Pallaver, Hans Kautzky, Steve Johnston, and Mike Diveley. To record pressure three 0 to 400 psi gauges were used.

To record strain, Steve Johnston and Hans Kautzky positioned and recorded strain changes. The procedure used was to place all five tanks on the ground. Each tank was filled with water. Then each tank separately was hydrostatically pressurized to 375 psi. Readings were taken at 25 psi intervals.

Two attachments.

Maximum Strain Gauge Readings 6/19 to 7/13

Tank #27297-1

	#1	#4	#7	#10
Lowest	0	-10	-15	-20
High	-30	+270	+442	+530
*Psi	900	8,400	13,710	16,500

Tank #27297-2

	#1	#4	#7	#10
Low	-10	0	0	0
High	-61	160	128	228
*Psi	1,530	4,800	3,840	6,840

Tank #27297-3

	#1	#4	#7	#10
Low	40	15	90	105
High	230	100	580	660
*Psi	5,700	2,550	14,700	16,650

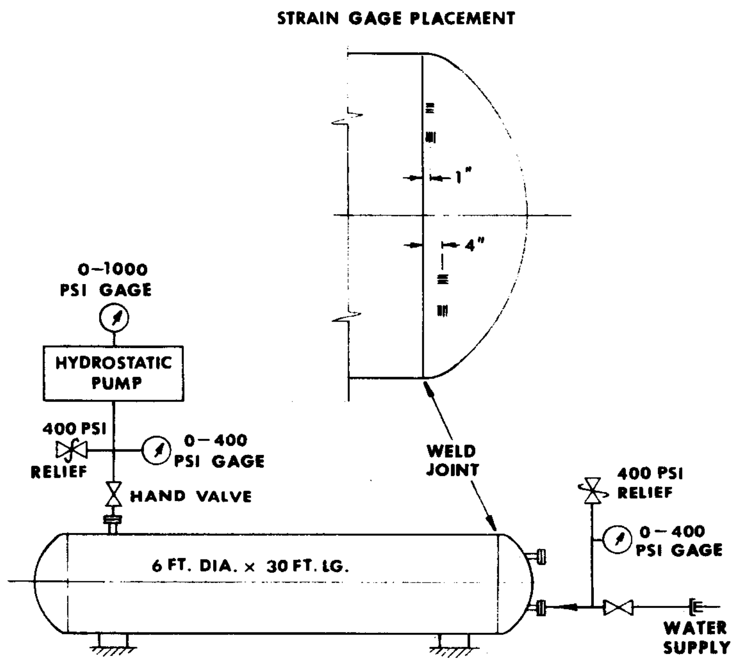
Tank #27297-4

	#1	#4	#7	
Low	0	20	28	
High	15	312	455	
*Psi	450	8,700	12,810	

Tank #27297-5

	#1	#4	#7	#10
Low	62	4	256	32
High	21	-201	-30	-158
*Psi	1,230	6,150	8,850	5,700

* $\sigma = \frac{\Delta L}{\ell} \times E$


STRAIN GAGE PLACEMENT
1"
4"
0-1000
PSI GAGE
HYDROSTATIC
PUMP
400 PSI
RELIEF
0-400
PSI GAGE
HAND VALVE
WELD
JOINT
400 PSI
RELIEF
0-400
PSI GAGE
6 FT. DIA. × 30 FT. LG.
WATER
SUPPLY

VII. A. 12. EXPANSION SYSTEM

After the assembly of the system components and the performance of all necessary hydrostatic testing and flushing, the system was prepared for initial operational testing.

The purposes of the test were to determine the adequacy of the design relative to that required for chamber operation, the overall system operating characteristics, and the reliability of the various components. As per the system design parameters, operation of the system was possible without the attachment of a chamber load.

The initial testing was carried out for approximately 15,000 total pulses and was terminated due to excessive leakage through the main expansion valve when closed which in turn, prevented proper resetting of the actuator. The test indicated, that, as a whole, the system was sound. An efficiency of 50% employing N_2 as the drive gas was measured.

After the initial test, the actuator was dismantled and examined. The leakage through the expansion valve was found to be due to a mechanical interference between the spool and its cage which caused both members to progressively deform during pulsing. The interference was corrected, the components were repaired, and the valve was reassembled. The low efficiency was felt to be due to a combination of the long connection between the drive gas bottles and the drive piston, the various connections in these lines, and the losses; i.e., heating of the N_2 gas during pulsing. As a result of this thinking, the bottles were repositioned, lines were shortened, connections were streamlined, and preparations were made to allow for pulsing with He^4 rather than N_2.

A subsequent test was conducted after the abovementioned modifications. Turn-on went smoothly, and pulsing was established with an overall stroke of 4.0 inches (nominal for operation) with a repetition rate of 80 pulses per minute. Under these conditions an efficiency of 83% was measured. All systems functioned well during the run with some minor difficulties encountered in Ross valve operation, accumulator bag damage, etc. These difficulties, under the test circumstances, proved to be a valuable training means for system troubleshooting and operation. The test was concluded after an excess of 250,000 pulses, and the system was shutdown for inspection.

Inspection of the major components indicated that no major damage was encountered during the run. Two of the system bumpers were found to be degraded, a condition determined to be due to insufficient edge restraint. This condition has been removed, and the components re-assembled. Some cavitation and scoring of the bouncers was detected, and corrective measures were taken in these areas.

The initial tests were considered to be successful, and a high level of confidence was obtained in the system's capabilities. It was determined, that, under the test conditions, the system can be run with one high pressure oil pump, one recompression oil circuit, and one Ross air circuit. The redundancy afforded by these conditions will enhance the reliability and manageability of the system during actual operation.

VII. A. 13. HELIUM REFRIGERATOR

The helium refrigerator test consists of three parts; qualify the liquefier as satisfying the performance specification (100ℓ/hr), liquefy into a test pot situated at the magnet end of the helium dewar to magnet dewar transfer lines to study the liquefier performance under various loading conditions while duplicating the magnet warm gas returns, and a liquid helium boiloff test on the helium (Z) dewar.

After an initial run in which the 10,000ℓ dewar was cooled from nitrogen temperature to operating temperature and liquid helium puddled in the bottom, two performance runs were made. The first resulted in a 80ℓ/hr rate by the accepted definition* and was limited by the source gas on hand to a total of ≈1000ℓ liquefied. The test ending June 23, 1972, had the performance at 90ℓ/hr and was terminated at ≈5000ℓ liquefied when all attempts to increase the rate failed. A third test aimed at resolving conflicting compressor flow measurements and engine flow calculations is imminent at this printing.

As the current difficulties are resolved, the test objective will switch to the test pot simulation of the magnet load. At the completion of this test the helium refrigerator is ready to cool the magnet.

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* 100ℓ/hr into a dewar with constant level; i.e., no displaced cold gas.

VII. A. 14. HYDROGEN REFRIGERATOR

The hydrogen test consists of four parts; make the area hydrogen safe, refrigeration with atmospheric liquid nitrogen precooling (4.4kW), refrigeration with subcooled (pumped) liquid nitrogen precooling (6.6kW), and a liquid hydrogen ("A") dewar boiloff test (0.75%/day).

The refrigerator test defined refrigeration as equivalent to the heat applied at liquid temperatures, by means of an electrically heated liquid transfer line between the cold box and the "A" dewar, that would not raise the dewar pressure. The "A" boiloff test consisted of warming to ambient temperatures and measuring the tank boiloff at constant dewar pressure.

The first A tank fill and the initial refrigerator test served to exercise the system functions, but reached only 2.8kW with atmospheric liquid nitrogen precooling before a long list of minor modifications and a leaky compressor bypass valve required shutdown.

The second test reached 3.3kW with atmospheric liquid nitrogen precooling, and revealed capacity problems with the liquid nitrogen vacuum pump before third stage rings required that the compressor be shutdown.

The compressor was reworked by the manufacturer, and provisional improvements made to the liquid nitrogen vacuum pump before the third test. This test reached a capacity of 4.1kW (atmospheric liquid nitrogen) before third stage rings forced a shutdown. Subsequent investigation revealed fundamental second and third stage alignment problems that are currently being corrected in a major machine overhaul by the manufacturer.

A boiloff test on the "A" dewar between the second and third tests measured 0.9%/day @ 30 psia and 1/3 full. This is in reasonable agreement with 0.75% at 15 psia and full, the specified conditions.

A fourth test aimed at demonstrating 6.6kW refrigeration, for a week, will follow as soon as compressor overhaul is complete (estimated to be one week at the time of this printing). The liquid nitrogen vacuum pump has been modified under warranty and independently tested to specified capacity.

VII. MISCELLANEOUS

B. Operation

Prepared by

National Accelerator Laboratory

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VII. MISCELLANEOUS

B. Operation

VII. B. 1. ORGANIZATION OF CREWS

The organization of the operating crews is recognized as amongst the most important cooldown preparation made. The depth of crew has, member by member, been optimized by extensive personnel searches in this and the other national laboratories, in associated industry, and in the general technical labor market at the time of employment. The crew balance has been achieved by distributing the experts, born of the extensive pre-cooldown testing and assembly programs, amongst the different crews. A bi-level training program (see Training Program) is aimed at further balancing the lead and general crew members laterally.

The logical organization is intended to be five shifts allowing an 8-5 maintenance shift to pick up the long term maintenance, on-going modification and improvement programs, and emergency breakdown services. This organization allows the operating crew, particularly the 8-4 crew, to concentrate on chamber operation, significantly improving picture rates. In recognition of the fact that the crew will be cooling down and operating this chamber for the first time, with the consequent level of unanticipated problems, the crews have been initially organized in a 4-shift rotation to increase around the clock depth and problem solving strength.

VII. B. 2. TRAINING PROGRAMS

A bi-level training program has been run concurrently, aimed at two objectives; (1) assure that all members of the operating crew are properly exposed to the various subsystem approaches, installed equipment and functions, and (2) that the expected lead members, those with the greatest experience, judgment and aptitude, attend courses sufficiently detailed to allow the discussion of the function of "every valve in the system".

The first was entitled the "15' Chamber Lecture Series", invited all members of the bubble chambers (15' and 30"),was held once each week for nominally one hour, and was liberally supported by the appropriate graphs, simplified schematics, graphic panel drawings and typewritten material distributions. The lecture series content follows:

Lecture I	May 12, 1972	"Hydrogen Bubble as a High Energy Physics Research Tool" by W. B. Fowler
Lecture II	May 22, 1972	"Cryogenics - A Review of the Important Properties" by G. T. Mulholland
Lecture III	May 30, 1972	"Hydrogen Refrigerator System" by G. T. Mulholland
Lecture IV	June 5, 1972	"Magnets" by J. Purcell
Lecture V	June 15, 1972	"Helium Refrigerator System" by P. C. Vander Arend
Lecture VI	June 22, 1972	"Expansion System" by R. C. Niemann
Lecture VII	June 28, 1972	"Vacuum System - Magnet, Main and Window Systems" by M. W. Morgan, G. T. Mulholland and W. M. Smart
Lecture VIII	July 7, 1972	"Chamber Cooldown" by P. C. Vander Arend
Lecture IX	July 13, 1972	"Cameras/Optics" by W. M. Smart, H. Kautzky and F. R. Huson
Lecture X	July 17, 1972 (scheduled)	"Physics that Comes Out" by F. R. Huson

The second, entitled "Operating Lectures", was limited to smaller groups (typically ten) of the 15-foot's best prepared crew members. The number was limited to enhance participation and allow a constructively critical atmosphere to prevail. The course material was the first draft of operating instructions for the various aspects of the chamber. The object was to teach a course in which the text book, the first draft, was further refined using the feedback from the students to accomplish, in effect, a ten-man review. The instructions incorporating these comments is then called the "final form".

The following is a list of operating instructions,now in "final form", that resulted from the courses given:

		Number of Attendees	Hours
CHAMBER COOLDOWN	P. C. Vander Arend	13	10(Est.)
EXPANSION SYSTEM	R. C. Niemann, G. T. Mulholland and F. R. Huson	15	16
HELIUM REFRIGERATOR SYSTEM	P. C. Vander Arend	11	10
HYDROGEN COOLING LOOPS	P. C. Vander Arend	10	8
HYDROGEN REFRIGERATOR TEST	P. C. Vander Arend	9	14

VII. B. 3. PROCEDURES ASSOCIATED WITH THE MAGNETIC FIELD

FORCE ON FREE STEEL OBJECTS NEAR THE NAL 15-FOOT BUBBLE CHAMBER MAGNET

Wesley M. Smart February 7, 1972

This note is designed to give the maximum possible magnetic force on steel objects near the magnet; more exact calculations for specific steel objects will be given in a later note.

1. Assumptions. The force ($\vec{F}$) on a magnetic dipole in a magnetic field is given by

$$\vec{F} = (\vec{M}.\nabla)\ \vec{B}$$

where $\vec{M}$ is the magnetic moment induced in the steel object by the magnetic field ($\vec{B}$). The magnetic field and its derivities can be calculated rather easily from the coil location and current, but the induced magnetic moment is a complicated function of the field, object shape, and object orientation. However steel saturates and this puts an upper limit on the magnetic moment per unit volume for any shaped object. In addition, the torque on the object will tend to align $\vec{M}$ and $\vec{B}$. Therefore, in this note I have assumed that $\vec{M}||\vec{B}$ and that the object is saturated such that $|\vec{M}| = \frac{KV}{4\pi}$ where K - 20,000 gauss and V is the volume of the object (in cm^3). The density of steel is assumed to be 0.2854 lb/in^3.

2. Forces on Steel Objects. Figure 1 gives curves of constant ratio of magnetic force to weight for saturated steel objects as a function of radial distance from the magnet center (in feet) on the horizontal axis and vertical distance on the vertical axis. The major features of Building B are also shown in the figure. It is important to remember, however, that the horizontal axis is radial distance from the magnet center, so that the building features shown in figure 1 are correct only for the vertical plane through the magnet center and parallel to the north and south walls.

3. Shape Required for Saturation. Let A be the ratio of magnet force to weight at a given position obtained from figure 1, and let R be the ratio of length to diameter of a solid steel rod. As a rough estimate, the rod will be saturated if:

$$R \geq R_S \qquad \text{where } R_S = \frac{10}{A}$$

Thus, $R_S = 2$ if A = 5 and $R_S = 100$ if A = 0.1. If $R<R_S$ then the magnetic force to weight ratio will be reduced to roughly $\frac{AR}{R_S}$.

Caution: It must be remembered that the above formulas in this section give only rough estimates; if a more accurate calculation is required, I have a computer program to do it.

4. Impact Velocities on Vacuum Tank. Under the assumptions of Section 1, it can be shown that $\vec{F} = \nabla(\vec{M}.\vec{B})$. If we redefine F to include the force due to gravity then $\vec{F} = \nabla(\vec{M}.\vec{B} - mgz)$. Thus, we can define a potential energy U: $U = mgz - \vec{M}.\vec{B}$, such that $F = -\nabla U$. When a steel object moves from point 1 to point 2 under this force, conservation of energy requires that

$$T_1 + U_1 + T_2 + U_2$$

where $T = 1/2\ mv^2$. If the object starts at rest at point 1, its velocity at point 2 will be given by

$$\begin{aligned} 1/2\ mV_2{}^2 &= U_1 - U_2 \\ &= mg\ (z_1 - z_2) - |\vec{M}|\ (|\vec{B}_1| - |\vec{B}_2|) \\ &= mg\ \Delta z - |\vec{M}|\Delta B \end{aligned}$$

Converting units and using the density of steel as 0.2854 lb/in.^{3} gives:

$$\frac{1}{2} V^2 = g\ \Delta z - (0.2169)\Delta B$$

where V is in ft/sec; g in ft/sec^2 ($g = 32$ ft/sec^2); Δz ($= z_1 - z_2$) is in ft; and ΔB ($=|\vec{B}_1|-|\vec{B}_2|$) is in gauss. Table I gives some examples. Impact velocity on the vacuum tank for any steel object starting from rest inside the building is limited to be 90 ft/sec (62 mph) or less, on the beam window is limited to 65 ft/sec (44 mph), but on the vacuum tank window in optics well #2 or 3 it could be 108 ft/sec (74 mph).

While the final velocity is easy to calculate, the trajectory requires more effort. Figure 2 shows some approximate trajectories obtained by hand calculation.

5. Recommended Safety Precautions. Before turning the magnet on:

5.1 Position crane within 20 feet of west end of building and lock breaker in off position.

5.2 Lower elevator to 717'6" level and lock breaker in off position.

5.3 Search roof and walls of building B to within 20 feet of west wall for any loose ferromagnetic or other objects and remove them. This search should include the entire pit area, the platforms at 730' and 742'6", and the tops of all equipment in building B.

5.4 Close doors to pump room.

5.5 Rope off an area at least 30' from the magnet center outside the building.

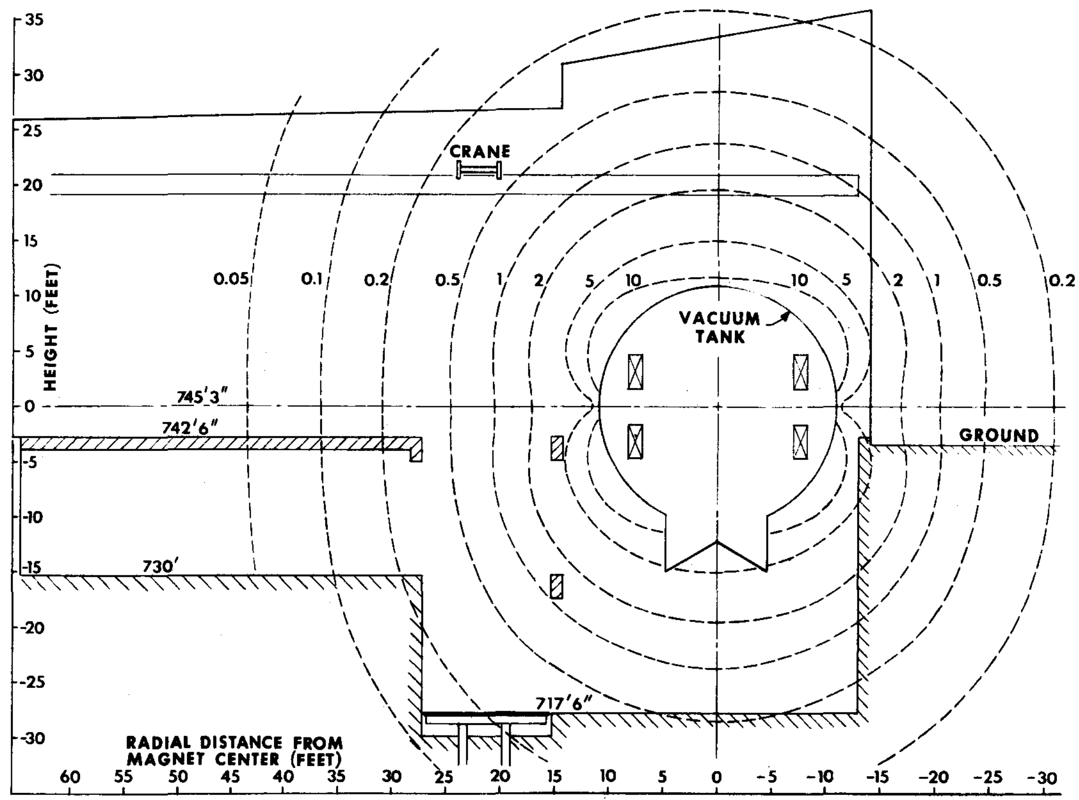
5.6 Cover over any open optics wells and leave them covered until the magnet is on full field.

5.7 Prohibit anyone with any ferromagnetic objects, especially tools, nails, gas bottles, etc., from crossing to within 30' of the magnet center.

It is further recommended that the first time the magnet is turned on that there be no more liquid hydrogen in the bubble chamber than is absolutely necessary for magnet cooling.

TABLE I

z_1 ft	r_1 ft	B_1 Gauss	z_2 ft	r_2 ft	B_2 Gauss	V_2 ft/sec	V_2 MPH	COMMENTS
36	0	362	11	0	8962	73.01	49.8	Roof straight down
-23.3	0	1305	-12	0	7302	43.36	29.6	"Fall" up from pit
36	-	≡0	-6	9.2	12806	90.79	61.9	Worst case to vacuum tank
36	-	≡0	7.2	.3	17477	97.07	66.2	Into optics well #1
36	-	≡0	5.9	3.9	22642	108.38	73.9	Into optics well #2 or 3
36	-	≡0	0	11.0	4292	64.54	44.0	Roof to beam window
0	-	≡0	0	11.0	4292	43.14	29.4	Flat to beam window
36		0	11	0	0	40.0	27.3	Roof straight down/ magnet off



HEIGHT (FEET)
RADIAL DISTANCE FROM MAGNET CENTER (FEET)
CRANE
VACUUM TANK
GROUND
745'3"
742'6"
730'
717'6"
0.05
0.1
0.2
0.5
1
2
5
10
10
5
2
1
0.5
0.2
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30

Figure 1.

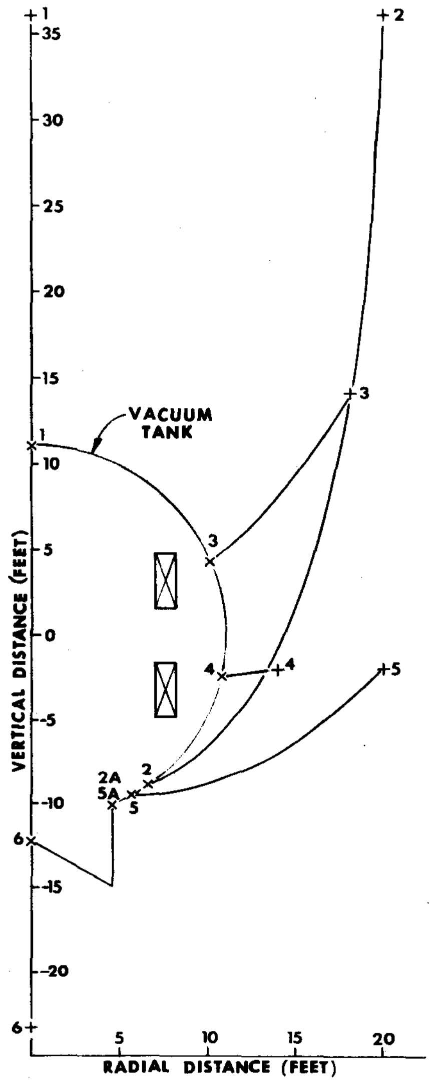


Figure 2.

