PRESSURE VESSEL ENGINEERING NOTE
PER MANDATORY STANDARD SD37
(CHAPTER 14.1, LAB SAFETY MANUAL)

Prepared by: R.W. Fast
Preparation date: JUL 16 1986

5.1 Description and Identification

Fill in the label information below:

This vessel conforms to engineering standard SD37

Vessel Title Muon Lab helium dewar - inner vessel

Vessel Number RD-1139

Vessel Drawing Number 2753.700-MD-193318

← Obtain from Division/Section Safety Officer

Maximum Allowable Working Pressure (MAWP) 100 PSID, 85 PSIG

Working Temperature Range 100 °F -452 °F

Contents liquid helium

Designer/Manufacturer CDM Machining & Fabrication Co., Commerce City, Colorado

Test Pressure (if tested at Fermi) **Acceptance Date:**

PSI, Hydraulic Pneumatic

Accepted as conforming to standard by
K.C. Stanfield

← Actual signature required in this space

of Division/Section Research Division

NOTE: Any subsequent changes in contents, pressures, temperatures, valving, etc., which affect the safety of this vessel shall require another review and test.

Reviewed by: J. Hem **Date:** 7/31/86

Director's signature (or designee) if the vessel is for manned areas but doesn't conform to the requirements of the standard.

Date:

Lab Property Number(s): 55367

Lab Location Code: NEU NMS **(obtain from Safety Officer)**

Purpose of Vessel(s): To contain liquid helium as part of the refrigeration system for the superconducting magnets in the Muon Laboratory.

Vessel Capacity/Size: 460 litres, 36-inch diameter x 76 inches

Normal Operating Pressure (OP) 9 PSIG (1.6 ata)

MAWP-OP = 70 PSI

Is the above enough to provide relief cracking pressure tolerance plus system uncertainty tolerance per M-9. YES

As an option, provide a photo of the entire vessel in the Appendix.

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List the numbers of all pertinent drawings and the location of the originals. (Append copies).

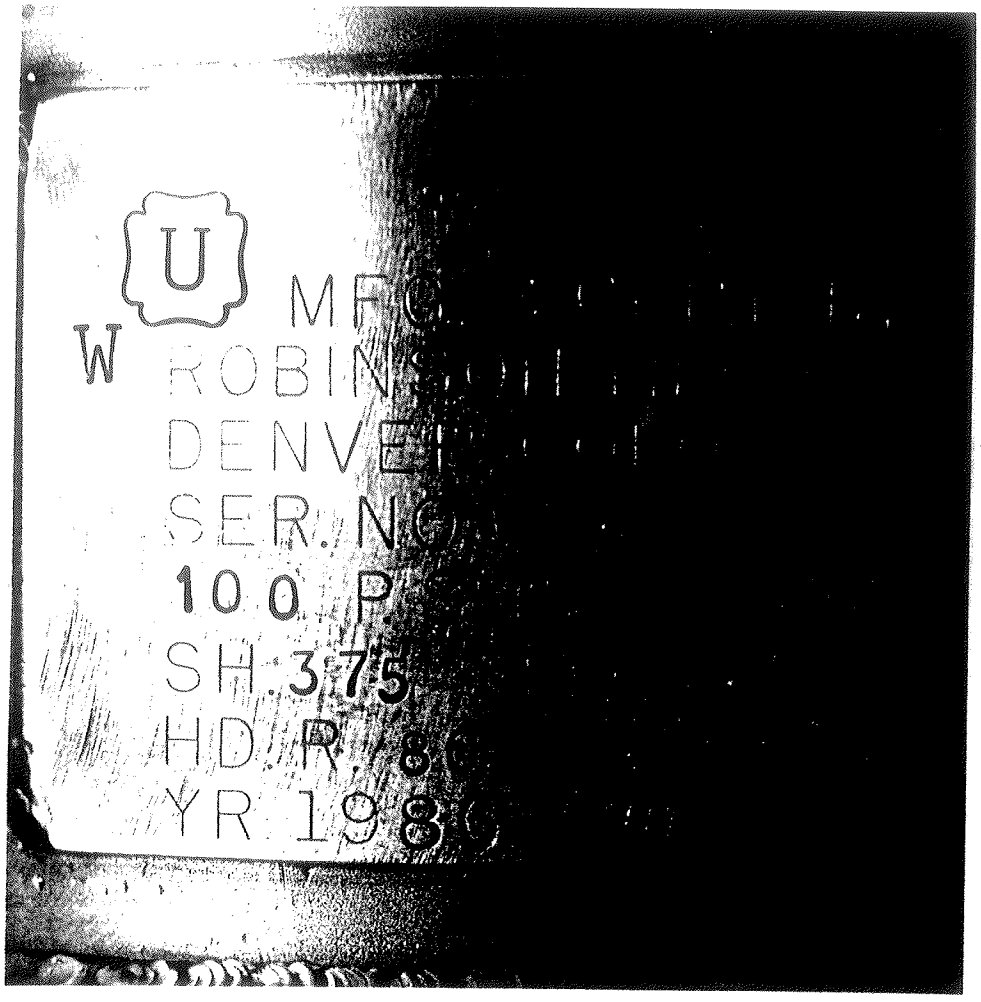
Drawing #	Location of Original
2753.700-MD-193318	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193319	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193320	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193325	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193328	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193329	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193333	Wilson Hall - 11E, RD/Cryo

5.2 Design Verification

Does the vessel(s) have a U stamp? Yes X No _____. If "Yes", fill out data below and skip page 3; if "No", fill out page 3 and skip this page.

Staple photo of U stamp plate below.

Copy "U" label details to the side if photo is not clear of if copies are unreadable.



Copy data here:

