PIPE SIZING:
FOR
SOLENOID/VLPC
CRYOGENIC SYSTEMS

D-ZERO ENGINEERING NOTE # 3823.115- EN-416

February 20, 1995
rev. 6/26/95: changes in italics

Russ Rucinski and Steve Sakla
RD/DØ Mech.

Approved : _____

A handwritten signature in black ink, appearing to read 'Russ Rucinski', is written over a horizontal line. The signature is stylized with a large, looping 'R' and a cursive 'S'.

PRELIMINARY BUILDING TRANSFER LINE DESIGNS

Russ Rucinski 2/21/95

REV. 6/29/95 NOT TO SCALE

Plotted Tue Feb 21 15:38:29 CST 1995 by rucinski

FIGURE 1

PRELIMINARY BUILDING TRANSFER LINE DESIGNS

Russ Rucinski 2/21/95
 REV. 6/24/95 NOT TO SCALE

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FIGURE 2

TABLE 1 : SOLENOID PIPE SECTIONS

LINE #	FLUID	DESCRIPTION	TYPE	FROM	TO	PIPE OR TUBE SIZE	INSIDE DIA. (IN.)	LINEAR LENGTH (FT.)	# OF ELBOWS	# TEES THRU RUN	# TEES THRU BRANCH	VALVES
4	LHE	SUPPLY (HUT3)	U-TUBE	LHE DEWAR	X-FER LINE	3/4" OD X .035	0.68	5	2	0	0	0
5	LHE	SUPPLY	X-FER LINE	U-TUBE	U-TUBE	5/8" OD X .049	0.527	125	9	4	0	1 DIVRTR.
6	LHE	SUPPLY (HUT4)	U-TUBE	X-FER LINE	CONTROL DEWAR	3/4" OD X .035	0.68	10	2	0	0	0
7	LHE	RETURN (HUT5)	U-TUBE	CONTROL DEWAR	X-FER LINE	3/4" OD X .035	0.68	10	2	0	0	0
8	LHE	RETURN	X-FER LINE	U-TUBE	U-TUBE	D _{W40} = Concentric	1.0 0.427	125	9	4	0	1 PV, 1 CV
9	HE	RETURN	U-TUBE	X-FER LINE	X-FER LINE (VLPC)	3/4" OD X .035	0.68	3	2	0	0	0
10	LN2	SUPPLY	U-TUBE	LIN HEADER	X-FER LINE	3/8" OD x .049 + 1/2" OD x .035	.277 0.43	3	2	0	0	0
11	LN2	SUPPLY	X-FER LINE	U-TUBE	TEE	3/8" OD x .049 + 1/2" OD x .049	.277 0.402	1	1	0	0	0
12	LN2	SUPPLY (SHIELD)	X-FER LINE	TEE	U-TUBE	3/8" OD X .049	0.277	124	9	2	1	1 PV
13	LN2	SUPPLY (SHIELD)	U-TUBE	X-FER LINE	CONTROL DEWAR	1/2" OD x .035	0.43	10	2	0	0	0
14	LN2	SUPPLY (INTERCEPT)	X-FER LINE	TEE	U-TUBE	3/8" OD X .049	0.277	124	9	2	1	1 PV
15	LN2	SUPPLY (INTERCEPT)	U-TUBE	X-FER LINE	CONTROL DEWAR	1/2" OD x .035	0.43	10	2	0	0	0
16	LN2	RETURN (SHIELD)	U-TUBE	CONTROL DEWAR	X-FER LINE	1/2" OD x .035	0.43	10	2	0	0	0
17	LN2	RETURN (SHIELD)	X-FER LINE	U-TUBE	U-TUBE	3/8" OD X .049	0.277	125	9	2	0	0
18	LN2	RETURN (SHIELD)	U-TUBE	X-FER LINE	TEE	1/2" OD x .035	0.43	1	1	0	1	0
19	LN2	RETURN (INTERCEPT)	U-TUBE	CONTROL DEWAR	X-FER LINE	1/2" OD x .035	0.43	10	2	0	0	0
20	LN2	RETURN (INTERCEPT)	X-FER LINE	U-TUBE	U-TUBE	3/8" OD X .049	0.277	125	9	2	0	0
22	LN2	RETURN (INTERCEPT)	U-TUBE	X-FER LINE	TEE	1/2" OD x .035	0.43	1	1	0	1	0
23	LN2	RETURN	U-TUBE	TEE	GN2 VENT HEADER	1/2" OD x .035	0.43	5	1	0	0	0
24	HE	(COOLDOWN/ QUENCH)	U-TUBE	CONTROL DEWAR	X-FER LINE	1/2" SCH. 10 3/4" OD X .035	.674 0.68	10	2	0	0	0
25	HE	(COOLDOWN/ QUENCH)	X-FER LINE	U-TUBE	U-TUBE	1/2" SCH. 10 3/4" OD X .065	.674 0.62	125	9	2	0	0
26	HE	(COOLDOWN/ QUENCH)	U-TUBE	X-FER LINE	HE COOLDOWN RETURN	1/2" SCH. 10 3/4" OD X .035	.674 0.68	5	2	0	0	0
27	HE	SUPPLY (COOLDOWN)	U-TUBE	COOLDOWN LINE	X-FER LINE	3/4" OD X .035	0.68	5	4	0	0	1 DIVRTR.

REV. 6/26/95
RAC

TABLE 2: VLPC PIPE SECTIONS

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LINE #	FLUID	DESCRIPTION	TYPE	FROM	TO	PIPE OR TUBE SIZE	INSIDE DIA. (IN.)	LIN. LENGTH (FT.)	# OF ELBOWS	# TEES THRU RUN	# TEES THRU BRANCH	VALVES
38	HE	SUPPLY	U-TUBE	HTX6	AH FEED CAN	1/2" OD X .049	0.402	5	2	0	0	0
39	LHE	SUPPLY	U-TUBE	LHE DEWAR	AH FEED CAN	1/2" OD X .049	0.402	5	2	0	0	0
40	HE	WEST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE	1/2" OD X .049 3/8" OD X .035	.402 .305	2	1	1	0	0
41	LHE	WEST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE	1/2" OD X .049 3/8" OD X .035	.402 .305	2	1	1	0	0
42	HE	WEST HE SUPPLY	X-FER LINE	3-WAY VALVE	U-TUBE	1/2" OD X .049 3/8" OD X .035	.402 .305	123	9	3	0	1 DV
43	HE	WEST HE SUPPLY	U-TUBE	CH FEED CAN	BAYONET CAN	3/8" OD X .035	0.305	12	2	0	0	0
44	HE	WEST HE SUPPLY	X-FER LINE	BAYONET CAN	VALVE BOX	3/8" OD X .035	0.305	47	6	1	0	0
45	HE	WEST HE SUPPLY	X-FER LINE	VALVE BOX	VLPC	3/8" OD X .035	0.305	24	2	0	0	0
46	HE	EAST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE	3/8" OD X .035	0.305	2	0	1	1	0
47	HE	EAST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE	3/8" OD X .035	0.305	2	0	0	1	0
48	HE	EAST HE SUPPLY	X-FER LINE	3-WAY VALVE	U-TUBE	3/8" OD X .035	0.305	123	9	3	0	1 DV
49	HE	EAST HE SUPPLY	U-TUBE	CH FEED CAN	BAYONET CAN	3/8" OD X .035	0.305	12	2	0	0	0
50	HE	EAST HE SUPPLY	X-FER LINE	BAYONET CAN	VALVE BOX	3/8" OD X .035	0.305	47	6	1	0	0
51	HE	EAST HE SUPPLY	X-FER LINE	VALVE BOX	VLPC	3/8" OD X .035	0.305	24	2	0	0	0
52	HE	EAST HE RETURN	X-FER LINE	VLPC	VALVE BOX	3/8" OD X .035	0.305	24	2	0	0	1 PV
53	HE	EAST HE RETURN	X-FER LINE	VALVE BOX	BAYONET CAN	5/8" OD X .049 3/8" OD X .035	.527 .305	47	6	0	0	0
54	HE	EAST HE RETURN	U-TUBE	BAYONET CAN	CH FEED CAN	3/8" OD X .035	0.305	12	2	0	0	0
55	HE	EAST HE RETURN	X-FER LINE	CH FEED CAN	3-WAY VALVE	3/8" OD X .035	0.305	123	9	3	1	1 DV
56	HE	EAST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (COOLDOWN RETURN)	3/8" OD X .035	0.305	2	2	1	1	1 CV
57	HE	EAST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (VALVE BOX)	3/8" OD X .035	0.305	2	2	2	1	1 CV
58	HE	WEST HE RETURN	X-FER LINE	VLPC	VALVE BOX	3/8" OD X .035	0.305	24	1	0	0	1 PV
59	HE	WEST HE RETURN	X-FER LINE	VALVE BOX	BAYONET CAN	3/8" OD X .035	0.305	47	6	0	0	0
60	HE	WEST HE RETURN	U-TUBE	BAYONET CAN	CH FEED CAN	3/8" OD X .035	0.305	12	2	0	0	0
61	HE	WEST HE RETURN	X-FER LINE	CH FEED CAN	3-WAY VALVE	3/8" OD X .035	0.305	123	9	2	0	1 DV
62	HE	WEST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (COOLDOWN RETURN)	3/8" OD X .035	0.305	2	2	0	2	1 CV
63	HE	WEST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (VALVE BOX)	3/8" OD X .035	0.305	1	1	0	2	1 CV
64	HE	WEST HE RETURN	X-FER LINE	3-WAY VALVE	TEE	3/8" OD X .035	0.305	2	1	1	2	1 CV
65	HE	RETURN	X-FER LINE	U-TUBE FROM SOL. X-FER LINE	TEE	1/2" OD X .049	0.402	1	1	2	1	0
66	HE	RETURN	U-TUBE	AH FEED CAN	COOLDOWN RETURN LINE	3/4" OD X .035 3/8" OD X .049	.68 .402	5	2	0	0	0
67	HE	RETURN	U-TUBE	AH FEED CAN	VALVE BOX	3/4" OD X .035	0.68	4	0	0	0	0
68	LN2	SUPPLY	U-TUBE	LN2 HEADER	AH FEED CAN	1/2" OD X .049 3/8" OD X .035	.402 .305	3	2	0	0	0
69	LN2	SUPPLY	X-FER LINE	AH FEED CAN	CH FEED CAN	1/2" OD X .049 3/8" OD X .035	.402 .305	125	9	2	0	0
70	LN2	SUPPLY	U-TUBE	CH FEED CAN	BAYONET CAN	3/8" OD X .049	0.377	12	2	0	0	0
71	LN2	SUPPLY	X-FER LINE	BAYONET CAN	VALVE BOX	3/8" OD X .049	0.377	47	6	1	0	0
72	LN2	SUPPLY	X-FER LINE	VALVE BOX	VLPC WEST	3/8" OD X .049	0.277	24	3	1	1	1 PV
73	LN2	SUPPLY	X-FER LINE	VALVE BOX	VLPC EAST	3/8" OD X .049	0.277	24	3	1	1	1 PV
74	LN2	SUPPLY	X-FER LINE	VLPC WEST	VALVE BOX	3/8" OD X .049	0.377	24	0	0	1	0
75	LN2	SUPPLY	X-FER LINE	VLPC EAST	VALVE BOX	1/2" OD X .049 3/8" OD X .035	.402 .305	24	1	1	0	0
76	LN2	RETURN	X-FER LINE	VALVE BOX	BAYONET CAN	1/2" OD X .049 3/8" OD X .035	.402 .305	47	6	1	0	0
77	LN2	RETURN	U-TUBE	BAYONET CAN	CH FEED CAN	3/8" OD X .049	0.377	12	2	0	0	0
78	LN2	RETURN	X-FER LINE	CH FEED CAN	AH FEED CAN	3/8" OD X .049	0.377	125	9	2	0	0
79	LN2	RETURN	U-TUBE	AH FEED CAN	GN2 VENT HEADER	1/2" OD X .049 3/8" OD X .035	.402 .305	5	2	0	0	0
* VLPC SERPENTINE LENGTH = 16 FT												
* # OF ELBOWS IN SERPENTINE = 18												

Solenoid Helium Steady State Pressure drops

Some preliminary calculations were done to estimate the steady state helium heat loads, flowrates and pressure drops expected for each section of piping. See appendices I, J, and K. The total pressure drop from the tubing sizes were on the order of 3.2 psi as shown in the summary table in appendix K, page K12. Essentially all this pressure drop occurred in the long return pipe, line # 8. The pressure drop was based on line # 8 being a concentric tube with hydraulic radius of 0.347". *The return pipe, line #8 was looked into further. See appendix L. It was determined that a 1 1/2" sch. 10 pipe will be used giving a hydraulic radius of 1.057". The total steady state pressure drop then is on the order of 0.1 psi for the piping. Allowing all the pressure drops to occur across control valves.*

Solenoid Nitrogen flowrates and pressure drops

The nitrogen flowrate requirements for cooldown and steady state are considered in calculations in appendix F. The maximum pressure drop allowed for the nitrogen circuit inlet to outlet is 30 psi, based on the current storage dewar operating pressure. Per the Solenoid bid spec., the required nitrogen cooldown flowrate shall not exceed 5 g/s. With the current selected pipe sizes nitrogen flow will less be than 5 g/s until the return piping fluid is less than 150 K. This means initially we may cannot deliver the full 5 g/s. I feel this is acceptable however. The pressure drop for steady state nitrogen requirements is expected to be less than 1 psi (with control valves full open). See appendix G.

VLPC Helium Cooldown flowrates

The LHe line sizes for the VLPC were determined by first calculating the required flow rates during cooldown. These calculations are shown in "VLPC Cooldown & Flow Rates Etc." of appendix D and are summarized in Table 7. A cooldown rate of 5 K/hr was used in these calculations.

Table 7: VLPC COOLDOWN FLOW RATES

STEP	VLPC TEMP [K]	GAS TEMP IN [K]	GAS TEMP OUT [K]	TIME [hrs]	MASS FLOW RATE REQ'D [g/s]
1	300 to 250	200	250	10	.84
2	250 to 200	150	200	10	.89
3	200 to 150	100	150	10	.92
4	100 to 90	80	90	4	3.1

It was concluded that step 4's pressure drop would be about 3.6 times larger than step 1's. Therefore the cooldown lines were sized for a flow rate of 3.1 g/s with an inlet temperature of 80K and an outlet temperature of 90K (refer to appendix D).

VLPC Helium Cooldown Pressure drops

A list of the various piping sections along with their corresponding lengths and number of elbows, tees, and valves. Each pipe section was given a number. See table 4 for a listing of the VLPC pipe sections.

Pressure drops due to friction, valves, tees, bends, etc. were then calculated for the given pipe sizes and inlet/exit states. The VLPC cooldown piping was first sized by assuming a pressure drop of 95 psig, an inlet temperature of 80K GHe and an outlet temperature of 90K through the supply and return lines respectively. Resistance coefficients were calculated for four segments of the piping. In the second step of the calculation, pressure drops were calculated for each segment taking into account the change in density due to changes in pressure. Summing the individual pressure drops resulted in a rough estimated pressure drop of 59.1 psi. These numbers are summarized in table 9 *for the initial supply size of 3/8" OD and return size of 1/2" OD tubes.* See Appendix E for the raw calculations. ** After looking at steady state pressure drops, the line sizes for the supply and return were increased to 1/2" OD and 5/8" OD respectively. Therefore pressure drops listed in Table 9 will be less.*

**Table 9: VLPC Helium Cooldown piping pressure drop summary
for 3/8" supply & 1/2" return sizes. ***

PIPE SECTION	PRESSURE DROP (PSIA)
Supply line 38	0.44
West supply lines + VLPC cryostat	27.4
West return lines	28.1
Return line 66	3.2
Total Delta P =	59.1 psi

VLPC Helium Steady State Pressure drops

The expected pressure drop for 3/8" OD x 0.035 wall supply tubing for a steady state flow of 5 g/s and a transfer line heat load of 10 W was conservatively estimated at 4.6 psi per 100 ft. This prompted the increase in size to 1/2" OD x 0.049 wall tubing. The calculated pressure drop for the two phase supply would be 1.2 psi per 100 ft. Backing off on the conservatism and figuring approx. 200 ft. of equivalent length a real estimate of the supply pressure drop from the refrigerator to the VLPC cryostat is about 1 psi. See Appendix H, page H4.

The expected pressure drop for the return 5/8" OD x 0.049" wall tube with 5 g/s, 6.5 K gas flowing is 0.6 psig. Since the supply and return tubing accounts for less than 2 psi pressure drop, there is approximately 10 psi available across the control valve and cryostat. See Appendix H, page H3.

VLPC Nitrogen flowrates and pressure drops

The nitrogen tube sizes were chosen from a practical size standpoint. It is impractical to go to a size smaller than 3/8" OD. Based on experience with the solenoid nitrogen calculations, I conclude that pressure drop in the VLPC nitrogen piping will be negligible for the required flowrates. No formal calculations were done.

Table of Contents for the Appendices

Raw Engineering Calculations

Appendix A: Solenoid Cooldown and Flowrates etc.

Appendix B: Estimated flowrate thru Solenoid cooldown piping and delta P.

Appendix C: Solenoid pipe size: Comparison to CDF.

Appendix D: Calculation to determine VLPC Cooldown and flow rates required.

Appendix E: VLPC Piping: Total pressure drop in cooldown phase.

Appendix F: Delta P for Solenoid LN2 transfer line.

Appendix G: Solenoid transfer line steady state conditions.

Appendix H: VLPC LHe line sizing for steady state conditions.

Appendix I: Heat loads for Solenoid & VLPC transfer lines

Appendix J: Steady state heat loads to solenoid transfer line.

Appendix K: Solenoid steady state calcs. Helium piping.

Appendix L: Solenoid steady state calcs. Helium return piping.

SUBJECT

VLPC LHE LINE SIZING.
FOR STEADY STATE CONDITIONS

NAME

RUSS RUCINSKI

DATE

1-26-95

REVISION DATE

CONSIDER STEADY STATE MASS FLOW
VLPC CRYOSTATS.

CHECKED: Todd Lucht 4/4/95
CHECKED: Steve Sakla 3/2/95
REQ'D FOR

IN SOLENOID DESIGN REPORT $Q_{TOTAL} = 270 W$, A HIGH
ESTIMATE. CURRENT ESTIMATES ARE 70 W PER CRYOSTAT
AND PERHAPS AN ADDITIONAL 40 W FOR TRANSFER LINES
& JUMPERS $Q_{TOTAL} = 180 W$.

TO BE CONSERVATIVE USE 270 W NUMBER.

$$\dot{m}_{ss} = \frac{Q_{ss}}{\Delta h} = \frac{270 W}{45.35 \frac{J}{g} - 14.29 \frac{J}{g}} = 8.69 \frac{g}{s}$$

↑ (P=.12 MPa, T=6.5 K) ↑ (SAT. LIQID, 0.1743 MPa)

RETURN CONDITIONS

CALCULATE ΔP_{100} FOR $\dot{m} = 4.35 \frac{g}{s}$ $T = 6.5 K$, $P = .14 MPa$

SAY

3/8" O.D. x .035 WALL, ID = .305

$$Re = \frac{4\dot{m}}{\pi D \mu} = \frac{4 \cdot (.00435 \frac{kg}{s})}{\pi (.305 m) (.0254 \frac{m}{N}) (1.726 \times 10^{-6} Pa \cdot s)}$$

$$= 414,214 \quad f = .013$$

$$\rho = 11.90 \frac{kg}{m^3} \quad \Delta P = 3.62 \frac{kg \cdot m}{s^2} \quad K = \frac{FL}{D}$$

CRANE,
EQ. 3-14
EQ. 2-4

$$K_{100} = (.013) \frac{(100 \text{ ft.})}{\frac{.305}{12} \text{ ft.}} = 51.1$$

$$q = \frac{\dot{m}}{\rho} = \frac{.00435 \frac{kg}{s}}{11.90 \frac{kg}{m^3}} = 3.655 \times 10^{-4} \frac{m^3}{s} \times \left(\frac{3.28}{1 m} \right)^3$$

$$= \frac{0.0129}{.035 \times 10^{-5}} \frac{ft^3}{s}$$

$$\Delta P_{100} = 3.62 \frac{(51.1) (.74351 \frac{lb}{ft^3}) (1.035 \times 10^{-5} \frac{ft^3}{s})^2}{(.305 m)^4} = 1.7 \times 10^{-6} \text{ psi}$$

$$= 2.645 \text{ psig}$$

$$\Delta P_{100} = 11.84 \text{ PSI}$$

3.42 for .402 ID.