Position #	Impact ft/sec	Velocity mph
1	73.0	49.8
2	90.5	61.7
2A	83.7	57.1
3	66.4	45.3
4	37.7	25.7
5	66.2	45.2
5A	64.8	44.2
6	43.4	29.6

May 26, 1972

TO: DICK PAGES, DUSAF

FROM: WESLEY M. SMART, NEUTRINO LAB

SUBJECT: MAGNETIC FORCES ON STEEL COMPONENTS OF BUILDING "B"

This is to formalize the earlier conversations between you and Russ Huson and myself concerning the above subject. For our safety records, we will need a memorandum from you confirming that the components below will be able to withstand the calculated magnetic forces. (For reference I have considered the accelerator beam to be traveling North.)

1. Vertical I-beams at building corners around chamber. The horizontal force inward toward the chamber center at the bottom of the NW and SE I-beams is 1000 lb, NE 1190 lb, and SW 850 lb. There are additional forces on these I-beams from the steel wall channels bolted to them. The total force toward the South at the NW and toward the North at the SW I-beam are not supported by wall channels and are about 1365 lb and 1140 lb respectively.

2. Wall channels on the North, East and South walls.

Wall Channel	Horizontal Force Inward Toward Chamber Center (lbs)	Vertical Force (lbs)	Torque (ft lbs)
Lowest North	834	360 (up)	1830 outer
Lowest East	854	235 (up)	1490 end
Lowest South	623	304 (up)	1722 down
Second North	535	-236 (down)	79 outer
Second East	478	-248 (down)	38 end
Second South	451	-161 (down)	167 down
Third North	167	-213 (down)	590 outer
Third East	150	-203 (down)	602 end
Third South	158	-176 (down)	471 up

Here the torque on the lowest wall channels is probably the most serious problem.

3. Diagonal braces on North wall. The force inward on the brace which runs from the lower NW to the upper NE is 290 lb; from the lower NE to the upper NW is 320 lb. This force is a maximum at about 10 feet along the brace from the bottom and there it is about 18 lb per foot.

4. Steel pipes for sprinklers and hot water. The horizontal force inward toward the chamber center averages 2 to 3 times the weight for these pipes. At 5 feet from the 22-foot spherical vacuum tank, it can be as high as 5 times the weight; but never exceeds 10 times the weight unless the pipes are more than 1 foot inside the concrete wall of Building "B".

I estimate the specific numbers given above to be corrected to within ±20%, but the 5 and 10 times figures quoted are "worst case" upper limits. If you require more specific information in any case, I will be happy to try to provide it.

June 14, 1972

TO: WESLEY M. SMART, NEUTRINO LAB.

FROM: R. E. PAGES, DUSAF

REF: MAGNETIC FORCES ON STEEL COMPONENTS OF BUILDING "B"

We have reviewed the design of the members influenced by magnetic forces in Building "B" (as outlined in your Memo of May 26, 1972) with the following results:

1) The Vertical I-Beams at Building Corners Around Chamber.

These columns are designed for the load of the traveling crane which will not be present when the magnet is on. The crane forces are considerably larger than the magnet forces so that no undesirable loads should occur.

2) Wall Channels on the North, East and North Walls.

The horizontal and vertical forces on these members, i.e. wind girts, are far less than their capacity. The torque presents a slightly different problem since the rotational rigidity of the members is very small. Rotations which cause the inner end to go down would be resisted by the sag rods and the connection between the girt and the corrugated wall material without distress. Rotations which would cause the inner end of the girt to go up would have to be restrained by bending of the outer wall. Although this can be probably be done safely we would recommend that straps or rods at the same spacing as the "sag rods" be added to connect the lower line of girts to the base angle. This would directly transfer the force to the concrete wall and eliminate any need for questionable structure response by the walls.

3) Diagonal Braces on North Wall.

The force on these members would cause them to move in and act as a cable or pure tension member. The end connection of this member is capable of resisting at least 18,000 lb before failure would occur.

This would require a 1 inch deflection of the member. Since deflection of 2 inches or 3 inches do not appear to have serious consequences changes in these members appears unnecessary.

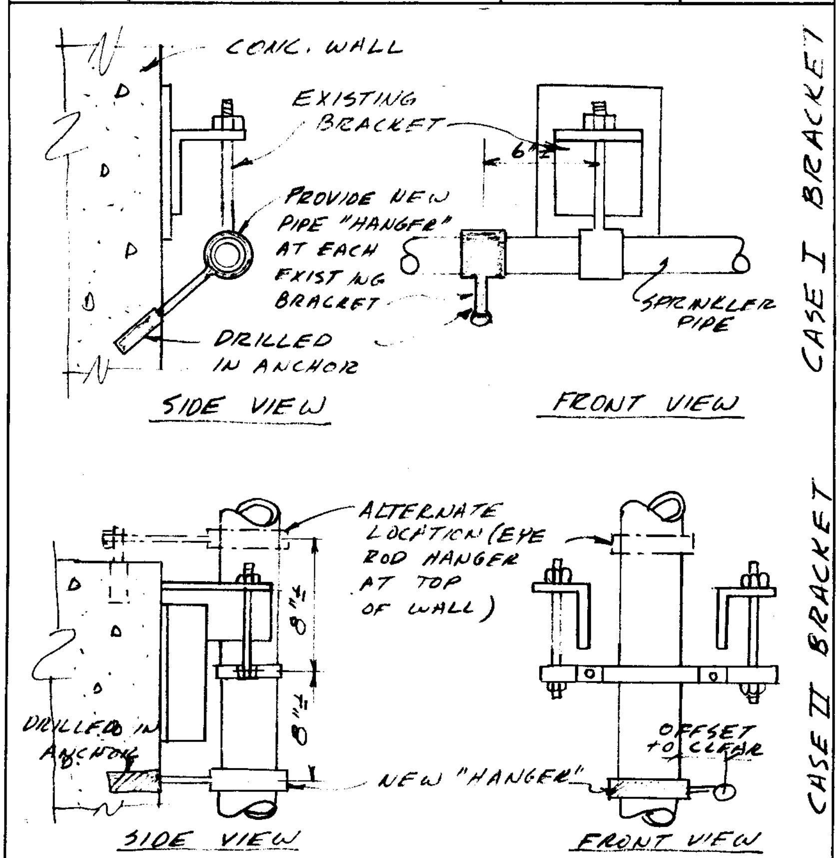
4) Steel Pipes for Sprinklers and Hot Water.

A previous review of the forces on the sprinkler pipes indicated that their connection was adequate for forces up to 5 times their weight. The problem with the sprinklers is primarily with the angle between the force and the support. A brief visual inspection at an early date indicated some revision was necessary and sketches illustrate the work have been prepared and the remedial work completed.

This review does not extend to the considerable amount of NAL installed piping and members on the job since details of their size and weight are not available.

DUSAF — DANIEL, URBAHN, SEELYE & FULLER
ARCHITECTURE § ENGINEERING § CONSTRUCTION MANAGEMENT

ADDED SPRINKLER BRACING	JOB No. 8-2-2	SHEET No. 1
FOR NEUTRINO II	DESIGNED BY RLP	DATE 2/8/72
LAB - B	APPROVED	



NOTE: DRILLED IN INSERT, HANGER & HANGER RODS SHALL BE CAPABLE OF RESISTING 200 LBS OF FORCE PER INCH OF DIAMETER OF PIPE SUPPORTED

VII. B. 4. PROCEDURES ASSOCIATED WITH HYDROGEN AREAS

The procedures required to bring hydrogen into the properly constructed, functionally complete, pressure tested and leak-checked system are as follows:

1. <u>Clear and Close the Area</u>

   (a) Clear the area of all but the required process equipment.

   (b) Clear all stairways, corridors and exits, check exit sign function.

   (c) Secure area gates, check or post "Liquid Hydrogen Area" and "No Smoking" signs.

   (d) Secure north end of the entry corridor with signs and a closed gate.

   (e) Turn on blue "Hydrogen in the Area" lights at all entries and check operation of each light.

2. <u>Lock-Out Non-Explosion Proof Equipment</u>

   (a) Lock out all assembly power (Key 33), remove all temporary wiring.

   (b) Lock out the high bay crane at the west end of the high bay (Key 33).

   (c) Check the lock on the elevator disconnect switch (Key 33).

   (d) Lock out all welding outlets (Key 33).

   (e) Remove to Control Room all 110V adaptor pigtails -- check all 110V outlets.

3. <u>Secure and Pressurize the Pump Room</u>

   (a) Carefully close all doors.

   (b) Check the operation of the positive pressure system, test, and then arm the positive pressure alarm.

   (c) Post "Restricted Thoroughfare" signs at all single door entries.

4. Check the Operation of All Purge Systems

   (a) Test and then arm the purge pressure alarm.

   (b) Set and check all flow indicating valves at 5 SCFH.

5. Enable H_2 Monitoring Equipment

   (a) Turn on all H_2 monitors.

   (b) Check the calibration of each head at the calibration gas panel, (1% H_2 in air) with the high level warning horn disarmed.

   (c) After notifying the Control Room and a P.A. Test Announcement, test the high level alarm and valve closure, expansion stop interlocks and audible alarm -- reset warning horn and alarm.

6. Pump and Purge

Proceed with the pump and purge in strict accordance with the Operating Instructions, being sure to purge all stacks that will be, or may be, used in the operation.

Shutdown of Hydrogen Areas

Reverse the pump and purge of Procedure 6 above, as described in the Operating Instructions, secure all hydrogen systems in a tamper-proof manner, but continue H_2 monitoring until quasi-permanent means (caps, blanks, blinds, removed transfer lines, etc.) close all lines entering the area in question.

VII. B. 5. DOCUMENTS AVAILABLE TO CREW

1. Operating Instructions

   (a) Operating Procedures for the Hydrogen Refrigerator Cold Box H and Liquid Hydrogen Storage Tank A

   (b) Operating Instructions for the Helium System of the 30,000 Liter Bubble Chamber

   (c) Cooling Loops of the 30,000 Liter Bubble Chamber

   (d) Expansion System Actuator Operating Procedures for the 30,000 Liter Bubble Chamber

   (e) Chamber Cooldown/Warm-Up

   (f) Main Vacuum

   (g) Magnet Vacuum System

   (h) Window Vacuum System

   Bound in one book with a central index and cross-reference. The items above currently exist as individual references.

2. General Lecture Series Notes

   (a) "The Bubble Chamber as a High Energy Physics Research Tool"

   (b) "Cryogenics - A Review of the Important Properties"

   (c) "Hydrogen Refrigerator System"

   (d) "Magnets"

   (e) "Helium Refrigerator System"

   (f) "Expansion System"

   (g) "Vacuum System - Magnet, Main and Window Systems"

   (h) "Chamber Cooldown"

   (i) "Camera/Optics"

   (j) "The Physics that Comes Out"

3. Manufacturers'File

   A complete, by manufacturer, cross reference to the process code designation, file of contract specifications, installation, operation and maintenance, and instrument manuals on installed equipment is being assembled and will be available in the control room for use by the operating crew.

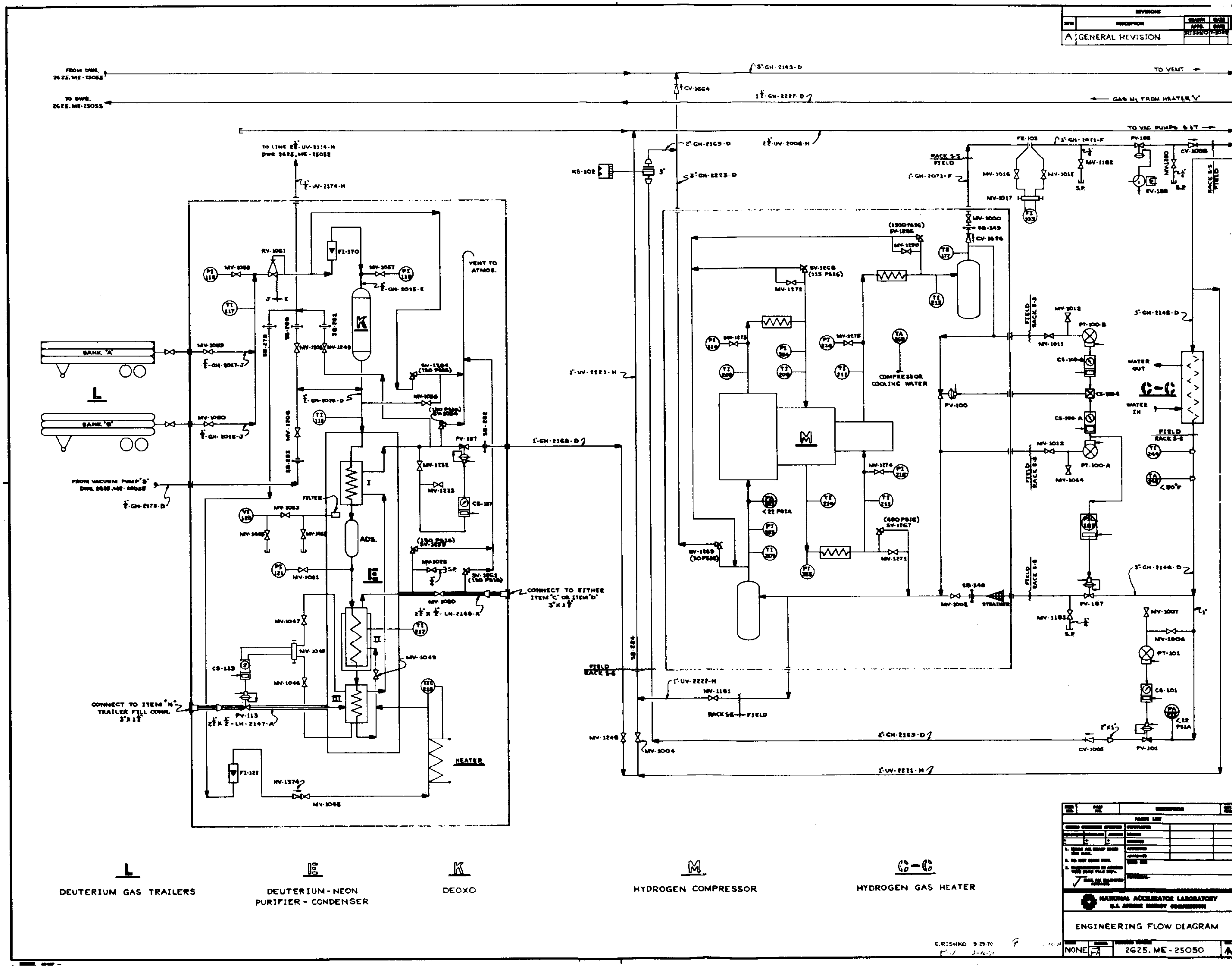
4. Graphic Panels and Engineering Flow Diagrams

A strenuous, conscious effort has been made to schematically portray the more important process valves; i.e., in general those valves other than maintenance, pump and purge, etc., on the control room panels housing the pneumatic controllers and solenoid pushbutton switches. The size of the panels in most cases is determined not by the mounted equipment, but by space required to draw a representative schematic. We call these "graphic panels". The schematic is done on a clear, acetate blueprint that is strippable to allow modification, addition or deletion for clarity to be made with the minimum of trouble.

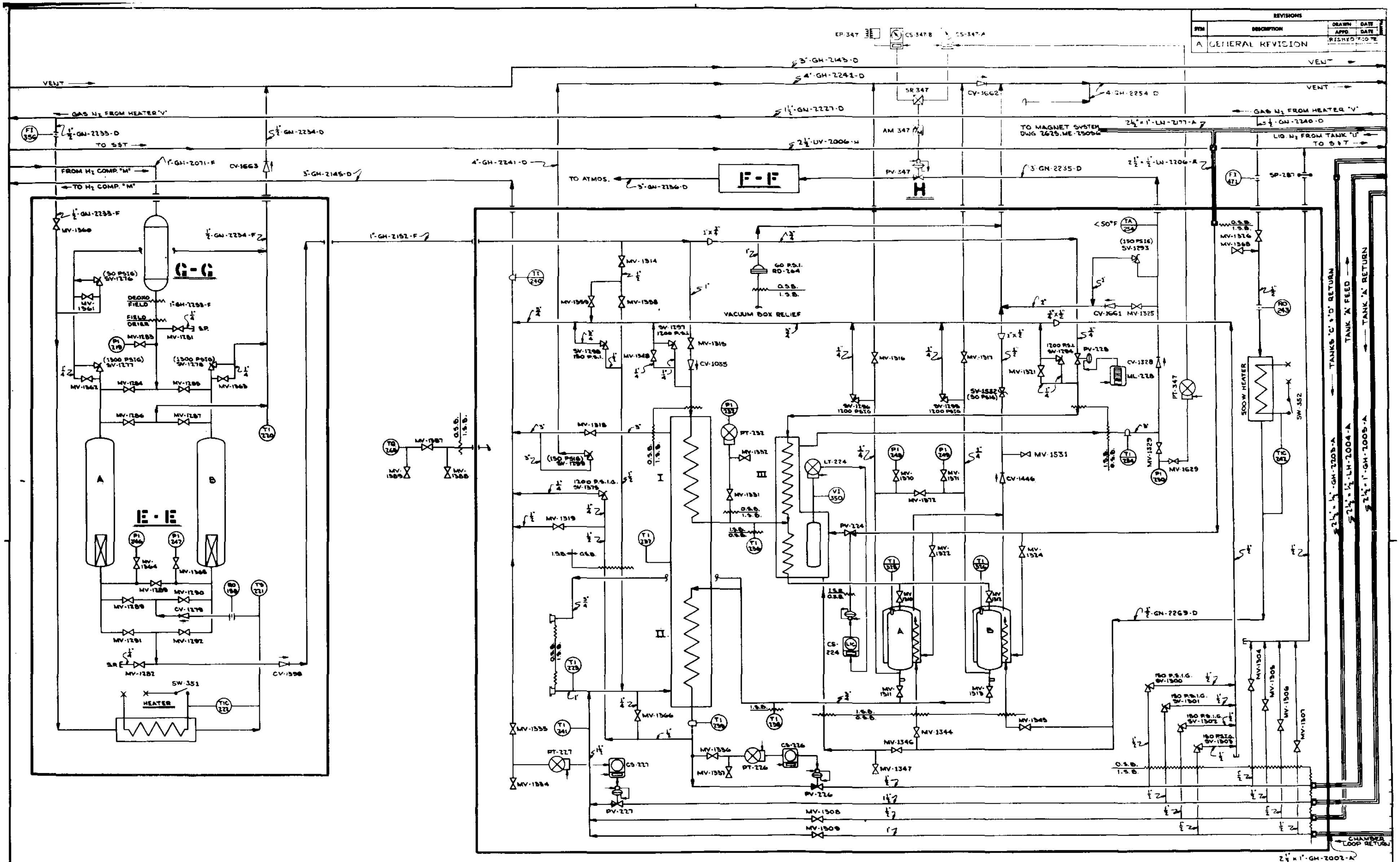
The engineering drawings are laterally match-lined to be continuous flow, reduced to 8-1/2" x 11", attached at the match-lines and folded like a one dimensional road map to pocket carrying size. Each operator will have a copy and be encouraged to make notes on it, color code it, etc., as he sees fit.

5. Subsystem Logs

Log forms for the purpose of collecting information for current awareness, and current or later correlations will be available in final form at the time of cooldown. The tests performed (see Tests) have led to particularly well-developed logs that emphasize the problem or high correlation areas. The cooldown will require only one non-field tested log; i.e., the chamber cooling loop log.