MFG & CERT BY

ROBINSON MFG. CO

DENVER, COLO

SER NO 1-6

100 PSI AT -452F

SH 375 HD 375

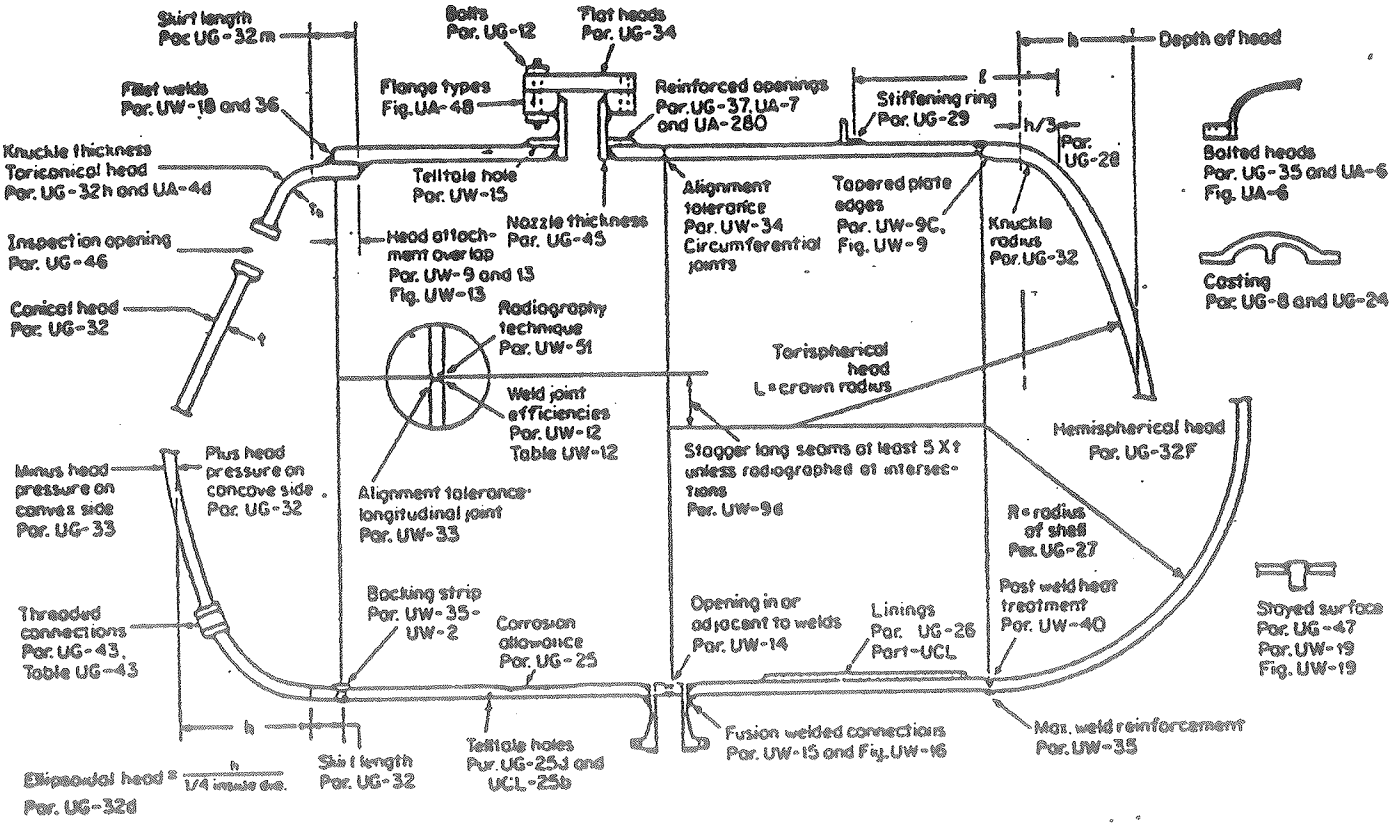
HD R 80-10

YR 1986

U

W

On the sketch below, circle all applicable sections of the ASME code per Section VIII, Division I. List the results of all calculations. (Insert copies of calculations in the appendix).



Summary of ASME Code

Item	Reference ASME Code Section	CALCULATION RESULT (Required thickness or stress level vs. actual thickness or calculated stress level)
Not Applicable	- Vessel is Code Stamped	vs.
		vs.
		vs.
		vs.
		vs.

If this vessel is exceptional or had exceptional parts, list their details under 5.6. Yes _____ No X

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5.3 System Venting. Provide the system schematic in the Appendix. if the vessel safety is system sensitive. See Fig. 1.

Is it possible to isolate the relief valves by a valve from the vessel?

Yes _____ No X

If "Yes", the system must conform to M-5. Provide an explanation on the appended schematic. (An isolatable vessel, not conforming to M-5 violates the Standard.)

Is the relief cracking pressure set at or below the M.A.W.P.?

Yes X No _____ Actual setting 85 PSI G
(A no response violates the Standard.)

Is the pressure drop of the relief system at maximum anticipated flow such that vessel pressure never rises above the following? (UG 125)

Yes X No _____

110% of MAWP (one relief)
116% of MAWP (multiple reliefs)
121% of MAWP (unexpected heat source)

Provide test or calculational proof in the Appendix. Appendix A, B, C and D.
(Non-conforming pressure rises violate the Standard.)

List of reliefs and settings:

	Manufacturer	Relief	Setting	Flow Rate	Size
SV-310-H	Anderson, Greenwood Corp.	81S1216-F	85 psig	812 SCFM-air	orifice 0.503 in^2
SV-330-H	Fike Metal Products Corp.	CPV-UT-1"	90 psig	940 SCFM-air	1"

Is the relief device an ASME stamped device? Yes X No _____

5.4 Operating Procedure

Is an operating procedure necessary for the safe operation of this vessel?

Yes ____ No X . If "Yes", please append.

5.5 Welding Information

Has the vessel been fabricated in a Fermilab shop? Yes _____ No X

If "Yes", append a copy of the welding shop statement of welder qualification and a copy of the Welding Procedure Specification (WPS) used to weld this vessel.

5.6 Exceptional, Existing, Used, and Non-Manned Area Vessels

Is this vessel or any part thereof in the above categories? Yes _____ No X

If "Yes", follow the Engineering Note requirements for documentation in free form below.

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FERMILAB
ENGINEERING NOTE

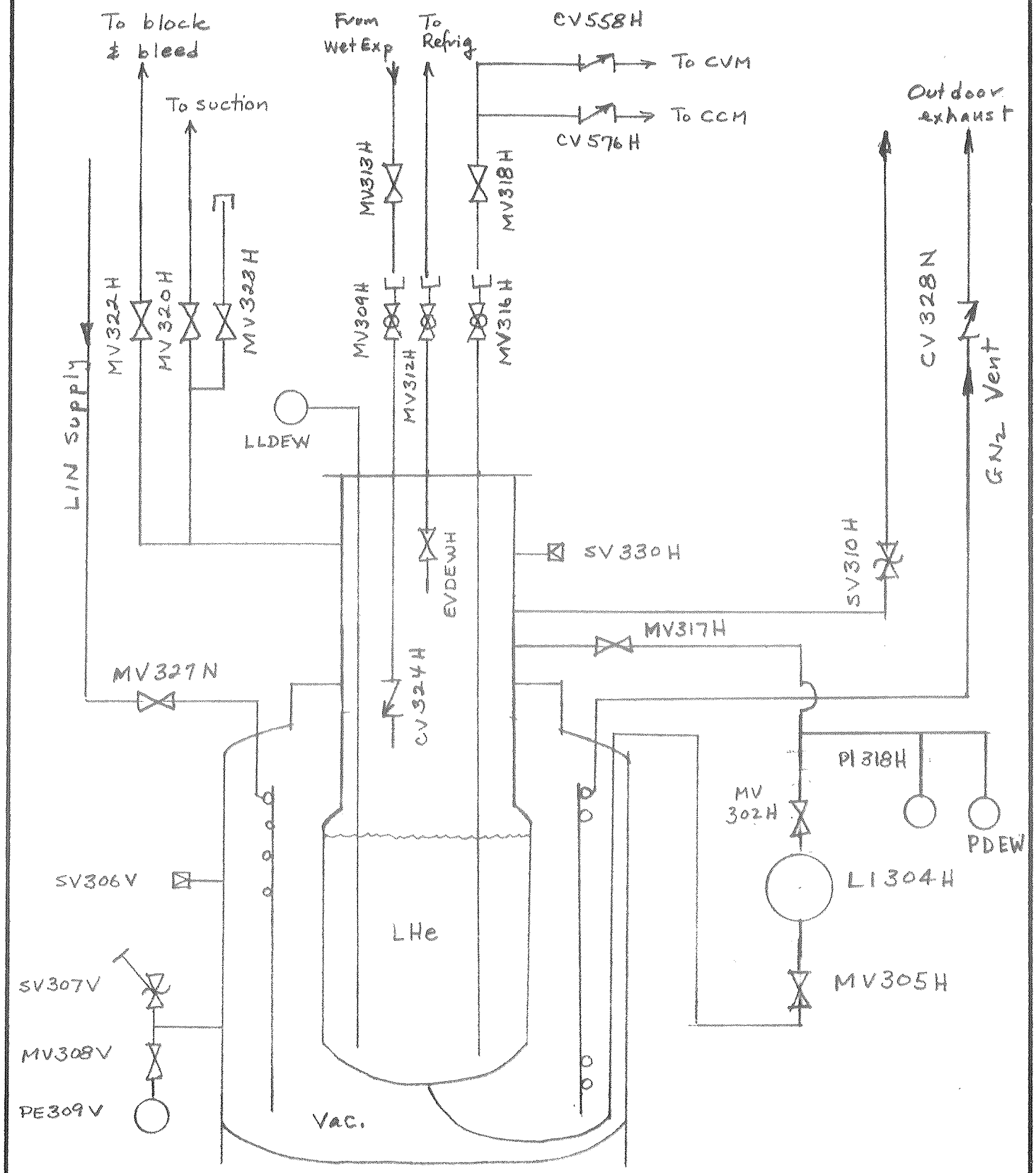
SECTION	PROJECT	SERIAL-CATEGORY	PAGE
			5

SUBJECT: Fig 1. Flow Schematic

NAME:

DATE:

REVISION DATE:



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Appendix A: Heat load to inner (LHe) vessel upon loss of vacuum

OBJECT

To calculate the heat load on the inner vessel following a sudden, massive loss of insulating vacuum. The heat loads specifically due to gas conduction and air condensation are calculated.