1.124 PSI

Known: $\dot{m} = 50/\text{s}$ $1/2"$ OD $\times$ 0.049 wall
 $T = 6.5\text{K}$ ID = 0.402 in = 0.0102 m
 $P = 0.12\text{MPa}$ L = 200 ft = 60.96 m

Find: ΔP for this flow rate & pipe size.

Sol'n: $Re = \frac{\rho V D}{\mu}$ $V = \frac{Q}{A} \rightarrow Q = \frac{\dot{m}}{\rho}$, $A = \frac{\pi D^2}{4}$
 $V = \frac{(\dot{m}/\rho)}{(\pi D^2/4)} = \frac{4\dot{m}}{\pi \rho D^2} \rightarrow (2)$

$$Re = \frac{(\cancel{\rho})}{\mu} \left(\frac{4\dot{m}}{\pi \cancel{\rho} D^2} \right)$$

$$= \frac{4\dot{m}}{\pi \mu D} = \frac{4(5 \times 10^{-3} \text{ kg/s})}{\pi (1.705 \times 10^{-4} \frac{\text{N}\cdot\text{s}}{\text{m}^2})(0.0102\text{m})}$$

$$\mu(T=6.5\text{K}, P=0.12\text{MPa}) = 1.705 \times 10^{-4} \text{ Pa}\cdot\text{s}$$

$$\rho(T=6.5\text{K}, P=0.12\text{MPa}) = 997.6 \text{ kg/m}^3$$

$$= 366,063. \frac{[\text{kg/s}]}{[\frac{\text{N}\cdot\text{s}}{\text{m}^2}]} = 1$$

$\rightarrow f = 0.014$ (Fig. 8.14, "Intro. to Fluid Mech", Fox & McDonald)

$$\left(\frac{P_1}{\rho} + \alpha_1 \frac{\bar{V}_1^2}{2} + g z_1 \right) - \left(\frac{P_2}{\rho} + \alpha_2 \frac{\bar{V}_2^2}{2} + g z_2 \right) = h_{L_T} \rightarrow (1)$$

$\bar{V}_1 \approx \bar{V}_2$
 $P_1 - P_2 = \rho h_{L_T}$ $h_{L_T} = f \frac{L}{D} \frac{\bar{V}^2}{2}$ $\bar{V} = 6.13 \text{ m/s}$ (from (2))

$$= (997.6 \text{ kg/m}^3)(0.014) \frac{(60.96\text{m})}{(0.0102\text{m})} \frac{(6.13 \text{ m/s})^2}{2}$$

$$= 15682.68 \frac{\text{kg}}{\text{m}\cdot\text{s}^2}$$

$$= 15682.68 \text{ Pa}$$

$$= \underline{\underline{2.27 \text{ psi}}}$$

STEVE SAKLA
6-29-95

$$\Delta P = f \frac{L}{D} \frac{\bar{V}^2}{2}$$

$$= f \frac{L}{D} \frac{16 \dot{m}^2}{2 \pi^2 \rho^2 D^4}$$

$$= K \frac{16 \dot{m}^2}{2 \pi^2 \rho^2 D^4}$$

$$\Delta P = \left(f \frac{L}{D}\right) (\rho) \left(\frac{16 Q^2}{2 \pi^2 D^4}\right) = K^{0.81} \frac{\rho Q^2}{D^4}$$

$$\Delta = 0.81 K \left[\frac{16 \dot{m}^2}{\text{in}^4} \right] \left[\frac{\text{ft}^3}{\text{s}} \right]^2 = 0.81 K \frac{16 \dot{m} - \text{ft}^3}{\text{in}^4 - \text{s}^2}$$

$$0.81 \frac{16 \dot{m} - \text{ft}^3}{\text{in}^4 - \text{s}^2} \left(\frac{31.08 \text{ s}}{16 \dot{m}} \right) \left(\frac{16 \dot{m}}{31.08 \text{ s}} \right) \left(\frac{12 \text{ in}}{\text{ft}} \right)^2 =$$

$$\dot{m} = 0.00435 \text{ kg/s}$$

$$T = 6.51 \text{ K}$$

$$P = 0.14 \text{ MPa}$$

$$ID = 0.305 \text{ in}$$

$$\rho = 11.9 \text{ kg/m}^3$$

$$\mu = 1.726 \times 10^{-6} \text{ Pa-s}$$

$$Re = \frac{4 \dot{m}}{\pi D \mu} = \frac{4 (0.00435 \text{ kg/s})}{\pi \left(\frac{0.305 \text{ m}}{12.328} \right) (1.726 \times 10^{-6} \frac{\text{N-s}}{\text{m}^2})} = 414,108 \rightarrow f = 0.0137$$

$$\frac{\Delta P}{\rho} + \alpha \frac{\bar{V}^2 - \bar{V}_1^2}{2} = f \frac{L}{D} \frac{\bar{V}^2}{2}$$

$$V = \frac{4 \dot{m}}{\pi D^2} = \frac{4 \dot{m}}{\pi \rho D^2}$$

$$\Delta P = \left(f \frac{L}{D}\right) \rho \frac{\bar{V}^2}{2} =$$

$$V = \frac{4 (0.00435 \text{ kg/s})}{\pi (11.9 \text{ kg/m}^3) \left(\frac{0.305}{12.328} \right)^2} = 7.75 \text{ m/s}$$

$$\Delta P = (0.0137) \left(\frac{100 \text{ ft}}{0.305 \text{ ft}} \right) (11.9 \text{ kg/m}^3) \frac{(7.75^2 \text{ m}^2/\text{s}^2)}{2}$$

$$\Delta P = 192.63 \text{ Pa} = 2.8 \text{ psi} \leftarrow \text{FOR } 1/2" \text{ OD TUBING.}$$

$$\Delta P_{100} (2.8 \text{ psi}) \times \frac{(0.305)^4}{(0.527)^4} = 0.314 \text{ psig for } 5/8" \text{ OD TUBING}$$

$$\Delta P_{200} = 0.6 \text{ psig}$$

SUBJECT

VLPC He SUPPLY PIPING

NAME

RUSS RUCINSKI

DATE

6/28/95

REVISION DATE

CALCULATE ΔP_{100} FOR $\dot{m} = 5 \text{ g/s}$ FLOWING THRU EACH
3/8" OD x .035" TUBE.

CONSIDER 3.5 W - U-TUBE + 2 W TRANSFER LINE + 3.5 W U-TUBE + 1 W TRANS.
SAY 10 WATTS HEAT LEAK FROM LHe STORAGE DEWAR
TO VLPC CRYOSTAT.

STATE ①

LHe DEWAR
SAT. LIQ.
 $T = 4.80 \text{ K}$
 $P = 9.6 \text{ psig}$
 $h_L = 13.85 \text{ J/g}$

$$h_2 = h_1 + \frac{10 \text{ WATTS}}{5 \text{ g/s}} = 13.85 + 2 = 15.85 \text{ J/g}$$

SAY STATE ②

$$P_2 = .16 \text{ MPa} = 8.5 \text{ psig}$$

$$h_L = 11.96$$

$$h_g = 24.12$$

$$x_2 = \frac{h - h_f}{h_g - h_f} = \frac{15.85 - 11.96}{24.12 - 11.96} = 0.32$$

FOR WORST CASE I WILL CALCULATE THE ΔP FOR
STATE 2 CONDITIONS.

USING TK SOLVER ΔP 2 PHASE PROGRAM,

$$\Delta P_{100} = 4.6 \text{ psig.}$$

THIS IS TOO LARGE.

TRYING 1/2" x .049 TUBE $\Delta P_{100} = 1.2 \text{ psig}$

THE PIPING LENGTH IS PROBABLY EQUIVALENT TO 200 FE.

$$\text{LESS CONSERVATIVE } \dot{m} = \frac{180}{270} \times 8.69 \frac{\text{g}}{\text{s}} \times \frac{1}{2} = 2.9 \frac{\text{g}}{\text{s}}$$

FOR THIS $\dot{m}$,

$$\Delta P_{100} = 0.45 \text{ psi}$$

← SUPPLY
LINE

SUBJECT

2φ HE RETURN PIPING
SOLENOID

NAME

RUSS RUCINSKI

DATE

5/26/95

REVISION DATE

MAX. FLOW = $4 \frac{9}{5}$ FROM BID SPEC.

HEAT LOAD FOR MAGNET SYSTEM = $11.1 \text{ W} + 6 \text{ W} + 28.8 \frac{\text{J}}{\text{hr.}}$

HEAT LOAD FROM LHe DEWAR TO MAGNET SYSTEM = 10 WATTS

STATE (1)

$$P_1 = 1.8 \text{ ATM}$$

SAT. LIQUID

$$T = 4.91 \text{ K}$$

$$h_1 = 14.86 \frac{\text{J}}{\text{g}}$$

$$h_{1.5} = h_1 + \frac{Q_{1 \rightarrow 1.5}}{\dot{m}} = 14.86 \frac{\text{J}}{\text{g}} + \frac{27.1 \frac{\text{J}}{\text{s}}}{4 \frac{9}{5}}$$

$$h_{1.5} = 21.635 \frac{\text{J}}{\text{g}}$$

STATE (1.5)

$$h_{1.5} = 21.635$$

STATE (2)

$$P_2 = .12 \text{ MPa}$$

$$x_2 = 1.0$$

$$h_2 = h_g = 30.61 \frac{\text{J}}{\text{g}}$$

$$\dot{m}_2 = 1 \frac{9}{5}$$

STATE (3) 2φ

$$P_3 = .12 \text{ MPa} \quad T = 4.41 \text{ K}$$

$$\dot{m}_3 = 3 \frac{9}{5}$$

$$h_3 = 18.643 \frac{\text{J}}{\text{g}} \quad \text{FROM BELOW}$$

$$h_f = 11.07 \frac{\text{J}}{\text{g}}$$

$$h_g = 30.61 \frac{\text{J}}{\text{g}}$$

$$x_3 = .3876$$

$$\frac{1}{4} h_2 + \frac{3}{4} h_3 = (1.0) h_{1.5}$$

$$\frac{1}{4} (30.61) + \frac{3}{4} h_3 = 21.635 \Rightarrow h_3 = 18.643$$

$$x_3 = \frac{h_3 - h_f}{h_g - h_f} = \frac{18.643 - 11.07}{30.61 - 11.07} = \underline{0.3876}$$

$$\sigma = .0802 \frac{\text{dyne}}{\text{cm}} \text{ FROM pg. 7 NIST TABLES}$$

$$= .0802 \frac{\text{dyne}}{\text{cm}} \times 1.0 \times 10^{-5} \frac{\text{N}}{\text{dyne}} \times 1 \times 10^2 \frac{\text{cm}}{\text{m}} = .000082 \frac{\text{N}}{\text{m}}$$

SUBJECT

2Ø He RETURN PIPING

NAME

RUSS RUCINSKI

DATE

5-30-95

REVISION DATE

FOR THESE CONDITIONS w/ $L = 200$ Ft AND A 1" SCH. 10
PIPE w/ 1Ø 5/8" OD TUBE, $D_H = .472$ ",

$\Delta P = 1.486$ BASED ON LOCKHART MARTINELLI

(NOTE: SLIGHT
MISTAKE
 $D = .427$ " IN CALC.
NOT .472")

SEE TK SOLVER PRINT OUT. THIS IS TOO LARGE A ΔP .
MUST CHOOSE A LARGER PIPE SIZE

TRY 1 1/2" SCH. 10 PIPE, $ID = 1.682$ "

$$D_H = 1.682 - .625 = 1.057 \text{ in.}$$

MUCH BETTER $\Delta P = .02$ PSI, IN WAVEY/STRATIFIED
FLOW REGIME ON MODIFIED NAMEKOV BAKER DIAGRAM.
1 1/2" SCH. 10 IS THE BEST SIZE. THE RADIATION
SHIELD IS 3.5" OD. SO THERE IS PLENTY OF
ROOM FOR THIS SIZE.

St	Input	Name	Output	Unit	Comment
					Russ Rucinski 5/30/95
					Return He pipe for Solenoid
					1" pipe w/ 5/8" tube inside
					Lockhart Martinelli correlation
					for two phase pressure drop
					through an adiabatic horizontal pipe
		valid	'accurate		model validity
		flow	'turbulen		flow type
		f	.01906103		friction factor ; Must enter a guess
.000005		epsilon		ft	pipe roughness
.427		D		in	Pipe inside diameter
200		L		ft	Length of pipe
		A	9.2387E-5	m^2	cross sectional area
4		mdot		g/s	Total mass flow rate
121.1		rhoL		kg/m^3	Liquid density
20.17		rhog		kg/m^3	density of the gas
3.18		muL		μPa-s	Liquid viscosity
1.323		muG		μPa-s	Gas viscosity
.000082		sigmaL		N/m	Surface tension of liquid
.3876		x			quality = mdotG/mdot
		ReL	90430		Reynold's # for liquid
		mdotL	.0024496	kg/s	Mass flow rate for liquid
		ReG	137600		Reynold's # for gas
		mdotG	.0015504	kg/s	Mass flow rate for gas
		dpdLL	5.1012286	Pa/m	ΔP/ΔL for the liquid
		dpdLTP	168.10555	Pa/m	ΔP/ΔL for the two phase
		deltaP	1.4863285	psig	Total pressure drop for the pipe ← Too LARGE, Go to NEXT SIZE
		phiL	5.7405518		Lockhart-Martinelli parameter
		X	.67244052		Lockhart-Martinelli parameter
.2		m			L-M constant; Look up in Table 7.19
.2		n			L-M constant; Look up in Table 7.19
.184		CG			L-M constant; Look up in Table 7.19
.184		CL			L-M constant; Look up in Table 7.19
20		C			L-M constant; Look up in Table 7.19
		lambda	1.4281346		Baker diagram dimensionless parameter
1.2		rhoair		kg/m^3	density of air
998		rhoH2O		kg/m^3	density of water
		sigh	534.12427		Baker diagram dimensionless parameter
.073		sigmaH2		N/m	Surface tension of water
1000		muH2O		μPa-s	viscosity of water
		BakerXa	1210		X - axis value for Baker plot
		BakerYa	8660	lbm/hr-ft	Y - axis value for Baker plot
		c	1		
		M	1		
		RsubL	.17419928		Volume fraction of liquid phase
		RsubG	.82580072		Volume fraction of gas phase
		GasVel	1.0075104	m/s	Gas velocity
		LiqVel	1.2568736	m/s	Liquid velocity

St	Input	Name	Output	Unit	Comment
					Russ Rucinski 5/30/95
					Return He pipe for Solenoid
					1 1/2" pipe w/ 5/8" tube inside
					Lockhart Martinelli correlation
					for two phase pressure drop
					through an adiabatic horizontal pipe
		valid	'accurate		model validity
		flow	'turbulen		flow type
		f	.02260289		friction factor ; Must enter a guess
.000005		epsilon		ft	pipe roughness
1.057		D		in	Pipe inside diameter
200		L		ft	Length of pipe
		A	.00056612	m^2	cross sectional area
4		mdot		g/s	Total mass flow rate
121.1		rhoL		kg/m^3	Liquid density
20.17		rhog		kg/m^3	density of the gas
3.18		muL		μPa-s	Liquid viscosity
1.323		muG		μPa-s	Gas viscosity
.000082		sigmaL		N/m	Surface tension of liquid
.3876		x			quality = mdotG/mdot
		ReL	36530		Reynold's # for liquid
		mdotL	.0024496	kg/s	Mass flow rate for liquid
		ReG	55580		Reynold's # for gas
		mdotG	.0015504	kg/s	Mass flow rate for gas
		dpdLL	.0650814	Pa/m	ΔP/ΔL for the liquid
		dpdLTP	2.1275204	Pa/m	ΔP/ΔL for the two phase
		deltaP	.01881077	psig	Total pressure drop for the pipe
		phiL	5.7175294		Lockhart-Martinelli parameter
		X	.67767548		Lockhart-Martinelli parameter
.2		m			L-M constant; Look up in Table 7.19
.25		n			L-M constant; Look up in Table 7.19
.184		CG			L-M constant; Look up in Table 7.19
.316		CL			L-M constant; Look up in Table 7.19
20		C			L-M constant; Look up in Table 7.19
		lambda	1.4281346		Baker diagram dimensionless parameter
1.2		rhoair		kg/m^3	density of air
998		rhoH2O		kg/m^3	density of water
		sigh	534.12427		Baker diagram dimensionless parameter
.073		sigmaH2		N/m	Surface tension of water
1000		muH2O		μPa-s	viscosity of water
		BakerXa	1210		X - axis value for Baker plot
		BakerYa	1410	lbm/hr-ft	Y - axis value for Baker plot
		c	1		} SEE FIGURE WAVE/STRATIFIED REGIME
		M	1		
		RsubL	.17490072		Volume fraction of liquid phase
		RsubG	.82509928		Volume fraction of gas phase
		GasVel	.16456003	m/s	Gas velocity
		LiqVel	.20429237	m/s	Liquid velocity

RUSS RUCINSKI
5/30/95

FERMILAB TWO PHASE HELIUM FLOW TESTS

Figure 1: Baker diagram with Mamedov curves for two phase helium in horizontal channels

[FROM DP EN 3823.111-EN-338]

3
5

PIPE SIZING:
FOR
SOLENOID/VLPC
CRYOGENIC SYSTEMS

D-ZERO ENGINEERING NOTE # 3823.115- EN-416

February 20, 1995

Russ Rucinski and Steve Sakla
RD/DØ Mech.

Approved : _____

Introduction

The addition of a solenoid magnet and VLPC detectors are two of a number of upgrades which will occur at the D-Zero detector in the near future. Both of these upgrades will require cryogenic services for their operation. The purpose of this engineering note is to document the pipe/tube size choices made for these cryogenic services. This was done by calculating the required flow rates to cool down the magnet and VLPC's over a reasonable length of time and to determine the required piping sizes for a given allowable pressure drop. The pressure drops for steady state conditions also are addressed. The cool down requirements drove the pipe size decision. The raw engineering calculations that were done for this project are included as an appendix to this note. The body of this document discusses the methods and results of the calculations. As a quick summary, Figures 1 and 2 show the size selections. Tables 1 and 2 give a more detailed size and description of each section of Solenoid and VLPC transfer line.

VLPC Detector/Cryostat Description

The main detecting component of the VLPC detector is the VLPC (Visible Light Photon Counter) chip. These chips have an optimum performance at a temperature of about 6.5K which will be maintained through the use of a cryostat. Two cryostats, named east and west, will be used to maintain the cold temperatures of the chips through the use of liquid helium. Liquid nitrogen will be used to intercept some of the heat leak coming in to the cryostat. These cryogens will be supplied to the cryostat via a vacuum jacketed transfer line and u-tubes. The transfer lines begin at the LHe refrigerator location near the southeast corner of the D-Zero cleanroom. The VLPC supply and return lines share a common vacuum jacketed line. These lines will originate at the valve box on the refrigerator side and will run along the south wall, see figure 4. The building side route for the VLPC line follows the same path as the solenoid, see figure 5. The detector side VLPC piping can be seen in figure 6. For more description see the D0 engineering note "Cryogenic Line routing: Refrigerator to VLPC Cryostats and Solenoid", D0 note # 3823.115-EN-413.