A GENERAL REVISION
TO VENT
GAS N2 FROM HEATER 'V'
TO VAC. PUMPS
FROM DWG. 2625.ME-25055
TO DWG. 2625.ME-25055
VENT TO ATMOS.
BANK 'A'
BANK 'B'
FROM VACUUM PUMP 'B' DWG. 2625.ME-25055
CONNECT TO EITHER ITEM 'C' OR ITEM 'D'
CONNECT TO ITEM 'N' TRAILER FILL CONN.
FILTER
ADS.
HEATER
COMPRESSOR COOLING WATER
WATER OUT
WATER IN
STRAINER
FIELD
RACK 5-5
L
DEUTERIUM GAS TRAILERS
E
DEUTERIUM-NEON PURIFIER-CONDENSER
K
DEOXO
M
HYDROGEN COMPRESSOR
C-C
HYDROGEN GAS HEATER
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
ENGINEERING FLOW DIAGRAM
E.RISHKO
NONE
2625.ME-25050



G-G DEOXO

E-E DRIER ASSEMBLY

F-F NITROGEN VACUUM PUMP

H HYDROGEN REFRIGERATOR COLD BOX

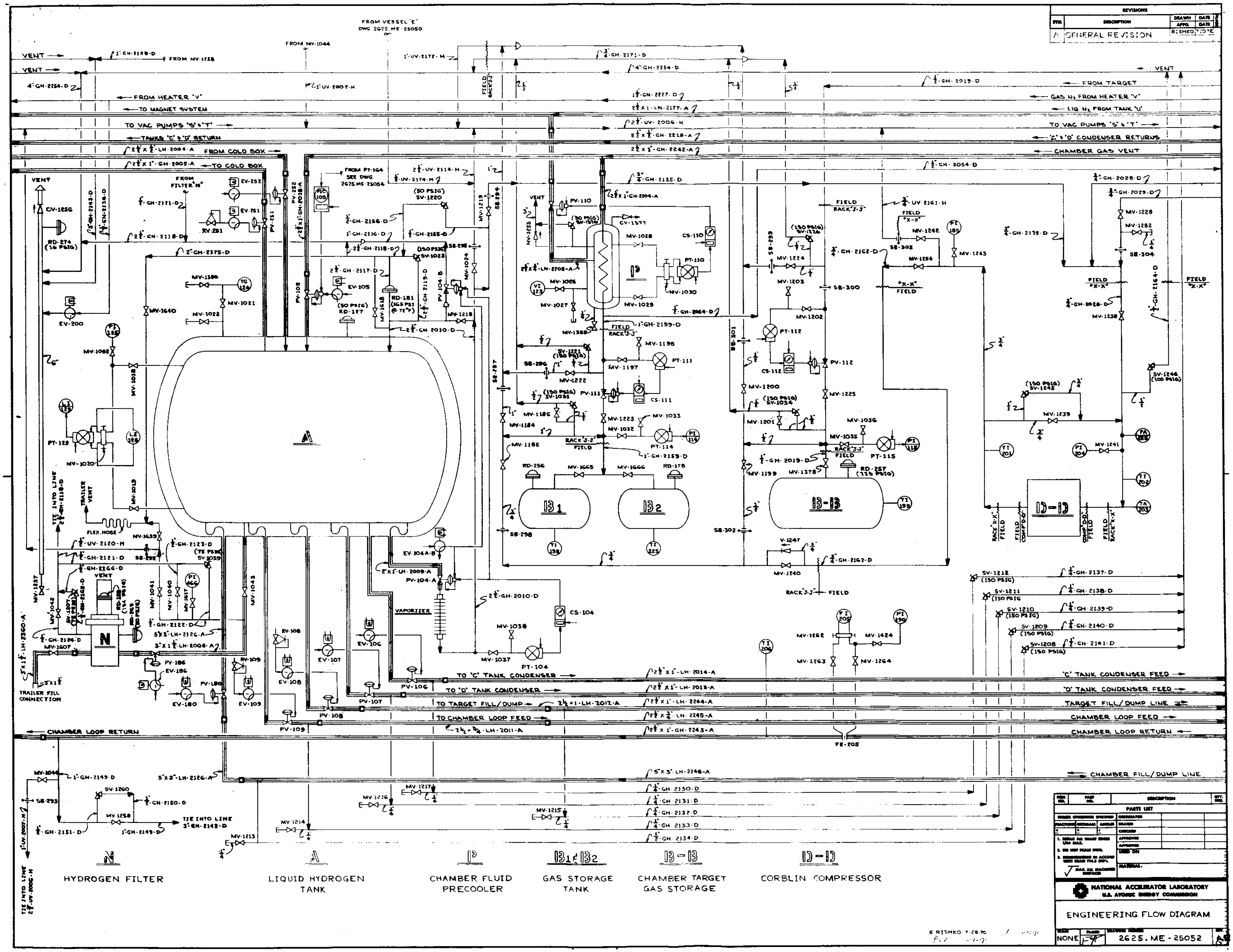
ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.

PARTS LIST

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

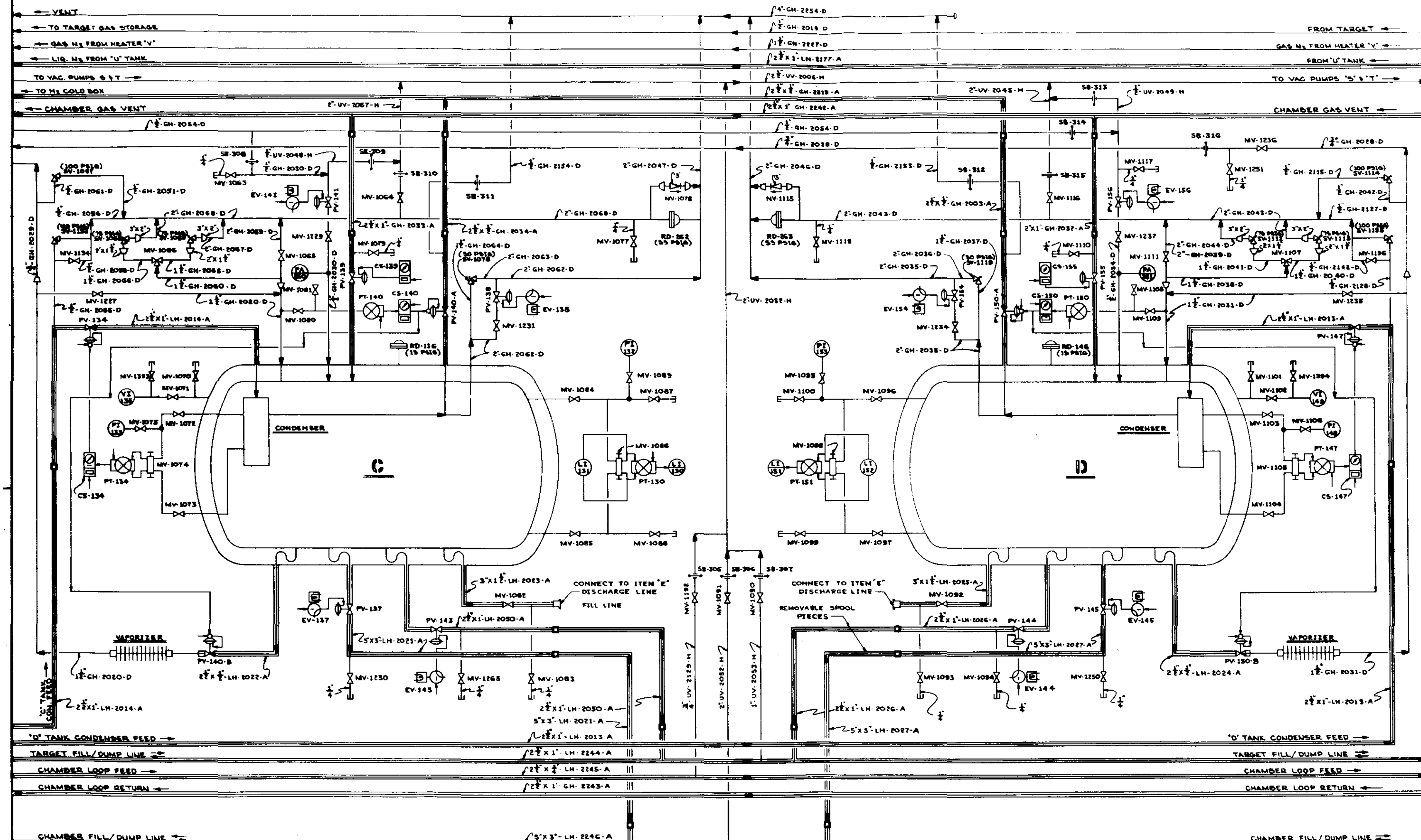
ENGINEERING FLOW DIAGRAM

2625.ME-25051 A



REVISIONS
A GENERAL REVISION
VENT
FROM VESSEL "E" DWG 2625.ME-25050
FROM MV-1044
FROM HEATER "V"
TO MAGNET SYSTEM
TO VAC PUMPS "S" & "T"
TANKS "C" & "D" RETURN
FROM COLD BOX
TO COLD BOX
FROM TARGET
GAS N2 FROM HEATER "V"
LIQ. N2 FROM TANK "U"
"C" & "D" CONDENSER RETURNS
CHAMBER GAS VENT
TRAILER FILL CONNECTION
CHAMBER LOOP RETURN
VAPORIZER
TO "C" TANK CONDENSER
TO "D" TANK CONDENSER
TO TARGET FILL/DUMP
TO CHAMBER LOOP FEED
"C" TANK CONDENSER FEED
"D" TANK CONDENSER FEED
TARGET FILL/DUMP LINE
CHAMBER LOOP FEED
CHAMBER LOOP RETURN
CHAMBER FILL/DUMP LINE
N HYDROGEN FILTER
A LIQUID HYDROGEN TANK
P CHAMBER FLUID PRECOOLER
B1 & B2 GAS STORAGE TANK
B-B CHAMBER TARGET GAS STORAGE
D-D CORBLIN COMPRESSOR
PARTS LIST
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
ENGINEERING FLOW DIAGRAM
NONE
2625.ME-25052

SYM	DESCRIPTION		DRAWN	DATE
A	DELETED LINES	1 1/2"-GH-2000-D, 1 1/2"-GH-2001-D	RISHKO	7-10-72



C

LIQUID NEON-HYDROGEN TANK

D

LIQUID DEUTERIUM TANK

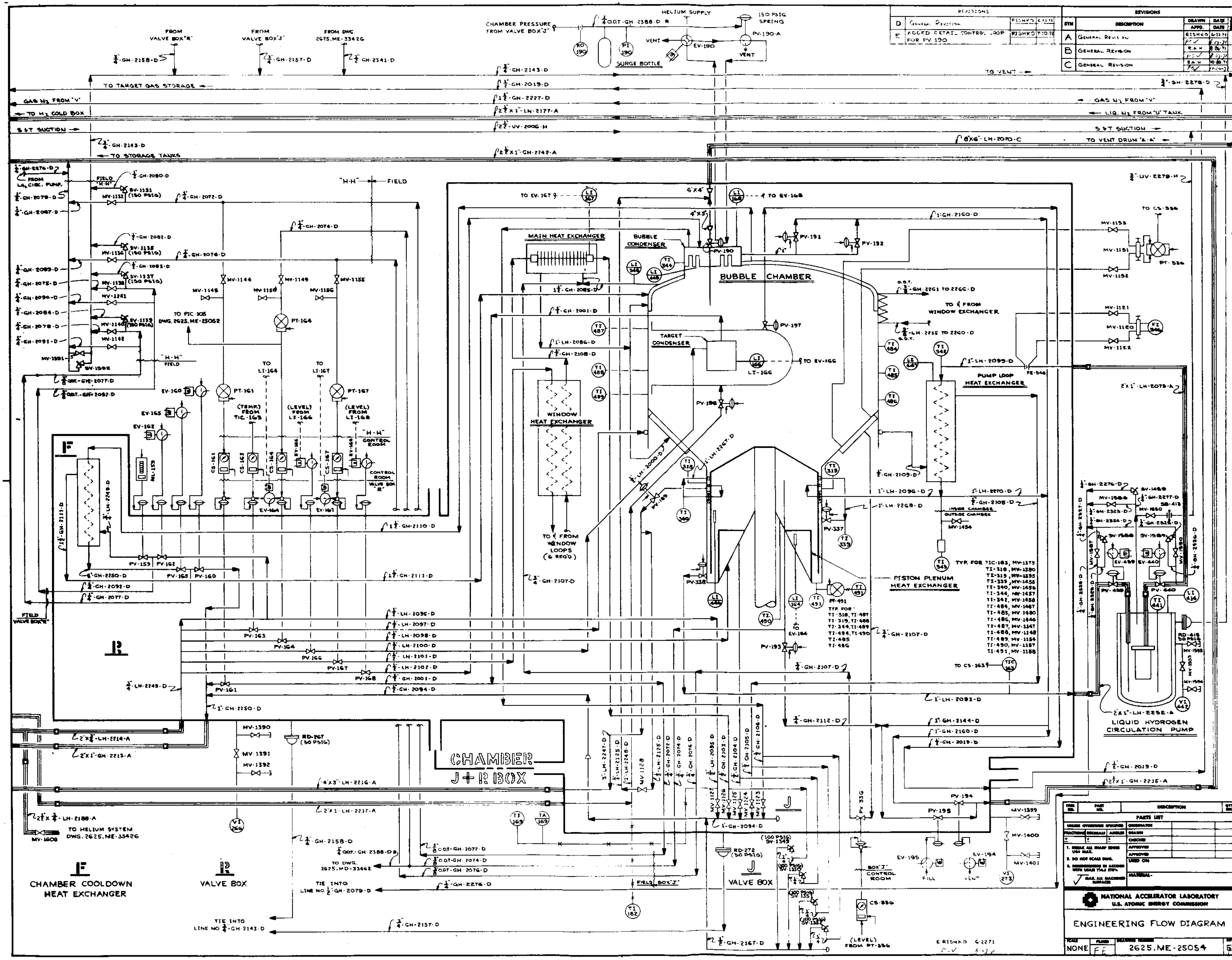
E. RISHKO 7-27-70

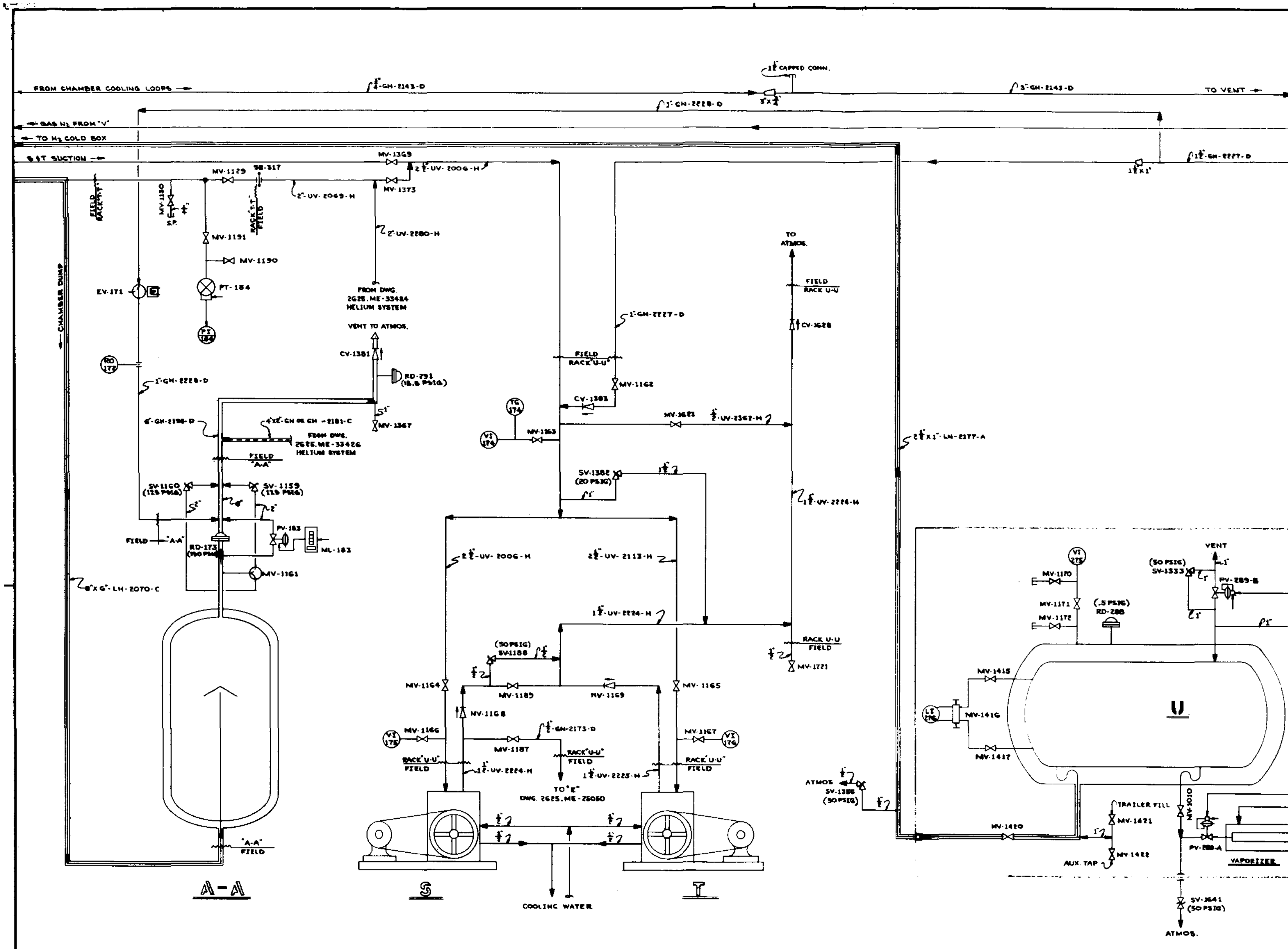
PARTS LIST

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

ENGINEERING FLOW DIAGRAM

NONE | 2625.ME-25053 | A


REVISIONS
A GENERAL REVISION
B GENERAL REVISION
C GENERAL REVISION
D GENERAL REVISION
E ADDED DETAIL CONTROL LOOP FOR PV-190
CHAMBER PRESSURE FROM VALVE BOX "J"
HELIUM SUPPLY
150 PSIG SPRING
SURGE BOTTLE
FROM VALVE BOX "R"
FROM VALVE BOX "J"
FROM DWG. 2625.ME-33426
TO TARGET GAS STORAGE
GAS N2 FROM "V"
TO H2 COLD BOX
S&T SUCTION
TO STORAGE TANKS
TO VENT
GAS N2 FROM "V"
LIQ. N2 FROM "U" TANK
TO VENT DRUM "A-A"
MAIN HEAT EXCHANGER
BUBBLE CONDENSER
BUBBLE CHAMBER
TARGET CONDENSER
WINDOW HEAT EXCHANGER
TO & FROM WINDOW EXCHANGER
PUMP LOOP HEAT EXCHANGER
TO & FROM WINDOW LOOPS (6 REQ'D)
PISTON PLENUM HEAT EXCHANGER
INSIDE CHAMBER
OUTSIDE CHAMBER
CONTROL ROOM
LIQUID HYDROGEN CIRCULATION PUMP
CHAMBER J + R BOX
TO HELIUM SYSTEM DWG. 2625.ME-33426
TIE INTO LINE NO. 1/2"-GH-2079-D
TIE INTO LINE NO. 3/4"-GH-2143-D
FIELD BOX "J"
BOX "J" CONTROL ROOM
FILL
VENT
(LEVEL) FROM PT-336
F
CHAMBER COOLDOWN HEAT EXCHANGER
R
VALVE BOX
J
VALVE BOX
PARTS LIST
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
ENGINEERING FLOW DIAGRAM
NONE
2625.ME-25054