GENERAL ASSUMPTIONS

1. That the heat sinking capability of the radiation shield is negligible.

2. That there is no flow into the inner vessel from the circuit elements on the downstream side, i.e. the superconducting magnets. This situation can be achieved completely by removing the connecting u-tubes and partially because of the check valves (CV-558-H and CV-576-H) in the transfer line to the magnets.

SYSTEM PARAMETERS

Surface area of inner vessel

Total surface area = area of cylindrical shell and straight flange
+ area of Brighton 80-10 heads
+ area of neck
= (36 ϕ x 15 lg)+(2 x 39.5 ϕ)
+ (8.625 ϕ x 44-3/4 lg)
= (11.8 + 17.0 + 8.4) ft^2
= 37.2 ft^2

Volume of vessel

Total volume = volume of cylinder and heads
+ volume of neck
= (36 ϕ x 15 lg)+(2 x 22 gal) +
(8.625 ϕ x 44-3/4 lg)
= (250.3 + 166.5 + 42.9) L = 459.7 L

Maximum LHe volume (excluding neck) = 416.8 L

Surface area of outer vessel

= area of cylindrical shell + area of Brighton ASME F&D heads + area of neck
= (42 ϕ x 29.625 lg)+(2 x 45 ϕ)+(16 ϕ x 34 lg)
= (27.1 + 22.0 + 11.9) ft^2 = 61.0 ft^2

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DESCRIPTION OF FAILURE MODES

There are two general failures which result in loss of insulating vacuum: (1) a leak in the inner vessel, with the outer (vacuum) shell remaining intact, which allows helium to infiltrate the multi-layer insulation (MLI) up to a pressure determined by the relief device on the vacuum space and (2) a leak in the outer vessel, with the inner vessel intact which allows ambient air to pass into the MLI up to a maximum pressure of 15 psia. The former causes a helium gas conduction heat load to the balance of the contents in the inner vessel; the latter a liquid air condensation heat load. The first of these failures will, since the inner vessel and piping is Code stamped, be considered as "unexpected"; the second will not be "unexpected".

We will not address double failures, e.g. simultaneous leaks in both inner and outer vessels.

CALCULATIONS

Heat load - helium gas conduction

The heat load, q, to the inner vessel for gas conduction is given as

$$q = UA\,(100-t) \qquad \text{(Eq. A1)}$$

where

U = thermal conductance = thermal conductivity/insulation thickness
A = surface area of outer vessel = 61.0 ft^2
t = temperature, inner vessel at the relief pressure

We shall evaluate U for the helium gas at $100^{\circ}F$,

k = thermal conductivity of He at 1 ata and $100^{\circ}F$ (311 K)
= 1.587 mW/cm-K (NBS Tech Note 631)
= 0.09171 Btu/hr-ft-$^{\circ}F$

y = thickness of insulation
= radial thickness of vacuum insulating space
= 3" = 0.25 ft

and

$$U(He) = 0.09171/0.25 = 0.3668 \text{ Btu/hr-ft}^2\text{-}^{\circ}F$$

At the relief pressure of 85 psig (6.8 ata), t = 6.4 K = $11.5^{\circ}R$ = $-448^{\circ}F$. With these parameter values the gas conduction heat load is calculated to be

$$q(He) = (0.3668)(61.0)(548) \text{ Btu/hr} = 12261 \text{ Btu/hr} = 3594 \text{ W.}$$

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Heat load - condensation

The condensation heat load was estimated using Fig. 6.3 of NBS Monograph 111, "Technology of Liquid Helium", which is reproduced as Fig. A1.

It can be seen from the assembly drawing (2753.7-MD-193317) that the dewar has a total of 64 layers of multi-layer insulation (MLI). The heat flux of 15,000 Btu/hr found in Fig. A1 with a total surface area of 40 ft^2 and 1 inch of MLI will be used as the worst-case condensation heat load: q = 15,000 Btu/hr = 4400 W.

Heat load summary - loss of vacuum

Source of heat	Heat Load	
Gas conduction - helium	3,600 W	12,300 Btu/hr
Liquid air condensation	4,400 W	15,000 Btu/hr

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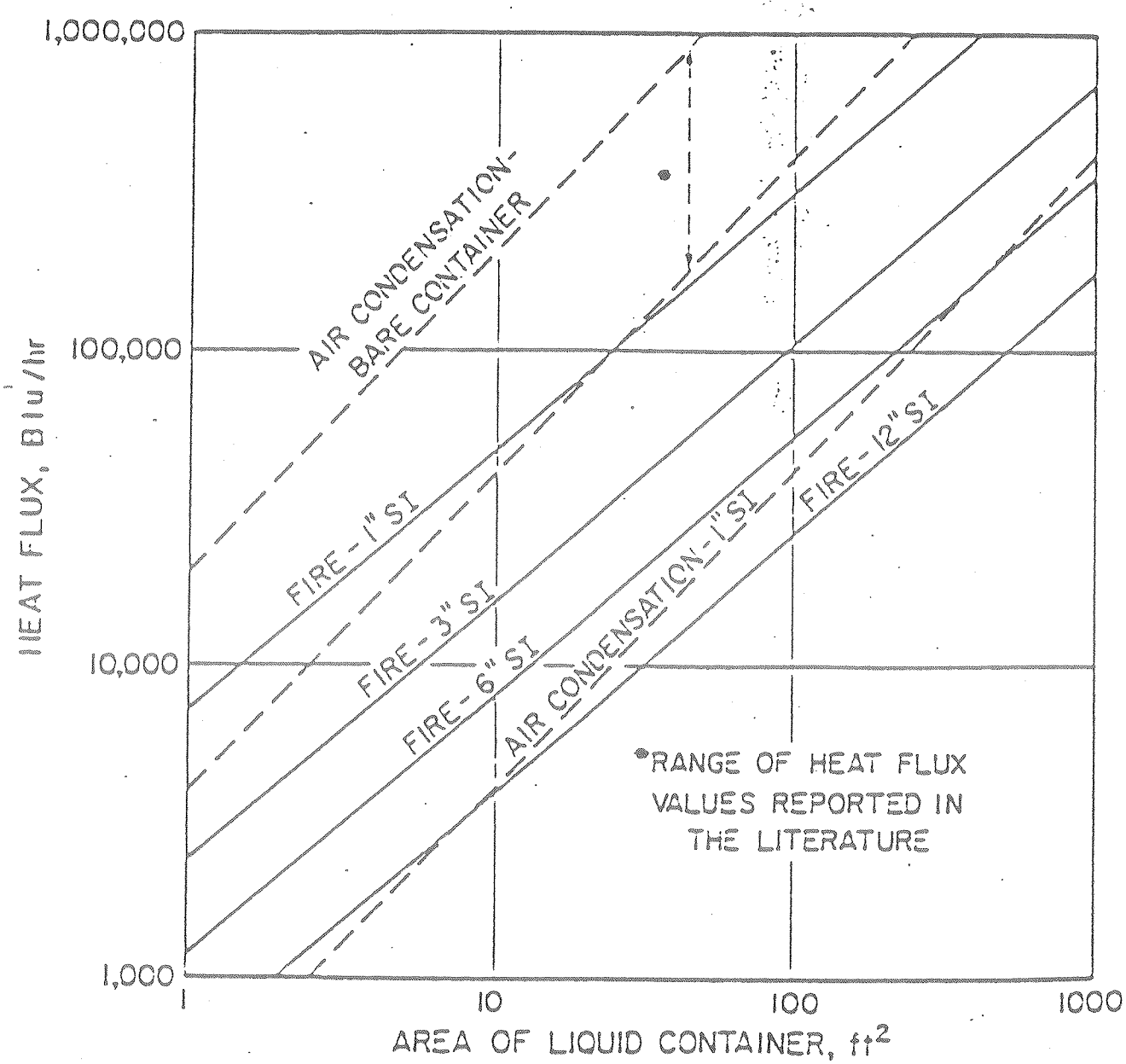

FIGURE A1. *Estimated total heat flux versus area for air condensation and fire conditions in multilayer (SI) insulated liquid helium containers.*

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Appendix B: Heat load to inner (LHe) vessel upon operator error

OBJECT

To calculate the heat load on the inner vessel following an operator error.