Solenoid Magnet Description

The solenoid magnet will provide a 2 tesla magnetic field in the inner bore of the central calorimeter. It will operate at approximately 4.9K which will be obtained by means of indirect cooling from liquid helium. As with the VLPC cryostat liquid nitrogen

PRELIMINARY BUILDING TRANSFER LINE DESIGNS

Russ Rucinski 2/21/95

Plotted Tue Feb 21 15:38:29 CST 1995 by rucinski

FIGURE 1

TABLE 1 : SOLENOID PIPE SECTIONS

LINE #	FLUID	DESCRIPTION	TYPE	FROM	TO	PIPE OR TUBE SIZE	INSIDE DIA. (IN.)	LINEAR LENGTH (FT.)	# OF ELBOWS	# TEES THRU RUN	# TEES THRU BRANCH	VALVES
4	LHE	SUPPLY (HUT3)	U-TUBE	LHE DEWAR	X-FER LINE	3/4" OD X .035	0.68	5	2	0	0	0
5	LHE	SUPPLY	X-FER LINE	U-TUBE	U-TUBE	5/8" OD X .049	0.527	125	9	4	0	1 DIVRTR.
6	LHE	SUPPLY (HUT4)	U-TUBE	X-FER LINE	CONTROL DEWAR	3/4" OD X .035	0.68	10	2	0	0	0
7	LHE	RETURN (HUT5)	U-TUBE	CONTROL DEWAR	X-FER LINE	3/4" OD X .035	0.68	10	2	0	0	0
8	LHE	RETURN	X-FER LINE	U-TUBE	U-TUBE	Concentric	0.427	125	9	4	0	1 PV, 1 CV
9	HE	RETURN	U-TUBE	X-FER LINE	X-FER LINE (VLPC)	3/4" OD X .035	0.68	3	2	0	0	0
10	LN2	SUPPLY	U-TUBE	LIN HEADER	X-FER LINE	1/2" OD x .035	0.43	3	2	0	0	0
11	LN2	SUPPLY	X-FER LINE	U-TUBE	TEE	1/2" OD X .049	0.402	1	1	0	0	0
12	LN2	SUPPLY (SHIELD)	X-FER LINE	TEE	U-TUBE	3/8" OD X .049	0.277	124	9	2	1	1 PV
13	LN2	SUPPLY (SHIELD)	U-TUBE	X-FER LINE	CONTROL DEWAR	1/2" OD x .035	0.43	10	2	0	0	0
14	LN2	SUPPLY (INTERCEPT)	X-FER LINE	TEE	U-TUBE	3/8" OD X .049	0.277	124	9	2	1	1 PV
15	LN2	SUPPLY (INTERCEPT)	U-TUBE	X-FER LINE	CONTROL DEWAR	1/2" OD x .035	0.43	10	2	0	0	0
16	LN2	RETURN (SHIELD)	U-TUBE	CONTROL DEWAR	X-FER LINE	1/2" OD x .035	0.43	10	2	0	0	0
17	LN2	RETURN (SHIELD)	X-FER LINE	U-TUBE	U-TUBE	3/8" OD X .049	0.277	125	9	2	0	0
18	LN2	RETURN (SHIELD)	U-TUBE	X-FER LINE	TEE	1/2" OD x .035	0.43	1	1	0	1	0
19	LN2	RETURN (INTERCEPT)	U-TUBE	CONTROL DEWAR	X-FER LINE	1/2" OD x .035	0.43	10	2	0	0	0
20	LN2	RETURN (INTERCEPT)	X-FER LINE	U-TUBE	U-TUBE	3/8" OD X .049	0.277	125	9	2	0	0
22	LN2	RETURN (INTERCEPT)	U-TUBE	X-FER LINE	TEE	1/2" OD x .035	0.43	1	1	0	1	0
23	LN2	RETURN	U-TUBE	TEE	GN2 VENT HEADER	1/2" OD x .035	0.43	5	1	0	0	0
24	HE	(COOLDOWN/ QUENCH)	U-TUBE	CONTROL DEWAR	X-FER LINE	3/4" OD X .035	0.68	10	2	0	0	0
25	HE	(COOLDOWN/ QUENCH)	X-FER LINE	U-TUBE	U-TUBE	3/4" OD X .065	0.62	125	9	2	0	0
26	HE	(COOLDOWN/ QUENCH)	U-TUBE	X-FER LINE	HE COOLDOWN RETURN	3/4" OD X .035	0.68	5	2	0	0	0
27	HE	SUPPLY (COOLDOWN)	U-TUBE	COOLDOWN LINE	X-FER LINE	3/4" OD X .035	0.68	5	4	0	0	1 DIVRTR.

TABLE 2: VLPC PIPE SECTIONS

5

LINE #	FLUID	DESCRIPTION	TYPE	FROM	TO	PIPE OR TUBE SIZE	INSIDE DIA. (IN.)	LIN. LENGTH (FT.)	# OF ELBOWS	# TEES THRU RUN	# TEES THRU BRANCH	VALVES
38	HE	SUPPLY	U-TUBE	HTX6	AH FEED CAN	1/2" OD X .049	0.402	5	2	0	0	0
39	LHE	SUPPLY	U-TUBE	LHE DEWAR	AH FEED CAN	1/2" OD X .049	0.402	5	2	0	0	0
40	HE	WEST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE	3/8" OD X .035	0.305	2	1	1	0	0
41	LHE	WEST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE			2	1	1	0	0
42	HE	WEST HE SUPPLY	X-FER LINE	3-WAY VALVE	U-TUBE	3/8" OD X .035	0.305	123	9	3	0	1 DV
43	HE	WEST HE SUPPLY	U-TUBE	CH FEED CAN	BAYONET CAN	3/8" OD X .035	0.305	12	2	0	0	0
44	HE	WEST HE SUPPLY	X-FER LINE	BAYONET CAN	VALVE BOX	3/8" OD X .035	0.305	47	6	1	0	0
45	HE	WEST HE SUPPLY	X-FER LINE	VALVE BOX	VLPC	3/8" OD X .035	0.305	24	2	0	0	0
46	HE	EAST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE	3/8" OD X .035	0.305	2	0	1	1	0
47	HE	EAST HE SUPPLY	X-FER LINE	U-TUBE	3-WAY VALVE	3/8" OD X .035	0.305	2	0	0	1	0
48	HE	EAST HE SUPPLY	X-FER LINE	3-WAY VALVE	U-TUBE	3/8" OD X .035	0.305	123	9	3	0	1 DV
49	HE	EAST HE SUPPLY	U-TUBE	CH FEED CAN	BAYONET CAN	3/8" OD X .035	0.305	12	2	0	0	0
50	HE	EAST HE SUPPLY	X-FER LINE	BAYONET CAN	VALVE BOX	3/8" OD X .035	0.305	47	6	1	0	0
51	HE	EAST HE SUPPLY	X-FER LINE	VALVE BOX	VLPC	3/8" OD X .035	0.305	24	2	0	0	0
52	HE	EAST HE RETURN	X-FER LINE	VLPC	VALVE BOX	3/8" OD X .035	0.305	24	1	0	0	1 PV
53	HE	EAST HE RETURN	X-FER LINE	VALVE BOX	BAYONET CAN	3/8" OD X .035	0.305	47	6	0	0	0
54	HE	EAST HE RETURN	U-TUBE	BAYONET CAN	CH FEED CAN	3/8" OD X .035	0.305	12	2	0	0	0
55	HE	EAST HE RETURN	X-FER LINE	CH FEED CAN	3-WAY VALVE	3/8" OD X .035	0.305	123	9	3	1	1 DV
56	HE	EAST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (COOLDOWN RETURN)	3/8" OD X .035	0.305	2	2	1	1	1 CV
57	HE	EAST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (VALVE BOX)	3/8" OD X .035	0.305	2	2	2	1	1 CV
58	HE	WEST HE RETURN	X-FER LINE	VLPC	VALVE BOX	3/8" OD X .035	0.305	24	1	0	0	1 PV
59	HE	WEST HE RETURN	X-FER LINE	VALVE BOX	BAYONET CAN	3/8" OD X .035	0.305	47	6	0	0	0
60	HE	WEST HE RETURN	U-TUBE	BAYONET CAN	CH FEED CAN	3/8" OD X .035	0.305	12	2	0	0	0
61	HE	WEST HE RETURN	X-FER LINE	CH FEED CAN	3-WAY VALVE	3/8" OD X .035	0.305	123	9	2	0	1 DV
62	HE	WEST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (COOLDOWN RETURN)	3/8" OD X .035	0.305	2	2	0	2	1 CV
63	HE	WEST HE RETURN	X-FER LINE	3-WAY VALVE	VJ LINE (VALVE BOX)	3/8" OD X .035	0.305	1	1	0	2	1 CV
64	HE	WEST HE RETURN	X-FER LINE	3-WAY VALVE	TEE	3/8" OD X .035	0.305	2	1	1	2	1 CV
65	HE	RETURN	X-FER LINE	U-TUBE FROM SOL. X-FER LINE	TEE	1/2" OD X .049	0.402	1	1	2	1	0
66	HE	RETURN	U-TUBE	AH FEED CAN	COOLDOWN RETURN LINE	1/2" OD X .049	0.402	5	2	0	0	0
67	HE	RETURN	U-TUBE	AH FEED CAN	VALVE BOX	3/4" OD X .035	0.58	4	0	0	0	0
68	LN2	SUPPLY	U-TUBE	LN2 HEADER	AH FEED CAN	3/8" OD X .049	0.277	3	2	0	0	0
69	LN2	SUPPLY	X-FER LINE	AH FEED CAN	CH FEED CAN	3/8" OD X .049	0.277	125	9	2	0	0
70	LN2	SUPPLY	U-TUBE	CH FEED CAN	BAYONET CAN	3/8" OD X .049	0.277	12	2	0	0	0
71	LN2	SUPPLY	X-FER LINE	BAYONET CAN	VALVE BOX	3/8" OD X .049	0.277	47	6	1	0	0
72	LN2	SUPPLY	X-FER LINE	VALVE BOX	VLPC WEST	3/8" OD X .049	0.277	24	3	1	1	1 PV
73	LN2	SUPPLY	X-FER LINE	VALVE BOX	VLPC EAST	3/8" OD X .049	0.277	24	3	1	1	1 PV
74	LN2	SUPPLY	X-FER LINE	VLPC WEST	VALVE BOX	3/8" OD X .049	0.277	24	0	0	1	0
75	LN2	SUPPLY	X-FER LINE	VLPC EAST	VALVE BOX	3/8" OD X .049	0.277	24	1	1	0	0
76	LN2	SUPPLY	X-FER LINE	VALVE BOX	BAYONET CAN	3/8" OD X .049	0.277	47	6	1	0	0
77	LN2	RETURN	U-TUBE	BAYONET CAN	CH FEED CAN	3/8" OD X .049	0.277	12	2	0	0	0
78	LN2	RETURN	X-FER LINE	CH FEED CAN	AH FEED CAN	3/8" OD X .049	0.277	125	9	2	0	0
79	LN2	RETURN	U-TUBE	AH FEED CAN	GN2 VENT HEADER	3/8" OD X .049	0.277	5	2	0	0	0
* VLPC SERPENTINE LENGTH = 16 FT.												
* # OF ELBOWS IN SERPENTINE = 18

FIGURE 4

FIGURE 5

SUBJECT

LINE DRAWING OF VLPC PLATFORM PIPING

NAME

RUSS RUCINSKI

DATE _____

12-8-94

REVISION DATE

FIGURE 6

intercepts will be used. Along with liquid helium the liquid nitrogen will be supplied via a vacuum jacketed transfer line and u-tubes. These line will essentially follow the same path as the VLPC piping (figure 4) in the assembly hall. A line drawing of the solenoid building side transfer line can be seen in figure 5. Via u-tubes the transfer line connects to the control dewar mounted on the detector. The routing path on the detector is described in chapter 5 of the solenoid design report (Fermilab-TM-1886) and is also shown graphically in figure 7. The helium supply and return lines in the transfer line will consist of two concentric pipes. The supply line will run inside the return line to make use of the enthalpy of the return cold gas. Preliminary Flow schematics for both the VLPC and solenoid piping (FNAL Drg. 3823.115-ME-317223) are shown in figures 8 thru 10.

Solenoid Helium Cooldown flowrates

The LHe line sizes for the solenoid were determined by first calculating the required flow rates during cooldown. These calculations are shown in "Solenoid Cooldown & Flow Rates Etc." of appendix A and are summarized in Table 3. A cooldown rate of 5 K/hr was used in these calculations. It should be noted that it is planned to limit the actual rate to 2 K/hr.

Table 3: SOLENOID COOLDOWN FLOW RATES

STEP	SOLENOID TEMP [K]	GAS TEMP IN [K]	GAS TEMP OUT [K]	TIME [hrs]	DELTA H COLD MASS [J]	MASS FLOW RATE REQ'D [g/s]
1	300 to 250	200	250	10	6.42E+07	6.9
2	250 to 200	150	200	10	6.05E+07	6.5
3	200 to 150	100	150	10	5.44E+07	5.8
4	100 to 90	80	90	4	6.59E+06	8.8

The mass flow rates of steps 1&4 were the largest. The largest pressure drop of the steps was determined by noting that $\Delta P \propto \frac{f L W^2}{\rho d^5}$. The corresponding pressure drops were ratioed to determine which was larger. It was concluded that step 1's pressure drop would be about 2.6 times larger than step 4's. Therefore the cooldown lines should be sized for a flow rate of 7 g/s with an inlet temperature of 200K and an outlet temperature of 300K (refer to appendix A).

FIGURE 7

"PRELIMINARY: REF. ONLY"
S-7-86

NO.	DESCRIPTION	NO.	DESCRIPTION	NO.	DESCRIPTION
1	SAFETY INTERLOCK SYSTEM	11	SAFETY INTERLOCK SYSTEM	21	SAFETY INTERLOCK SYSTEM
2	SAFETY INTERLOCK SYSTEM	12	SAFETY INTERLOCK SYSTEM	22	SAFETY INTERLOCK SYSTEM
3	SAFETY INTERLOCK SYSTEM	13	SAFETY INTERLOCK SYSTEM	23	SAFETY INTERLOCK SYSTEM
4	SAFETY INTERLOCK SYSTEM	14	SAFETY INTERLOCK SYSTEM	24	SAFETY INTERLOCK SYSTEM
5	SAFETY INTERLOCK SYSTEM	15	SAFETY INTERLOCK SYSTEM	25	SAFETY INTERLOCK SYSTEM
6	SAFETY INTERLOCK SYSTEM	16	SAFETY INTERLOCK SYSTEM	26	SAFETY INTERLOCK SYSTEM
7	SAFETY INTERLOCK SYSTEM	17	SAFETY INTERLOCK SYSTEM	27	SAFETY INTERLOCK SYSTEM
8	SAFETY INTERLOCK SYSTEM	18	SAFETY INTERLOCK SYSTEM	28	SAFETY INTERLOCK SYSTEM
9	SAFETY INTERLOCK SYSTEM	19	SAFETY INTERLOCK SYSTEM	29	SAFETY INTERLOCK SYSTEM
10	SAFETY INTERLOCK SYSTEM	20	SAFETY INTERLOCK SYSTEM	30	SAFETY INTERLOCK SYSTEM

FROM NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

**D-ZERO DETECTOR UPGRADE
SOLINUS & VLPC
CYCLOTRON FLOW DIAGRAM**

SAFETY RELIEF VALVE SETTINGS

VALVE NO.	RELIEF PRESSURE (PSIA)	RELIEF PRESSURE (PSIG)	RELIEF PRESSURE (BAR)	RELIEF PRESSURE (MPA)
1	150	135	10.3	7.2
2	150	135	10.3	7.2
3	150	135	10.3	7.2
4	150	135	10.3	7.2
5	150	135	10.3	7.2
6	150	135	10.3	7.2
7	150	135	10.3	7.2
8	150	135	10.3	7.2
9	150	135	10.3	7.2
10	150	135	10.3	7.2
11	150	135	10.3	7.2
12	150	135	10.3	7.2
13	150	135	10.3	7.2
14	150	135	10.3	7.2
15	150	135	10.3	7.2
16	150	135	10.3	7.2
17	150	135	10.3	7.2
18	150	135	10.3	7.2
19	150	135	10.3	7.2
20	150	135	10.3	7.2
21	150	135	10.3	7.2
22	150	135	10.3	7.2
23	150	135	10.3	7.2
24	150	135	10.3	7.2
25	150	135	10.3	7.2

FIGURE 9

NOTE:
1) ALL TYPICAL VALUES ARE BASED ON THE ASSUMPTION
OF 100% EFFICIENCY AND NO LEAKS.

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"PRELIMINARY: REV. ONLY"
8-13-88

REV.	DATE	DESCRIPTION OF CHANGE	BY
1	8-13-88	INITIAL DESIGN	W. J. B. / J. B. B.

SAFETY LIST

NO.	DESCRIPTION	STATUS	DATE
1	SAFETY RELIEF VALVE	OK	8-13-88
2	SAFETY RELIEF VALVE	OK	8-13-88
3	SAFETY RELIEF VALVE	OK	8-13-88
4	SAFETY RELIEF VALVE	OK	8-13-88
5	SAFETY RELIEF VALVE	OK	8-13-88
6	SAFETY RELIEF VALVE	OK	8-13-88
7	SAFETY RELIEF VALVE	OK	8-13-88
8	SAFETY RELIEF VALVE	OK	8-13-88
9	SAFETY RELIEF VALVE	OK	8-13-88
10	SAFETY RELIEF VALVE	OK	8-13-88
11	SAFETY RELIEF VALVE	OK	8-13-88
12	SAFETY RELIEF VALVE	OK	8-13-88
13	SAFETY RELIEF VALVE	OK	8-13-88
14	SAFETY RELIEF VALVE	OK	8-13-88
15	SAFETY RELIEF VALVE	OK	8-13-88
16	SAFETY RELIEF VALVE	OK	8-13-88
17	SAFETY RELIEF VALVE	OK	8-13-88
18	SAFETY RELIEF VALVE	OK	8-13-88
19	SAFETY RELIEF VALVE	OK	8-13-88
20	SAFETY RELIEF VALVE	OK	8-13-88
21	SAFETY RELIEF VALVE	OK	8-13-88
22	SAFETY RELIEF VALVE	OK	8-13-88
23	SAFETY RELIEF VALVE	OK	8-13-88
24	SAFETY RELIEF VALVE	OK	8-13-88
25	SAFETY RELIEF VALVE	OK	8-13-88

**D-ZERO DETECTOR UPGRADE
COLLISION HALL OPERATION
CRYOGENIC FLOW DIAGRAM**

DATE: 8-13-88
BY: W. J. B. / J. B. B.
3025.110-000-017223

ω

For comparison, D-Zero engineering note #3823.111-EN-359 documents more complex calculations for a cooldown rate of 2K/hr. The highest mass flow for this cooldown rate was 4.4 g/s as shown in 3823.111-EN-359. (See table 4 below). Therefore, the flow rate of 7 g/s used to size the cooldown lines will be a conservative number.

Table 4 Helium Flow Results [FROM EN-359]

Step	Inlet Temperature [Kelvin]	Exit Temperature [Kelvin]	Inlet Enthalpy [J/g]	Exit Enthalpy [J/g]	Inlet Pressure [psig]	Exit Pressure [psig]	Mass Flow [g/s]
1	175	275	925	1444	8.9	5	1.2
2	125	225	665	1184	7.7	5	1.2
3	80	175	431	924	6.5	5	1.1
4	80	125	431	665	7.7	5	1.9
5	80	95	431	509	13.8	5	4.4
6	4.6	80	30.2	431	7	5	2.3
7	4.6	60	30.2	327	7	5	2.7
8	4.6	45	30.2	249	7	5	3.3
9	4.6	35	30.2	197	7	5	3.8
10	4.6	27.5	30.2	158	7	5	4.4
11	4.6	22.5	30.2	132	7	5	4.7
12	4.6	17.5	30.2	105	7	5	5.5
13	4.6	12.5	30.2	78.6	7	5	6.7
14	4.6	8.75	30.2	58.0	7	5	8.3
15	4.6	6	30.2	41.8	7	5	10.4

Solenoid Helium Cooldown Pressure drops

The first step in performing these calculations was to generate a list of the various piping sections along with their corresponding lengths and number of elbows, tees, and valves. Each pipe section was given a number. See table 1 for a listing of the solenoid pipe sections.