A-A

CHAMBER VENT KNOCK-OUT DRUM

S

UTILITY VACUUM PUMP

T

UTILITY VACUUM PUMP

U

LIQUID NITROGEN TANK

V

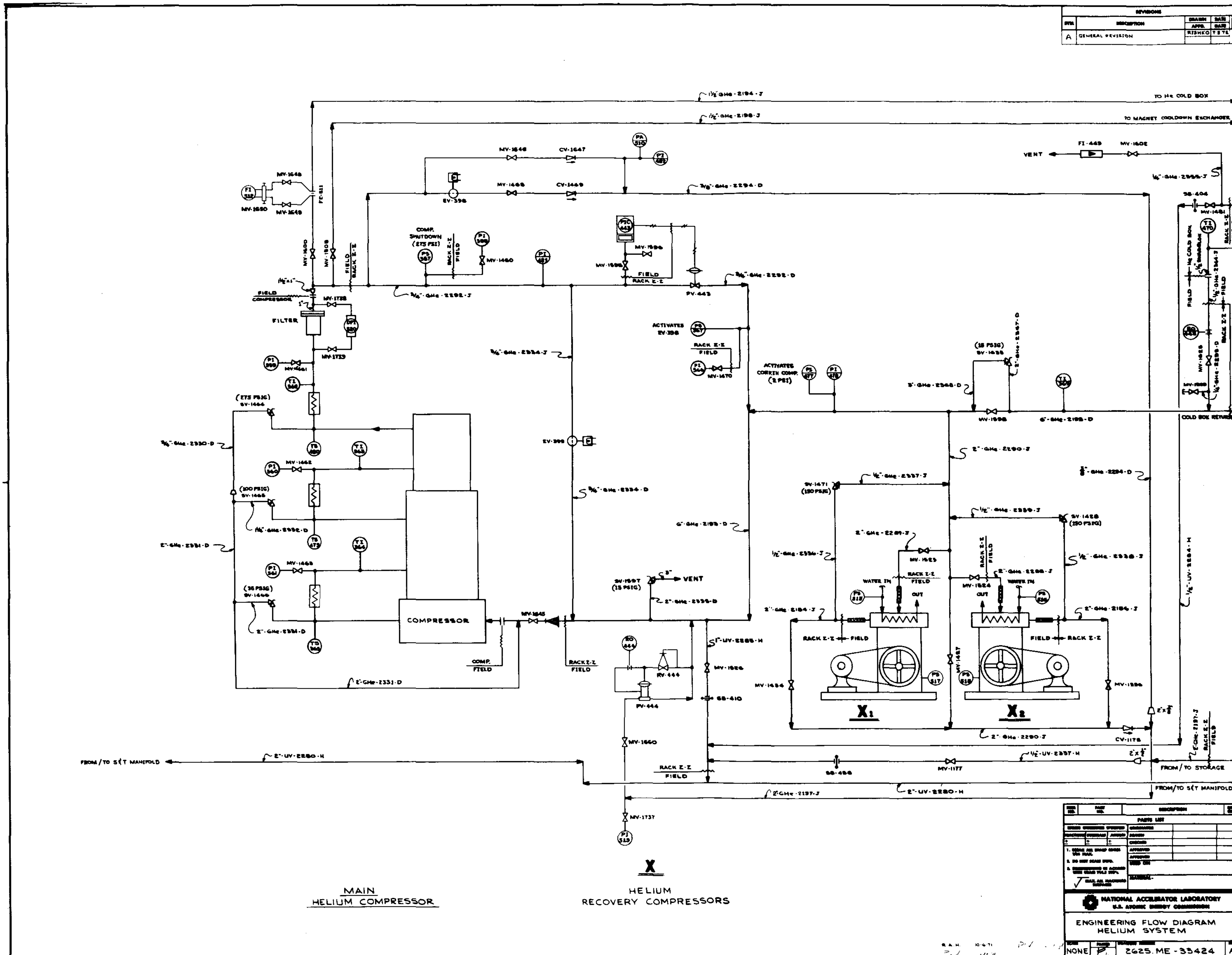
NITROGEN VAPORIZER-HEATER

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

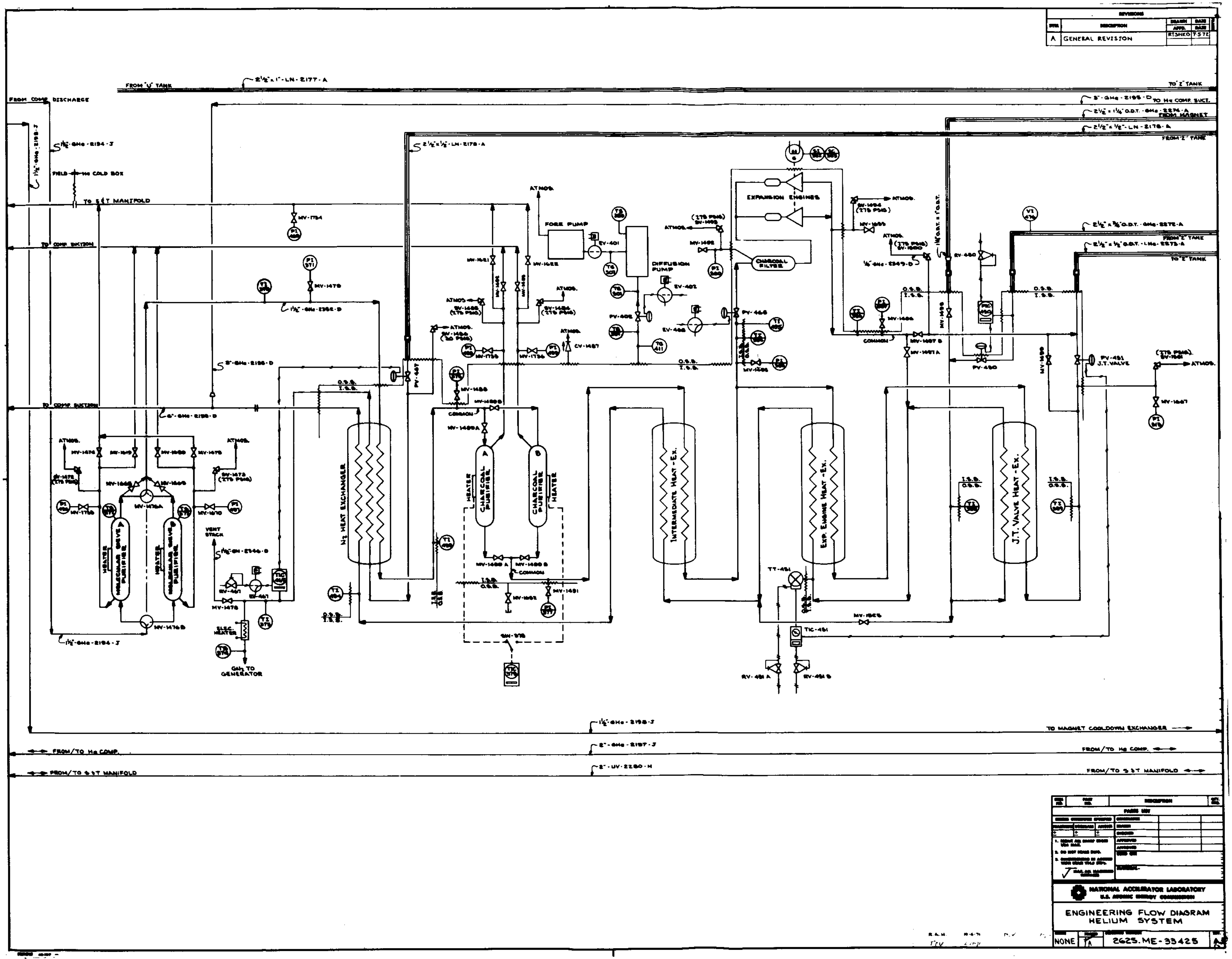
ENGINEERING FLOW DIAGRAM

E RISHKO 8-3-70

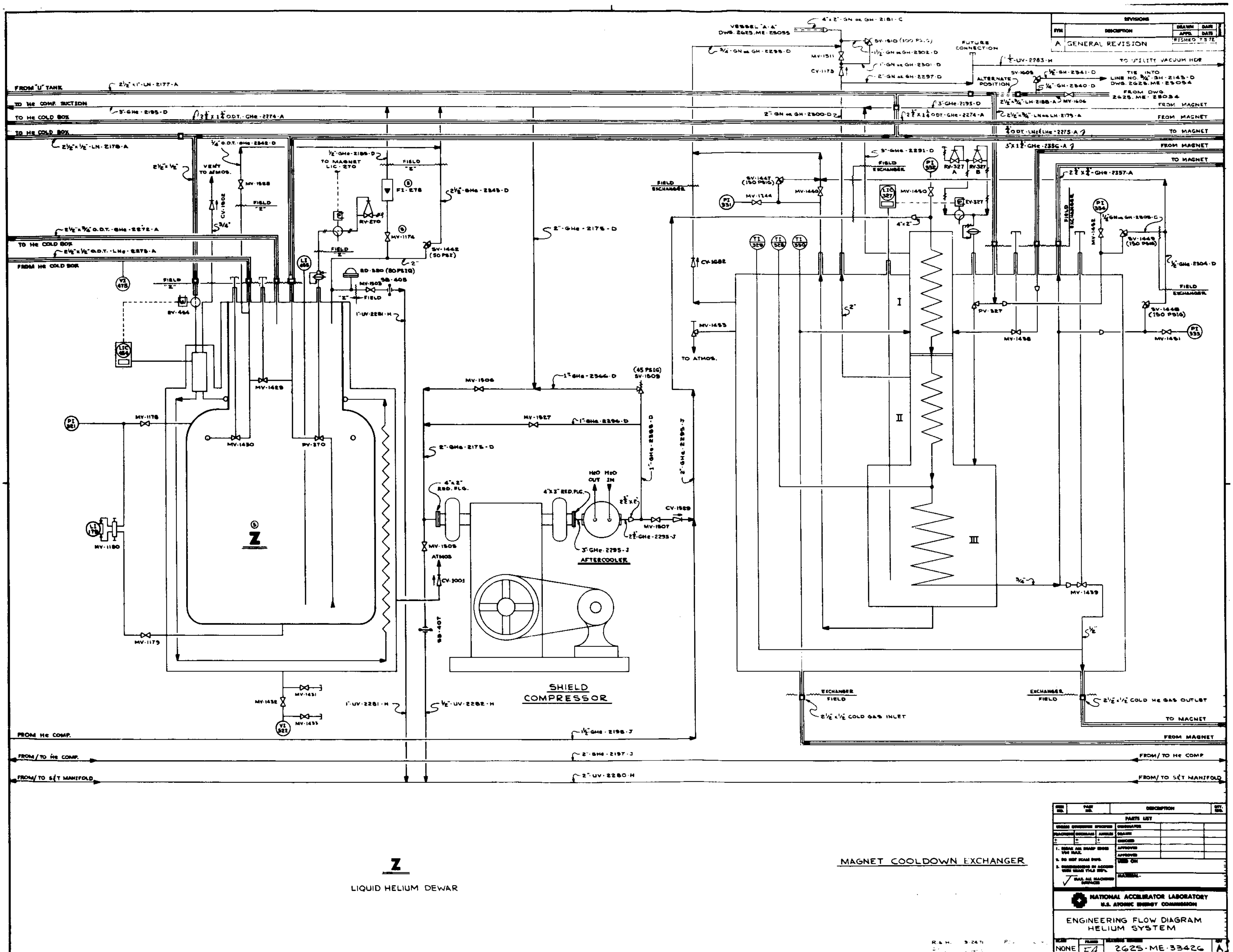
NONE | 2625.ME-25055 | A

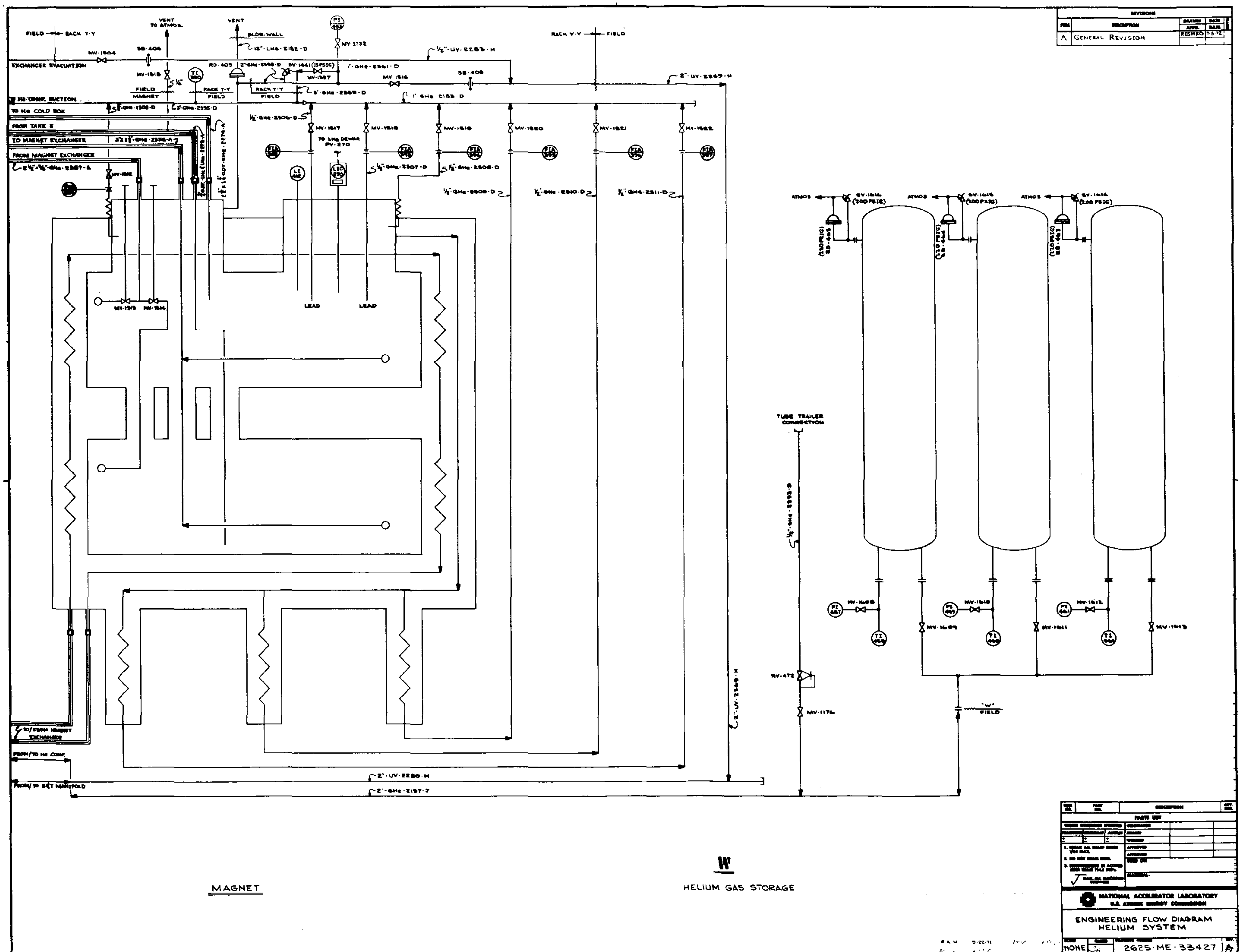


TO He COLD BOX
TO MAGNET COOLDOWN EXCHANGER
VENT
COMPRESSOR
FILTER
FIELD
COMPRESSOR
COLD BOX RETURN
FROM PURIFIER
PURIFIER EVACUATION
FROM/TO S&T MANIFOLD
FROM/TO STORAGE
WATER IN
OUT
X1
X2
MAIN
HELIUM COMPRESSOR
X
HELIUM
RECOVERY COMPRESSORS
A GENERAL REVISION
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
ENGINEERING FLOW DIAGRAM
HELIUM SYSTEM
NONE
2625.ME-33424
A

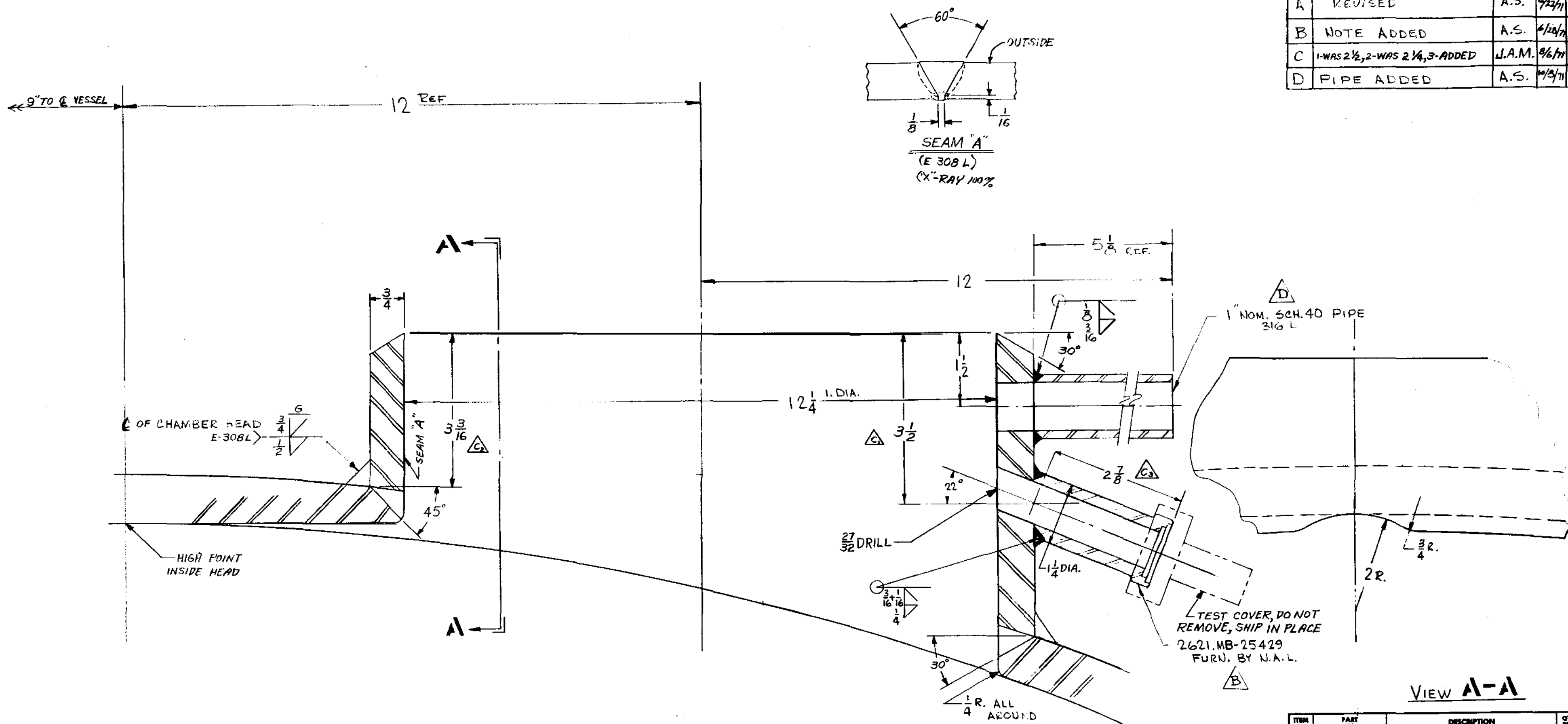


REVISIONS
A GENERAL REVISION
FROM 'U' TANK
TO 'Z' TANK
FROM COMP. DISCHARGE
TO COMP. SUCTION
FROM MAGNET
FROM 'Z' TANK
TO S.T MANIFOLD
FIELD He COLD BOX
FORE PUMP
DIFFUSION PUMP
EXPANSION ENGINES
CHARCOAL FILTER
ATMOS.
COMMON
O.S.S.
I.S.S.
N2 HEAT EXCHANGER
CHARCOAL PURIFIER
HEATER
INTERMEDIATE HEAT-EX.
EXP. ENGINE HEAT-EX.
J.T. VALVE HEAT-EX.
MOLECULAR SIEVE PURIFIER
VENT STACK
ELEC. HEATER
GN2 TO GENERATOR
J.T. VALVE
TO MAGNET COOLDOWN EXCHANGER
FROM/TO He COMP.
FROM/TO S.T MANIFOLD
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
ENGINEERING FLOW DIAGRAM
HELIUM SYSTEM
NONE
2625.ME-33425


REVISIONS
A GENERAL REVISION
FROM "U" TANK
TO He COMP. SUCTION
TO He COLD BOX
FROM He COLD BOX
TO UTILITY VACUUM HDR
FUTURE CONNECTION
ALTERNATE POSITION
FROM MAGNET
TO MAGNET
VENT TO ATMOS.
TO MAGNET LIC-270
TO ATMOS.
SHIELD COMPRESSOR
AFTERCOOLER
H2O OUT
H2O IN
2 1/2" x 1/2" COLD GAS INLET
2 1/2" x 1/2" COLD He GAS OUTLET
FROM He COMP.
FROM/TO He COMP.
FROM/TO S&T MANIFOLD
Z
LIQUID HELIUM DEWAR
MAGNET COOLDOWN EXCHANGER
PARTS LIST
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
ENGINEERING FLOW DIAGRAM
HELIUM SYSTEM
NONE
2625-ME-33426
A


REVISIONS
A GENERAL REVISION
VENT TO ATMOS.
VENT
BLDG. WALL
EXCHANGER EVACUATION
FIELD
BACK Y-Y
MAGNET
He COMP. SUCTION
TO He COLD BOX
FROM TANK 2
TO MAGNET EXCHANGER
FROM MAGNET EXCHANGER
TO LHe DEWAR PV-270
LEAD
LEAD
MV-1513
MV-1514
MV-1517
MV-1518
MV-1519
MV-1520
MV-1521
MV-1522
MV-1516
MV-1504
MV-1732
SB-406
RD-403
2"-UV-2369-H
1/2"-UV-2283-H
1"-GHe-2183-D
TO/FROM MAGNET EXCHANGER
FROM/TO He COMP.
FROM/TO SET MANIFOLD
2"-UV-2280-H
2"-GHe-2197-7
TUBE TRAILER CONNECTION
RV-472
MV-1176
ATMOS
SV-1614 (100 PSIG)
SV-1615 (100 PSIG)
SV-1616 (100 PSIG)
(110 PSIG)
MV-1608
MV-1609
MV-1610
MV-1611
MV-1612
MV-1613
"W" FIELD
MAGNET
HELIUM GAS STORAGE
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
ENGINEERING FLOW DIAGRAM
HELIUM SYSTEM
NONE
2625-ME-33427
A

REVISIONS			
SYM	DESCRIPTION	DRAWN / APPD.	DATE
A	REVISED	A.S.	4/22/71
B	NOTE ADDED	A.S.	6/28/71
C	1-WAS 2½, 2-WAS 2¼, 3-ADDED	J.A.M.	8/6/71
D	PIPE ADDED	A.S.	10/8/71



ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.

PARTS LIST

UNLESS OTHERWISE SPECIFIED				
FRACTIONS ± 1/64	DECIMALS ± ~	ANGLES ± 1/2°	ORIGINATOR	
			DRAWN	A. SKLIBOLY 3/10/71
			CHECKED	L. KULA 6/22/71
			APPROVED	
			APPROVED	

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD's.
125 √ MAX. ALL MACHINED SURFACES

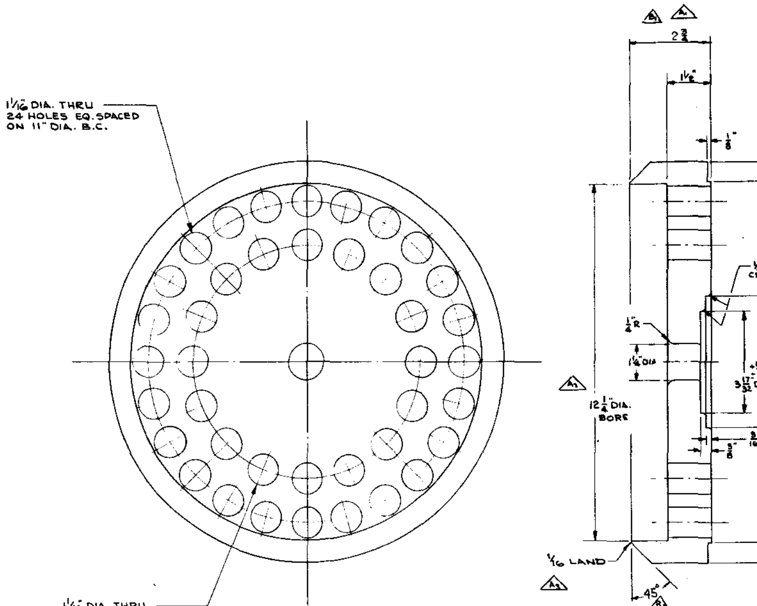
USED ON: 2621.ME-25271

MATERIAL: 316 L

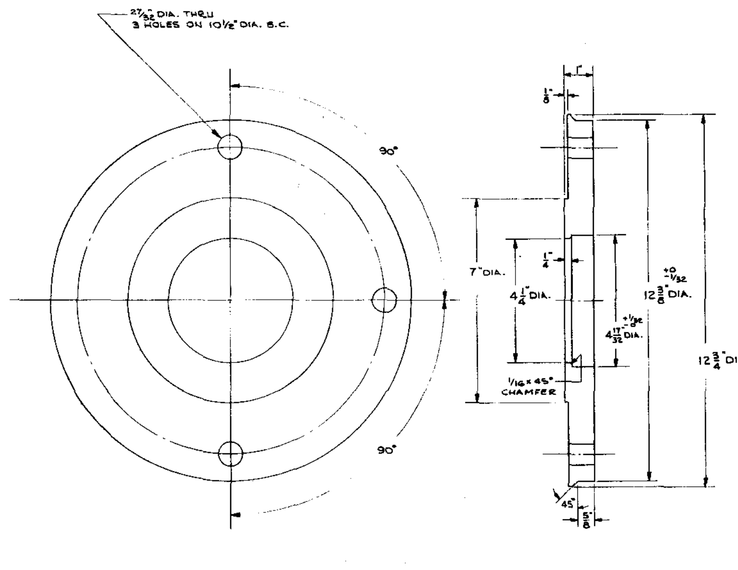
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

30K LITER HYDROGEN B.C.
CHAMBER BUBBLE CONDENSER PORT
DETAIL

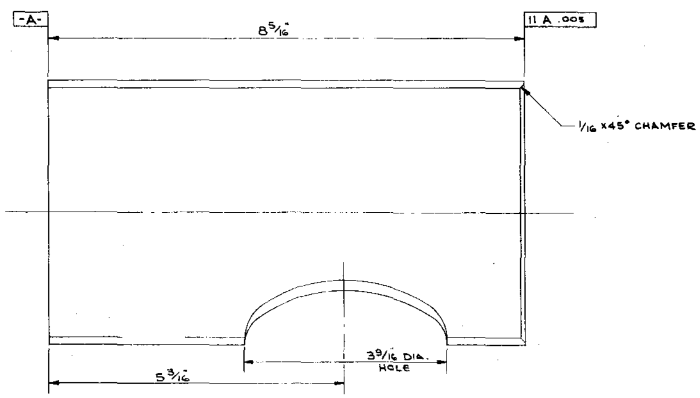
SCALE	FILMED	DRAWING NUMBER	REV.
1" = 1"		2621.MD-25368	D



DET'L ITEM-1



DET'L ITEM-2



DET'L ITEM-3
SCALE ~ FULL

REVISIONS			
SYM	DESCRIPTION	DRAWN / APPD.	DATE / DATE
A1	ADD 12 1/4 DIM	AVGERENOS	12-9-71
A2	ADD 12 1/4 BORE		
A3	ADD 1/16 LAND		
B1	WAS 1 3/4	AVGERENOS	1-26-72
B2	WAS 30°		
B3	WAS TP 304		

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.
3		PIPE, 4"-SCH 10 x 8 7/16 LG, STSTL, WLD, TP304	1
2		PLATE, 1" THK x 12 7/8" DIA, STSTL, TP 304	1
1 (B3)		PLATE, 1 1/2" THK x 13 7/8" DIA, STSTL, TP 316L	1

PARTS LIST

UNLESS OTHERWISE SPECIFIED			
FRACTIONS	DECIMALS	ANGLES	ORIGINATOR
± 1/64	±	± 1/2°	DRAWN
			CHECKED
			APPROVED
			APPROVED

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD's.