DESCRIPTION OF FAILURE MODE

With the helium storage dewar full of LHe and with the refrigerator at 300 K, the compressor is turned on and 300 K He gas fed into the dewar.

CALCULATIONS

Wet engine throughput

Volume/stroke = 2 pistons [2" ϕ x (0.7)(2" stroke)]*

$= 2(3.14\ in^2)(1.4\ in)$

$= 8.792\ in^3 = 144.1\ cm^3$

Inlet conditions: 300 K, 18 ata (allowing 2 ata drop in HTX tube side and piping).

Mass/stroke = (inlet density)(volume/stroke)

$= (0.002901\ g/cm^3)(144.1\ cm^3/stroke)$

$= 0.419$ g/stroke

Maximum engine speed = 300 rpm

= 5 strokes/s

Maximum engine throughput W(WE) = (0.419 g/stroke)(5 strokes/s)

= 2.1 g/s

JT valve throughput**

Calculate quantity $A = 0.5\ C_f^2\ P_1$

where C_f = critical flow factor for valve = 0.9

P_1 = upstream pressure (psia) = 18 ata = 264.6 psia,

$A = (0.5)(0.9)^2(264.6\ psia)$

= 107.2 psia

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* T.J. Peterson, private communication.

**"Masoneilan Handbook for Control Valve Sizing", Sixth Edition, Masoneilan International, Inc. (1977)

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Since $A \leq (P_1 - P_2) = 250$ psia (P_2 = downstream pressure = 14.7 psia, the flow is critical and the mass flow rate W(lb/hr) is

$$W(JT) = 2.8\ C_v\ C_f\ P_1\ \sqrt{G_f},$$

where

C_v = valve flow coefficient

G_f = specific gravity of efflux gas at flowing temperature and 1 ata [G_f (air) = 1.0]

$$= \frac{0.0001625\ g/cm^3}{0.001177\ g/cm^3}$$

$$= 0.1381.$$

Then

$$W(JT) = (2.8)(0.2)(0.9)(264.6)\sqrt{0.1381}$$

$$= 49.56\ lb/hr = 6.25\ g/s.$$

Total possible throughput

Since J-T valve and wet engine are in parallel, add the throughputs:

$$W_T = W(WE) + W(JT)$$

$$= (2.1 + 6.25)\ g/s = 8.35\ g/s.$$

Heat loads

Assume that all the incoming 300 K gas is cooled to 4.76 K, the normal operating temperature of the dewar.

The enthalpy h(300 K, 1.6 ata) = 1573 J/g and h(4.76 K, 1.6 ata) = 28.98 J/g, so Δh = 1544 J/g and the associated heat load, $q = W_T\ \Delta h$ = (8.35 g/s)(1544 J/g) = 12892 W = 44000 Btu/hr.

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Appendix C: Sizing of relief devices on inner vessel

OBJECT

To demonstrate that the AGCO relief valve on the inner vessel is adequate for the worst failure mode considered, i.e. an operator error leading to the introduction of warm helium into the dewar when it is full of liquid.

PARAMETERS OF PROBLEM

Helium

Total He volume	= 460 L
Volume of saturated liquid	= 420 L
Volume of neck (assumed to contain saturated vapor)	= 40 L
Normal dewar operating pressure	= 1.6 ata (9 psig)
Normal operating temperature of LHe (saturated)	= 4.764 K
Density of saturated LHe at 1.6 ata	= 0.1113 g/cm^3
Mass of saturated LHe	= 46746 g
Density of saturated GHe at 1.6 ata	= 0.02915 g/cm^3
Mass of saturated GHe	= 1166 g
Total He mass	= 47912 g
Average specific volume	= 9.60 cm^3/g

Stainless Steel Dewar

Mass of 36" ϕ x 3/8" head with straight flange	= 148 lb
Mass of 36" ϕ x 12" shell	= 122 lb
Total mass of portion of dewar at 4.764 K	= 418 lb
	= 1.898 x 10^5 g

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Neck, Inlet Piping and AGCO Valve

Mass of 8 IPS - SCH 5 x 45" neck	= 37 lb
Mass of 1-1/2 IPS inlet fittings	= 15 lb
Mass of AGCO valve	= 25 lb
Total mass of neck, etc, initially at 300 K	= 77 lb
	= 35000 g

HEAT LOAD

A heat load of 13 kW, consistent with an operator-error failure mode, constant in time, was used for this analysis.

PRESSURE AND TEMPERATURE BEFORE RELIEF VALVE OPENS

During the time from the initial imposition of the heat load on the vessel and contents to the opening of the relief valve, the energy added to the system results in an increase in the internal energy. The temperature and pressure both increase during this isochoric (constant mass) process.

Table C1 gives the initial (1.6 ata) and final (6.8 ata) parameters of the fluid. The temperature of the fluid just before the relief valve opens is 6.54 K.

Table C1. System Properties Before Onset of Venting

Parameter	Units	Initial State	Final State
Specific volume	cm^3/g	9.60	9.60
Absolute pressure	ata	1.6	6.8
He temperature	K	4.76	6.54
Internal energy per unit mass	J/g	11.92	17.21
Change in internal energy per unit mass	J/g	--	5.29
Change in total internal energy	J	--	253,454
Time to absorb energy at 13 kW	s	--	19.5

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MASS FLOW RATE AFTER RELIEF VALVE OPENS

It is asumed that the relief valve is adequately sized so that the system vents at a constant pressure of 6.8 ata. Under this assumption any energy added to the system increases the total enthalpy:

$$dE = dH \qquad \text{(C1)}$$

$$\text{Power} = dE/dt = dH/dt$$

$$= d(mh)/dt$$

$$= h\ dm/dt + m\ dh/dt \qquad \text{(C2)}$$

and

$$h\ dm/dt = P - m\ dh/dt \qquad \text{(C3)}$$

To calculate the maximum dm/dt, assume m dh/dt = 0. Then

$$\dot{m} = dm/dt = P/h. \qquad \text{(C4)}$$

Since h is a function of time, so is $\dot{m}$; $\dot{m}(t) = P/h(t)$.

Table C2 gives the mass flow rate as a function of temperature starting at the initial fluid temperature calculated in the previous section. The maximum mass flow rate is seen to occur just after the relief valve opens. A mass flow rate of 550 g/s was used to determine relief valve size.

Table C2. Mass Flow Rate during 6.8 ata Venting

Temperature (K)	h (J/g)	m (g/s)
6.54	23.97	542
7.0	28.22	461
7.5	33.47	388
8.0	38.47	338

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TEMPERATURE OF He ENTERING RELIEF VALVE

One should not assume that the initial fluid temperature given in Table C2 (6.54 K) is the temperature of the gas entering the valve at the time of maximum flow - the gas will become somewhat warmer as it cools the neck, inlet piping and valve. This temperature rise can be estimated by solving the simultaneous equations for conservation of energy and heat transfer.