Pressure drops due to friction, valves, tees, bends, etc. were then calculated for the given pipe sizes and inlet/exit states. The solenoid cooldown piping was first sized by assuming a pressure drop of 95 psig, an inlet temperature of 200K GHe and an outlet temperature of 300K through the supply and return lines respectively. Resistance coefficients were calculated for each piping section and for the solenoid. Each coefficient was converted to correspond to an inner diameter of 0.68 in. since the i.d.'s of each section were not all the same. In the second step of the calculation, pressure drops were calculated for each individual pipe section taking into account the change in density due to changes in pressure. Summing the individual pressure drops resulted in a total pressure drop of 36.3 psi. These numbers are summarized in table 5.

Table 5: Solenoid Helium Cooldown piping pressure drop summary

PIPE SECTION	INLET TEMP (K)	OUTLET TEMP (K)	INLET PRESS (PSIA)	OUTLET PRESS (PSIA)	MASS FLOW (G/S)	RESISTANCE COEFFICIENT (K)	PRESSURE DROP (PSIA)
LINE 27	200	200	114.7	114.58	7	12.2	0.12
LINE 5	200	200	114.58	107.88	7	194.92	6.7
LINE 6	200	200	107.88	107.69	7	5.2	0.19
SOLENOID	200	300	107.69	86.09	7	430.2	21.6
LINE 24	300	300	86.09	85.72	7	5.44	0.37
LINE 25	300	300	85.72	79.61	7	90.84	6.11
LINE 26	300	300	79.61	79.35	7	3.41	0.26
COOLDOWN RETURN	300	300	79.35	78.38	7	13	0.97
					TOTAL DELTA P =		36.3 psi

It was estimated that using the total acceptable pressure drop of 95 psi, 200 K in, 300 K out, that the maximum cooldown flow rate obtainable would be 11.3 g/s.

Comparison to CDF pipe sizes: A simple comparison to CDF's pipe sizes was made. The calculations are in appendix C. The D-Zero solenoid cold mass is one-fourth that of CDF's. The cooldown rate for both solenoids will be the same so D-zero will only need one-fourth the mass flow rate during cooldown. For the same allowable pressure drop at one-fourth the flow the CDF pipe sizes could be reduced by 0.33. D-Zero's pipe sizes are compared to this number and are found to be larger.

Table 6: Comparison to CDF sizes

LINE SECTION	d _{CDF}	0.33*d _{CDF}	d _{D-Zero}
He supply	1.00" OD	0.33"	0.625" OD
He return	1.00" OD	.33"	0.75" OD
LN2 supply	0.5" OD	.17"	0.375" OD
N2 return	0.625" OD	.21"	0.375" OD

Solenoid Helium Steady State Pressure drops

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Some preliminary calculations were done to estimate the steady state helium heat loads, flowrates and pressure drops expected for each section of piping. See appendices I, J, and K. The total pressure drop from the tubing sizes were on the order of 3.2 psi as shown in the summary table in appendix K, page K12. Essentially all this pressure drop occurred in the long return pipe, line # 8. The pressure drop was based on line # 8 being a concentric tube with hydraulic radius of 0.347". This calculation was never given a final check or revised because it was decided that the cooldown process determined the required pipe sizes. It should be noted that the current size selection (Table 1 and figure 1) give line # 8 a larger hydraulic radius of 0.427". Therefore the helium steady state pipe pressure drops will be negligible.

Solenoid Nitrogen flowrates and pressure drops

The nitrogen flowrate requirements for cooldown and steady state are considered in calculations in appendix F. The maximum pressure drop allowed for the nitrogen circuit inlet to outlet is 30 psi, based on the current storage dewar operating pressure. Per the Solenoid bid spec., the required nitrogen cooldown flowrate shall not exceed 5 g/s. With the current selected pipe sizes nitrogen flow will less be than 5 g/s until the return piping fluid is less than 150 K. This means initially we may cannot deliver the full 5 g/s. I feel this is acceptable however. The pressure drop for steady state nitrogen requirements is expected to be less than 1 psi (with control valves full open). See appendix G.

VLPC Helium Cooldown flowrates

The LHe line sizes for the VLPC were determined by first calculating the required flow rates during cooldown. These calculations are shown in "VLPC Cooldown & Flow Rates Etc." of appendix D and are summarized in Table 7. A cooldown rate of 5 K/hr was used in these calculations.

Table 7: VLPC COOLDOWN FLOW RATES

STEP	VLPC TEMP [K]	GAS TEMP IN [K]	GAS TEMP OUT [K]	TIME [hrs]	MASS FLOW RATE REQ'D [g/s]
1	300 to 250	200	250	10	.84
2	250 to 200	150	200	10	.89
3	200 to 150	100	150	10	.92
4	100 to 90	80	90	4	3.1

It was concluded that step 4's pressure drop would be about 3.6 times larger than step 1's. Therefore the cooldown lines were sized for a flow rate of 3.1 g/s with an inlet temperature of 80K and an outlet temperature of 90K (refer to appendix D).

VLPC Helium Cooldown Pressure drops

A list of the various piping sections along with their corresponding lengths and number of elbows, tees, and valves. Each pipe section was given a number. See table 2 for a listing of the VLPC pipe sections.

Pressure drops due to friction, valves, tees, bends, etc. were then calculated for the given pipe sizes and inlet/exit states. The VLPC cooldown piping was first sized by assuming a pressure drop of 95 psig, an inlet temperature of 80K GHe and an outlet temperature of 90K through the supply and return lines respectively. Resistance coefficients were calculated for four segments of the piping. In the second step of the calculation, pressure drops were calculated for each segment taking into account the change in density due to changes in pressure. Summing the individual pressure drops resulted in a rough estimated pressure drop of 59.1 psi. These numbers are summarized in table 8. See Appendix E for the raw calculations.

Table 8: VLPC Helium Cooldown piping pressure drop summary

PIPE SECTION	PRESSURE DROP (PSIA)
Supply line 38	0.44
West supply lines + VLPC cryostat	27.4
West return lines	28.1
Return line 66	3.2
Total Delta P =	59.1 psi

VLPC Helium Steady State Pressure drops

The expected pressure drop for 3/8" OD x 0.035 wall tubing is less than 0.1 psi per 100 feet of tubing. See appendix H. No further calculations were done.

VLPC Nitrogen flowrates and pressure drops

The nitrogen tube sizes were chosen from a practical size standpoint. It is impractical to go to a size smaller than 3/8" OD. Based on experience with the solenoid nitrogen calculations, I conclude that pressure drop in the VLPC nitrogen piping will be negligible for the required flowrates. No formal calculations were done.

Table of Contents for the Appendices

Raw Engineering Calculations

Appendix A: Solenoid Cooldown and Flowrates etc.

Appendix B: Estimated flowrate thru Solenoid cooldown piping and delta P.

Appendix C: Solenoid pipe size: Comparison to CDF.

Appendix D: Calculation to determine VLPC Cooldown and flow rates required.

Appendix E: VLPC Piping: Total pressure drop in cooldown phase.

Appendix F: Delta P for Solenoid LN2 transfer line.

Appendix G: Solenoid transfer line steady state conditions.

Appendix H: VLPC LHe line sizing for steady state conditions.

Appendix I: Heat loads for Solenoid & VLPC transfer lines

Appendix J: Steady state heat loads to solenoid transfer line.

Appendix K: Solenoid steady state calcs. Helium piping.

SUBJECT

APPENDIX A:
SOLENOID COOLDOWN & FLOW RATES ETC.

NAME

RUSS RUCINSKI

DATE

11-9-94

REVISION DATE

PAGE 1-5 CHECKED BY S. SAKLA 11-11-94

MAGNET COLD MASS = 1460 kg ASSUME ALUMINUM (DESIGN REPORT APPENDIX A)

- DETERMINE MASS FLOW RATE OF He FOR CHOKED FLOW @ OUTLET VS. PIPE DIA.

$$V_{\text{SOUND}} = 1020 \text{ m/s FOR He @ 300 K } 1 \text{ atm} < P < 3 \text{ atm}$$

$$\dot{m} = \rho V A$$

$$\rho = \rho(T=300 \text{ K}, P=1 \text{ atm}) = .1625 \text{ kg/m}^3$$

$$A = \frac{\pi}{4} d^2$$

$$\dot{m}_{\text{CHOKED}} = \rho V_s \left(\frac{\pi}{4} \right) d^2 = (.1625 \frac{\text{kg}}{\text{m}^3}) (1020 \frac{\text{m}}{\text{s}}) \left(\frac{\pi}{4} \right) \times \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) d^2$$

$$\dot{m}_{\text{CHOKED}} = 130,180 \frac{\text{g}}{\text{s} \cdot \text{m}^2} \times \left[\frac{.0254 \text{ m}}{\text{in}} \right]^2 d^2$$

$$\dot{m}_{\text{CHOKED}} = 83.99 \frac{\text{g}}{\text{s} \cdot \text{in}^2} d^2$$

d (in.)	.25	.50	.62	.75
$\dot{m}$ (g/s)	5.25	21.0	32.3	47.2

SUBJECT APPENDIX A:
SOLENOID COOLDOWN & FLOW RATES ETC.

NAME
RUSS RUCINSKI

DATE
11-9-94

REVISION DATE

LOOK @ MAXIMUM COOLDOWN FLOW RATE REQ'D.

SAY $\frac{dT}{dt}_{max} = 5 \text{ K/HR}$ FOR SOLENOID.

*NOTE: THIS IS A ROUGH ANALYSIS NOT ITERATED TO 2 PLACE ACCURACY.

STEP 1

300 K to 250 K IN 10 HOURS.

$$\Delta H_{\text{COOL MASS}} = m \Delta h = 1460 \text{ kg} \left[170.4 \frac{\text{J}}{\text{g}} - 126.4 \frac{\text{J}}{\text{g}} \right] \left[\frac{1000 \text{ g}}{1 \text{ kg}} \right]$$

$$\Delta H_{\text{COOL MASS}} = 6.424 \times 10^7 \text{ J}$$

↑ ENTHALPY #'S FROM BNL
CRYOGENIC DATA BOOK
PS. VIII - A-1 ALUMINUM

SAY 200 K GAS IN, 250 K GAS OUT

$$h_{in} = 1054 \frac{\text{J}}{\text{g}} \quad h_{out} = 1314 \frac{\text{J}}{\text{g}} \quad \rho (P=0.2 \text{ MPa}, T=225 \text{ K}) = .028 \frac{\text{kg}}{\text{ft}^3}$$

$$\dot{m}_{REQ'D} = \frac{6.424 \times 10^7 \text{ J}}{10 \text{ HRS} \cdot \frac{1314 \frac{\text{J}}{\text{g}} - 1054 \frac{\text{J}}{\text{g}}}} = 24,708 \frac{\text{g}}{\text{HR}} = \underline{\underline{6.86 \frac{\text{g}}{\text{s}}}}$$

CHECK AVG HEAT LOAD

$$\bar{Q} = \frac{6.424 \times 10^7 \text{ J}}{10 \text{ HRS}} \cdot \frac{1 \text{ HR}}{3600 \text{ s}} = 1784 \text{ W}$$

CHECK AVG CONVECTION COEFF.

$$\bar{h} = \frac{\bar{Q}_{avg}}{A \Delta T_{me}} = \frac{1784 \text{ W}}{\pi (.015 \text{ m})(60.4 \text{ m})(50 \text{ K})} = 12.5 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

SEEMS TO BE A REASONABLE CONVECTION COEFFICIENT
EASILY OBTAINABLE FOR TURBULENT FLOW

$$Nu_D = 0.023 Re_D^{4/5} Pr^{0.3} \quad \text{EQ. 8.60 FUNDAMENTALS OF HEAT TRANSFER}$$

$$Re_D = 22,700 \frac{\rho P}{\mu} \approx 22,700 \frac{(.59 \frac{\text{kg}}{\text{m}^3})(.028 \frac{\text{kg}}{\text{ft}^3})}{(.59 \text{ mPa})(1.6 \times 10^{-2} \text{ cP})} \approx \frac{3.6 \times 10^4}{\text{ROUGHLY}}$$

$$Pr \approx .66$$

FROM CRANE EQ-3-3

SUBJECT

APPENDIX A:
SOLENOID COOLDOWN & FLOW RATES etc.

NAME

RUSS RUCINSKI

DATE

11-10-94

REVISION DATE

$$Nu_D \approx 0.023 (3.6 \times 10^4)^{4/5} (.66)^{.3} = 90.4 \approx 90$$

$$Nu_D = \frac{h d}{k}$$

$$h = \frac{Nu_D k}{d} = \frac{90 (.13 \text{ W/m} \cdot \text{K})}{(.59 \text{ in}) (.0254 \text{ m/in})} = 780 \text{ W/m}^2 \cdot \text{K}$$

CONCLUSION: WE HAVE PLENTY OF HEAT TRANSFER AREA AND COEFFICIENT TO COOLDOWN AT RATE OF 5 K/HR.

STEP 2

250K TO 200K @ 5 K/hr

$$\Delta H_{\text{COOL MASS}} = m \Delta h = 1460 \text{ kg} [126.4 \frac{\text{J}}{\text{g}} - 84.8 \frac{\text{J}}{\text{g}}] [\frac{1000 \text{ g}}{1 \text{ kg}}]$$

$$= 6.074 \times 10^7 \text{ J}$$

SAY 150 K GAS IN, 200 K GAS OUT

$$h_{\text{in}} = 795 \frac{\text{J}}{\text{g}} \quad h_{\text{out}} = 1055 \frac{\text{J}}{\text{g}} \quad \text{NOTE VALUES FOR } P = .2 \text{ MPa}$$

$$\dot{m}_{\text{REQ'D}} = \frac{6.074 \times 10^7 \text{ J}}{(10 \text{ hrs}) (1055 \frac{\text{J}}{\text{g}} - 795 \frac{\text{J}}{\text{g}})} \times \frac{1 \text{ hr}}{3600 \text{ s}} = \underline{\underline{6.5 \text{ g/s}}}$$

HEAT LOAD & CONVECTION COEFF. REQ'D WILL BE SIMILAR TO STEP 1.

STEP 3

200 K TO 150 K @ 5 K/hr

$$\Delta H_{\text{COOL MASS}} = m \Delta h = 1460 \text{ kg} [84.8 \frac{\text{J}}{\text{g}} - 47.55 \frac{\text{J}}{\text{g}}] \times \frac{1000 \text{ g}}{1 \text{ kg}} = 5.44 \times 10^7 \text{ J}$$

SAY 100 K GAS IN, 150 K GAS OUT

$$h_{\text{in}} = 535.1 \frac{\text{J}}{\text{g}} \quad h_{\text{out}} = 795 \frac{\text{J}}{\text{g}}$$

$$\dot{m}_{\text{REQ'D}} = \frac{5.44 \times 10^7 \text{ J}}{(10 \text{ hrs}) (795 \frac{\text{J}}{\text{g}} - 535.1 \frac{\text{J}}{\text{g}}) (3600 \text{ s})} = \underline{\underline{5.8 \text{ g/s}}}$$

SUBJECT

APPENDIX A
SOLENOID COOLDOWN & FLOW RATES etc

NAME

RUSS RUCINSKI

DATE

11-10-94

REVISION DATE

REQUIRED MASS FLOW RATES ARE GOING ALONG SAME DIRECTION IN TIME STEPS AS B. SQUIRES COOLDOWN NOTE EN-359. MY FLOW RATES ARE ROUGHLY 5.4 TIMES GREATER DUE TO INCREASED COOLDOWN RATE & CONSERVATIVE ΔT OF GAS OF 50K.

LOOK AT ONE OF WORST STEPS, * 5 100K TO 90K.

STEP 4

SOLENOID TEMP. 100K TO 90K

ALLOW 4 HRS FOR THIS STEP

$$\Delta H_{\text{COLD MASS}} = 1460 \text{ kg} \left[17.76 \frac{\text{J}}{\text{g}} - 13.25 \frac{\text{J}}{\text{g}} \right] \times \frac{1000 \text{ g}}{1 \text{ kg}} = 6.585 \times 10^6 \text{ J}$$

SAY 80K GAS IN, 90K GAS OUT

$$h_{\text{in}} = 431.2 \frac{\text{J}}{\text{g}} \quad h_{\text{out}} = 483.2 \frac{\text{J}}{\text{g}}$$

$$\dot{m}_{\text{REQ'D}} = \frac{6.585 \times 10^6 \text{ J}}{(4 \text{ HRS}) (483.2 \frac{\text{J}}{\text{g}} - 431.2 \frac{\text{J}}{\text{g}})} \times \frac{1 \text{ HR}}{3600 \text{ s}} = \underline{\underline{8.8 \text{ g/s}}}$$

$$\bar{Q} = \frac{6.585 \times 10^6 \text{ J}}{4 \text{ HRS} \times 3600 \frac{\text{s}}{\text{HR}}} = 457 \text{ W}$$

$$\bar{h}_{\text{REQ'D}} = \frac{\bar{Q}}{A \Delta T_{\text{avg}}} = \frac{457 \text{ W}}{\pi (0.015 \text{ m}) (60.4 \text{ m}) (10 \text{ K})} = 16 \frac{\text{W}}{\text{m}^2 \text{ K}}$$

CHECK CONVECTION COEFFICIENT OBTAINABLE.

$$Nu_D = 0.023 Re_D^{1/2} Pr^{1/3}$$

$$Re_D = 22,700 \frac{\rho P}{d \mu} \quad \rho = 8.8 \frac{\text{g}}{\text{s}} \times \frac{1}{0.07118 \frac{\text{lbm}}{\text{ft}^3}} \times \frac{2.21 \text{ lbm}}{1000 \text{ g}} = 0.27 \frac{\text{ft}^3}{\text{s}}$$

$$\rho = 1.14 \frac{\text{kg}}{\text{m}^3} \times (0.06248) = 0.07118 \frac{\text{lbm}}{\text{ft}^3} \quad \mu = 8.5 \mu\text{Pa-s} = 0.0085 \text{ cP}$$

$$Re = 22,700 \frac{(0.27 \frac{\text{ft}^3}{\text{s}}) (0.07118 \frac{\text{lbm}}{\text{ft}^3})}{(0.59 \text{ in}) (0.0085 \text{ cP})} = 8.7 \times 10^4$$

$$Pr = .68$$

SUBJECT APPENDIX A

SOLENOID COOLDOWN & FLOW RATES etc.

NAME

RUSS RUCINSKI

DATE

11-10-94

REVISION DATE

$$Nu_D = 0.023 (8.7 \times 10^4)^{4/5} (.68)^{0.3} = 183$$

$$h = \frac{Nu_D k}{d} = \frac{183 (.065 \text{ W/m}\cdot\text{K})}{(.59 \text{ in.}) (.0254 \text{ m/in.})} = 795 \frac{\text{W}}{\text{m}^2\text{K}}$$

I CONCLUDE THAT FOR STEP 5 WE HAVE PLENTY OF HEAT TRANSFER AREA AND CONVECTION COEFFICIENT FOR A 2.5 K/HR COOLDOWN RATE.