√ MAX. ALL MACHINED SURFACES

USED ON

MATERIAL-

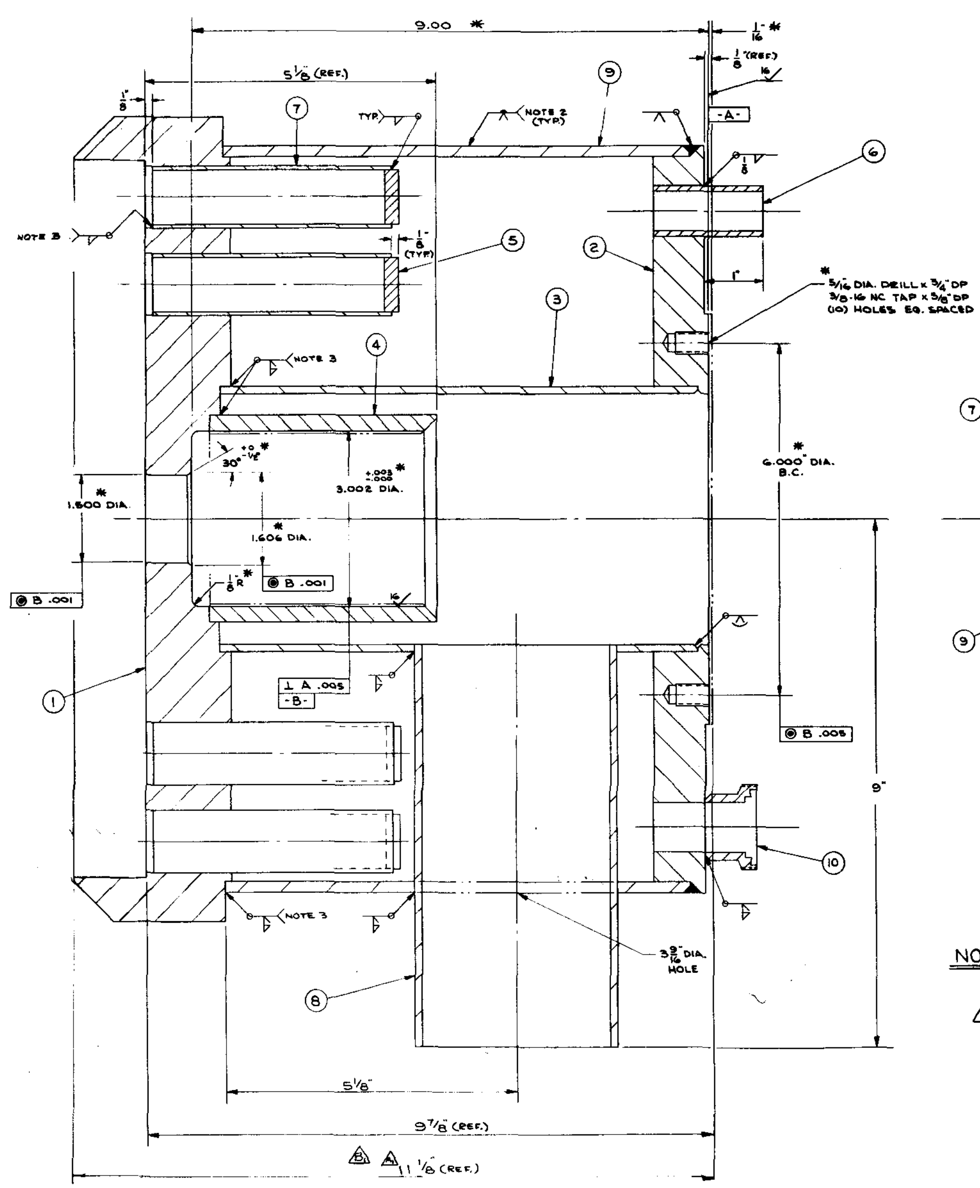
R.A.H. 7-29-71 PCV 8-26-71
PCV 8-26-71

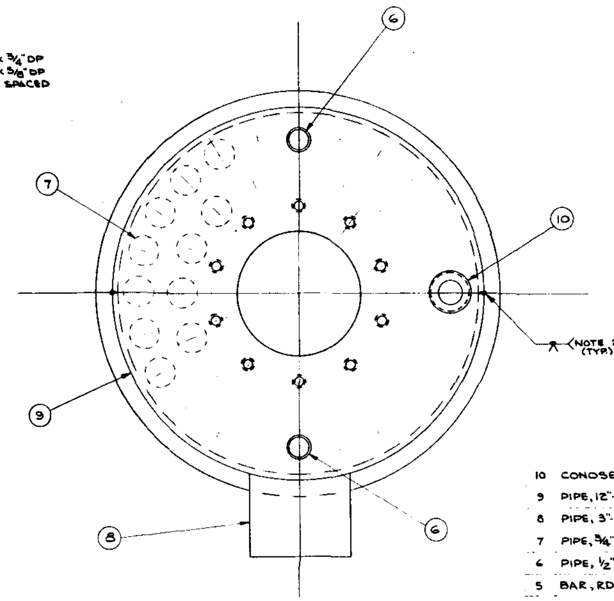
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

FLANGE DETAILS
BUBBLE CONDENSER
& CHAMBER VALVE PV-190

SCALE	FILMED	DRAWING NUMBER	REV.
HALF		2625-MD-25102	B3

RUNNING 40-107





END VIEW

HALF SCALE

NOTES:

* 1. MACHINE AFTER WELDING

2. SPLIT LONGITUDINAL FOR ASSEMBLY

(B2) 3. WELD WITH 308L ROD 4% TO 8% FERRITE CONTENT

REVISIONS			
SYM	DESCRIPTION	DRAWN / APPD.	DATE / DATE
A1	ADD 10 1/8 (REF.)	AVGERENOS	11-9-71
B1	WAS 10 1/8 (REF.)	AVGERENOS	1-19-72
B2	ADD NOTE 3		

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.
10		CONOSEAL, FEMALE, #56340-16, STSTL, AEROQUIP	1
9		PIPE, 12"-SCH 10 x 8 1/8" LG, STSTL, TP 304	1
8		PIPE, 3"-SCH 10 x 7 7/8" LG, STSTL, WLD, TP 304	1
7		PIPE, 3/4"-SCH 5 x 4 1/4" LG, STSTL, WLD, TP 304	40
6		PIPE, 1/2"-SCH 40 x 1 7/8" LG, STSTL, WLD, TP 304	2
5		BAR, RD, .906 DIA. x 1/4" THK, STSTL, TP 304	40
4		DETAIL ITEM-5 DWG NO. 2625-MD-25100	1
3		DETAIL ITEM-3 DWG NO. 2625-MD-25102	1
2		DETAIL ITEM-2 DWG NO. 2625-MD-25102	1
1		DETAIL ITEM-1 DWG NO. 2625-MD-25102	1

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTIONS	DECIMALS	ANGLES	ORIGINATOR		
± 1/64	± .010	± 1/2°	DRAWN		
			CHECKED		
			APPROVED		
			APPROVED		

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD'S.

√ MAX. ALL MACHINED SURFACES

USED ON

MATERIAL

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

SUB-ASSEMBLY #3
BUBBLE CONDENSER
& CHAMBER VALVE PV-190

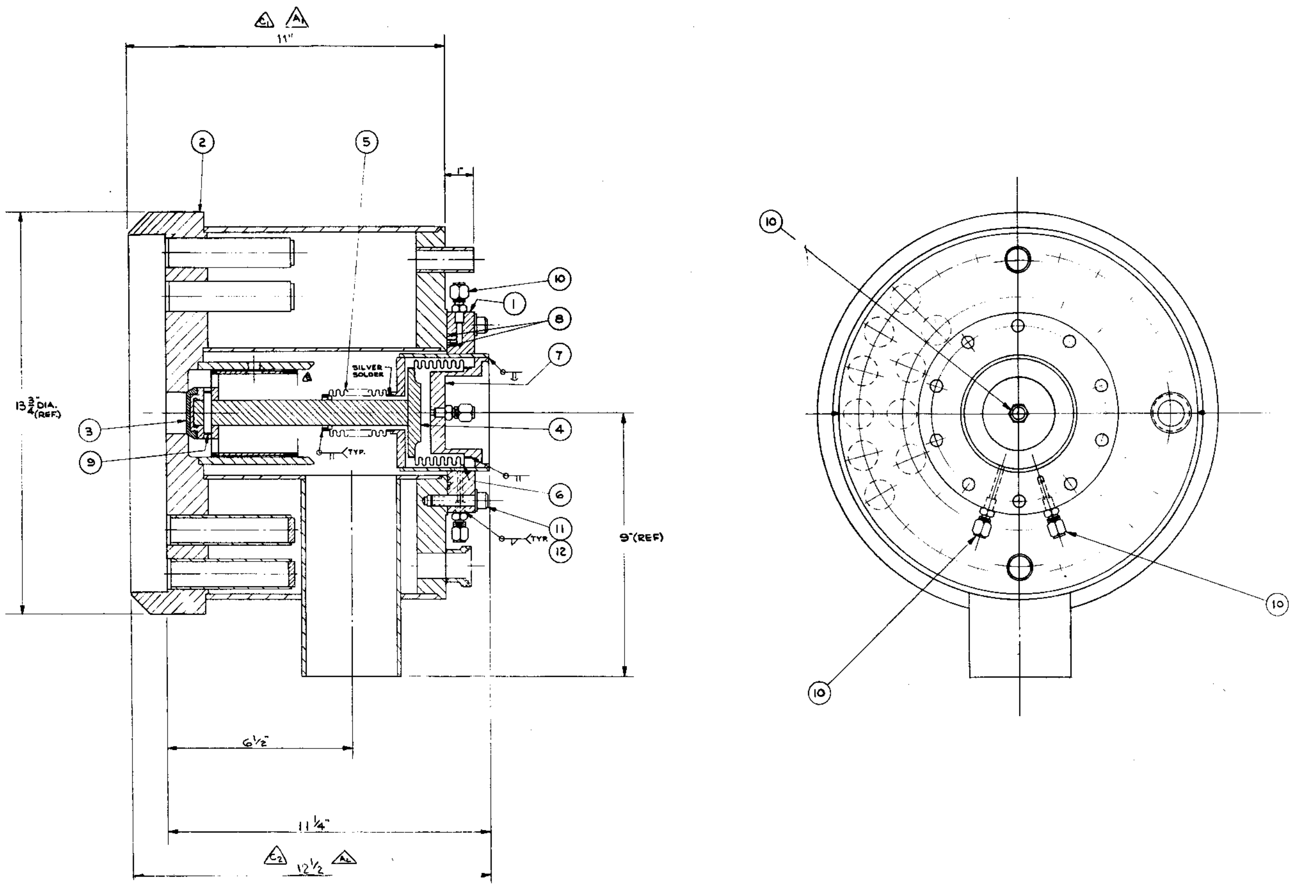
SCALE	FILMED	DRAWING NUMBER	REV.
FULL	FB	2625-MD-25104	B2

R.A.H. 8-23-71 PCV 8-26-71

PCV 8-26-71

BRUNING 40-107

REVISIONS			
SYM	DESCRIPTION	DRAWN / APPD.	DATE / DATE
A₁	WAS 9 3/4	AVGERENOS	12-9-71
A₂	ADDED 11 1/2 DIM.		
B	ADD BEARINGS	AVGERENOS	12-17-71
C₁	WAS 10"	AVGERENOS	1-26-72
C₂	WAS 11 1/2		



ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.
12		LOCK WASHER, 3/8" NOM. STSTL	10
11		CAPSCREW, SOC. HD, 3/8-16 NC x 1 1/2" LG, STSTL	10
10		REDUCER, SWAGELOK #400-R-5-304L	3
9		ROLL PIN, 1/4" DIA. x 1 1/2" LG, STSTL, TP 304	1
8		WIRE, .050 DIA. ANNEALED COPPER	AS REQ'D
7		DETAIL ITEM-4 DWG NO. 2625-MD-25100	1
6		BELLOWS DWG NO. 2625-MB-25458	1
5		BELLOWS DWG NO. 2625-MB-25457	1
4		PISTON ASSY #2 DWG NO. 2625-MD-25101	1
3		PLUG & TIP ASSY. DWG NO. 2625-MD-25101	1
2		SUB-ASSY #3 DWG NO. 2625-MD-25104	1
1		SUB-ASSY #2 DWG NO. 2625-MD-25103	1

PARTS LIST

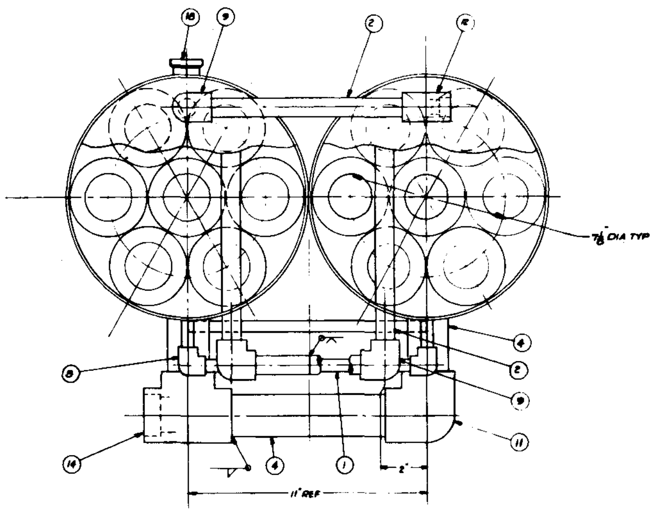
UNLESS OTHERWISE SPECIFIED			ORIGINATOR	R.A.H.	7-28-71
FRACTIONS	DECIMALS	ANGLES	DRAWN		
±	±	±	CHECKED		
1. BREAK ALL SHARP EDGES 1/64 MAX.			APPROVED	PCV	8-26-71
2. DO NOT SCALE DWG.			APPROVED	PW	8-26-71
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD's.			USED ON		
√ MAX. ALL MACHINED SURFACES			MATERIAL-		

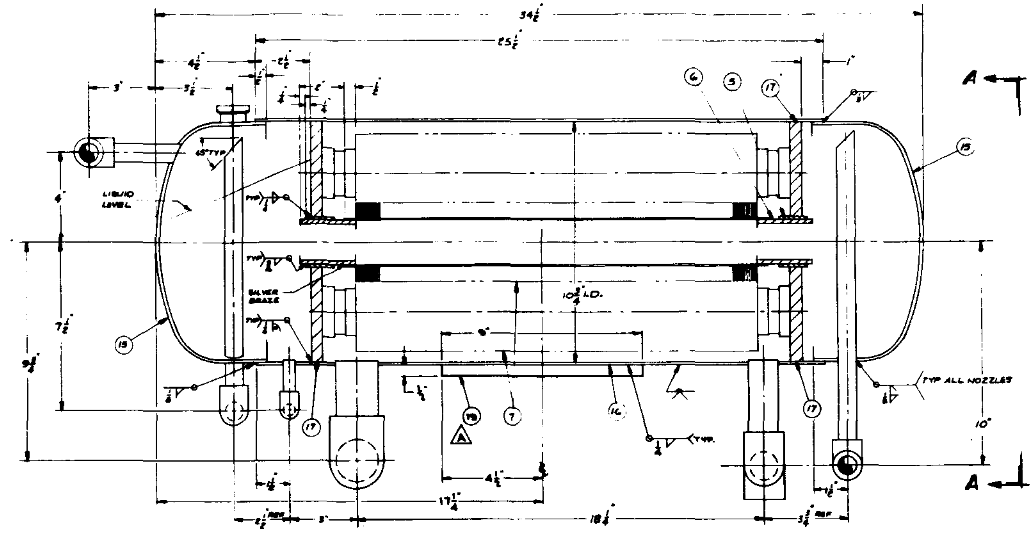
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

BUBBLE CONDENSER
& CHAMBER VALVE PV-190

SCALE	FILMED	DRAWING NUMBER	REV.
HALF		2625-MD-25092	C₂

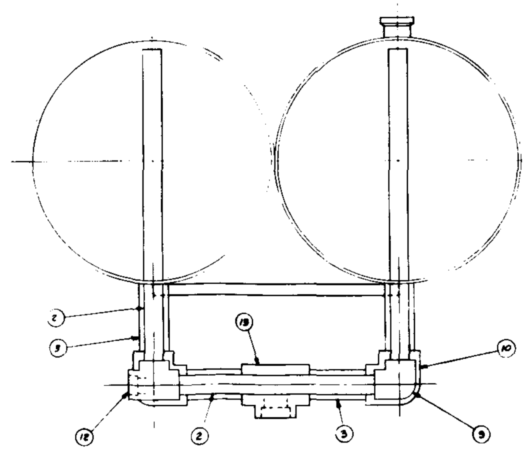
SYM.	REVISIONS DESCRIPTION	DRAWN / APPD.	DATE
A	ADDED ITEM # 19	R.A.H. / PCV	11-30-71 / 12-1-71





NOTES:

1. DESIGN PRESSURE : 165 PSIA
2. ALL WELDS TO BE VACUUM TIGHT & DYE PENETRANT CHECKED



VIEW AA

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.
19 (A)		PLATE [illegible] THK × 9" × 11", ST. STL. 304	1
18		FEMALE [illegible]NGE, CONOSEAL #54971-16 STSTL 304	1
17		PLATE, 1/2" THK × 10 3/4" DIA, STSTL 304	4
16		CYL., 10 3/4" ID × 25 1/2" LG × .125" THK, STSTL 304	2
15		PIPE CAP, 10"-SCH 5, STSTL 304	4
14		TEE, 1 1/2" IPS, SOC WELD, 2000# STSTL 304	1
13		TEE, 1" IPS, SOC WELD, 2000# STSTL 304	1
12		TEE, 1/2" IPS, SOC WELD, 2000#, STSTL 304	2
11		ELBOW, 1 1/2" IPS, SOC WELD, 2000#, STSTL 304	1
10		ELBOW, 1" IPS, SOC WELD, 2000#, STSTL 304	2
9		ELBOW, 1/2" IPS, SOC WELD, 2000#, STSTL 304	4
8		ELBOW, 1/4" IPS, SOC WELD, 2000# STSTL 304	2
7		FINNED TUBE, 1/2" OD × .083 WL × 17" LG, [illegible] × .020 × 8 FINS/INCH, 16" FINNED LENGTH, COPPER ([illegible])	14
6		TUBE, 2" OD × .120 WL × 2 1/2" LG, STSTL 304	28
5		PIPE, 2" SCH 80 × 1" LG, STSTL 304	28
4		PIPE, 1 1/2" - SCH 40, STSTL 304	
3		PIPE, 1" - SCH 40, STSTL 304	
2		PIPE, 1/2" - SCH 40, STSTL 304	
1		PIPE, 1/4" - SCH 40, STSTL 304	