Conservation of Energy Equations

Heat given up by neck, inlet fittings and relief valve,

$$Q_1 = M_W C_W [T_W(t) - T_W(t_o)] \qquad (C5)$$

Heat absorbed by helium flowing up neck and out valve in a time $t-t_o$

$$Q_2 = M_{He} C_{He} [T_{He}(t) - T_{He}(t_o)] \qquad (C6)$$

Where M_W = mass of neck and valve

C_W = specific heat of stainless steel at $T_W(t_o)$

T_W = temperature of neck, fittings and valve

t = final time

t_o = time at which valve opens = 19.5 s

M_{He} = mass of helium passing up neck and out valve in time $t-t_o$

C_{He} = specific heat of helium at constant pressure, at t_o

T_{He} = temperature of helium entering valve

Taking the time interval from 19.5 to 20.0 seconds: t_o = 19.5 s, t = 20.0 s, M_W = 35 kg, C_W = 500 J/kg-K, T_W (19.5) = 300 K and

$$Q_1 = 17500\ T_W(20) - 5.250 \times 10^6 \qquad (C7)$$

Also M_{He} = 275 g, C_{He} = 8.10 J/g-K, $T_{He}(19.5)$ = 6.54 K and

$$Q_2 = 2228\ T_{He}(20) - 14568 \qquad (C8)$$

and $-Q_1 = Q_2$

Heat Transfer Equation

Heat transferred from neck and valve to helium in a time $t-t_o$

$$Q_3 = h\ A\ [T_W(t) - T_{He}(t)]\ (t - t_o) \qquad (C9)$$

with $hA = h_n A_n + h_f A_f$

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where h_n = coefficient of heat transfer between flowing helium and dewar neck

h_f = coefficient of heat transfer between flowing helium and inlet fittings and relief valve

A_n = heat transfer area of neck

A_f = heat transfer area of fittings

Also $Q_3 = - Q_1 = Q_2$ (C10)

The heat transfer coefficients are calculated from the standard equation (e.g. Eq. 2.20, R.B. Scott, "Cryogenic Engineering") for heat transfer in a smooth pipe:

$$h = 0.023 \frac{k}{D} \left(\frac{DG}{\mu} \right)^{0.8} P_r^{0.4} \qquad \text{(C11)}$$

where

$k = k(T)$ = thermal conductivity of fluid

$\mu = \mu(T)$ = viscosity of fluid

$P_r = P_r(T)$ = Prandtl number of fluid

D = diameter of pipe

G = mass velocity of fluid

$= \dot{m}/A$

$\dot{m}$ = mass flow rate of fluid

A = cross section area of pipe.

I grouped the temperature dependent terms together

$$h = 0.023 \frac{G^{0.8}}{D^{0.2}} \frac{k(T)\, P_r(T)^{0.4}}{\mu(T)^{0.8}} = \text{constant } f(T) \qquad \text{(C12)}$$

and searched for a maximum value of $f(T)$ at 7 ata. The results are given in Table C3; I used the maximum value of $f(T) = 1.075$ in Eq. C12:

$$h = 0.025 \frac{G^{0.8}}{D^{0.2}} \qquad \text{(C13)}$$

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Table C3. Temperature Dependence of h
for Helium at 7 ata

Temp (K)	k (W/cm-K)	μ (g/cm-s)	P_r	$f(T) = \frac{k\ P_r^{0.4}}{\mu^{0.8}}$
6	0.234×10^{-3}	34.2×10^{-6}	0.845	0.858
6.5	0.241	31.9	1.02	0.960
7.0	0.234	29.7	1.22	1.060
7.5	0.223	28.2	1.28	1.075
8.0	0.215	27.5	1.20	1.028
9	0.210	27.3	1.05	0.960
10	0.213	27.9	0.945	0.918
12	0.225	29.7	0.844	0.879
14	0.241	31.8	0.799	0.871
16	0.256	34.0	0.773	0.868
20	0.286	38.2	0.746	0.871

NOTE: Values taken from NBS-631

Using Eq. C12 and a mass flow of 550 g/s, D_n = 8.407", D_f = 1.61"

$$h_n = 0.025 \frac{[550/0.25\ \pi\ (21.4)^2]^{0.8}}{(21.4)^{0.2}}$$

$$= 0.0190 \quad J/cm^2\text{-}K$$

$$h_f = 0.025 \frac{[550/0.25\ \pi\ (4.09)^2]^{0.8}}{(4.09)^{0.2}}$$

$$= 0.374\ J/cm^2\text{-}K.$$

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A_n = 8.407" ID x 44.75" long

= 1182 in^2 = 7626 cm^2

A_f = 1.61" ID x 14" long

= 71 in^2 = 457 cm^2

and therefore

$hA = (0.019)(7626) + (0.374)(457)$

= 316 J/K.

From this

$$Q_3 = 158\ T_w(20) - 158\ T_{He}(20) \tag{C14}$$

Simultaneous Solution

The equations to be solved simultaneously are

$$Q_1 = 17500\ T_w(20) - 5.25 \times 10^6 \tag{C7}$$

$$Q_2 = 2228\ T_{He}(20 - 14568 \tag{C8}$$

$$Q_3 = 158\ T_w(20) - 158\ T_{He}(20) \tag{C14}$$

$$Q_1 = Q_2 = Q_3. \tag{C10}$$

The solution is

$T_{He}(20) = 25.8$ K ; $T_w(20) = 297.5$ K

SIZING OF AGCO RELIEF VALVE

For Anderson-Greenwood relief valves, the following relationship applies:

$$A = \frac{W\ (TZ)^{1/2}}{CKP_1\ (M)^{1/2}} \tag{C15}$$

where: W = Mass flow rate (lb/hr)

T = Temperature of fluid flowing through valve (^oR)

Z = Compressibility factor = 1.0

M = Molecular weight = 4

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P_1 = Inlet pressure, absolute = 100 psia

K = Valve coefficient of discharge, 0.816

C = Gas constant based on ratio of specific heats at standard conditions, 377 for helium.

For W = 550 g/s = 4361 lb/hr and T = 25.8 K = 46.4 ^{o}R; A = 0.483 in^2. It can easily been shown that A has a maximum value for this combination of flow rate and temperature. The G-orifice valve installed on the inner vessel (SV-310-H) has an orifice area of 0.503 in^2.

CONCLUSION

The G-orifice Anderson-Greenwood relief valve is adequate for the operator error failure mode and hence for any of the less serious failure modes.

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Appendix C': Sizing of relief devices on inner vessel for fire

OBJECT

To show that the 1" Fike rupture disk on the inner vessel is sized in accordance with appropriate standards for fire or unexpected hazards.

REFERENCES

1. "ASME Boiler and Pressure Vessel Code," Section VIII, Division 1, Paragraph UG-125(c)(2).

2. "Pressure Relief Device Standards", Compressed Gas Association, CGA S-1.3-1980.

3. Catalog 7383, Fike Metal Products Corp., Blue Springs, MO., p. 10.

REQUIRED SIZE OF RELIEF DEVICE

Using the compressed Gas Association standard for pressure relief devices: $Q_a = G_i\ UA^{0.82}$, where G_i = 52.5 for helium, U = thermal conductivity of insulation/insulation thickness. In this case we will use the thermal conductivity of helium at 500 K (the average between 1200°F and 5 K) and 1 ata: 2.21 mW/cm-K = 0.128 Btu/hr-ft-°F. The insulation thickness is 3" and therefore U = 0.128/.25 = 0.511 Btu/hr-ft^2-°F. The size of the relief device should be

$$Q_a = (52.5)(0.511)(61.0)^{0.82} = 781 \text{ SCFM-air.}$$

CAPACITY OF INSTALLED RUPTURE DISK

The Fike rupture disk model CPV-UT-1", has a set pressure of 90 psig. It has a capacity which may be calculated by reference to the Fike catalog. To determine whether flow is sonic or subsonic, assume an exit pressure P_e = 15 psia and a relieving pressure P_o = 90 psig = 105 psia, giving P_e/P_o = 0.142. Comparing this ratio with the quantity $(2/k+1)^{k/k-1}$ where k = ratio of specific heats = 1.66 for helium, which is equal to 0.4881, we determine that the flow through the rupture disk is sonic. The flow capacity, FC(disk), of a rupture disk in SCFM-air is calculated by

$$FC\ (Disk) = 11.4\ P_o a$$

where

P_o = absolute relieving pressure

a = flow area (in^2)

For the rupture disk installed on the dewar with a 0.785 in^2 and P_o = 105 psia, we calculate a flow capacity FC (disk) = 939 SCFM - air, which is in excess of the requirement.