→ WE NEED TO SIZE COOLDOWN LINES FOR ACCEPTABLE ΔP WITH $\dot{m} = 7 \text{ g/s}$, $T = 200 \text{ K IN}$, 300 K OUT [STEP 1]

AND $\dot{m} = 9 \text{ g/s}$, $T = 80 \text{ K IN}$, 100 K OUT [STEP 5]

• DETERMINING WHICH ΔP WILL BE LARGEST;

$$\Delta P \propto \frac{f L W^2}{\rho d^5} \quad \frac{\Delta P_{\text{STEP 1}}}{\Delta P_{\text{STEP 4}}} = \frac{f_1 W_1^2 \rho_1}{f_4 W_4^2 \rho_1}$$

$$f_1 = .03 \quad f_5 = 0.018 \quad \text{FROM MOODY DIAGRAM}$$

$$\rho_5 = .07118 \frac{\text{lbm}}{\text{ft}^3} \quad \rho_1 = .023 \frac{\text{lbm}}{\text{ft}^3}$$

SUBSTITUTING;

$$\frac{\Delta P_{\text{STEP 1}}}{\Delta P_{\text{STEP 4}}} = \frac{(.03)(7)^2(.07118)}{(.018)(9)^2(.023)} = 2.6 \quad \therefore \text{STEP 1 } \Delta P \text{ WILL BE GREATER}$$

CONCLUSION:

SIZE COOLDOWN LINES FOR AN ACCEPTABLE ΔP WITH

$$\dot{m} = 7 \text{ g/s}, \quad T = 200 \text{ K IN}, \quad T = 300 \text{ K OUT}$$

SPECIFIC HEAT, ENTHALPY of ALUMINUM

Sources of Data:

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Table of Selected Values

Temp. °K	C _p J/gm-°K	H J/gm	Temp. °K	C _p J/gm-°K	H J/gm
1	0.000 10*		60	0.214	3.64
1	.000 051	0.000 025	70	.287	6.15
2	.000 108	.000 105	80	.357	9.37
3	.000 176	.000 246	90	.422	13.25
4	.000 261	.000 463	100	.481	17.76
6	.000 50	.001 21	120	.580	28.4
8	.000 88	.002 6	140	.654	40.7
10	.001 4	.004 9	160	.713	54.4
15	.004 0	.018	180	.760	69.2
20	.008 9	.048	200	.797	84.8
25	.017 5	.112	220	.826	101.0
30	.031 5	.232	240	.849	117.8
35	.051 5	.436	260	.869	135.0
40	.077 5	.755	280	.886	152.5
50	.142	1.85	300	.902	170.4

* Superconducting

Reprinted from WADD TECH. REPORT 60-56

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ESTIMATE FLOW RATE THRU
SOLENOID COOLDOWN PIPING (He) & ΔP

NAME
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1-18-95
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FLOW PATH: LINE 27 → 5 → 6 → SOLENOID → 24 → 25 → 26 → ^{COOLDOWN} RETURN LINE

ACCEPTABLE ΔP is 95 psi

$$\dot{m}_{\text{req'd}} = 7.0 \text{ g/s}$$

$$P_{\text{INLET}} = 100 \text{ psig} \quad P_{\text{OUTLET}} = 5 \text{ psig} \rightarrow \Delta P = 95 \text{ psig}$$

$$T_{\text{INLET}} = 200 \text{ K} \quad T_{\text{OUTLET}} = 300 \text{ K}$$

SUM UP RESISTANCE (COEFFICIENTS, K):

{ REFERENCE

{ CRANE TECHNICAL PAPER NO. 410 }

$$K = f \frac{L}{D} \rightarrow \text{Viscosity / friction losses (Eg 2-4)}$$

$$K = 30f \rightarrow 90^\circ \text{ elbows (Pg A-29)}$$

$$K = 20f \rightarrow \text{Tee thru Run (Pg. A-29)}$$

$$K = 60f \rightarrow \text{Tee thru Branch (Pg A-29)}$$

$$K = \frac{891 d^4}{(C_v)^2} \rightarrow \text{Valves / fittings (Eg. 3-16 RE-ARRANGED)}$$

$$K_a = K_b \left(\frac{d_a}{d_b} \right)^4 \rightarrow \text{Conversion of K between different diameter piping (Eg 2-5)}$$

$$\rho_{\text{in}} (200 \text{ K}, 0.8 \text{ MPa}) = 1.92 \text{ kg/m}^3 = 0.12 \text{ lbm/ft}^3 \quad \mu_{\text{in}} = 0.015 \text{ cp}$$

$$\rho_{\text{out}} (300 \text{ K}, 0.14 \text{ MPa}) = 0.22 \text{ kg/m}^3 = 0.014 \text{ lbm/ft}^3 \quad \mu_{\text{out}} = 0.02 \text{ cp}$$

$$\text{Assume } q_{\text{in}} = \frac{\dot{m}}{\rho_{\text{in}}} = \left(\frac{7 \text{ g/s}}{1.92 \text{ kg/m}^3} \right) \left(\frac{\text{kg}}{1000 \text{ g}} \right) \left(\frac{\text{ft}}{0.3 \text{ m}} \right)^3 = \frac{0.135 \text{ ft}^3/\text{s}}{0.3 \text{ m}}$$

$$\text{Assume } q_{\text{out}} = \frac{\dot{m}}{\rho_{\text{out}}} = \left(\frac{7 \text{ g/s}}{0.22 \text{ kg/m}^3} \right) \left(\frac{\text{kg}}{1000 \text{ g}} \right) \left(\frac{\text{ft}}{0.3 \text{ m}} \right)^3 = \frac{1.18 \text{ ft}^3/\text{s}}{0.3 \text{ m}}$$

$$Re_{\text{in}} = 22700 \frac{q_{\text{in}}}{\mu_{\text{in}}} = 22700 \frac{(0.135)(0.12)}{(0.015)(0.60)} = 40,860 \rightarrow f = 0.022$$

$$Re_{\text{out}} = 22700 \frac{(1.18)(0.014)}{(0.02)(0.60)} = 31,250 \rightarrow f = 0.023$$

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ESTIMATED FLOW RATE THRU
SOLENOID COOLDOWN PIPING (He) ΔP

NAME

STEVE JAKLA CHECKED 1-23-95 RAR

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1-19-95

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INLET:

$$K_{27} = f \frac{L}{D} + 4(30f) + \frac{891 d^4}{C_v^2} = 0.022 \left(\frac{5}{0.68/12} \right) + 120(0.022) + \frac{891(0.68^4)}{5^2}$$

$$K_{27} = \underline{\underline{12.2}}$$

$$K'_5 = f \frac{L}{D} + 9(30f) + 4(20f) = 0.022 \left(\frac{125}{0.527/12} \right) + 350(0.022) = 70.32$$

$$K_5 = 70.32 \left(\frac{0.68}{0.527} \right)^4 = \underline{\underline{194.92}}$$

$$K_6 = f \frac{L}{D} + 2(30f) = 0.022 \left(\frac{10}{0.68/12} \right) + 60(0.022) = \underline{\underline{5.2}}$$

SOLENOID:

$L = 148$ ft, 12 elbows, $d = 0.62$ in (chimney)

$L = 198$ ft, 2 valves $C_v = 3.3$, $d = 0.59$ in (Solenoid)

$L = 31$ ft, $d = 0.43$ in (Subcooler)

$$K_c = f \frac{L}{D} + 12(30f) = 0.023 \left(\frac{148}{0.62/12} \right) + 12(30)(0.023) = \underline{\underline{74.16}}$$

$$K'_5 = f \frac{L}{D} + 2 \frac{891 d^4}{C_v^2} = 0.023 \left(\frac{198}{0.59/12} \right) + 2 \frac{891(0.59^4)}{3.3^2} = 112.5$$

$$K_5 = 112.5 \left(\frac{0.62}{0.59} \right)^4 = \underline{\underline{137.1}}$$

$$K'_{\text{SUBCOOLER}} = f \frac{L}{D} = 0.023 \left(\frac{31}{0.43/12} \right) = 19.9$$

$$K_{\text{SUBCOOLER}} = 19.9 \left(\frac{0.62}{0.43} \right)^4 = \underline{\underline{86}}$$

$$K'_{\text{SOLENOID}} = 74.16 + 137.1 + 86 = 297.3$$

$$K_{\text{SOLENOID}} = 297.3 \left(\frac{0.68}{2.62} \right)^4 = \underline{\underline{430.2}}$$

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SOLENOID SHUTDOWN PIPING (H_c) & ΔP

NAME
STEVE SAKLA *CHECKED 1-17-95 RAL*
DATE
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OUTLET:

$$K_{24} = f \frac{L}{D} + 2(30f) = 0.023 \left(\frac{10}{0.62/12} \right) + 60(0.023) = \underline{5.44}$$

$$K'_{25} = f \frac{L}{D} + 9(30f) + 2(20f) = 0.023 \left(\frac{125}{0.62/12} \right) + 310(0.023) = 62.78$$

$$K_{25} = 62.78 \left(\frac{0.68}{0.62} \right)^4 = 90.84$$

$$K_{26} = f \frac{L}{D} + 2(30f) = 0.023 \left(\frac{5}{0.62/12} \right) + 60(0.023) = 3.41$$

$$K'_{\text{VENT}} = f \frac{L}{D} = (0.023) \left(\frac{350}{1.097/12} \right) = 88.1$$

$$K_{\text{VENT}} = 88.1 \left(\frac{0.68}{1.097} \right)^4 = 13.0$$

$$K_{\text{TOTAL}} = \underline{\underline{755.21}}$$

→ Following pages will calculate pressure drops for individual pipe sections to compare w/ original pressure drop assumption of 95 psig.

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ESTIMATED FLOW RATE THRU
SOLENOID (COOLDOWN PIPING/He): ΔP

NAME

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LINE 27:

$$K_{27} = 12.2 \quad g = \frac{\dot{m}}{\rho} = \left(\frac{7 \text{ g/s}}{1.92 \text{ kg/m}^3} \right) \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \left(\frac{3.3 \text{ ft}}{\text{m}} \right)^3 = 0.13 \text{ ft}^3/\text{s}$$

$$\Delta P_{27} = 3.62 \frac{(12.2)(0.12)(0.13^2)}{0.68^4} = 0.12 \text{ psig}$$

LINE 5:

$$K_5 = 194.92 \quad g = 0.13 \text{ ft}^3/\text{s}$$

$$\Delta P_5 = 3.62 \frac{(194.92)(0.12)(0.13)^2}{0.68^4} = 6.7 \text{ psig} = 0.046 \text{ MPa}$$

LINE 6:

$$P = 0.8 - 0.05 = 0.75 \text{ MPa} \quad \rho(0.75 \text{ MPa}, 200 \text{ K}) = 1.796 \text{ kg/m}^3 = 0.110 \text{ lbm/ft}^3$$

 $K_6 = 5.2$

$$g = \left(\frac{7 \text{ g/s}}{1.796 \text{ kg/m}^3} \right) \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \left(\frac{3.3 \text{ ft}}{\text{m}} \right)^3 = 0.14 \text{ ft}^3/\text{s}$$

$$\Delta P_6 = 3.62 \frac{(5.2)(0.110)(0.14^2)}{0.68^4} = 0.19 \text{ psig}$$

SOLENOID:Assume 15 psig drop through solenoid $K_s = 430.2$

$$P_1 = 92.99 \text{ psig} = 0.74 \text{ MPa}$$

$$\bar{P} = 0.69 \text{ MPa}$$

$$\bar{\rho} = 1.32 \text{ kg/m}^3 = 0.082 \text{ lbm/ft}^3$$

$$P_2 = P_1 - 15 = 77.96 \text{ psig} = 0.64 \text{ MPa}$$

$$\bar{T} = 250 \text{ K}$$

$$g = \left(\frac{7 \text{ g/s}}{1.32 \text{ kg/m}^3} \right) \left(\frac{3.3^3}{1000} \right) = 0.19 \text{ ft}^3/\text{s}$$

$$\Delta P_s = 3.62 \frac{(430.2)(0.082)(0.19^2)}{0.68^4} = 21.6 \text{ psig}$$

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SOLENOID (COOLDOWN PIPING (He)) & ΔP

NAME

STEVEN STAKLA ^{checked 1.23.95} RAR

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LINE 24:

$$K_{24} = 5.44 \quad \rho(300 \text{ K}, 0.59 \text{ MPa}) = 0.96 \text{ kg/m}^3 = 0.0588 \text{ lbm/ft}^3$$

$$g = \left(\frac{7 \text{ g/s}}{0.85 \text{ kg/m}^3} \right) \left(\frac{3.33}{1000} \right) = 0.3 \text{ ft}^3/\text{s}$$

$$\Delta P_{24} = \frac{3.62 (5.44) (0.059) (0.26^2)}{0.684} = 0.37 \text{ psig}$$

LINE 25:

$$K_{25} = 90.84 \quad \rho = 0.0588 \text{ lbm/ft}^3 \quad g = 0.26 \text{ ft}^3/\text{s}$$

$$\Delta P_{25} = \frac{3.62 (90.84) (0.0588) (0.26^2)}{0.684} = 6.11 \text{ psig}$$

LINE 26:

$$K_{26} = 3.41 \quad \rho(300 \text{ K}, 0.55 \text{ MPa}) = 0.88 \text{ kg/m}^3 = 0.054 \text{ lbm/ft}^3$$

$$g = \left(\frac{7 \text{ g/s}}{0.61 \text{ kg/m}^3} \right) \left(\frac{3.33}{1000} \right) = 0.286 \text{ ft}^3/\text{s}$$

$$\Delta P_{26} = \frac{3.62 (3.41) (0.054) (0.286^2)}{0.684} = 0.26 \text{ psig}$$

COOLDOWN
RETURN:

$$K_{\text{VENT}} = 13 \quad \rho = 0.054 \text{ lbm/ft}^3 \quad g = 0.286 \text{ ft}^3/\text{s}$$

$$\Delta P_{\text{VENT}} = \frac{3.62 (13) (0.054) (0.286^2)}{0.684} = 0.97 \text{ psig}$$

$$\Delta P_{\text{TOTAL}} = 36.32 \text{ psig}$$

→ SINCE $\Delta P_{\text{TOTAL}} = 36.3 \text{ psig}$ IS LESS THAN ALLOWABLE/ACCEPTABLE $\Delta P = 100$

PIPE SIZES ARE CORRECT. $\dot{m}_{\text{max}}$ WILL BE GREATER THAN 7.0 g/s.

ESTIMATING AMOUNT $\Delta P \propto W^2$

$$W_1 = W_2 \sqrt{\frac{\Delta P_1}{\Delta P_2}} = 7.0 \text{ g/s} \sqrt{\frac{95}{36.32}} = 11.3 \text{ g/s}$$

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SUBJECT

SOLENOID PIPE SIZE: COMPARISON
TO CDF

NAME

RUSS RUCINSKI

DATE

3-19-95

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IT CAN BE ASSUMED THAT COOLDOWN PROCESS ALSO DROVE THE CDF SOLENOID PIPE SIZING. IT IS USEFUL TO TAKE A COMPARABLE LOOK AT THE SIZES USED FOR CDF AND THOSE CHOSEN FOR DØ.

THE ACTUAL COOLDOWN FLOWRATES ARE DRIVEN BY THERMAL COLD MASS.

DØ	MAGNET COLD MASS	= 1460 kg	REF. DESIGN REPORT TABLE A.1 TM-1886 REF. CDF DESIGN REPORT APPENDIX A
CDF	"	= 5568 kg	

$$M_{DØ}/M_{CDF} = 1460/5568 \approx \frac{1}{4}$$

FROM CRANE TECHNIUM PAPER #10

$$\Delta P \propto \frac{FLW^2}{\rho d^5}$$

COMPARING THE TWO SYSTEMS & ASSUMING L, ρ, F APPROX. THE SAME;

$$d_{DØ}^5 = d_{CDF}^5 \left[\left(\frac{W_{DØ}}{W_{CDF}} \right)^2 \left(\frac{\Delta P_{CDF}}{\Delta P_{DØ}} \right) \right]$$

WE CAN SAY THAT THE ACCEPTABLE ΔP FOR CDF & DØ ARE THE SAME.

$$\frac{\Delta P_{CDF}}{\Delta P_{DØ}} \approx 1.0$$

THE MASS FLOW RATE FOR DØ WILL BE $\frac{1}{4}$ LESS THAN THAT REQ'D FOR CDF SINCE IT HAS $\frac{1}{4}$ MASS.

SUBSTITUTING

$$d_{DØ}^5 = d_{CDF}^5 \left[\left(\frac{1}{4} \right)^2 (1) \right]$$

$$d_{DØ} = (.33) d_{CDF}$$

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SUBJECT

SOLENOID PIPE SIZE ; COMPARISON TO CDF

NAME

RUSS RUCINSKI

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3-15-95

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THE SIZES FOR CDF'S TRANSFER LINE AND THE CORRESPONDING
.33 d_{CDF} AND ACTUAL DØ DIAMETERS SELECTED
ARE IN THE TABLE BELOW:

LINE SECTION	d_{CDF}	.33 d_{CDF}	$d_{DØ}$
HE SUPPLY	1.00" O.D.	.33"	.625" O.D.
HE RETURN	1.00" O.D.	.33"	.75" O.D. *
LN ₂ SUPPLY	.50" O.D.	.17"	.375" O.D.
LN ₂ RETURN	.625" O.D.	.21"	.375" O.D.

SEPARATE
* COOLDOWN RETURN LINE
STEADY STATE RETURN
IS $D_{INTERNAL} = .427"$

AS ONE CAN SEE FROM THE ABOVE TABLE, THE
DØ PIPE SIZES EXCEED THE COMPARABLE
CDF SIZE WHEN RATIOED ON THE BASIS
OF $m_{DØ}/m_{CDF} = 1/4$ AND ALL OTHER PARAMETERS
BEING EQUAL.