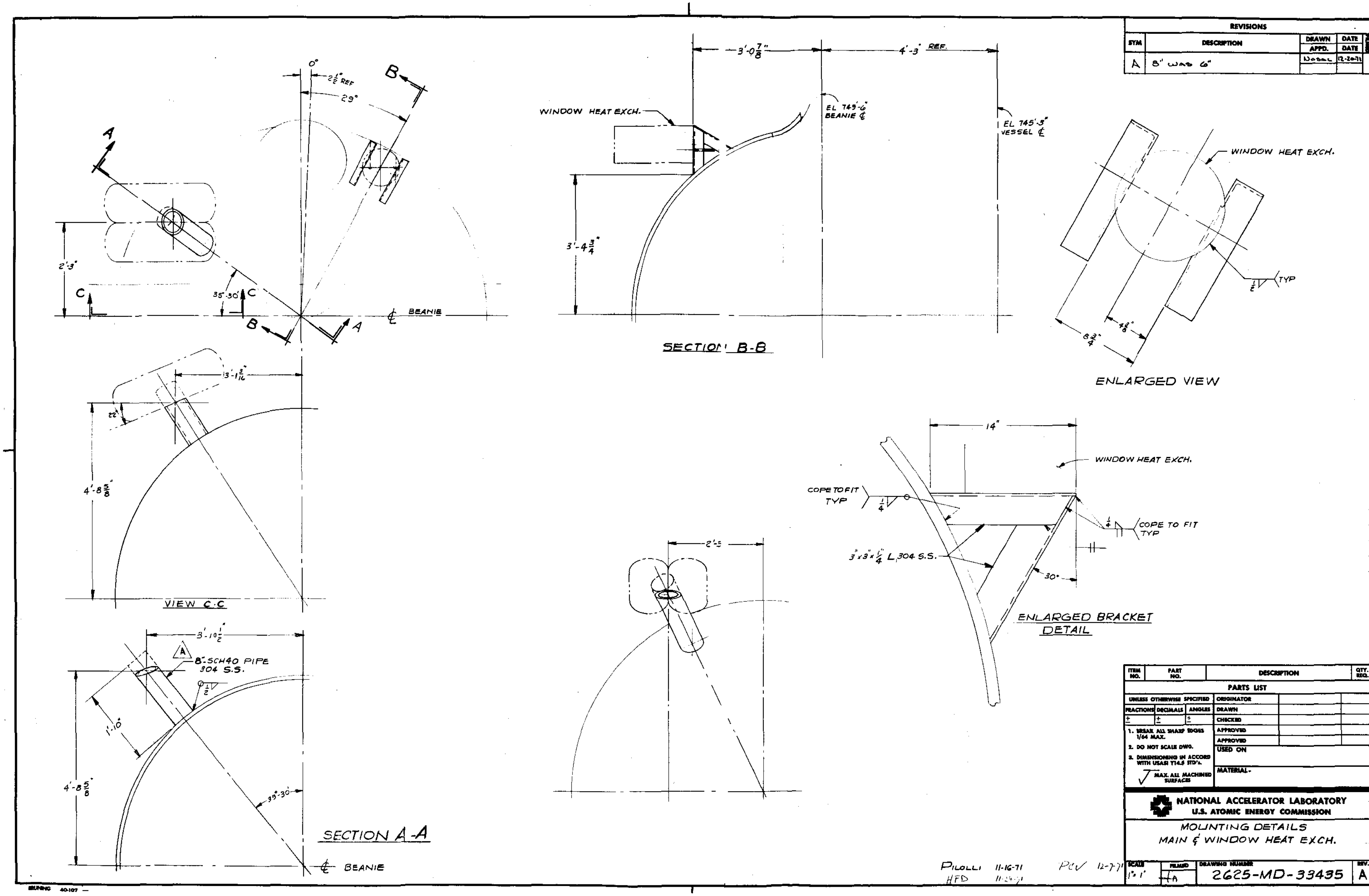
PARTS LIST

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

MAIN HEAT EXCHANGER

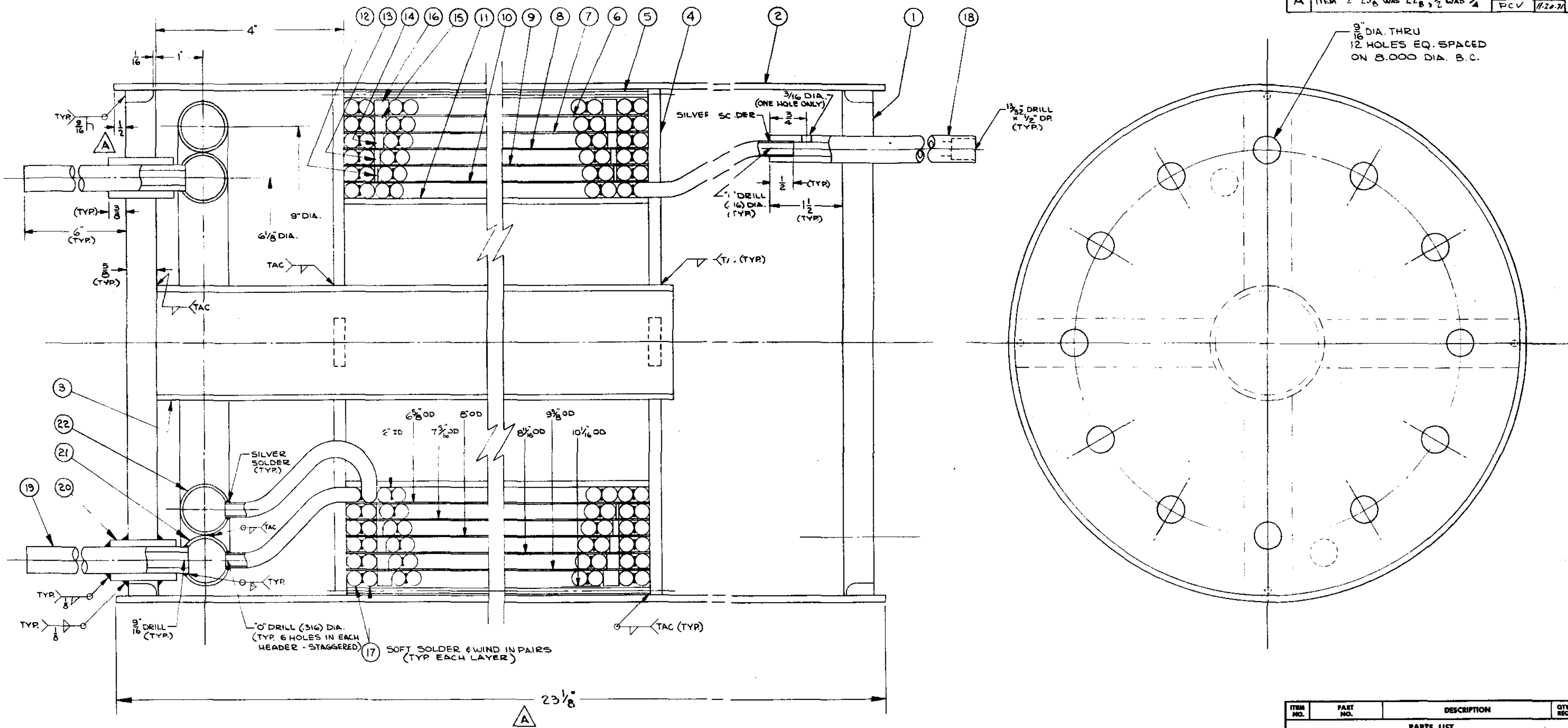
HALF | 2625-ME-25094 | A

PILOLLI 9-9-71



REVISIONS
SYM
DESCRIPTION
DRAWN
APPD.
DATE
A
8" WAS 6"
12-20-71
0°
$2\frac{1}{2}$° REF
29°
B
A
2'-3"
C
35°-30'
C
B
A
℄ BEANIE
WINDOW HEAT EXCH.
3'-0$\frac{7}{8}$"
4'-3" REF.
EL 749'-6" BEANIE ℄
EL 745'-3" VESSEL ℄
3'-4$\frac{3}{4}$"
SECTION B-B
WINDOW HEAT EXCH.
$\frac{1}{2}$ TYP
4$\frac{5}{8}$"
8$\frac{3}{4}$"
ENLARGED VIEW
3'-1$\frac{3}{16}$"
22°
4'-8$\frac{5}{8}$"
VIEW C-C
3'-10$\frac{1}{2}$"
8"-SCH40 PIPE
304 S.S.
$\frac{1}{2}$
1'-10"
4'-8$\frac{5}{8}$"
35°-30'
SECTION A-A
℄ BEANIE
2'-5
14"
WINDOW HEAT EXCH.
COPE TO FIT
TYP
$\frac{1}{4}$
$\frac{1}{4}$
COPE TO FIT
TYP
3"x3"x$\frac{1}{4}$" L, 304 S.S.
30°
ENLARGED BRACKET
DETAIL
ITEM NO.
PART NO.
DESCRIPTION
QTY. REQ.
PARTS LIST
UNLESS OTHERWISE SPECIFIED
FRACTIONS
DECIMALS
ANGLES
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD'S.
MAX. ALL MACHINED SURFACES
ORIGINATOR
DRAWN
CHECKED
APPROVED
APPROVED
USED ON
MATERIAL-
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
MOUNTING DETAILS
MAIN & WINDOW HEAT EXCH.
PILOLLI 11-16-71
PCV 12-7-71
SCALE
1"=1'
FILMED
DRAWING NUMBER
2625-MD-33435
REV.
A

SYM	REVISIONS DESCRIPTION	DRAWN / APPD.	DATE
A	ITEM #2 23 1/8" WAS 22 7/8, 1/2" WAS 1/4"	R.A.H. / PCV	11-20-71 / 11-20-71



NOTE:
WIND STRIPS (ITEMS 12 THRU 16) ALONG WITH TUBES

ITEM	QTY	DESCRIPTION
14	1	STRIP, 3/16" x 5/16" x 32' LG, BRASS
13	1	STRIP, 1/8" x 5/16" x 32' LG, BRASS
12	1	STRIP, 1/16" x 5/16" x 32' LG, BRASS
11	1	TUBE, 6" O.D. x .065 WL, STSTL, SMLS, TP 304
10	1	SHEET, #22 (.029) GA. x 13 1/8" x 20 29/32", STSTL 304
9	1	SHEET, #22 (.029) GA. x 13 1/8" x 23 1/16", STSTL 304
8	1	SHEET, #22 (.029) GA. x 13 1/8" x 25 7/32", STSTL 304
7	1	SHEET, #22 (.029) GA. x 13 1/8" x 27 3/8", STSTL 304
6	1	SHEET, #22 (.029) GA. x 13 1/8" x 29 1/2", STSTL 304
5	4	ROD, 1/8 DIA x 13 1/8 LG, STSTL, TP 304
4	8	BAR, FLAT, 1/4 x 1 x 4 1/4 LG, STSTL, TP 304
3	1	PIPE, 2"-SCH 10 x 17 5/8" LG, STSTL, WLD, TP 304
2 (A)	1	PIPE, 10"-SCH 5 x 23 1/8" LG, STSTL, WLD, TP 304
1	2	PLATE, 5/8 THK x 10 3/8" DIA. STSTL, TP 304

ITEM	QTY	DESCRIPTION
22	1	PIPE, 3/4"-SCH 40 x 19 1/4" LG, STSTL, WLD, TP 304
21	1	PIPE, 3/4"-SCH 40 x 28 9/32" LG, STSTL, WLD, TP 304
20	2	PIPE, 1/2"-SCH 80 x 1 3/8" LG, STSTL, WLD, TP 304
19	2	PIPE, 1/4"-SCH 80 x 7 1/4" LG, STSTL, WLD, TP 304
18	12	PIPE, 1/4"-SCH 80 x 8 1/8" LG, STSTL, WLD, TP 304
17	12	TUBE, 5/16" O.D. x .030 WL x 32' LG, SMLS COPPER
16	1	STRIP, 5/16" x 5/16" x 32' LG, BRASS
15	1	STRIP, 1/4" x 5/16" x 32' LG, BRASS

BRUNING 40-107

RAH 4-25-71
PC✓ 9-13-71

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.

PARTS LIST

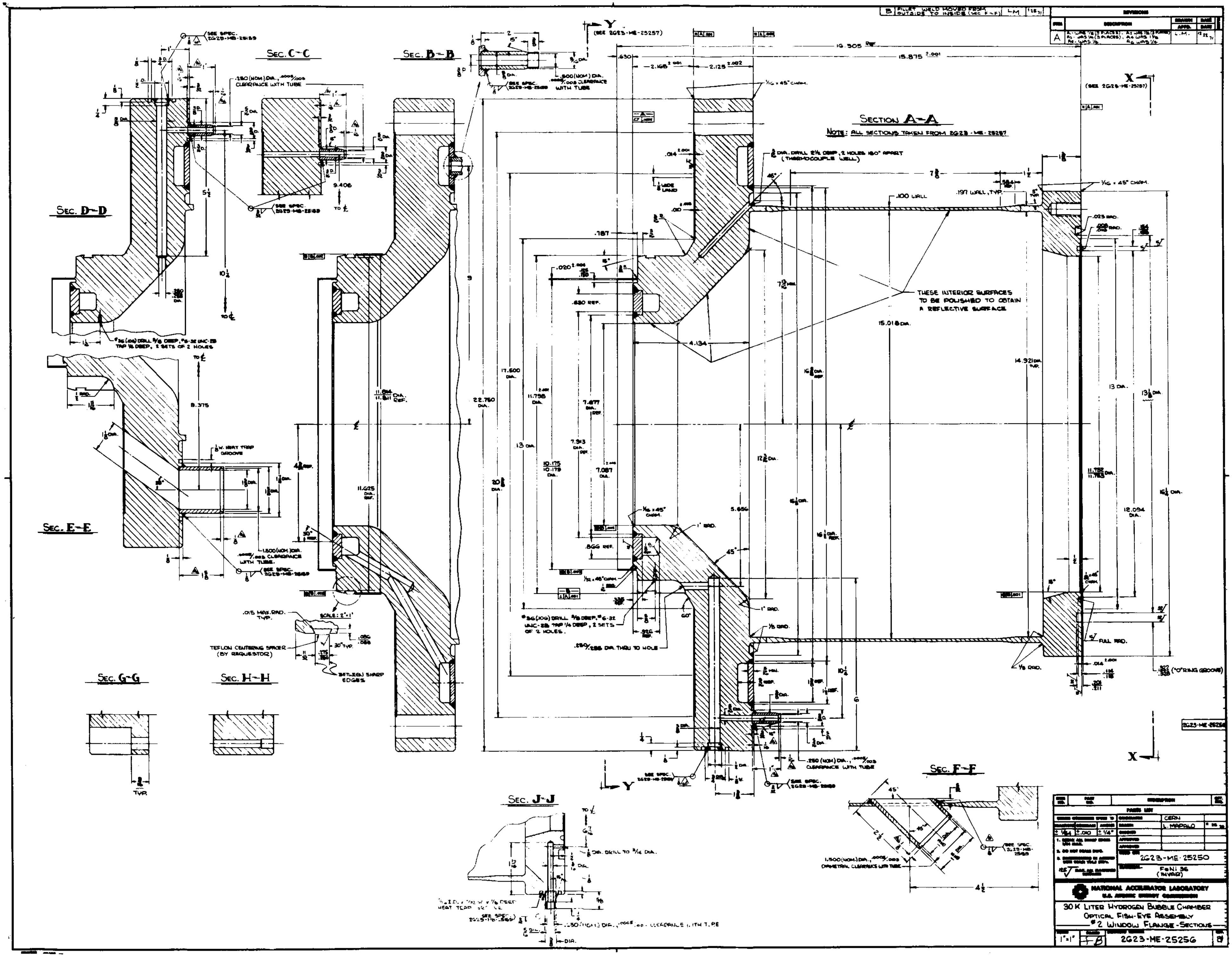
UNLESS OTHERWISE SPECIFIED: FRACTIONS ± DECIMALS ± ANGLES ±
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD'S.
√ MAX. ALL MACHINED SURFACES

ORIGINATOR / DRAWN / CHECKED / APPROVED / APPROVED / USED ON / MATERIAL-

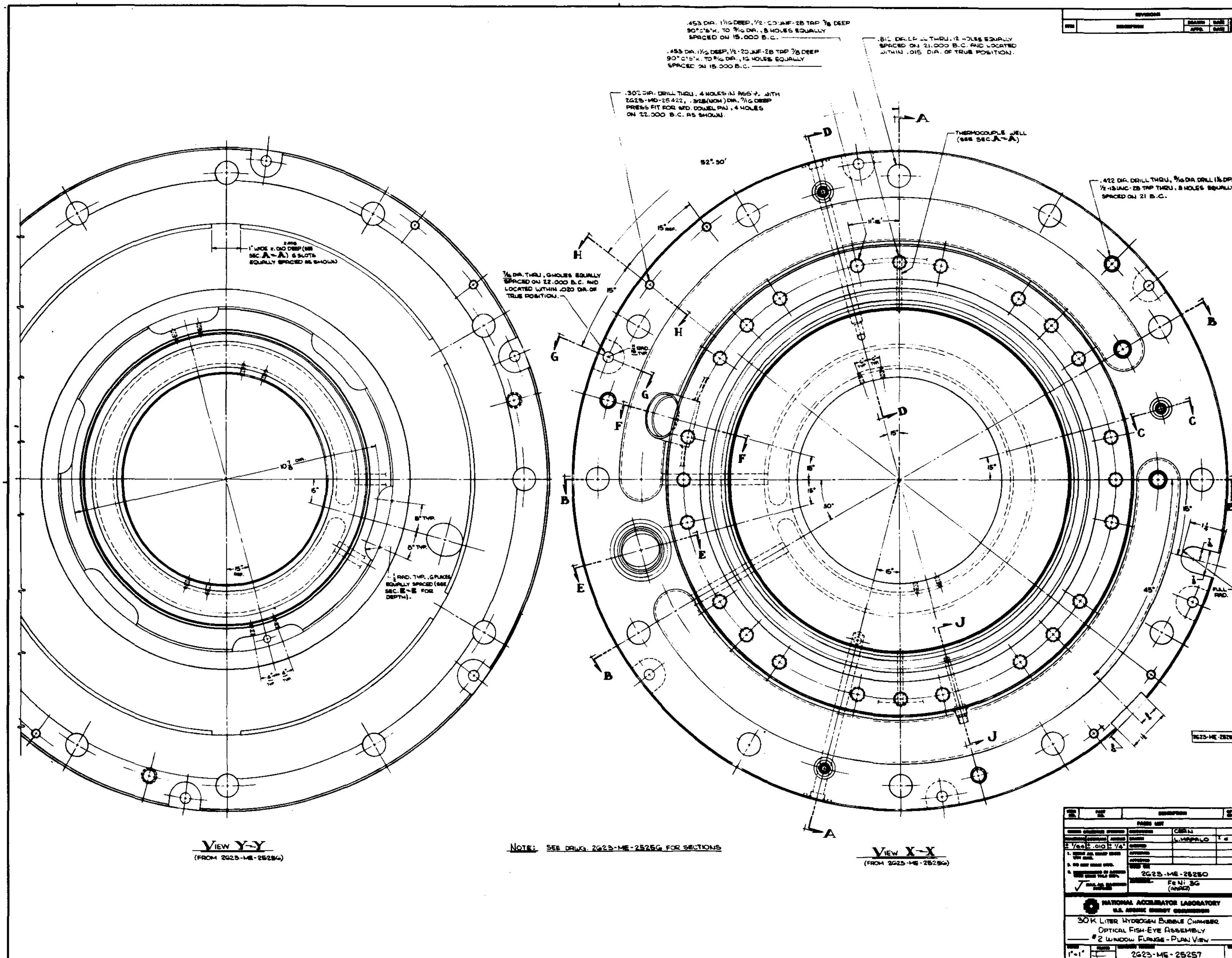
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