CONCLUSION

The 1" rupture disk is adequate for the fire condition.

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Appendix D: Summary of flow losses in the relief valve inlet and discharge piping

OBJECT

To summarize the calculations which show that the maximum pressure in the vessel when venting is less than the 110% MAWP permitted by the ASME Boiler and Pressure Vessel Code.

GEOMETRY OF HEADERS

Figure D1 is an overall diagram of the inlet and discharge piping.

FLOW RATES

The maximum mass flow rate calculated in Appendix C (550 g/s) was used.

PRESSURE DROP IN DEWAR NECK

Temperature of Gas

A helium gas temperature of 25.8 K was used in the neck.

Mach Number

The Mach number is the ratio of the fluid velocity to the speed of sound in the fluid:

$$MN = \frac{\text{fluid velocity}}{\text{speed of sound in fluid}} .$$

If the Mach number is less than 0.3, the flow may be treated as incompressible, if greater the flow is compressible.

The density of helium at 6.8 ata and 25.8 K is 0.01276 g/cm^3 = 0.796 lb/ft^3. The volume flow rate is (550 g/s)/(0.01276 g/cm^3) = 43103 cm^3/s = 2630 in^3/sec. The neck is 8-inch, Sch 5 pipe (I.D. ≐ 8.407"). The sonic velocity at 6.8 ata and 25.8 K is 307 m/s = 12086 in/sec.

MN(8) = Mach Number for 8-inch, Sch 5 neck

$$= \frac{(2630\ \text{in}^3/\text{sec})/(0.25)(\pi)(8.407)^2}{12086}$$

$$= 0.004 \text{ (incompressible)}$$

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NATIONAL ACCELERATOR LABORATORY
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT

NAME

DATE | REVISION DATE

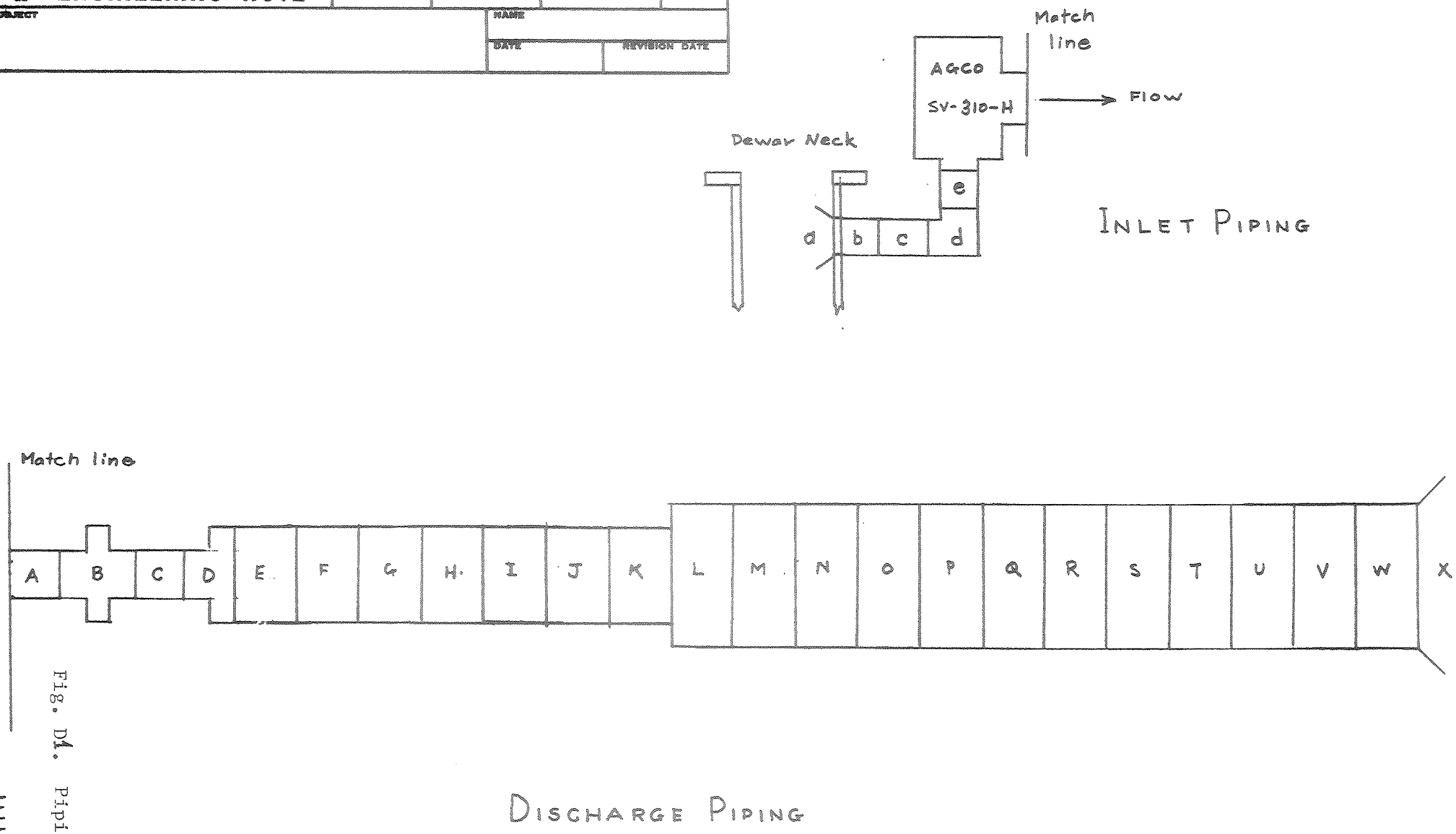

Fig. D1. Piping schematic

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Table D1. Parameterization of Dewar Neck

Description	L/d	L(in)	d(in)	f	K = fL/d
Entrance contraction[2]	34	--	--	0.014	0.475
Neck pipe	5.32	44.75	8.407	0.014	0.075
		Total			0.550

Pressure Drop

A standard equation for the pressure drop of an incompressible fluid in valves, fittings and pipe was used:[1]

$$\Delta P = 3.62\ K\ \rho\ q^2/d^4 \qquad \text{(D1)}$$

where

K = resistance coefficient (dimensionless)

ρ = density of He in pipe (lb/ft^3)

q = flow rate (ft^3/sec)

d = inner diameter of pipe (in).

Table D1 characterizes the dewar neck (K = 0.55). For the neck

$\rho = 0.796\ lb/ft^3$

$q = 1.52\ ft^3/sec$

$d = 8.407$ in

and therefore

$$\Delta P(n) = \frac{(3.62)(0.55)(0.796)(1.52)^2}{(8.407)^4}$$

$$= 0.008 \text{ psi - negligible}$$

JUL 16 1966

PRESSURE DROP IN VALVE INLET PIPING

Temperature of Gas

A helium gas temperature of 25.8 K was used for this piping.

Mach Number

For the inlet piping use the sonic velocity for helium at 6.8 ata and 25.8 K, 307 m/s = 12086 in/sec. The volume flow rate for a mass flow rate of 550 g/s is (550 g/s)/(0.01276 g/cm^3) = 43103 cm^3/s = 2630 in^3/sec.

MN(1.5) = Mach number for 1-1/2" inlet pipe

$$= \frac{(2630\ \text{in}^3/\text{sec})/(0.25)(\pi)(1.61\ \text{in})^2}{12086\ \text{in/sec}}$$

$$= 0.107$$

and the flow is incompressible.

Pressure Drop

Table D2 gives the parameters of the inlet piping. Using equation D1

with

K = 0.884 (from Table D2)

ρ = density of He at 6.8 ata and 25.8 K = 0.01276 g/cm^3 = 0.796 lb/ft^3

q = 2630 in^3/sec = 1.522 ft^3/sec,

$\Delta P(i) = (3.62)(0.884)(0.796)(1.522)^2/(1.61)^4 = 0.88$ psi.