SUBJECT

CALCULATION TO DETERMINE
1st & 2nd LOWEN FLOW RATES REQUIRED

NAME

SEVEN JAK A

DATE

11-16-94

REVISION DATE

1-26-95 ^ΔRPCHECKED 12-94 R.
RUCINSEI

$$x_{cu} = 37.25 \text{ m}^3/\text{cass} \times 48 \text{ cass}/\text{cryostat} = 1782 \text{ m}^3 \text{ Cu per Cryostat}$$

$$x_{cu} = 0.0292 \text{ m}^3/\text{cryostat}$$

$$M_{cu} = (0.0292 \text{ m}^3)(8900 \text{ kg/m}^3) = \underline{\underline{259.9 \text{ kg}}}$$

$$x_{ss} = 18.6 \text{ m}^3/\text{cass} \times 48 \text{ cass}/\text{cryostat} = 892.8 \text{ m}^3/\text{cryostat}$$

$$x_{ss} = 0.0146 \text{ m}^3/\text{cryostat}$$

$$M_{ss} = (7900 \text{ kg/m}^3)(0.0146 \text{ m}^3) = \underline{\underline{115.34 \text{ kg}}}$$

- Heat transfer is between helium tubing lines & copper block

$$D = 1.875, d = 0.375, L = 4.43$$

$A_Q \equiv$ Heat transfer area

$$A_Q = \left(\frac{\pi d}{2} \right) [9L + 4\pi D] = \frac{1}{2} \left(\frac{\pi}{2} \right) (0.375) [9(4.43) + 4\pi(1.875)]$$

$$A_Q = 37.4 \text{ in}^2 \left(\frac{\text{ft}^2}{12 \text{ in}} \right)^2 \left(\frac{\text{m}}{3.3 \text{ ft}} \right)^2 = 0.024 \text{ m}^2 \text{ per 4 cassettes}$$

$$A_Q = \left(\frac{0.024 \text{ m}^2}{4 \text{ cassettes}} \right) (48 \text{ cassettes}) = 0.288 \text{ m}^2/\text{cryostat}$$

$$\bar{Q}_{\text{cryostat}} = (135 - .45 \bar{T}) \text{ W} \quad \Delta$$

↑ Per Cryostat

SUBJECT

VLPC COOLDOWN & FLOW RATES

NAME

STEVE SAKLA

DATE

11-22-94

REVISION DATE

1-26-95 ^{RA}

CHECKED 12-94

R. RUCINSKI

Step 1: 300K $\rightarrow$ 250 K in 10 hrs

$$\left(\frac{dT}{dt}\right)_{\max} = 5 \text{ } ^\circ\text{K/hr}$$

$$\Delta H_{cu} = 259.9 \text{ kg} (79.6 - 60.7) \frac{\text{kJ}}{\text{kg}} = 4912.1 \text{ kJ}$$

$$\Delta H_{ss} = 115.34 \text{ kg} \left(444 \frac{\text{J}}{\text{kg}\cdot\text{K}}\right) 50 \text{ K} = 2560.5 \text{ kJ}$$

$$\bar{Q}_T = \frac{(4912.1 + 2560.5) \text{ kJ}}{10 \text{ hrs}} \left(\frac{\text{hr}}{3600 \text{ s}}\right) + \cancel{583 \text{ W}} = 218.8 \text{ W} \quad \Delta$$

Assume: 200 K GHe in, 250 K GHe out

$$\rho (P=0.2 \text{ MPa}, T=225 \text{ K}) = 0.43 \frac{\text{g}}{\text{cm}^3} = 0.027 \frac{\text{lbm}}{\text{ft}^3}$$

$$h_{in} = 1054 \frac{\text{J}}{\text{g}} \quad h_{out} = 1314 \frac{\text{J}}{\text{g}} \quad \Delta h = 260 \frac{\text{J}}{\text{g}}$$

$$\dot{m}_{req'd} = \frac{\frac{218.8 \text{ W}}{260 \frac{\text{J}}{\text{g}}}}{260 \frac{\text{J}}{\text{g}}} = 0.84 \frac{\text{g}}{\text{s}} \quad \Delta$$

$$\bar{h}_{req'd} \equiv \text{Avg. convection coefficient} = \frac{\bar{Q}_T}{A \Delta T} = \frac{218.8 \text{ W}}{(0.288 \text{ m}^2)(50 \text{ K})} = 15.2 \frac{\text{W}}{\text{m}^2\cdot\text{K}} \quad \Delta$$

$$Nu_D = 0.023 Re_D^{1/5} Pr^{0.3}$$

$$f = (0.82 \frac{\text{g}}{\text{s}}) \left(\frac{\text{ft}^3}{0.027 \frac{\text{lbm}}{\text{ft}^3}}\right) \left(\frac{2.21 \text{ lbm}}{1000 \text{ g}}\right) = 0.067 \frac{\text{ft}^3}{\text{s}}$$

$$Re_D = 22700 \frac{\text{g}}{\text{m}^2\cdot\text{s}}$$

$$Re_D = 22700 \frac{(0.067)(0.027)}{(0.016)(0.375)} = 6844 \quad *$$

$$Pr \approx 0.66 \quad Nu_D = 0.023 (6844)^{1/5} (0.66)^{0.3} = 23.76 \quad *$$

$$h = \frac{Nu_D k}{d} = \frac{(23.76) \left(0.128 \frac{\text{W}}{\text{m}\cdot\text{K}}\right)}{(0.375 \text{ in})(0.0254 \text{ m/in})} = 319.3 \frac{\text{W}}{\text{m}^2\cdot\text{K}} \quad \Delta$$

* MINOR REV. NOT CARRIED THRU

SUBJECT

VLPC COOLDOWN & FLOW RATES

NAME

STEVE SARLA

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11-22-94

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1-26-95 RAR

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STEP 2: 250 → 200 K $(\frac{dT}{dt})_{\max} = 5 \text{ K/hr}$

$$\Delta H_{\text{cu}} = 359.9 \text{ kg} (60.7 - 42.4) \frac{\text{kJ}}{\text{kg}} = 4756.2 \text{ kJ}$$

$$\Delta H_{\text{ss}} = 115.34 \text{ kg} (416 \frac{\text{J}}{\text{kg-K}}) (50 \text{ K}) = 2399.1 \text{ kJ}$$

$$\bar{Q}_T = \frac{(4756.2 + 2399.1) \text{ kJ}}{10 \text{ hrs.}} \left(\frac{\text{hr}}{3600 \text{ s}} \right) + \frac{33.75}{17.6} \text{ W} = \frac{233}{216.4} \text{ W}$$

Assume: 150 K G1te in, 200 K G1te out

$$\rho (P = 0.2 \text{ MPa}, T = 175 \text{ K}) = 0.55 \text{ kg/m}^3 = 0.034 \text{ lbm/ft}^3$$

$$h_{\text{in}} = 793 \frac{\text{J}}{\text{g}} \quad h_{\text{out}} = 1055 \frac{\text{J}}{\text{g}}$$

$$\dot{m}_{\text{reg'd}} = \frac{233}{(1055 - 793) \frac{\text{J}}{\text{g}}} = \frac{0.89 \text{ g/s}}{\Delta}$$

$$\bar{h} = \frac{233}{(0.288 \text{ m}^2) (50 \text{ K})} = \frac{16.2}{15.63} \frac{\text{W}}{\text{m}^2 \cdot \text{K}} \Delta$$

$$g = (0.83 \text{ g/s}) \left(\frac{\text{ft}^3}{0.034 \text{ lbm}} \right) \left(\frac{2.2 \text{ lbm}}{1000 \text{ g}} \right) = 0.054 \text{ ft}^3/\text{s}$$

$$Re_D = \frac{22700 (0.034) (0.054)}{(0.014) (0.375)} = 7938.5^*$$

$$Nu_D = (0.023) (7938.5)^{4/5} (0.66)^{0.3} = 26.75^*$$

$$h = \frac{(26.75) (0.11 \frac{\text{W}}{\text{m-K}})}{(0.375 \mu) (0.0254 \text{ m/in})} = \frac{308.9}{\text{m}^2 \cdot \text{K}} \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

Δ
* MINOR REV. .83 g/s TO .89 g/s
NOT ENTERED THEN

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VLPC COOLDOWN & FLOW RATES

NAME

STEVEN SAKLA

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R. RUCINSKI

STEP 3 200 K $\rightarrow$ 150 K $\left(\frac{dT}{dt}\right)_{\max} = 5 \text{ K/hr.}$

$$\Delta H_{\text{ex}} = 2599 \text{ kg} (42.4 - 25.3) \frac{\text{kJ}}{\text{kg}} = 4444.3 \text{ kJ}$$

$$\Delta H_{\text{ss}} = 115.34 \text{ kg} (369.5 \frac{\text{J}}{\text{kg} \cdot \text{K}}) (50 \text{ K}) = 2130.9 \text{ kJ}$$

$$\bar{Q}_T = \frac{(4444.3 + 2130.9) \text{ kJ}}{10 \text{ hrs}} \left(\frac{\text{hr}}{3600 \text{ s}} \right) + 56.25 \text{ W} = 238.9 \text{ W} \quad \triangle$$

Assume 100 k GHe in, 150 k GHe out

$$\rho (T = 125 \text{ K}) = 0.77 \frac{\text{kg}}{\text{m}^3} = 0.048 \frac{\text{lbm}}{\text{ft}^3}$$

$$h_{\text{in}} = 535.1 \frac{\text{J}}{\text{g}} \quad h_{\text{out}} = 793 \frac{\text{J}}{\text{g}}$$

$$\dot{m}_{\text{reg'd}} = \frac{238.9 \frac{\text{J}}{\text{s}}}{(793 - 535.1) \frac{\text{J}}{\text{g}}} = 0.92 \frac{\text{g}}{\text{s}}$$

$$\bar{h}_{\text{reg'd}} = \frac{238.9 \text{ W}}{(0.288 \text{ m}^2)(50 \text{ K})} = 16.59 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

$$g = (0.82 \frac{\text{g}}{\text{s}}) \left(\frac{\text{ft}^3}{0.648 \text{ lbm}} \right) \left(\frac{2.216 \text{ km}}{1000 \text{ g}} \right) = 0.038 \frac{\text{ft}^3}{\text{s}}$$

$$Re_b = \frac{22700 \left(\frac{\text{ft}^3}{\text{s}} \right) (0.038) (0.048)}{(0.011) (0.375)} = 10038$$

$$Nu_D = (0.023) (10038)^{4/5} (0.66)^{0.3} = 32.3$$

$$h = \frac{(32.3) \left(\frac{\text{W}}{\text{m}^2 \cdot \text{K}} \right)}{(0.375 \text{ m}) (0.0254 \text{ m/in})} = 291.6 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

* REV. .82 g/s TO .92 g/s NOT CARRIED THRU $\triangle$

SUBJECT

VLPC COOLDOWN & FLOW RATES

NAME

STEVE SAKKA

DATE

11-22-94

REVISION DATE

11-26-95 RPR

CHECKED 12/94
R. RUCINSKI

STEP 4 100 K → 90 K $\frac{dT}{dt} = 2.5 \frac{K}{hr}$

$$\Delta H_{cu} = 259.9 \text{ kg} (10.6 - 8.2) \frac{\text{kJ}}{\text{kg}} = 623.8 \text{ kJ}$$

$$\Delta H_{ss} = 115.34 \text{ kg} (272 \frac{\text{J}}{\text{kg-K}}) (10 \text{ K}) = 313.7 \text{ kJ}$$

$$\bar{Q} = \frac{(623.8 + 313.7) \text{ kJ}}{4 \text{ hrs.}} \left(\frac{hr}{3600 \text{ s}} \right) + 92.25 \frac{157.32}{47.8} \text{ W} = 112.97 \text{ W}$$

Assume 80 K GHe in, 90 K GHe out

$$h_{in} = 431.2 \frac{\text{J}}{\text{g}}$$

$$h_{out} = 483.2 \frac{\text{J}}{\text{g}}$$

$$\rho(T=85 \text{ K}) = 1.14 \frac{\text{kg}}{\text{m}^3} = 0.071 \frac{\text{lbm}}{\text{ft}^3}$$

$$\dot{m}_{req'd} = \frac{112.97 \frac{\text{J}}{\text{s}}}{(483.2 - 431.2) \frac{\text{J}}{\text{g}}} = \frac{3.06}{2.2} \frac{\text{g}}{\text{s}}$$

$$\bar{h}_{req'd} = \frac{112.97 \text{ W}}{(0.258 \text{ m}^2)(10 \text{ K})} = \frac{54.6}{3.2} \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

$$g = \left(\frac{3.1}{2.2} \frac{\text{g}}{\text{s}} \right) \left(\frac{\text{ft}^3}{0.071 \text{ lbm}} \right) \left(\frac{2.2 \text{ lbm}}{1000 \text{ g}} \right) = 0.068 \frac{\text{ft}^3}{\text{s}}$$

$$Re_0 = 22700 \frac{(0.068)(0.071)}{(0.009)(0.375)} = 32.73 \quad 45,757$$

$$Nu_0 = (0.023) \left(\frac{45757}{32.73} \right)^{1/5} (0.66)^{0.3} = 82.6 \quad 108.6$$

$$h = \frac{108.6}{(0.375 \text{ in})(0.0254 \text{ m/in})} = \frac{753}{57.3} \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

SUBJECT

VLPC COOLDOWN & FLOW RATES

NAME

STEVE SAKA

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1-26-95 RAR

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Determine Largest ΔP :

For $\dot{m} = 0.84 \text{ g/s}$ @ $\bar{T} = 225 \text{ K}$ (STEP 1)
 $\rho = 0.43 \text{ kg/m}^3$

For $\dot{m} = 3.1 \text{ g/s}$ @ $\bar{T} = 85 \text{ K}$ (STEP 4)
 $\rho = 1.14 \text{ kg/m}^3$

$$\Delta P \propto \frac{f L W^2}{\rho d^5} \Rightarrow \frac{\Delta P_1}{\Delta P_4} = \frac{f_1 W_1^2 \rho_4}{f_4 W_4^2 \rho_1} = \frac{(0.033)(0.84^2)(1.14)}{(0.023)(3.1^2)(0.43)} = 0.53 \cdot 28$$

$\therefore \Delta P_{\text{STEP 4}}$ is largest

CONCLUSION:

Size cooldown lines for an acceptable pressure drop
using $\dot{m} = 3.1 \text{ g/s}$, $T = 80 \text{ K in}$, 90 K out
⚠

NOTE: ALL CALCULATIONS WERE DONE ON A
PER CRYOSTAT BASIS.

SPECIFIC HEAT, ENTHALPY of COPPER
(10° to 300°K)

Sources of Data:

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Table of Selected Values

Temp. °K	C _p J/gm-°K	H* J/gm	Temp. °K	C _p J/gm-°K	H* J/gm
10	0.000 86	0.0024	100	0.254	10.6
15	.002 7	.0107	120	.288	16.1
20	.007 7	.034	140	.313	22.1
25	.016	.090	160	.332	28.5
30	.027	.195	180	.346	35.3
40	.060	.61	200	.356	42.4
50	.099	1.40	220	.364	49.6
60	.137	2.58	240	.371	56.9
70	.173	4.13	260	.376	64.4
80	.205	6.02	280	.381	72.0
90	.232	8.22	300	.386	79.6

$$- \bar{h} = \int_0^T C_p dT$$

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SUBJECT

VLPC PIPING - TOTAL PRESSURE DROP IN COOLDOWN PHASE

NAME

STEVE. SAKLA & RUSS RUCINSKY

DATE

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FLOW PATH: (WEST)
40 → 42 → 43 → 44 → 45 → VLPC → 58 → 59 → 60 → 61 → 62 → 66
LINE 38
(EAST)
46 → 47 → 48 → 49 → 50 → 51 → VLPC → 52 → 53 → 54 → 55 → 56 → 66

NOTE: LINES 38 & 66 will have flow rates of $6.2 \frac{g}{s}$ because flow will split into East/West VLPC lines
(Refer to dwg. 3823-115-ME-317223 pg. 2 of 3)
Pressure drop calculations will be performed for only one set of the VLPC lines (East/West) since both have identical lengths, bends, and valve components.

VLPC Serpentine: Line length = 16 ft.
Elbows = 18

ASSUME ALL ^{SUPPLY} TUBE SIZES $\frac{3}{8}$ " O.D. x .049 wall
ID = .277"
RETURNS ARE $\frac{1}{2}$ " O.D. x .049 wall
ID = .402"
 $\dot{m} = 3.1 \frac{g}{s}$

$P_{in} = 100 \text{ psig}$

$P_{out} = 5 \text{ psig}$

$T_{in} = 80 \text{ K}$

$T_{out} = 90 \text{ K}$

$\rho_{in} = 4.75 \frac{kg}{m^3}$

$\rho_{out} = .756 \frac{kg}{m^3}$

$\mu_{in} = 8.43 \times 10^{-6} \text{ Pa}\cdot\text{s}$ $\mu_{out} = 8.94 \times 10^{-6} \text{ Pa}\cdot\text{s}$

$$Re = \frac{\rho V D}{\mu} = \frac{4 \dot{m}}{\pi D \mu}$$

$$Re = \frac{4(0.0031)}{\pi (\frac{.277}{12})(8.73 \times 10^{-6})} = 19,600 \text{ WEST SUPPLY}$$

$$\Downarrow f_{\text{WEST SUPPLY}} = .026$$

$$Re = \frac{4(0.0031)}{\pi (\frac{.402}{12})(8.94 \times 10^{-6})} = 13,200 \text{ WEST RETURN}$$

$$\Downarrow f_{\text{WEST RETURN}} = .028$$

Material	16.	447	60.2	216	384	490	574	680	975	609	654				
Armco (99.75% pure)		7870	447	72.7	20.7	95.6 215	80.6 384	65.7 490	53.1 574	42.2 680	32.3 975	28.7 609	31.4 654		
Carbon steels															
Plain carbon (Mn ≤ 1%, Si ≤ 0.1%)		7854	434	60.5	17.7			56.7 487	48.0 559	39.2 685	30.0 1169				
AISI 1010		7832	434	63.9	18.8			58.7 487	48.8 559	39.2 685	31.3 1168				
Carbon-silicon (Mn ≤ 1%, 0.1% < Si ≤ 0.6%)		7817	446	51.9	14.9			49.8 501	44.0 582	37.4 699	29.3 971				
Carbon-manganese- silicon (1% < Mn ≤ 1.65%, 0.1% < Si ≤ 0.6%)		8131	434	41.0	11.6			42.2 487	39.7 559	35.0 685	27.6 1090				
Chromium (low) steels															
$\frac{1}{2}$ Cr- $\frac{1}{2}$ Mo-Si (0.18% C, 0.65% Cr, 0.23% Mo, 0.6% Si)		7822	444	37.7	10.9			38.2 492	36.7 575	33.3 688	26.9 969				
1 Cr- $\frac{1}{2}$ Mo (0.16% C, 1% Cr, 0.54% Mo, 0.39% Si)		7858	442	42.3	12.2			42.0 492	39.1 575	34.5 688	27.4 969				
1 Cr-V (0.2% C, 1.02% Cr, 0.15% V)		7836	443	48.9	14.1			46.8 492	42.1 575	36.3 688	28.2 969				
Stainless steels															
AISI 302		8055	480	15.1	3.91			17.3 512	20.0 559	22.8 585	25.4 606				
AISI 304	1670	7900	477	14.9	3.95	9.2 272	12.6 402	16.6 515	19.8 557	22.6 582	25.4 611	28.0 640	31.7 682		
AISI 316		8238	468	13.4	3.48			15.2 504	18.3 550	21.3 576	24.2 602				
AISI 347		7978	480	14.2	3.71			15.8 513	18.9 559	21.9 585	24.7 606				
Lead	601	11340	129	35.3	24.1	39.7 118	36.7 125	34.0 132	31.4 142						
Magnesium	923	1740	1024	156	87.6	169 649	159 934	153 1074	149 1170	146 1267					
Molybdenum	2894	10240	251	138	53.7	179 141	143 224	134 261	126 275	118 285	112 295	105 308	98 330	90 380	86 459
Nickel															
Pure	1728	8900	444	90.7	23.0	164 232	107 383	80.2 485	65.6 592	67.6 530	71.8 562	76.2 594	82.6 616		
Nichrome (80% Ni, 20% Cr)	1672	8400	420	12	3.4			14 480	16 525	21 545					
Inconel X-750 (73% Ni, 15% Cr, 6.7% Fe)	1665	8510	439	11.7	3.1	8.7	10.3	13.5	17.0	20.5	24.0	27.6	33.0		
Niobium	2741	8570	265	53.7	23.6	55.2 188	52.6 249	55.2 274	58.2 283	61.3 292	64.4 301	67.5 310	72.1 324	79.1 347	
Palladium	1827	12020	244	71.8	24.5	76.5 168	71.6 227	73.6 251	79.7 261	86.9 271	94.2 281	102 291	110 307		
Platinum															
Pure	2045	21450	133	71.6	25.1	77.5 100	72.6 125	71.8 136	73.2 141	75.6 146	78.7 152	82.6 157	89.5 165	99.4 179

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VLPC PIPING - TOTAL PRESSURE DROP IN COOLDOWN PHASE

NAME

STEVE SIKIA/RUSS RUCINSKI

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12-26-94

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SUM UP RESISTANCE COEFFICIENTS, K.