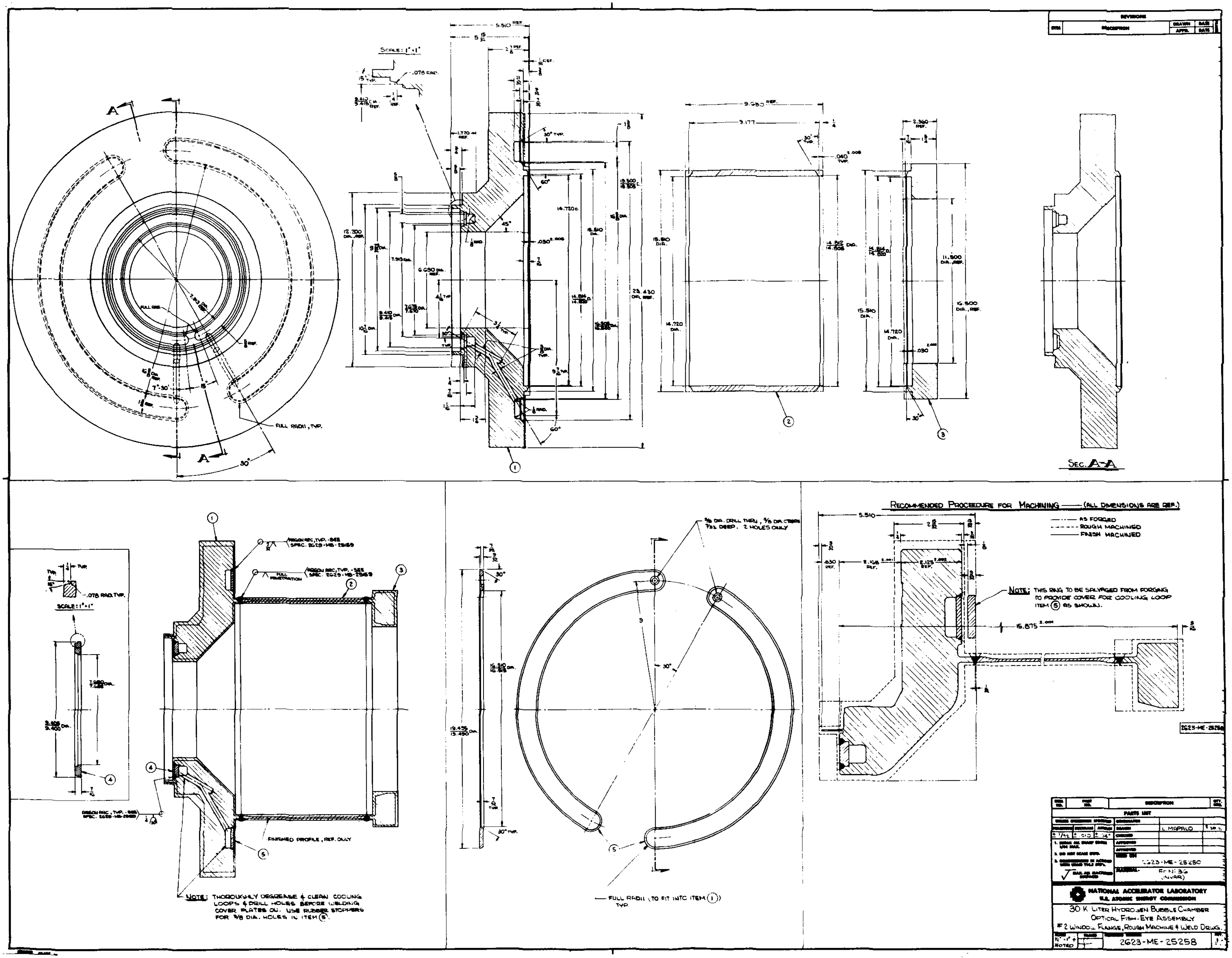
WINDOW COOLING LOOP

SCALE	FILMED	DRAWING NUMBER	REV.
FULL		2625-MD-25089	A

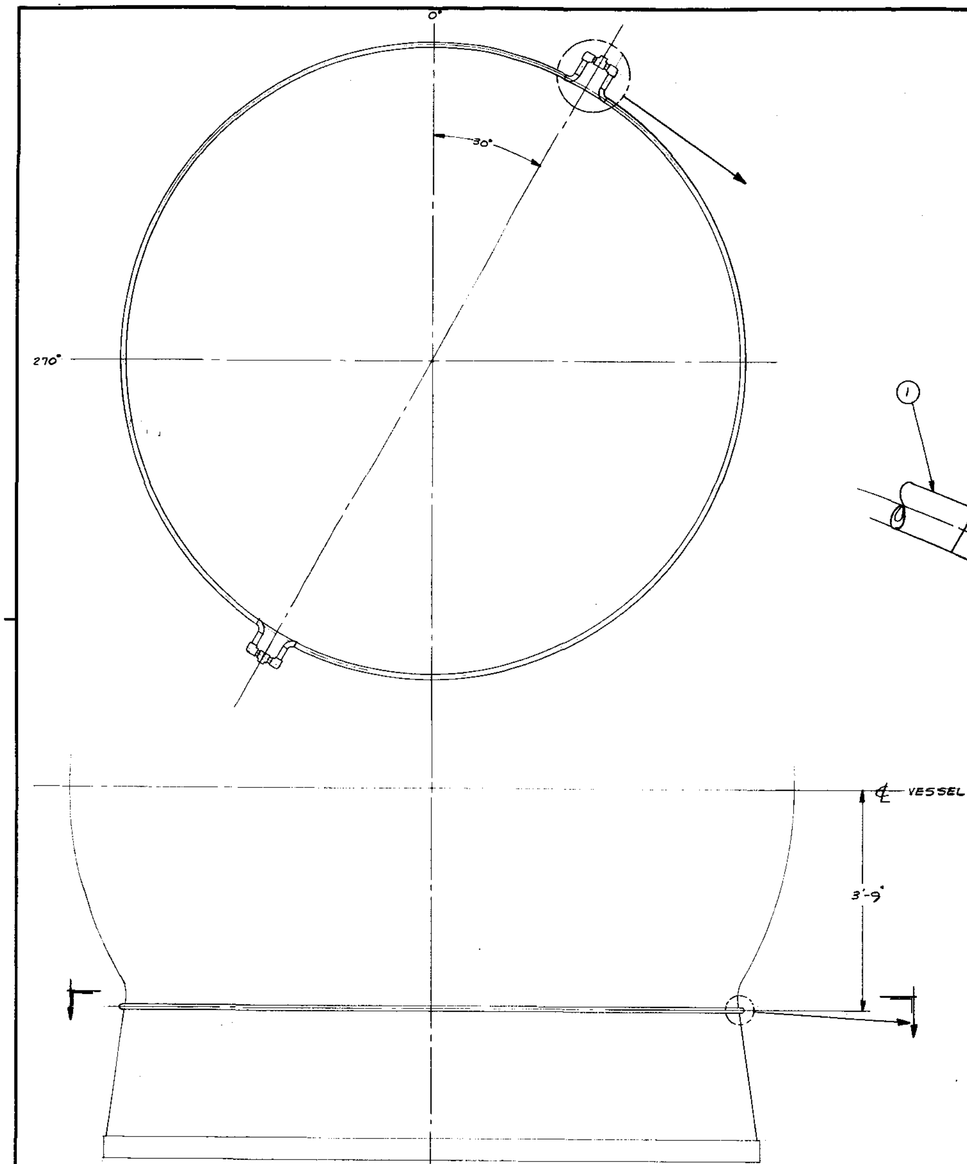


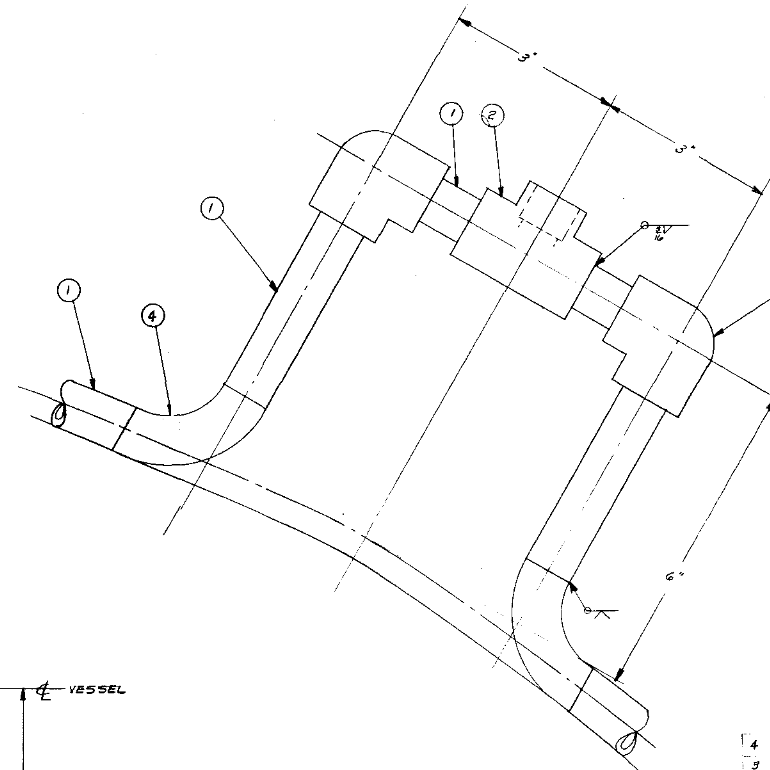
Sec. C-C
Sec. B-B
Sec. D-D
Sec. E-E
Sec. G-G
Sec. H-H
Sec. J-J
Sec. F-F
Section A-A
Note: All sections taken from 2G23-ME-25257
These interior surfaces to be polished to obtain a reflective surface
Teflon centering spacer (by requestor)
CERN
L. Mapalo
2G23-ME-25250
FeNi 36 (INVAR)
National Accelerator Laboratory
U.S. Atomic Energy Commission
30 K Liter Hydrogen Bubble Chamber
Optical Fish-Eye Assembly
#2 Window Flange-Sections
1"=1"
2G23-ME-25256

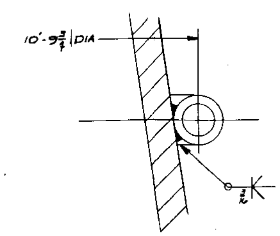

.453 DIA. 1 1/16 DEEP, 1/2-20 UNF-2B TAP 7/8 DEEP 90° C'S'K. TO 9/16 DIA., 8 HOLES EQUALLY SPACED ON 15.000 B.C.
.453 DIA. 1 1/16 DEEP, 1/2-20 UNF-2B TAP 7/8 DEEP 90° C'S'K. TO 9/16 DIA., 16 HOLES EQUALLY SPACED ON 15.000 B.C.
THERMOCOUPLE WELL (SEE SEC. A-A)
.422 DIA. DRILL THRU, 9/16 DIA DRILL 1 1/8 DP, 1/2-13 UNC-2B TAP THRU, 8 HOLES EQUALLY SPACED ON 21 B.C.
1" WIDE x .010 DEEP (SEE SEC. A-A) 6 SLOTS EQUALLY SPACED AS SHOWN
52°-30'
1/2 RAD. TYP., 6 PLACES EQUALLY SPACED (SEE SEC. E-E FOR DEPTH).
View Y-Y
(FROM 2G23-ME-25256)
NOTE: SEE DRWG. 2G23-ME-25256 FOR SECTIONS
View X-X
(FROM 2G23-ME-25256)
± 1/64
± .010
± 1/4°
CERN
L. MAPALO
2G23-ME-25250
Fe Ni 36 (INVAR)
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
30 K LITER HYDROGEN BUBBLE CHAMBER
OPTICAL FISH-EYE ASSEMBLY
#2 WINDOW FLANGE - PLAN VIEW
1"=1"
2G23-ME-25257



SCALE: 1" = 1"
SEC. A-A
RECOMMENDED PROCEDURE FOR MACHINING —— (ALL DIMENSIONS ARE REF.)
AS FORGED
ROUGH MACHINED
FINISH MACHINED
NOTE: THIS RING TO BE SALVAGED FROM FORGING TO PROVIDE COVER FOR COOLING LOOP ITEM (5) AS SHOWN.
5/8 DIA. DRILL THRU, 7/8 DIA. C'BORE 7/32 DEEP. 2 HOLES ONLY
FULL RADII (TO FIT INTO ITEM (1)) TYP.
FINISHED PROFILE, REF. ONLY
NOTE: THOROUGHLY DEGREASE & CLEAN COOLING LOOPS & DRILL HOLES BEFORE WELDING COVER PLATES ON. USE RUBBER STOPPERS FOR 5/8 DIA. HOLES IN ITEM (5).
PARTS LIST
L. MAPALO
± 1/32
± .010
± 1/4°
2623-ME-25250
FeNi 36 (INVAR)
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
30 K LITER HYDROGEN BUBBLE CHAMBER
OPTICAL FISH-EYE ASSEMBLY
#2 WINDOW FLANGE, ROUGH MACHINE & WELD DRWG.
1/2" = 1" & NOTED
2623-ME-25258







REVISIONS			
SYM	DESCRIPTION	DRAWN / APPD.	DATE / DATE

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.
4		ELBOW, ½" IPS SCH80, STSTL 304 B.W.	4
3		ELBOW, ½" IPS, SOC WELD, 2000#, STSTL304	4
2		TEE, ½" IPS, SOC WELD, 2000#, STSTL 304	2
1		PIPE, ½" SCH80, STSTL 304	

PARTS LIST

UNLESS OTHERWISE SPECIFIED

FRACTIONS	DECIMALS	ANGLES
±	±	±

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD's.

√ MAX. ALL MACHINED SURFACES

ORIGINATOR		
DRAWN		
CHECKED		
APPROVED		
APPROVED		

USED ON

MATERIAL-

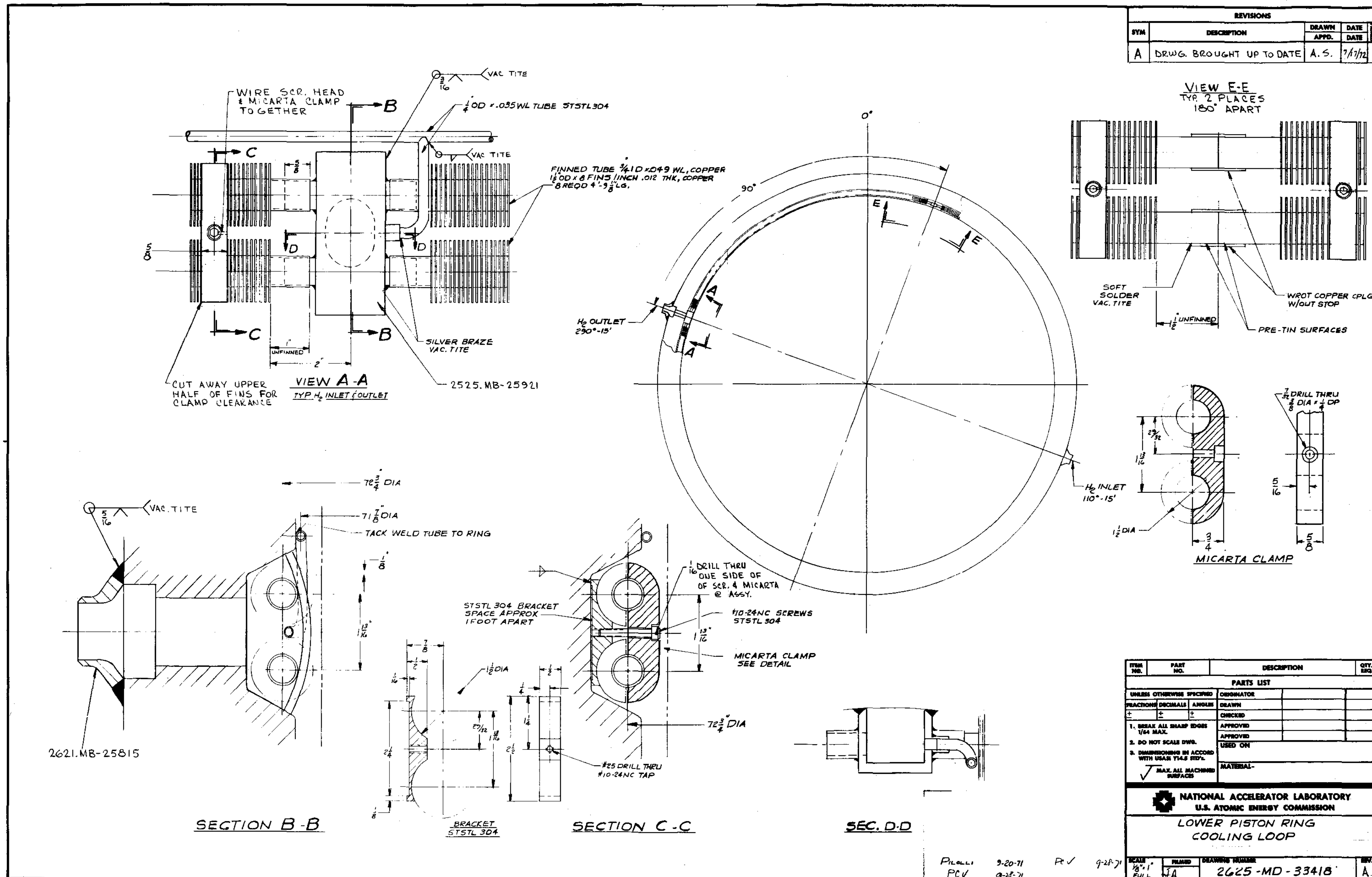
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

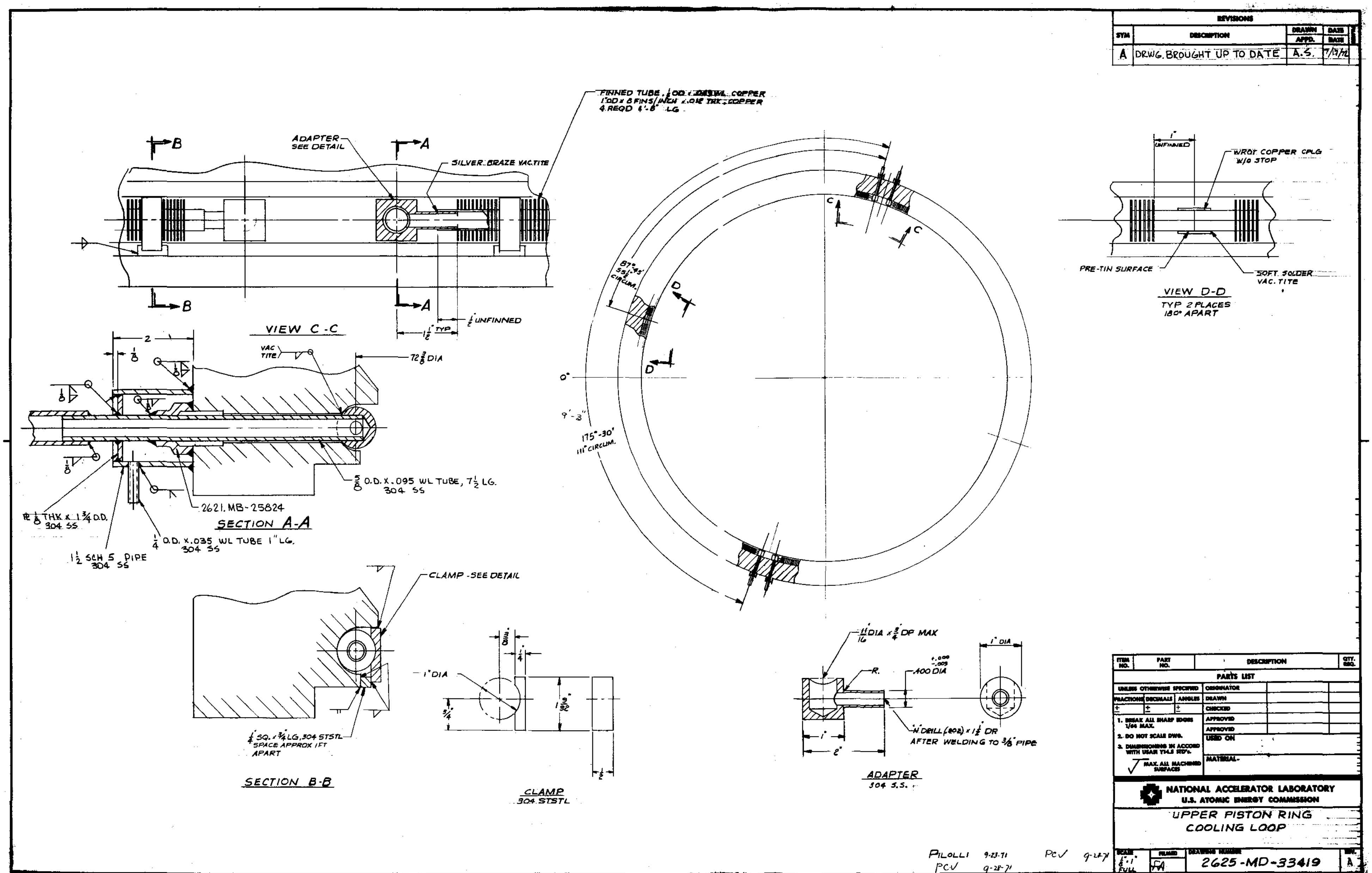
CHAMBER
SUPPORT SKIRT
EXCHANGER

SCALE	FILMED	DRAWING NUMBER	REV.
1"=1' FULL	F	2625-MD-33420	

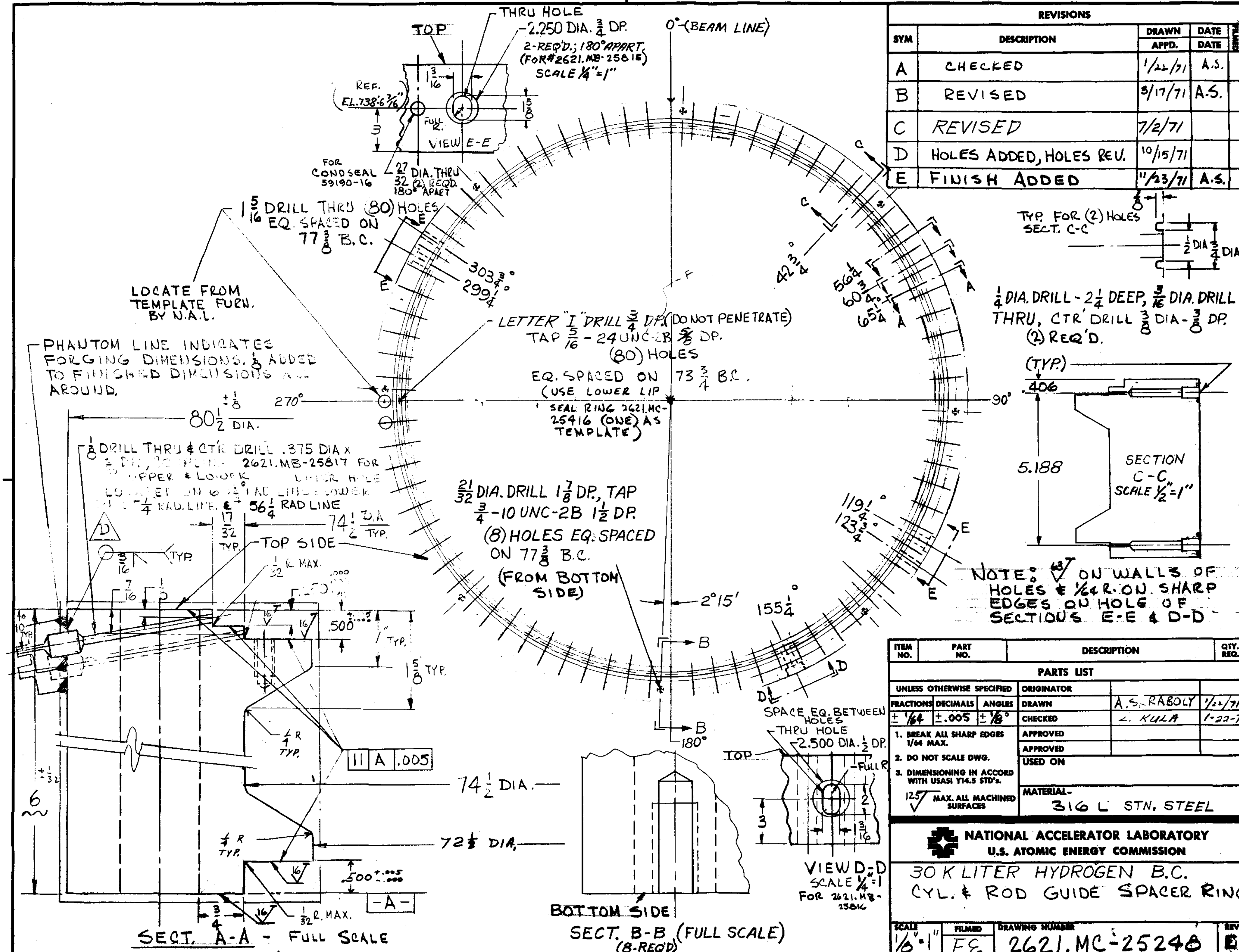
PILOLLI 9-27-71 PCV 9-28-71
PCV 9-28-71

BRUNING 40-107


REVISIONS
SYM | DESCRIPTION | DRAWN / APPD. | DATE
A | DRWG. BROUGHT UP TO DATE | A.S. | 7/17/72
VIEW E-E
TYP. 2 PLACES 180° APART
SOFT SOLDER VAC. TITE
WROT COPPER CPLG W/OUT STOP
1 1/2" UNFINNED
PRE-TIN SURFACES
WIRE SCR. HEAD & MICARTA CLAMP TOGETHER
1/4 OD x .035 WL TUBE STSTL 304
VAC TITE
FINNED TUBE 3/4 ID x .049 WL, COPPER 1 1/2 OD x 8 FINS/INCH .012 THK, COPPER 8 REQD 4'-9 1/8" LG.
SILVER BRAZE VAC. TITE
2525.MB-25921
CUT AWAY UPPER HALF OF FINS FOR CLAMP CLEARANCE
VIEW A-A
TYP. H2 INLET & OUTLET
1" UNFINNED
2"
0°
90°
H2 OUTLET 290°-15'
H2 INLET 110°-15'
7/32 DRILL THRU 3/8 DIA x 1/4 DP
1 1/2 DIA
MICARTA CLAMP
72 3/4" DIA
71 7/8" DIA
TACK WELD TUBE TO RING
VAC. TITE
2621.MB-25815
SECTION B-B
1/16 DRILL THRU ONE SIDE OF OF SCR. & MICARTA @ ASSY.
STSTL 304 BRACKET SPACE APPROX 1 FOOT APART
#10-24NC SCREWS STSTL 304
MICARTA CLAMP SEE DETAIL
#25 DRILL THRU #10-24NC TAP
BRACKET STSTL 304
SECTION C-C
SEC. D-D
PARTS LIST
UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD'S.
MAX. ALL MACHINED SURFACES
ORIGINATOR
DRAWN
CHECKED
APPROVED
USED ON
MATERIAL-
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
LOWER PISTON RING COOLING LOOP
SCALE 1/8" = 1' FULL
DRAWING NUMBER 2625-MD-33418
REV. A