Table D2. Parameterization of Inlet Piping

Item	Description	L/d	L(in)	d(in)	f	K=fL/d
a	Entrance contraction[2]	21.9	--	--	0.021	0.460
b	1-1/2" coupling	1.24	2	1.61	0.021	0.026
c	1-1/2" nipple	1.24	2	1.61	0.021	0.026
d	1-1/2"-90° LR elbow	14	--	1.61	0.021	0.294
e	1-1/2" nipple	1.24	2	1.61	0.021	0.026
f	1-1/2" union	1.24	2	1.61	0.021	0.026
g	1-1/2" nipple	1.24	2	1.61	0.021	0.026
				TOTAL		0.884

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PRESSURE DROP - RELIEF VALVE

The AGCO relief valve is equipped with adjustable blowdown. Blowdown is the difference between the set pressure and the resealing pressure. Standard AGCO relief valves of this type have a maximum blowdown of about 20%. Therefore, with a set pressure of 85 psig, the valve will reseal with a differential of 68 psig. This means that when the valve is open the pressure drop across it is 68 psi.

PRESSURE DROP IN 2-inch EXIT PIPING

Temperature of Gas

Assume that a flow of 550 g/s enters the 2-inch piping at 25.8 K, the temperature at which it flows through the valve. To calculate the average temperature of the helium in the 2-inch piping we solve simultaneous equations as was done in Appendix C:

$$Q_1 = 1121\ T_w - 3.36 \times 10^5 \qquad \text{(D2)}$$

$$Q_2 = 1150\ T_{He} - 26466 \qquad \text{(D3)}$$

It can be shown from helium properties data that the maximum heat transfer coefficient in the range 20-50 K is 0.2 W/cm^2-K. Therefore for a 0.4 s time interval

$$Q_3 = 60.3\ T_w - 60.3\ T_{He}. \qquad \text{(D4)}$$

The solution of these equations is $T_{He} = 35.4$ K, $T_w = 288.6$ K.

Mach Number

Using an average temperature of 30 K, at which the density at 1 ata is 0.001623 g/cm^3, the volume flow rate is 550/0.001623 $cm^3/s = 3.39 \times 10^5\ cm^3/s$ = 20678 in^3/sec. The sonic velocity in helium at 1 ata and 30 K is 323.5 m/s = 12736 in/sec. The Mach number in the 2-inch piping therefore is

$$MN(2) = \frac{(20678)/(0.25)(\pi)(2.067)^2}{12736}$$

$$= 0.48$$

and the flow is compressible.

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Pressure Drop

Using a standard equation for the pressure drop of a compressible fluid in valves, fittings and pipes:[3]

$$w = 0.525\ Y\ d^2 \left(\frac{\Delta P}{Kv}\right)^{0.5} \qquad \text{(D5)}$$

where

w = mass flow = 1.21 lb/sec

Y = expansion factor = 0.5

d = pipe I.D. = 2.067 in

K = 0.653 (from Table D3)

v = specific volume of helium at 1 ata and 30 K = 9.87 ft^3/lb

Then

$$\Delta P(2) = \frac{K\ v\ w^2}{0.276\ Y^2\ d^4} \qquad \text{(D6)}$$

$$= \frac{(0.653)(9.87)(1.21)^2}{(0.276)(0.25)(2.067)^4}$$

$$= 7.49 \text{ psi}$$

PRESSURE DROP IN 4-inch EXIT PIPING

Temperature of Gas

An average helium temperature of 150 K was assumed for the 4-inch discharge piping.

Mach Number

The density of helium at 1 ata and 150 K is 0.0003249 g/cm^3. The volume flow rate is 1.69×10^6 cm^3/s = 1.03×10^5 in^3/sec. The sonic velocity is 721.3 m/s = 2.84×10^4 in/sec. Therefore

$$MN(4) = \frac{(1.03 \times 10^5)/(0.25)(\pi)(4.26)^2}{2.84 \times 10^4}$$

$$= 0.26 \text{ (incompressible).}$$

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Pressure Drop

$$\Delta P = 3.62\ K\ \rho\ q^2/d^4 \qquad \text{(D1)}$$

For $K = 1.84$ (from Table D3)

$\rho = 0.0203\ lb/ft^3$

$q = 59.8\ ft^3/sec$

$d = 4.26$ in

and

$\Delta P(4) = 1.47$ psi

PRESSURE DROP IN 6-inch EXIT PIPING

Temperature of Gas

A temperature of 300 K was used for the gas in the 6-inch piping.

Mach Number

The density of helium at 1 ata and 300 K is $0.0001625\ g/cm^3 = 0.010\ lb/ft^3$. The volume flow rate is $3.38 \times 10^6\ cm^3/s = 2.06 \times 10^5\ in^3/sec$. The sonic velocity is $1020\ m/s = 4.02 \times 10^4$ in/sec. Therefore

$MN(6) = 0.16$ (incompressible).

Pressure Drop

For $K = 2.62$ (Table D3)

$\rho = 0.010\ lb/ft^3$

$q = 119.5\ ft^3/sec$

$d = 6.357$ in

$\Delta P(6) = 0.83$ psi

JUL 16 1980

Table D3. Parameterization of Discharge Piping

Item	Description	L/d	L (in)	d (in)	f(d)	K=fL/d	ΣK
A	2" nipple	2.90	6	2.067	0.019	0.055	
B	2" union	1.45	3	2.067	0.019	0.028	ΣK(2)=0.653
C	2" nipple	1.45	3	2.067	0.019	0.028	
D	2"-4" reducer	28.5	--	2.067	0.019	0.542	
E	4" pipe-Sch 10	5.63	24	4.26	0.017	0.096	
F	4"-90° LR elbow	14	--	4.26	0.017	0.238	
G	4" bellows	3	--	3.750	0.017	0.051	ΣK(3.75)=0.102
H	4" pipe	28.2	120	4.26	0.017	0.479	ΣK(4) = 1.843
I	4"-90° LR elbow	14	--	4.26	0.017	0.238	
J	4" bellows	3	--	3.750	0.017	0.051	
K	4" pipe	28.2	120	4.26	0.017	0.479	
L	4"-6" reducer	18.4	--	4.26	0.017	0.313	
M	6" tee-flow thru run	20	--	6.357	0.015	0.300	
N	6" pipe-Sch 10	11.3	72	6.357	0.015	0.170	
O	6" bellows	3	--	5.875	0.015	0.045	ΣK(5.875)=0.135
P	6"-90° LR elbow	14	--	6.357	0.015	0.210	ΣK(6)=2.62
	6" pipe	17.7	108	6.357	0.015	0.255	
R	6" bellows	3	--	5.875	0.015	0.045	
S	6"-90° LR elbow	14	--	6.357	0.015	0.210	
T	6" bellows	3	--	5.875	0.015	0.045	
U	6" pipe	18.9	120	6.357	0.015	0.283	
V	6"-45° LR elbow	8	--	6.357	0.015	0.120	
W	6" pipe	8.34	53	6.357	0.015	0.125	
X	exit enlarge-ment, 6" - 34 sq.	63.4	--	6.357	0.015	0.950	

JUL 16 1986

SUMMARY OF PRESSURE DROPS

The above results are summarized in Fig. D2. Since the pressure in the dewar under this worst-case scenario is less than 1.1 MAWP, the vent piping is adequate.

REFERENCES

1. "Flow of Fluids through Valves, Fittings and Pipe," Crane Co., New York, Equation 3-14, pg. 3-4.
2. Ibid, Equation 2-10.1, pg. 2-11.
3. Ibid, Equation 3-20, pg 3-4.
4. Ibid, Equation 2-9.1, pg. 2-11.