$$K = f \frac{L}{D} \leftarrow \text{Viscosity / Friction}$$

$$K = 60f \leftarrow \text{Tee thru branch}$$

$$K = 30f \leftarrow 90^\circ \text{ elbows}$$

$$K = 20f \leftarrow \text{Tee thru Run}$$

$$K = 20f \leftarrow \text{Tee thru Run}$$

$$K = 8f \leftarrow \text{Pressure Valve}$$

$$K = \frac{891d^4}{(C_v)^2}$$

$$K = 100f \leftarrow \text{Check Valve}$$

$$Re = 27,000$$

→ SUPPLY (LINE 38): $L = 5f + \# \text{ elbows} = 2$ $f = 0.024$ $\frac{1}{2} \times .049 \text{ tube ID} = .402"$

$$K_{in} = f \frac{L}{D} + 2(30f) = 0.024 \left(\frac{5}{\frac{.402}{12}} \right) + 60(0.024) = \boxed{5.02}$$

$$K_{in} = 5.02 \left(\frac{.207}{.402} \right)^4 = .35$$

→ WEST VLPC SUPPLY LINES: 40 → 42 → 43 → 44 → 45 → VLPC

$$L_{total} = 2 + 123 + 12 + 47 + 24 + 16 = 224$$

$$f = 0.026 \quad K = 0.026 \left(\frac{224}{\frac{.277}{12}} \right) = \underline{252}$$

$$(\# 90^\circ \text{ elbows})_r = 1 + 9 + 2 + 6 + 2 + 18 = 38$$

$\uparrow$
VLPC

$$K_e = (38)(30)(0.026) = \underline{29.6}$$

$$(\# \text{ Tees Thru Run})_r = 1 + 3 + 1 = 5$$

$$K_{trr} = (5)(20)(0.026) = \underline{2.6}$$

VALVES: 1 DIVERTER VALVE, $C_v = 5.0$

$$K_v = \frac{891 (.277)^4}{5^2} = .0002 \rightarrow \text{NEGLECTABLE}$$

$$K_{TOTAL \text{ SUPPLY}} = 252 + 29.6 + 2.6 = \underline{284} \quad \text{BASED ON } .207" \text{ ID.}$$

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PRESSURE DROP VLPC PIPING COOLDOWN

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→ WEST VLPC RETURN LINES: 58 → 59 → 60 → 61 → 62

$$L_{\text{TOTAL}} = 24 + 47 + 12 + 123 + 2 = 208 \text{ ft.}$$

$$f = .028 \quad K = f \frac{L}{D} = .028 \frac{(208)}{\frac{.402}{12}} = 174$$

$$* 90^\circ \text{ ELBOWS} = 1 + 6 + 2 + 9 + 2 = 20$$

$$K_e = 20(30)(.028) = 16.8$$

$$* \text{TEES THRU RUN} = 2$$

$$K_{\text{TTA}} = 2 \times 20(.028) = 1.1$$

$$* \text{TEES THRU BRANCH} = 2$$

$$K_{\text{TTB}} = 2(60)(.028) = 3.4$$

VALVES: 1 CONTROL VALVE $C_v = 2.0$, 1 DIVERTER VALVE $C_v = 5.0$, 1 CHECK VALVE

$$K = \frac{891(.402)^4}{(2.0)^2} + \frac{891(.402)^4}{(5.0)^2} + 100(.028) = 5.8 + .9 + 2.8 = 9.5$$

$$K_{\text{TOTAL RETURN}} = 174 + 16.8 + 1.1 + 3.4 + 9.5 = \boxed{205} \text{ BASED ON } .402" \text{ ID.}$$

→ RETURN LINE: *66

L = 5 ft 2 ELBOWS, SAME AS SUPPLY *38

$$K_{\text{OUT}} = 5.02 \text{ BASED ON } .402" \text{ ID.}$$

PRESSURE DROP

$$* \text{ SUPPLY LINE: } \rho = 4.75 \frac{\text{kg}}{\text{m}^3} = .297 \frac{\text{lbm}}{\text{ft}^3}$$

$$q = \frac{\dot{m}}{\rho} = \left(\frac{6.2 \text{ g}}{\text{s}} \right) \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \left(\frac{2.2 \text{ lbm}}{1 \text{ kg}} \right) \left(\frac{\text{ft}^3}{.297 \text{ lbm}} \right) = .04593 \frac{\text{ft}^3}{\text{s}}$$

$$\Delta P_{38} = 3.62 \frac{\text{kg} \cdot \text{g}^2}{\text{d}^4} = 3.62 \frac{(5.02)(.297)(.04593)^2}{(.402)^4} = 0.436 \text{ psi}$$

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PRESSURE DROP FOR VLPC COOLDOWN PIPING

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• WEST VLPC SUPPLY LINES

$$\Delta P_{\text{SUPPLY}} = 3.62 \frac{(284)(.297 \frac{\text{lbm}}{\text{ft}^3})(.04593 \frac{\text{ft}^3}{\text{s}} \times 0.5)^2}{(.277)^4}$$

$$= \underline{27.4 \text{ psi}}$$

• WEST VLPC RETURN LINES

$$q = \frac{\dot{m}}{\rho} = \frac{3.1 \frac{\text{g}}{\text{s}}}{.756 \frac{\text{kg}}{\text{m}^3}} \times \frac{1 \text{ kg}}{1000 \text{ g}} \times \frac{35.314 \text{ ft}^3}{1 \text{ m}^3}$$
$$= .145 \frac{\text{ft}^3}{\text{s}}$$

$$\Delta P = 3.62 \frac{(205)(.047 \frac{\text{lbm}}{\text{ft}^3})(.145 \frac{\text{ft}^3}{\text{s}})^2}{(.402)^4} = \underline{28.1 \text{ psi}}$$

• RETURN LINE # 66

$$q = .0493 \frac{\text{ft}^3}{\text{s}} \times \frac{.297}{.047} = .3115 \frac{\text{ft}^3}{\text{s}}$$

$$\Delta P_{66} = 3.62 \frac{(5.02)(.047)(.3115 \frac{\text{ft}^3}{\text{s}})^2}{(.402)^4} = \underline{3.2 \text{ psi}}$$

SUMMARY

	ΔP
LINE 38 SUPPLY	0.4 psi
SUPPLY LINE + VLPC	27.4 psi
RETURN LINE	28.1 psi
LINE 66 RETURN	3.2 psi

$$\Delta P_{\text{TOTAL}} = 59.1 \text{ psi}$$

ROUGH
ESTIMATE

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SUBJECT

 ΔP FOR SOLENOID LN_2 TRANSFER LINE.

NAME

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FROM THE BID SPECIFICATION, THE N_2 FLOWRATE SHALL NOT EXCEED 5 g/s. AS A WORST CASE I WILL CALCULATE THE ΔP IN THE PIPING @ $T_{avg} = 300 K$. $P_{avg} = 30 psia$.

THE PIPE SIZES ARE ALREADY PRELIMINARILY SIZED.

FLOW PATH

SUPPLY: $10 \rightarrow 11 \rightarrow 12 \rightarrow 13$ (SHIELDS)
 $10 \rightarrow 11 \rightarrow 14 \rightarrow 15$ (INTERCEPT)

CALCULATIONS WILL ONLY BE DONE FOR THE SUPPLY FROM THE LN_2 HEADER TO THE SOLENOID. THE RETURN FLOW PATH IS IDENTICAL WITH REGARD TO PIPE SIZE AND LENGTHS. ANY LEFT OVER ΔP WILL BE / CAN BE USED AT THE CONTROL VALVES AND IN SOLENOID.

I WILL UTILIZE THE CHART "FLOW OF AIR THROUGH SCH. 40 STEEL PIPE" PG. B-15, CRANE TECHNICAL PAPER 410.

ΔP PER 100 FT IS GIVEN FOR VARIOUS FLOW RATES & PIPE SIZES.

CONVERTING 5 g/s TO FREE AIR;

$$\dot{q}'_m \approx 5 \text{ g/s} \times 878.54 \frac{\text{cm}^3}{\text{g}} \times \frac{60 \text{ s}}{1 \text{ min.}} \times \left[3.53 \times 10^{-5} \frac{\text{ft}^3}{\text{cm}^3} \right]$$

$$\dot{q}'_m = 9.30 \text{ scfm} \quad \uparrow \quad v(T=300K, P=1 \text{ atm})$$

LINE #10, 10 ft, .430" ID. ($\frac{1}{2}$ " OD x .035 wall) { LENGTH
 LINE #11 5 ft, " { ROUNDED UP
 LINE #12 124 ft + 9 ELBOWS + TEES etc. , .277" ID. { TO INCLUDE
 SAY 150 ft. { ELBOWS
 LINE #13 10 ft, .430" ID. { NOTE: THE FLOW
 RATE WILL
 BE 1/2 HERE
 DUE TO SPLIT

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ΔP FOR SOLENOID LN₂ TRANSFER LINE

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FROM TABLE; $\Delta P_{100} \Big|_{\substack{1/4" \text{ SCH 40} \\ \text{id} = .364"}} \approx \begin{matrix} 5.24 \text{ psi for } 9.3 \text{ scfm} \\ 1.33 \text{ psi for } 4.65 \text{ scfm} \end{matrix}$

A CONVERSION EQUATION IS GIVEN TO CORRECT FOR TRUE P.I.A.

$$\Delta P_a = \Delta P_{40} \left(\frac{d_{40}}{d_a} \right)^5$$

$$\Delta P_{100} \Big|_{.430" \text{ ID}} = \begin{matrix} (5.24 \text{ psi}) \times \left(\frac{.364}{.430} \right)^5 = 2.28 \text{ psi for } 9.3 \text{ scfm} \\ (1.33 \text{ psi}) \times \left(\frac{.364}{.430} \right)^5 = .578 \text{ psi for } 4.65 \text{ scfm} \end{matrix}$$

ALSO A CORRECTION NEEDS TO BE MADE FOR FLOWING PRESSURE = 30 psia. TABLE IS FOR 115 psia.

$$\Delta P_{100} \Big|_{\substack{.430" \text{ ID} \\ 30 \text{ psia}}} = \begin{matrix} (2.28 \text{ psi}) \left(\frac{115 \text{ psia}}{30 \text{ psia}} \right) = 8.74 \text{ psi for } 9.3 \text{ scfm} \\ (.578 \text{ psi}) \left(\frac{115}{30} \right) = 2.22 \text{ psi for } 4.65 \text{ scfm} \end{matrix}$$

SO FOR OUR CASE;

$$\Delta P_{10 \& 11} = 8.74 \text{ psi} \times \frac{15 \text{ FEET}}{100 \text{ FEET OF PIPE}} = \boxed{1.31 \text{ psi}}$$

FOR LINES 12 ONLY HALF OF FLOW IS PRESENT.

$$\Delta P_{100} \Big|_{\substack{.277" \text{ ID} \\ @ 110 \text{ psig}}} = 1.33 \text{ psi} \left(\frac{.364}{.277} \right)^5 = 5.21 \text{ psi for } 4.65 \text{ scfm}$$

CORRECTING FOR PRESSURE;

$$\Delta P_{100} \Big|_{\substack{.277" \text{ ID} \\ 30 \text{ psia}}} = 5.21 \text{ psi} \left(\frac{115 \text{ psia}}{30 \text{ psia}} \right) = 20.0 \text{ psi for } 4.65 \text{ scfm}$$

FOR OUR CASE, LINE 12 L = 150 ft. $\Delta P_{12} = \boxed{30 \text{ psi}}$

$$\Delta P_{13} = \frac{10}{100} \times 20 \text{ psi} \times \left(\frac{.277}{.430} \right)^5 = \boxed{0.22 \text{ psi}}$$

$$\Delta P_{\text{TOTAL}} \Big|_{\substack{10 \rightarrow 11 \rightarrow 12 \rightarrow 13 \\ 5 \text{ g/s, } 300 \text{ K} \\ 30 \text{ psia}}} = \boxed{31.5 \text{ psi}} \quad \text{THIS IS A VALUE FOR DISCUSSION.}$$

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ΔP FOR SOLENOID LN₂ TRANSFER LINE.

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1-25-95

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WHAT THIS VALUE OF 31.5 PSI MEANS IS THIS:

INITIALLY WHEN YOU FIRST START N₂ FLOW THE GAS WILL BE WARM. THE RETURN PIPING WILL BE WARMEST. UNTIL THE N₂ SHIELDS & INTERCEPTS COOL TO THE POINT WHERE THE AVERAGE RETURN TEMPERATURE IS LESS THAN 150 K, 5'S WILL NOT BE ACHIEVED.

THE STEADY STATE LN₂ HEAT LOAD IS APPROX 241 WATTS EQUIVALENT TO 5.4 L/HR PER THE DESIGN REPORT

$$\rho = 0.776 \text{ g/cc @ 2 ATM, LIQUID.}$$

$$\dot{m} = 5.4 \text{ L/HR} \times \frac{1000 \text{ CC}}{1 \text{ L}} \times 0.776 \text{ g/cc} \times \frac{1 \text{ HR}}{3600 \text{ S}} = 1.16 \text{ g/s}$$

FOR STEADY STATE.

FOR COOLDOWN TO BE POSSIBLE

$$\dot{m}_{g2} > \dot{Q}_{ss} / 2 (\bar{h}_{g2} - h_{f1})$$

REF. BARRON
"CRYOGENIC
SYSTEMS"
(EQ. 7.78)

FURTHERMORE

$$V_{sonic} = C_d (\gamma g_c R \bar{T}_{s2})^{1/2}$$

FROM "GASPAK" MAC APPLICATION

$$V_{sound} (N_2, T=293K, P=202 \text{ KPa}) = 349.2 \text{ m/s}$$

$$\dot{m}_{max} \Big|_{d=.277"10} = \rho V_{sound} \cdot A = (2.324 \text{ kg/m}^3) (349.2 \text{ m/s}) \left(\frac{\pi (.277 \text{ in.})^2}{4} \right) \left(\frac{.0254 \text{ m}}{1 \text{ in.}} \right) \times \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right)$$

$$\dot{m}_{max} = 31.55 \text{ g/s}$$

SUBJECT

 ΔP FOR SOLENOID LN₂ TRANSFER LINE.

NAME

RUSS RUCINSKI

DATE

1-25-95

REVISION DATE

SUBSTITUTING INTO Eq. 7.78;

$$\dot{Q}_{SS} = 241 \text{ WATTS} \quad \bar{h}_{g2} = 461.728 \frac{\text{J}}{\text{g}} \quad h_{F1} = 42.6585 \frac{\text{J}}{\text{g}}$$

$$\dot{m}_{g2} > \frac{241 \frac{\text{J}}{\text{s}}}{2 (461.728 - 42.6585 \frac{\text{J}}{\text{g}})} = \underline{0.288 \frac{\text{g}}{\text{s}}}$$

ESTIMATE AMOUNT OF WARM GAS YOU CAN GET THRU PIPING.

$$P_{DELTA} = 50 \text{ psia.} \quad \text{SAY } \Delta P_{\text{SOLENOID}} = 10 \text{ psi THEN } \Delta P_{\text{X-FER LINE}} = 25 \text{ psig.}$$

FOR VENT & RETURN PIPING; (FROM PG. 2)

$$\Delta P_{\text{TOTAL}} \left| \begin{array}{l} 10 \rightarrow 11 \rightarrow 12 \rightarrow 13 \rightarrow 16 \rightarrow 17 \\ 5 \frac{3}{4}, 300 \text{ K} \\ 30 \text{ psia AVG} \end{array} \right. = (31.5 \text{ psi}) \times 2 = 63 \text{ psi}$$

$$\Delta P \propto \dot{m}^2 \quad \dot{m}_{\text{EST.}}^2 = \left(5 \frac{3}{4}\right)^2 \times \left[\frac{25 \text{ psi}}{63 \text{ psi}}\right]$$

$$\dot{m}_{\text{EST.}} = 3.15 \frac{\text{g}}{\text{s}}$$

I CONCLUDE THAT THE CURRENT TUBING SIZES
FOR THE N₂ X-FER LINES ARE ACCEPTABLE
FOR COOLDOWN AND STEADY STATE OPERATION.

{ SEE 1-16-95 R RUCINSKI "SOLENOID TRANSFER LINE
STEADY STATE CONDITIONS" CALCULATIONS.

$$\Delta P_{\text{STEADY STATE}} < 1 \text{ psi}$$

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SUBJECT

SOLENOID TRANSFER LINE
STEADY STATE CONDITIONS

NAME

RUSS RUCINSKI

DATE

1-16-95

REVISION DATE

I WILL PRELIMINARILY SIZE THE TUBING BASED ON
STEADY STATE FLOW RATES.

LINE # 10 & #11: $m = 4.0 \text{ g/s}$ & $P_{inlet} = 50.0 \text{ psia}$.
ROUGHLY 10 FEET EQUIVALENT LENGTH

$$Q (\text{gal/min.}) = 4.0 \text{ g/s} \times \frac{2.2 \text{ lbs}}{1000 \text{ g}} \times \frac{1}{6.745 \text{ lbs/gal}} \times \frac{60 \text{ s}}{1 \text{ min}} = .08 \text{ gal/min}$$

THIS OFF SCALE FOR THE CVI CHART $\Delta P/\text{ft}$ VS. FLOW RATE

FROM CHART: $1/2'' \text{ O.D.} \times .049 \text{ WALL TUBE @ } 1 \text{ g/min, } \Delta P = .03 \text{ psi/ft}$.
 $\left\{ m = 4.0 \text{ g/s} \times \frac{1 \text{ g/min}}{.08 \text{ gal/min}} = 50 \text{ g/s} \right\}$

ON THIS COMMON SUPPLY PIPE, I DON'T WANT TO GO SMALLER.
2. MAKE IT $1/2'' \text{ O.D.} \times .035 \text{ WALL}$

FOR LINES AFTER LN_2 CONTROL VALVES.

SHIELD; #12 2.54 g/s

INTCEPT; #14 1.46 g/s

CHOOSE $3/8'' \times .049 \text{ WALL}$ ($0.277'' \text{ I.D.}$)

$$\Delta P \propto \frac{W^2}{d^5} \quad \Delta P_2 = K_1 \frac{W_2^2}{d_2^5}$$

$$\Delta P_1 = \Delta P_2 \frac{d_2^5}{d_1^5} \frac{W_1^2}{W_2^2}$$

$$\Delta P_1 = (.03 \text{ psi/ft}) \cdot \left[\frac{(.402 \text{ in.})}{(.277 \text{ in.})} \right]^5 \times \left[\frac{2.54}{50} \right]^2 = .0005 \text{ psi/ft}$$

LENGTH OF LINE = 125 ft

$\Delta P_{\text{total}} = .06 \text{ psi} ?$

$3/8'' \text{ O.D. TUBING IS FINE.}$

PRESSURE DROP CURVES

G2

The following curves may be helpful in determining the proper line size for your transfer requirement. These charts represent loss of pressure due to fluid flow through a pipe. Total pressure drop also includes additional loss of pressure (head) due to any increase in elevation

Please notice that a smaller diameter rigid pipe line can accommodate the same flow capacity as a larger diameter flex line. This is significant when considering heat-leak (liquid loss) and system purchase cost.

LIQUID NITROGEN

Pressure Drop Due to Fluid Flow

Rigid Piping — Flexible Piping - - - -

Each piping section undergoes helium mass spectrometer testing (1×10^{-9} cc/sec sensitivity) followed by a seven day vacuum retention test to ensure the vacuum integrity prior to shipment.

SUBJECT

VLPC LHE LINE SIZING

FOR STEADY STATE CONDITIONS

NAME

RUSS RUCINSKI

DATE

1-26-95

REVISION DATE

CONSIDER STEADY STATE MASS FLOW REQ'D FOR VLPC CRYOSTATS.

IN SOLENOID DESIGN REPORT $Q_{TOTAL} = 270 W$, A HIGH ESTIMATE. CURRENT ESTIMATES ARE 70 W PER CRYOSTAT AND PERHAPS AN ADDITIONAL 40 W FOR TRANSFER LINES & JUMPERS $Q_{TOTAL} = 180 W$.