REVISIONS
SYM
DESCRIPTION
DRAWN
APPD.
DATE
A DRWG. BROUGHT UP TO DATE A.S. 7/13/72
FINNED TUBE
1" OD x 8 FINS/INCH x .012 THK. COPPER
4 REQD
ADAPTER SEE DETAIL
SILVER BRAZE VAC.TITE
B
A
VIEW C-C
1/2" UNFINNED
1 1/2" TYP
2
1/8
VAC TITE
72 3/8 DIA
5/8 O.D. X .095 WL TUBE, 7 1/2 LG. 304 SS
2621.MB-25824
SECTION A-A
1/8 THK x 1 3/4 O.D. 304 SS
1/4 O.D. X .035 WL TUBE 1" LG. 304 SS
1 1/2 SCH 5 PIPE 304 SS
C
D
87°-45'
55 1/2" CIRCUM.
0°
9'-3"
175°-30'
111" CIRCUM.
1" UNFINNED
WROT COPPER CPLG W/O STOP
PRE-TIN SURFACE
SOFT SOLDER VAC. TITE
VIEW D-D
TYP 2 PLACES 180° APART
CLAMP - SEE DETAIL
1/4 SQ. x 3/4 LG. 304 STSTL
SPACE APPROX 1FT APART
SECTION B-B
1" DIA
3/4
1 9/32
1/2
CLAMP
304 STSTL
11/16 DIA x 3/4 DP MAX
R.
.400 DIA
+.000 -.005
1" DIA
"N" DRILL (.302) x 1 1/2 DP AFTER WELDING TO 3/8 PIPE
1"
2"
ADAPTER
304 S.S.
ITEM NO.
PART NO.
DESCRIPTION
QTY. REQ.
PARTS LIST
UNLESS OTHERWISE SPECIFIED
FRACTIONS
DECIMALS
ANGLES
ORIGINATOR
DRAWN
CHECKED
APPROVED
APPROVED
USED ON
MATERIAL
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD'S.
MAX. ALL MACHINED SURFACES
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
UPPER PISTON RING COOLING LOOP
PILOLLI 9-23-71
PCV 9-28-71
PCV 9-28-71
SCALE
FULL
FILMED
DRAWING NUMBER
2625-MD-33419
REV.
A



REVISIONS			
SYM	DESCRIPTION	DRAWN / APPD.	DATE
A	CHECKED	1/22/71	A.S.
B	REVISED	3/17/71	A.S.
C	REVISED	7/2/71	
D	HOLES ADDED, HOLES REV.	10/15/71	
E	FINISH ADDED	11/23/71	A.S.

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTIONS ± 1/64	DECIMALS ±.005	ANGLES ± 1/8°	ORIGINATOR		
			DRAWN	A.S. RABOLY	1/22/71
			CHECKED	L. KULA	1-22-71
			APPROVED		
			APPROVED		

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD's.

125 MAX. ALL MACHINED SURFACES

USED ON

MATERIAL- 316 L STN. STEEL

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

30 K LITER HYDROGEN B.C.
CYL. & ROD GUIDE SPACER RING

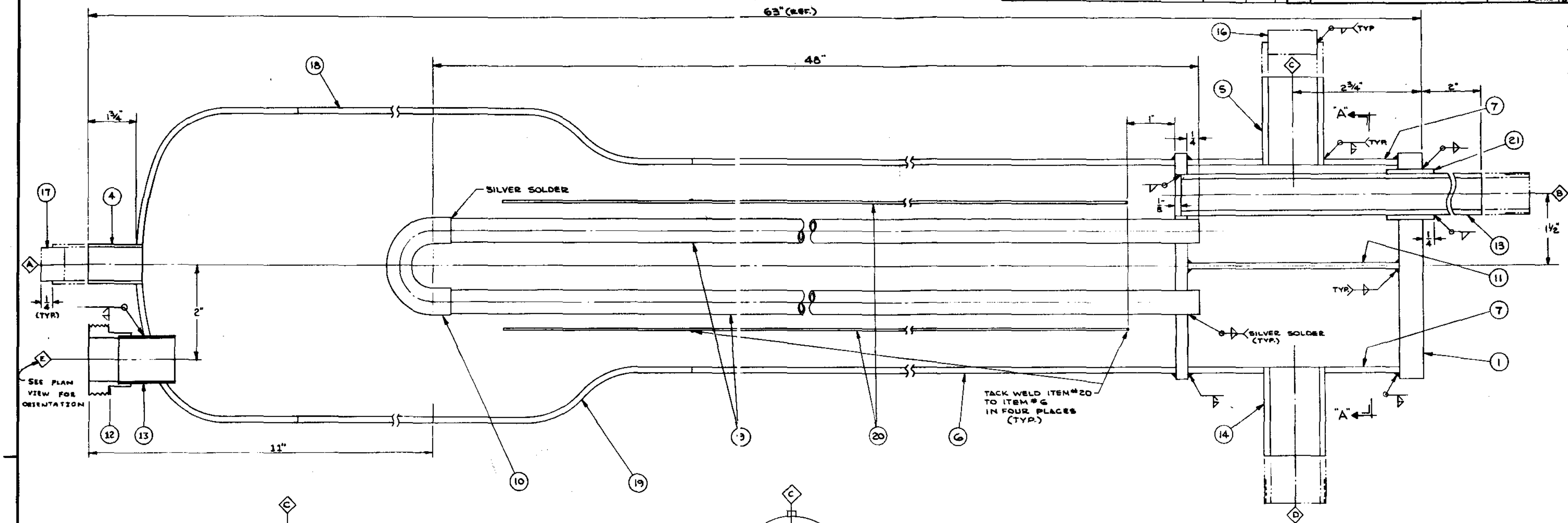
SCALE	FILMED	DRAWING NUMBER	REV.
1/6"=1"	FE	2621.MC-25248	E

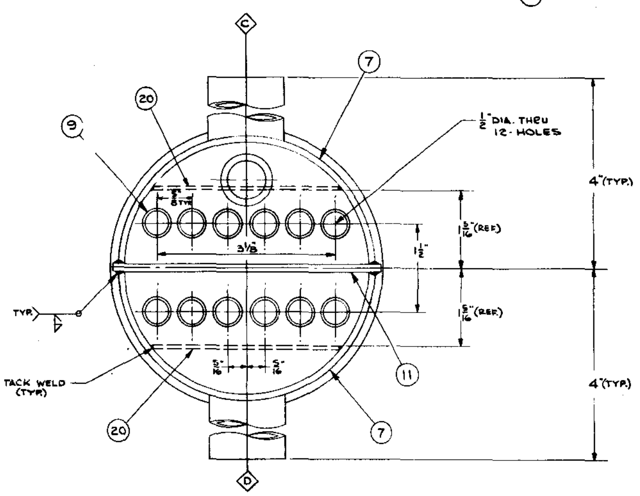
BRUNING 40-107

A	DELETED ITEMS 3 & 15 REVISED ITEMS 12 & 13, ADDED PLAN VIEW	RISHKO	12-2-71	

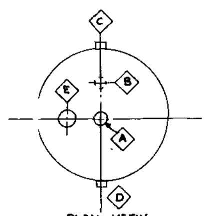
REVISIONS

SYM	DESCRIPTION	DRAWN / APPD.	DATE / DATE





SECTION "A-A"



PLAN VIEW

ITEM NO.	DESCRIPTION	QTY. REQ.
21	PIPE, 3/4"-SCH 10 × 1" LG, STSTL, WLD, TP 304	1

ITEM NO.	DESCRIPTION	QTY. REQ.
20	SHEET, #16 GA. (.059) THK × 3 1/4" × 45" LG, STSTL 304	2
19	REDUCER, CONC, 6" × 4"-SCH 10, STSTL, TP 304	1
18	PIPE, 6"-SCH 10 × 5" LG, STSTL, WLD, TP 304	1
17	BAR, RD, 9/16" DIA × 1/2" LG, STSTL, TP 304	1
16	BAR, RD, 1" DIA × 1/2" LG, STSTL, TP 304	1
(A)		
14	NIPPLE, T.O.E, 1"-SCH 40 × 3" LG, STSTL, WLD, 304	1
(A) 13	TUBE, 1" OD × .049 WL × 2" LG, STSTL, A213-TP304	1
(A) 12	CONOSEAL, 54857-16 1" OD. TP304 STSTL.	1
11	PLATE, 1/8" THK × 4 1/2" × 4 3/4", STSTL, TP 304	1

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.
10		RETURN BEND, 3/8", COPPER 1 1/2" C TO C	6
9		TUBE, 1/2" O.D. × .035 WL × 48" LG, SMLS, COPPER	12
8		CAP, 6"-SCH 10 × STSTL, TP 304	1
7		PIPE, 4"-SCH 10 × 4 1/2" LG, STSTL, WLD, TP 304	1
6		PIPE, 4"-SCH 10 × 42" LG, STSTL, WLD, TP 304	1
5		PIPE, 1"-SCH 40 × 3" LG, STSTL, WLD, TP 304	1
4		PIPE, 1/2"-SCH 40 × 3" LG, STSTL, WLD, TP 304	1
(A)			
2		PLATE, 1/4" THK × 4 3/4" O.D. STSTL, TP 304	1
1		PLATE, 1/2" THK. × 4 3/4" O.D, STSTL, TP 304	1

PARTS LIST

GENERAL NOTES:

1. CUT ITEM #7 IN HALF AND WELD BOTH PIECES TO ITEM #11
2. DESIGN PRESSURE IS 165 PSIA FOR ALL CIRCUITS

UNLESS OTHERWISE SPECIFIED				
FRACTIONS ±	DECIMALS ±	ANGLES ±	ORIGINATOR	
			DRAWN	
			CHECKED	
1. BREAK ALL SHARP EDGES 1/64 MAX.			APPROVED	
2. DO NOT SCALE DWG.			APPROVED	
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD'S.			USED ON	
√ MAX. ALL MACHINED SURFACES			MATERIAL-	

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

PUMP LOOP HEAT EXCHANGER

RAH 6-29-71 PCV 9-11-71
PCV 9-15-71

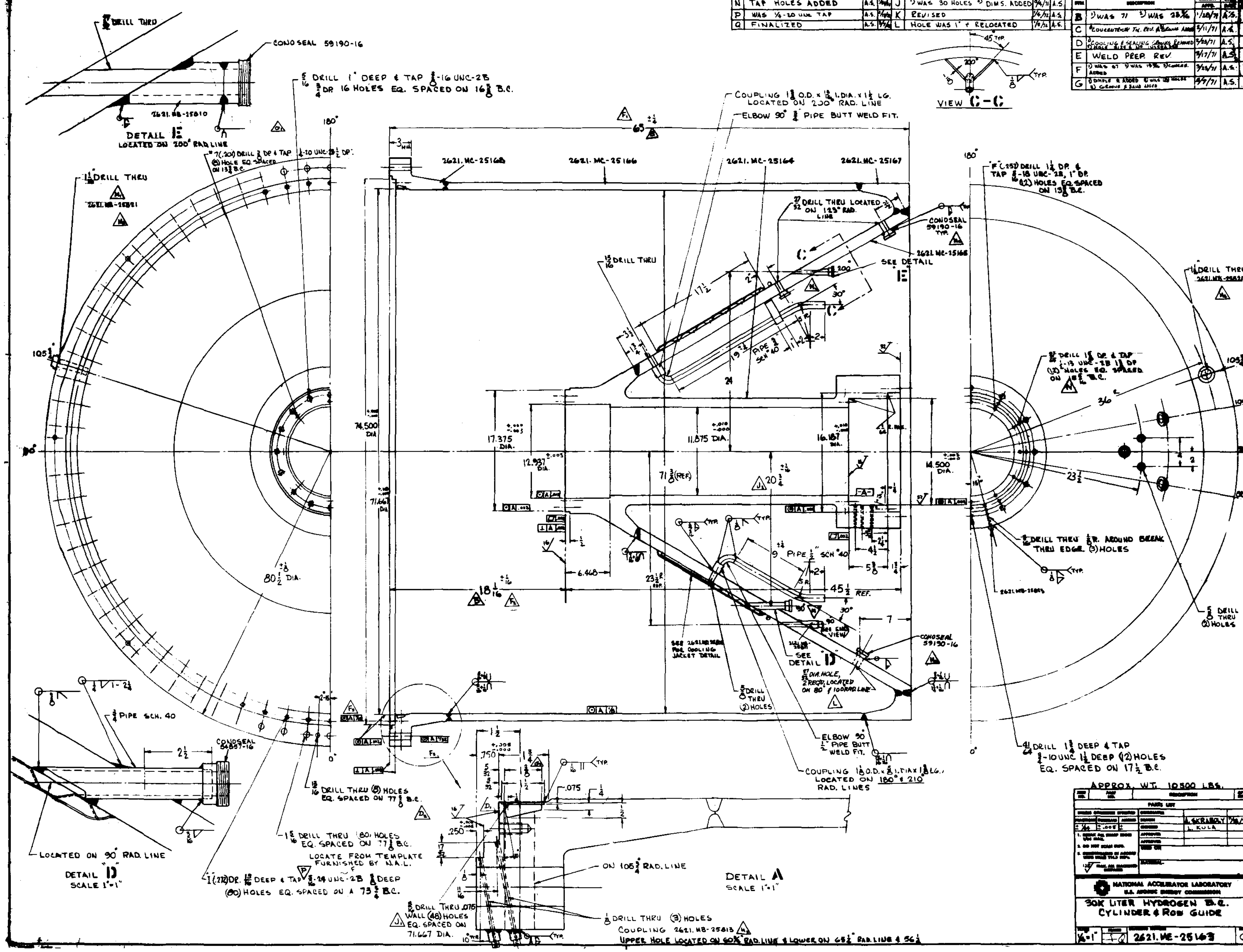
SCALE	FILMED	DRAWING NUMBER	REV.
FULL	A	2625-MD-25091	A

40-307

M	CTR BORE REMOVED & COUPLINGS ADDED	A.S.		H	REVISED		A.S.		
N	TAP HOLES ADDED	A.S.		J	1) WAS 30 HOLES 3) DIMS. ADDED		A.S.		
P	WAS 1/4-20 UNC TAP	A.S.		K	REVISED		A.S.		
Q	FINALIZED	A.S.		L	HOLE WAS 1" & RELOCATED		A.S.		

REVISIONS

SYM	DESCRIPTION	DATE	APPD.
B	1) WAS 71 2) WAS 28 3/16	1/28/71	A.S.
C	CONCENTRICITY TOL. REV. & SEALING ADDED	3/11/71	A.S.
D	COOLING & SEALING GROOVES REMOVED, HOLE SIZE & DP. ADDED	3/23/71	A.S.
E	WELD PREP. REV.	3/17/71	A.S.
F	1) WAS 65 2) WAS 19 5/16 3) CORRECT. ADDED	3/23/71	A.S.
G	1) DIMPLE & ADDED 2) WAS 20 HOLES 3) GROOVE & BAND ADDED	4/7/71	A.S.



APPROX. WT. 10500 LBS.

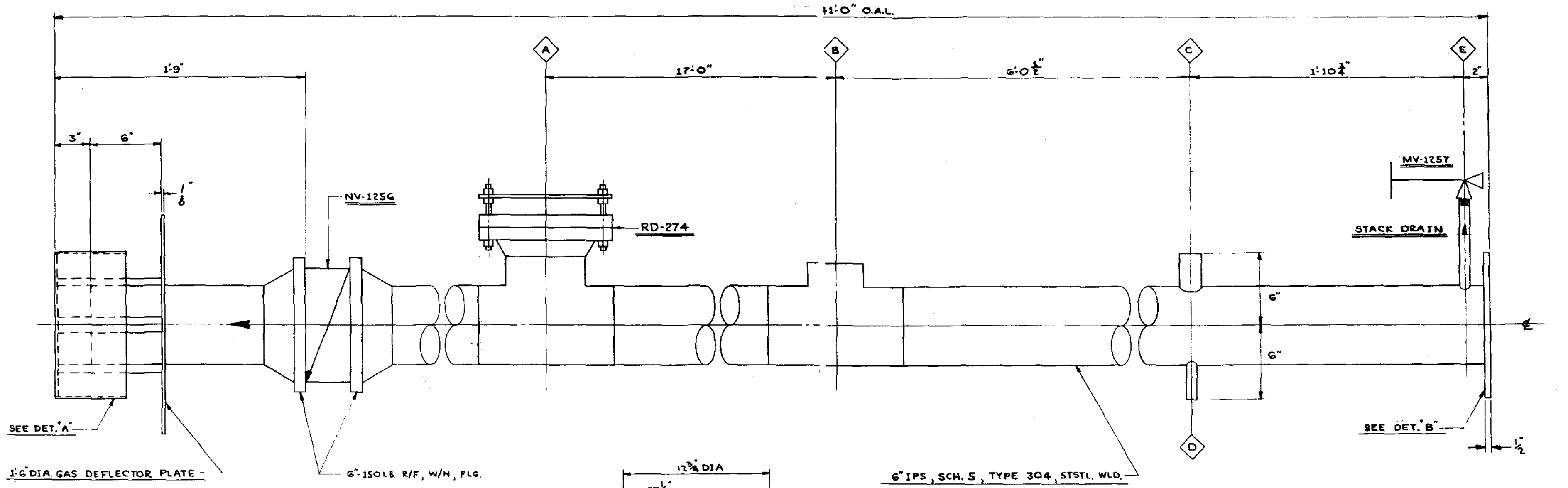
PARTS LIST

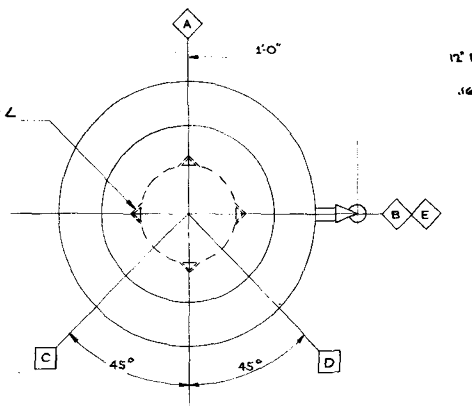
DRAWN: A. SKRABOLY
CHECKED: L. KULA

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

30K LITER HYDROGEN B.C.
CYLINDER & ROD GUIDE

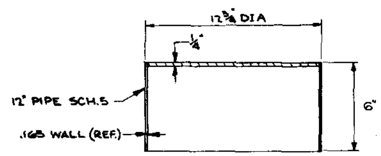
SCALE 1/8=1" | 2621.ME-25163 | Q





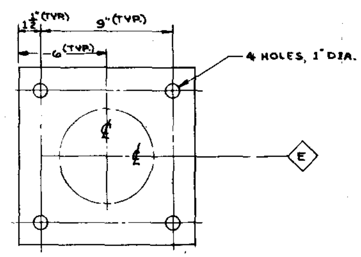
PLAN VIEW

TRUE ORIENTATION



DETAIL "A"

RAIN CAP



DETAIL "B"

BASE PLATE

NOZZLE CHART			
LETTER	SIZE	SCHEDULE	END PREPARATION
A	6" IPS	SCH. 5	——
B	4" IPS	SCH. 5	BUTT WELD
C	3" IPS	SCH. 10	BUTT WELD
D	1/2" IPS	SCH. 40	PLAIN END
E	1/2" IPS	SCH. 40	——

REVISIONS			
SYM	DESCRIPTION	DRAWN / APPD.	DATE / DATE

ITEM NO.	PART NO.	DESCRIPTION	QTY. REQ.

PARTS LIST

UNLESS OTHERWISE SPECIFIED: FRACTIONS ± DECIMALS ± ANGLES ±

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD'S.

MAX. ALL MACHINED SURFACES

ORIGINATOR
DRAWN
CHECKED — 1/25/71
APPROVED — 2/71
APPROVED
USED ON
MATERIAL-

NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION

"V-V"
MAIN HYDROGEN
VENT STACK

SCALE 3"=1'-0" | FILMED F | DRAWING NUMBER 2625.MD-25079 | REV.

E. RISHKO 12-30-70 PCV 12-31-70
PCV 12-31-70

BRUNING 40.107