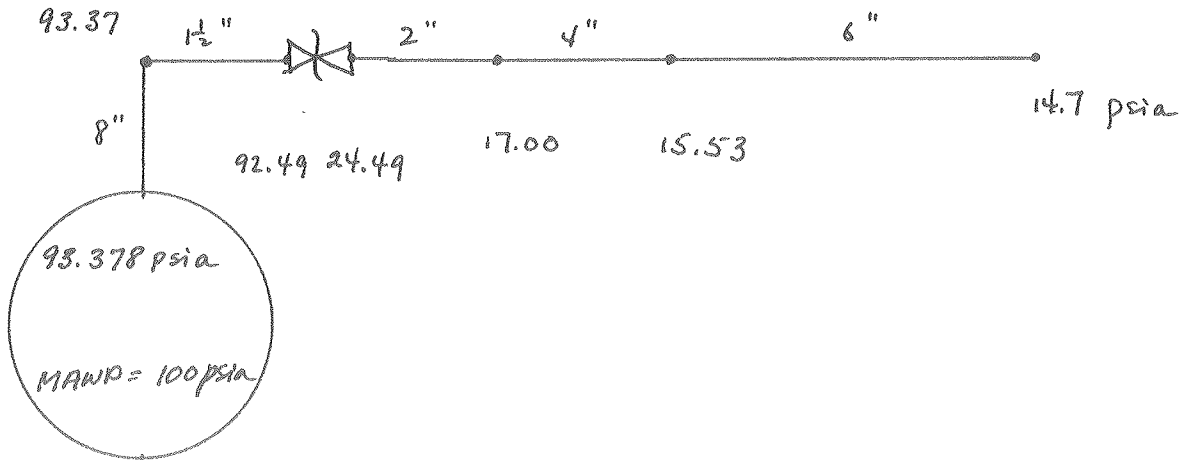

Fig. D2. Absolute pressure at various points in He vent.

JUL 16 1986

Vacuum Vessel Engineering Note
(per Mandatory Standard SD-41)

Prepared By R.W. Fast Date _____ Div/Sect RD/Cryo

Reviewed By Not Required Date _____ Div/Sect _____

Div/Dept Head Not Required Date _____ Div/Sect _____

I. Identification and Verification of Compliance

Fill in the Fermilab Engineering Conformance Label information below:

Vessel Title Muon Lab Helium Dewar - outer (vacuum) vessel

Vessel Number N/A

Vessel Drawing Number 2753.700-MD-193317 (2 shts)

Working Temperature Range -20 ^{0}F 100^{0}F

Designer/Manufacturer CDM Machining & Fabrication Corp. Commerce City, CO

Date of Manufacture April 1986

Acceptance Date _____

Director's signature (or designee) if vessel is for manned area and requires an exception to the provisions of this standard.

Not Required

Amendment No.:	Reviewed By:	Date:

II. Description of Vessel and Relief System

Laboratory location code NEU NMS

Laboratory property number N/A

Purpose of vessel Vacuum jacket for liquid helium vessel

List all pertinent drawings (append copies)

Drawing No.:	Location of Original:
2753.700-MD-193317	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193321	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193322	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193323	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193324	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193326	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193327	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193330	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193331	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193332	Wilson Hall - 11E, RD/Cryo
2753.700-MB-193334	Wilson Hall - 11E, RD/Cryo
2753.700-MC-193444	Wilson Hall - 11E, RD/Cryo

Is an operating procedure necessary for the safe operation of this vessel? No

If yes, supply the written procedure with this Engineering Note.

List all reliefs and settings. Provide a schematic of the relief system components, and appropriate calculations or test results to prove that overpressurization beyond the maximum allowable internal pressure will not occur. See Appendixes E, F and G

Manufacturer	Relief	Setting	Area	Size	ASME Stamped Device Yes/No
Fermilab Parallel Plate	SV-306-V	few inches of water	3.87 in^2	2 I.P.S.	No
CVI, Inc; pump-out, relief, V-1046-31	SV-307-V	few psi	Not avail.	1"	No

Welding Information

Has the vessel been fabricated in a Fermilab shop? Yes____ No X

If "Yes", append a copy of the welding shop statement of welder qualification.

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Appendix E: Vacuum Vessel Calculations

VOLUME OF INSULATING VACUUM SPACE

Over-all Volume of Vacuum Vessel

Lower dished head. The head is a 42-inch ASME dished head; according to the Brighton catalog the volume without the straight flange is 25.9 gal or 3.46 ft^3.

Upper dished head. Same as lower, 3.46 ft^3.

Cylindrical shell. 41.625" I.D. x 29.675"; 23.37 ft^3.

Neck. 16 IPS - Sch 10 (15.5" I.D.) x 34.250"; 3.74 ft^3.

Total volume = 34.03 ft^3

Volume of Inner Vessel and Neck

Lower dished head. A_3 36-inch, 80-10 dished head; without the straight flange, 22 gal or 2.94 ft^3.

Upper dished head. Same as lower, 2.94 ft^3.

Cylindrical shell. 35.250" I.D. x 15"; 8.47 ft^3.

Neck. 8 IPS x Sch 5 (8.407" I.D.) x 38.5"; 1.24 ft^3.

Total inner vessel and neck = 15.59 ft^3.

Net Volume of Insulating Vacuum Space

Total volume of vacuum vessel - volume of inner vessel and neck, 18.44 ft^3.

APPLICABLE VESSEL STANDARD

Since the volume of the vacuum space is less than 50 ft^3, the Fermilab standard SD-41 "Vacuum Vessels" does not apply.

JUL 16 1986

Appendix F: Relief device on vacuum jacket

OBJECT

To demonstrate that the relief device on the vacuum jacket is in accordance with established industrial practice, as given by CGA standards.

REQUIRED RELIEF DEVICE SIZE-INDUSTRIAL PRACTICE

CGA Pressure Relief Device Standards, S-1.3-1980, paragraph 4.9.2 refers to CGA Insulated Tank Truck Specification, CGA-341; for sizing of relief devices on the outer shell of vacuum insulated containers. This requirement is

$$A_r = 0.00024\ V$$

where A_r = required discharge area of relief device

V = water capacity of liquid (inner) vessel in pounds.

The inner vessel has a total volume of 460 L = 16.3 ft^3, so V = (16.3 ft^3) (62.4 lb/ft^3) = 1015 lb. The vacuum vessel is therefore required to have a relief device of at least A_r = 0.244 in^2. This relief device must be set to a pressure not exceeding the Code-calculated MAWP-internal or 25 psig, whichever is less.

The 2-inch parallel-plate relief device on the vacuum vessel provides 3.87 in^2 of discharge area and is, therefore, adequately sized. The device does not use springs and so relieves at a pressure of a few inches of water.

JUL 16 1986

Appendix G: Piping calculations - radiation shield and instrumentation tubing

OBJECT

To show that the radiation shield and instrumentation tubing is rated for at least 100 psid.

DESIGN STANDARD

The piping was designed in accordance with the ASME Code for Pressure Piping B31.3 - Chemical and Petroleum Refinery Piping.

CALCULATIONS FOR INTERNAL PRESSURE

Radiation shield tubing

Code: 304.1.2

Tubing parameters:

D = tubing O.D. = 0.5"
t = wall thickness = 0.065"
Material: Aluminum 6061-T6
Operating temperature: -320 ^{o}F

$$P_a = \frac{2\ SEt}{D-2Yt}$$

where S = allowable stress for material
E = quality factor
Y = material coefficient

For 6061-T6 aluminum, welded: S = 8000 psi, E = 1.0, Y = 0.4 and

$$P_a = \frac{16000\ t}{D-0.8t}$$

For the tubing used

$$P_a = \frac{(16000)(0.065)}{0.5 - (0.8)(0.065)} = 2321 \text{ psid}$$

= 2306 psig - since the tubing is in the vacuum space

JUL 16 1986

Instrumentation tubing

Code: 3041.2

Tubing parameters:

D = 0.25", t = 0.028", Material: stainless steel 304, operating temperature = -454°F, S = 20,000 psi, E = 1.0, Y = 0.4

$$\text{Therefore } P_a = \frac{(40000)(0.028)}{0.25 - (0.8)(0.028)}$$

= 4921 psid

= 4906 psig - since some of the tube is in the vacuum space.

JUL 16 1986