TO BE CONSERVATIVE USE 270 W NUMBER.

$$\dot{m}_{ss} = \frac{Q_{ss}}{\Delta h} = \frac{270 W}{45.35 \frac{J}{g} - 14.29 \frac{J}{g}} = 8.69 \frac{g}{s}$$

$\uparrow (P=.12 MPa, T=6.5 K) \quad \uparrow (SAT. LIQ. H_2O, 0.1743 MPa)$

CALCULATE ΔP_{100} FOR $\dot{m} = 4.35 \frac{g}{s}$ $T = 6.5 K$, $\bar{P} = .14$

SM

3/8" O.D. x .035 WALL, $i.d. = .305$

$$Re = \frac{4\dot{m}}{\pi D \mu} = \frac{4 \cdot (.00435 \frac{kg}{s})}{\pi (.305 m) (.0254 \frac{m}{N}) (1.726 \times 10^{-6} Pa \cdot s)}$$

$$= 414,214 \quad f = .013$$

$$\rho = 11.90 \frac{kg}{m^3} \quad \Delta P = 3.62 \frac{kg \cdot g^2}{m^4}$$

$$K = \frac{fL}{D}$$

CRANE,
EQ. 3-14
EQ. 2-4

$$K_{100} = (.013) \frac{(100 ft.)}{\frac{.305 m}{12}} = 51.1$$

$$q = \frac{\dot{m}}{\rho} = \frac{.00435 \frac{kg}{s}}{11.90 \frac{kg}{m^3}} = 3.655 \times 10^{-4} \frac{m^3}{s} \times \left(\frac{.3048 ft.}{1 m} \right)^3$$

$$= 1.035 \times 10^{-5} \frac{ft^3}{s}$$

$$\Delta P_{100} = 3.62 \frac{(51.1) (.74351 \frac{lb}{ft^3}) (1.035 \times 10^{-5} \frac{ft^3}{s})^2}{(.305 m.)^4} = 1.7 \times 10^{-6} psi$$

$$\Delta P_{100} < 0.1 psi$$

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SUBJECT

HEAT LOADS FOR SOLENOID & VLPC
TRANSFER LINES

NAME

RUSS FLORES

DATE

10-17-94

REVISION DATE

• LHe BAYONETS: CDF & DØ SOLENOID DESIGN REPORTS USE 1.3 W
PER BAYONET

CVI; $3/4 \times 2$ (LONG); 4.7 WATTS @ 20K

CVI; COOLDOWN MASS = $33 \text{ BTU} \times 1055 \frac{\text{J}}{\text{BTU}} = 34.3 \text{ KJ}$ (20K)

CRYOLAB; $1/2$ SIZE; $9.3 \frac{\text{BTU}}{\text{hr}} \times .293 = 2.7 \text{ WATTS}$

NOTE: CVI & CRYOLAB STINGERS ≈ 10 " LONG

SATELLITE REP. DESIGN; $1/2$ " SIZE: 1.4 W to 4K

($13 1/2$ " LONG STINGER) $3/4$ " SIZE: 1.86 W to 4K

$1/4$ " SIZE: 1.4 W to 4K

CONCLUSION: USE: 1.9 WATTS, $3/4$ " SIZE
1.4 WATTS, $< 3/4$ " SIZE

• LHe U-TUBES: CDF DESIGN REPORT 1.3 W

DØ DESIGN REPORT (5') 3.1 W {INCLUDES BAYONETS}

(10') 3.6 W " "

(15') 4.1 W " "

U-TUBE HEATLEAK = 2 BAYONETS + $0.1 \frac{\text{W}}{\text{ft}} \times L$

USE: 5' U-TUBE $\Rightarrow$ 4.3 W, $3/4$ " SIZE
3.3 W, $< 3/4$ " SIZE

10' U-TUBE $\Rightarrow$ 4.8 W, $3/4$ " SIZE
3.8 W, $< 3/4$ " SIZE

15' U-TUBE $\Rightarrow$ 5.3 W, $3/4$ " SIZE
4.3 W, $< 3/4$ " SIZE

{INCLUDES BAYONET ENDS}

• LHe TRANSFER LINE:

RULE OF THUMB 1 WATT/100 FT LENGTH.
FOR LN₂ RAD. SHIELDED LINE

FERMILAB

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CRYO UTILITIES
SOLENOID VALVE

SERIAL CATEGORY

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SUBJECT

HEAT LOADS FOR SOLENOID VALVE
TRANSFER LINES

NAME

RUSSELL R. ...

DATE

10-17-74

REVISION DATE

- LHe CONTROL VALVE : CDF DESIGN REPORT - 0.5 WATTS

CALLED BILL SOYAKS ADICKS - STD FERMILAB VALVE

 $Q = 0.66 W$ to 4 RELIEFS

USE 0.66 WATTS

- TRAPPED VOLUME RELIEFS :

ASSUME $\frac{1}{8}$ " O.D. x 0.028" WALL TUBING. STN. STL.ASSUME 12" OF LENGTH BEFORE TUBING IS SUNK TO LN₂ SHIELD

$$Q = \frac{K_m A (T_L - T_C)}{L} = \left(\frac{A}{L}\right) \cdot \left\{ \int_{4K}^{77} K_e dT - \int_{4K}^{45} K_e dT \right\}$$

$$= \frac{(0.00853 \text{ IN}^2)}{12 \text{ IN.}} \cdot \left\{ 349 \frac{W}{M} \right\} \cdot 0.0254 \frac{M}{IN.}$$

$$= 0.006 W$$

REF. BARRON CRYOGENIC
SYSTEMS

INSTRUMENTATION POINTS

&

TRAPPED VOL. RELIEFS

USE 0.01 W
PER INSTANCE

SUBJECT

HEAT LOADS FOR SOLENOID & V/LPC
TRANSFER LINES

NAME

RUSS RUCNSK

DATE

10-18-94

REVISION DATE

• LN₂ BAYONETS : REF. CDF DESIGN REPORT STD. SAVER BAYONET

USE 1.19 W FOR BAYONET PAIR

• LN₂ U-TUBES : SAVER U-TUBES HAVE 0.03 W/FT

U-TUBE HEAT LEAK = 2 BAYONETS + 0.08 W/FT

5' U-TUBE $\Rightarrow$ 2.8 W10' U-TUBE $\Rightarrow$ 3.2 W15' U-TUBE $\Rightarrow$ 3.6 W

{ INCLUDES BAYONET PAIR @ EACH END }

• LN₂ TRANSFER LINE : CVI #'S VT PIPE W/ MLI

INNER PIPE SIZE	3/4" O.D.	3/4" NPS	1" NPS	1 1/2" NPS	2" NPS	6" NPS
HEAT LEAK (WATTS/FT)	0.09	0.10	0.11	0.14	0.19	0.40

WITHOUT MLI, 6" RAD. SHIELD @ LN₂ TEMP

$$q' = 2.4 \text{ W/ft}$$

PER AMS CALCS.

DØ EN-344

CHIMNEY HEAT LOAD CALCS.

• LN₂ CONTROL VALVES :

$$Q = 0.66 \text{ WATTS} \times \frac{\int_{4K}^{300} KdT - \int_{4K}^{30} KdT}{\int_{4K}^{300K} KdT}$$

STN. 501.

$$= 0.66 \text{ W} \times \frac{3060 - 349}{3060} = 0.66 \text{ W} (.886) = 0.58 \text{ W}$$

USE Q = 0.6 W FOR STD.
SAVER C.V.

FERMILAB
ENGINEERING NOTE

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CRYO UTILITIES
SOLENOID/VLPC

SERIAL CATEGORY

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SUBJECT

HEAT LOADS FOR SOLENOID ± VLPC
TRANSFER LINES

NAME

RUSS RICHES

DATE

10-12-91

REVISION DATE

- TRAPPED VOL. RELIEFS

ASSUME 1/8" O.D. x .023" WALL TUBING S.S. x 12" LG.

$$Q = \frac{(.00353 \text{ in}^2)}{12 \text{ in}} \left\{ 3060 - 349 \frac{\text{W}}{\text{in}} \right\} \times .0254 \frac{\text{in}}{\text{in}}$$

$$= 0.05 \text{ W}$$

- INSTRUMENTATION

SAY $Q = 0.01 \text{ W}$ PER INSTANCE

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SRV J-135
VLPC & SOLENOID

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SUBJECT

STEADY STATE HEAT LOADS
TO SOLENOID TRANSFER LINE

NAME

RUCINSKI

DATE

10-20-94

REVISION DATE

- *4 - U-TUBE ASSUME 3/4 SIZE, 4.3 W
- *5 - X-FER LINE, NEGATIVE WATTS FLUID BEING SUBCOOLED BY LIQUID N₂
- *6 - U-TUBE 4.3 W
- *7 - " 4.3 W
- *8 - 125 FT x 1 W/100 FT = 1.25 W
 + HEAT LOAD FROM *5 = 3 INST./RELIEFS = .03 W
 + 0.66 W - VALVE
 + 3 INST/RELIEFS IN RETURN + 1 VALVE ON RETURN
 = 1.25 W + .03 + .66 W + .03 + .66 = 2.63 W
- PLUS AMOUNT OF SUBCOOLING DONE TO *6 T=4.91 to 4.73 K
- *9) - U-TUBE 4.3 W
- *10) U-TUBE LN₂ SUPPLY, ASSUME 3/4" ^{TIGG} SCH. 10S PIPE I.D. = .884"
 USE 5' U-TUBE → 2.8 W
- *11) SHUNT SECTION W/ NO Q.
- *12) ASSUME PIPE SHARES 1/4 OF HEAT LOAD TO THE RAD. SHIELD
- 125 FT x 0.40 W/FT = 50 W total
- 12.5 W for *12 + ^{TEMP.} VOL. RELIEF = 0.05 + ¹ CONTROL VALVE = .6 W
- 12.5 W for *14
- 12.5 W for *17
- 12.5 W for *20
- 12.5 + .05 + .6 = 13.15 = 13.2 W

FLOW RATE SPLIT BETWEEN SHIELD & INTERCEPTS

PER TABLE 4.3 IN DESIGN REPORT HEAT LOAD TO LN₂

SEE NEXT PAGE

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VLPC & SOLENOID

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SUBJECT

HEAT LOADS TO SOLENOID & VLPC
LINES

NAME

RUSS F. L. L.

DATE

10-20-94

REVISION DATE

*13) U-TUBE, 3/4" PIPE SIZE, 10' LONG $\rightarrow 3.2 W$ *14) HEAT LOAD $\rightarrow 12.5 W + 1 CV + 1 RELV = 13.2 W$ SMALLER FLOW SAY 1/2" O.D. tube x .035" WALL $\Rightarrow .430 W$ I.D.

*15) SAME AS #14, 1/2" PIPE SIZE, 10' LONG

*16) TO GET INLET CONDITIONS, WE NEED TO ADD HEAT LOAD PICKED UP IN SOLENOID
TO SHIELD LINE: $12 W + 73.8 + 28.08 = 113.9 W$ { SEE BELOW FOR DETAILS }THE FLUID VENTS TO ATM THEREFORE PRESSURE
WILL BE LOW, SAY 20 PSIA.*17) HEAT LOAD $\rightarrow 12.5 W + 1 TVR = .05 \approx 12.6 W$ *18) HEAT LOAD = ~~1~~ 1 BRACKET PAR + 1 FT OF U-TUBE
 $= 1.19 W + .08 W = 1.3 W$ *19) SAME AS #15 U-TUBE $Q = 3.2 W$ 10' U-TUBE
TO GET INLET CONDITIONS, NEED TO ADD $\left\{ \begin{array}{l} 6.6 + 16.7 \\ + 28.08 \\ = 51.4 W \end{array} \right\}$
TO CONTROL DEWAR INLET CONDITIONS.

*12) CONT. FLOW RATE SPLIT.

TOTAL HEAT LOADS: 50 W - X-FER LINE SECTION

.10 - TRAPPED VOL. RELIEF (2)

.6 W - CONTROL VALVE (SHIELD)

.6 W - " (INTCPT.)

 $3.2 \times 4 = 12.8 W$ - 4 U-TUBES

12 W - SHIELD STAND-OFFS

6.6 W - AXIAL SUPPORTS

16.7 - RADIAL SUPPORTS

130 W - RADIATION

FROM AMS
CALCS. 2/25/93

229.4 W

TOTAL =

FROM DESIGN
REPORT $130 W \frac{108}{250} = 56.16$ $73.84 W$ CHIMNEYSHIELD LINE

25 W - 1/2 OF X-FER LINE

.65 - CONTROL VALVE

6.4 - U-TUBES

12 W - SHIELD STAND-OFFS

73.8 W - INNER & OUTER SHIELDS

28.08 W - 1/2 OF CHIMNEY

145.93

INTCPT LINE

25 W - 1/2 OF X-FER LINE

.65 - CONTROL VALVES

6.4 - U-TUBES

6.6 - AXIAL SUPPORT

16.7 - RADIAL SUPPORT

28.08 W - 1/2 OF CHIMNEY LOAD

83.43 W

FERMILAB
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CRTO UTILITIES
VLPC & SOLENOID

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SUBJECT

HEAT LOADS TO SOLENOID & VLPC
LINES

NAME

RUSS RUCINSKI

DATE

10-21-94

REVISION DATE

*12) CONT.

$$\dot{m}_{\text{SHIELD}} = 4 \frac{9}{5} \times \frac{145.93 \text{ W}}{229.4 \text{ W}} = 2.54 \frac{9}{5}$$

$$\dot{m}_{\text{INTCPT}} = 4 \frac{9}{5} \times \frac{83.43 \text{ W}}{229.4} = 1.46 \frac{9}{5}$$

*20) TRANSFER LINE + 1 TRAPPED VAL RELIEF = 12.6 W

*22) HEAT LOAD: 1 BRAYONET PAIR + 1 FE OF U-TUBE
 $1.19 \text{ W} + .08 \text{ W} = 1.3 \text{ W}$

HELIUM PIPING

PRESSURE DROP FOR SINGLE PHASE FLOW

$$\Delta P = \frac{43.5 f L \rho q^2}{d^5}$$

$$q = \frac{\dot{m}}{\rho'} = \frac{(\text{g/s})}{(\text{kg/m}^3)} = \left| \frac{\text{g} \cdot \text{m}^3}{\text{kg} \cdot \text{s}} \right| \left(\frac{35.315 \text{ ft}^3}{\text{m}^3} \right) \left(\frac{\text{kg}}{2.205 \text{ lb}} \right) = 0.035 \frac{\text{m}^3}{\text{s}}$$

$$q = 0.035 \frac{\text{m}^3}{\text{s}} ; \dot{m} = [\text{g/s}], \rho' = [\text{kg/m}^3]$$

$$\rho = \left(\frac{\text{lb}}{\text{m}^3} \right) \left(\frac{2.216}{1 \text{ kg}} \right) \left(\frac{\text{m}^3}{35.315 \text{ ft}^3} \right) = 0.062 \rho'$$

$$\Delta P = \frac{43.5 f L}{d^5} (0.062 \rho') (0.035^2 \frac{\text{m}^2}{\text{s}^2})$$

$$\Delta P = \frac{0.003 f L}{d^5} \frac{\text{m}^2}{\text{s}^2} \Rightarrow$$

$$\Delta P = \frac{0.003 f L \text{m}^2}{\rho' d^5}$$

$$Re = 22,700 \frac{\rho P}{d \mu}$$

$$q = 0.035 \frac{\text{m}^3}{\text{s}}$$

$$\rho' = [\text{kg/m}^3]$$

$$\rho = 0.062 \rho'$$

$$\mu' = [\text{cP} \cdot \text{s}]$$

$$Re = \frac{22,700 (0.035 \frac{\text{m}^3}{\text{s}}) (0.062 \rho')}{d (10^{-3} \mu')}$$

$$\mu = (\text{MPa} \cdot \text{s}) \left(\frac{1}{10^6 \text{ Pa} \cdot \text{s}} \right) \left(\frac{\text{Pa} \cdot \text{s}}{0.1 \text{ Pa} \cdot \text{s}} \right) \left(\frac{100 \text{ centipoise}}{1 \text{ Pa} \cdot \text{s}} \right)$$

$$\mu = 10^3 \mu'$$

$$Re = \frac{49259 \text{ m}}{d \mu'}$$

LINE 4

$$T_1 = 4.91 \text{ K}$$

$$P_1 = 26.50 \text{ psia} = 0.18 \text{ MPa}$$

$$h_1 = 14.88 \text{ J/g}$$

$$x_1 = 0$$

$$T_2 = 4.91 \text{ K}$$

$$P_2 = 26.50 \text{ psia}$$

$$h_2 = 15.42 \text{ J/g}$$

$$x_2 = 0.05$$

$$h_2 = \frac{\Delta Q}{m} + h_1 = \frac{4.3}{8} + 14.88 = 15.42 \text{ J/g}$$

$$\text{Assume } P_2 = P_1: \quad x_2 = 0.05$$

ΔP_f Calculation:

$$\rho_L = 106.7 \text{ kg/m}^3$$

$$\mu_L = 2.864 \text{ MPa-s}$$

$$\rho_g = 34.01$$

$$\mu_g = 1.594 \text{ MPa-s}$$

$$\sigma_L = 0.5308 \frac{\text{dyne}}{\text{cm}} \left(1 - \frac{4.91}{5.195}\right) = 0.03 \frac{\text{dyne}}{\text{cm}}$$

$$= 3(10^{-5}) \text{ N/m}$$

$$\Rightarrow \Delta P_f = 0.006 \text{ psig}$$

ΔP_r Calculation:

$$*(K = 30 f_r \text{ for } 90^\circ \text{ elbows})$$

$$K = f \frac{L}{D} = 30 f$$

$$L = 30 D = 30 \left(\frac{0.62}{12} \right) = 1.55 \text{ ft}$$

$$\text{From table A-24} \rightarrow f_r \approx 0.0155$$

$$\Delta P_r = \Delta P_f \left(\frac{5 \text{ ft} + 2L}{5 \text{ ft}} \right) = \Delta P_f \left(\frac{8.1}{5} \right) = \underline{\underline{0.01 \text{ psig}}}$$

$$P_2 = \underline{\underline{26.49 \text{ psia}}}$$

St	Input	Name	Output	Unit	Comment
					Lockhart Martinelli correlation for two phase pressure drop through an adiabatic horizontal pipe
		valid	'accurate		model validity
		flow	'turbulen		flow type
		f	.01620391		friction factor ; Must enter a guess
.000005		epsilon		ft	pipe roughness
.62		D		in	Pipe inside diameter
5		L		ft	Length of pipe
		A	.00019478	m^2	cross sectional area
8		mdot		g/s	Total mass flow rate
106.7		rhoL		kg/m^3	Liquid density
34.01		rhog		kg/m^3	density of the gas
2.864		muL		μPa-s	Liquid viscosity
1.594		muG		μPa-s	Gas viscosity
.00003		sigmaL		N/m	Surface tension of liquid
.05		x			quality = mdotG/mdot
		ReL	214500		Reynold's # for liquid
		mdotL	.0076	kg/s	Mass flow rate for liquid
		ReG	20290		Reynold's # for gas
		mdotG	.0004	kg/s	Mass flow rate for gas
		dPdLL	7.3408407	Pa/m	ΔP/ΔL for the liquid
		dPdLTP	25.168498	Pa/m	ΔP/ΔL for the two phase
		deltaP	.00556327	psig	Total pressure drop for the pipe
		phiL	1.8516366		Lockhart-Martinelli parameter
		X	8.2850398		Lockhart-Martinelli parameter
.25		m			L-M constant; Look up in Table 7.19
.2		n			L-M constant; Look up in Table 7.19
.316		CG			L-M constant; Look up in Table 7.19
.184		CL			L-M constant; Look up in Table 7.19
20		C			L-M constant; Look up in Table 7.19
		lambda	1.7407229		Baker diagram dimensionless parameter
1.2		rhoair		kg/m^3	density of air
998		rhoH2O		kg/m^3	density of water
		sigh	1534.04		Baker diagram dimensionless parameter
.073		sigmaH2		N/m	Surface tension of water
1000		muH2O		μPa-s	viscosity of water
		BakerXa	50700		X - axis value for Baker plot
		BakerYa	870	lbm/hr-ft	Y - axis value for Baker plot
		c	1		
		M	1		
		RsubL	.54006278		Volume fraction of liquid phase
		RsubG	.45993722		Volume fraction of gas phase
		GasVel	.1312847	m/s	Gas velocity
		LiqVel	.6771178	m/s	Liquid velocity