Fermilab

SSC DETECTOR SOLENOID DESIGN NOTE #116

TITLE: SDC Solenoid Vacuum Vessel Relieving Pressure (Cylindrical Chimney)

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DATE: October 15, 1990

ABSTRACT: This Design Note contains the pressure relief calculation for the SDC solenoid vacuum vessel. The calculation uses the cylindrical chimney dimensions given in Design Note 115 and a relieving flow rate which appears to be reasonable at this time.

SUMMARY: Relieving pressure in the vacuum vessel is calculated using Bernoulli's equation with pressure losses included.

CONCLUSION: Vacuum vessel relieving pressure is 0.1 psig.

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SUBJECT	NAME	
SDC SOLENOID VACUUM VESSEL RELIEVING PRESSURE (CYLINDRICAL CHIMNEY)	A. M. STEFANIK	
	DATE 9/18/90	REVISION DATE

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SUBJECT: CHIMNEY PRESSURE DROP – CYLINDRICAL OUTER WALL (VACUUM VESSEL)

NAME: AMS

DATE: 9/20/90

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REFER TO §5.3 FOR LAYOUT & CHIMNEY DIMENSIONS.

1.0 CALCULATE CHIMNEY FLOW RESISTANCE WITH PARALLEL PLATE RELIEF DEVICE...

1.1. ENTRANCE LOSS AT VACUUM VESSEL – $K_{D_H} = 1$

1.2. ~34' OF ANNULAR FLOW AREA – $K_{D_H} = \frac{fL}{D_H}$

1.3. LOSS AT TEE TO CHIMNEY BAYONET BOX:

TEE RUN – $K_{D_H} = 20 f_T$

2' OF ANNULAR FLOW AREA – $K_{D_H} = \frac{fL}{D_H}$

RESTRICTION OF ANNULAR FLOW AREA BY 6"φ RADIATION SHIELD. MODEL AS AN ORIFICE.

$$W = 1891\, Y d_1^2\, C \sqrt{\Delta P\, \rho_1}$$

← CRANE TECHNICAL PAPER 410, 1988 "FLOW OF FLUIDS THROUGH VALVES, FITTINGS AND PIPE" EQUATION 3-22

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

$$W = 1891\, Y \left(\frac{4A_1}{\pi}\right) C \sqrt{\Delta P \rho_1}$$

$$= 2408\, Y A_1 C \sqrt{\Delta P \rho_1}$$

USE A SAFETY FACTOR OF 2 ON ΔP BECAUSE OF THIS NON-STANDARD FLOW RESTRICTION.

$$\therefore\ W = 1{,}700\, Y A_1 C \sqrt{\Delta P \rho_1}$$

TRANSVERSE INTERNAL AREA = 120.57 in²

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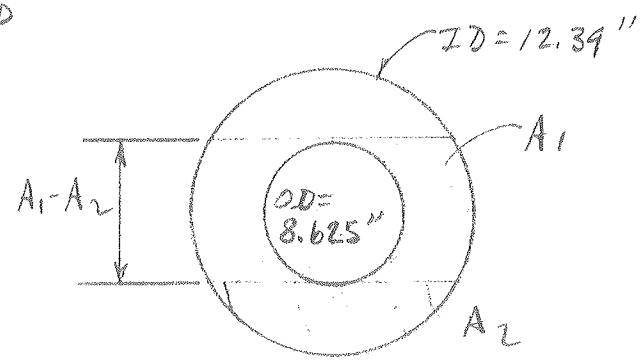
AREA OF SEGMENT = 120.57 $C_{H/D}$

FOR A_1: $\frac{H}{D} = \frac{\left(\frac{12.39}{2}\right)+\left(\frac{8.625}{2}\right)}{12.39}$

$= 0.848$

$\Rightarrow C_{H/D} = 0.904116$



$\therefore A_1 = 120.57\,(0.904116) = 109\ in^2$

FOR A_2: $\frac{H}{D} = \frac{\left(\frac{12.39}{2}\right)-\left(\frac{8.625}{2}\right)}{12.39} = 0.152 \Rightarrow C_{H/D} = 0.095884$

$A_2 = 120.57\,(0.095884) = 11.6\ in^2$

$A_1 - A_2 = 109 - 11.6 = 97.4\ in^2$

AREA BLOCKED BY INSULATED TEE BRANCH $= \frac{97.4\ in^2 - \pi\,(8.625\ in)^2/4}{2}$

$= 19.5\ in^2$

AREA BLOCKED BY INSULATED LN_2 SHIELD $= \pi\,\frac{(8.625)^2}{4} = 58.4\ in^2$

$A_F \equiv$ ANNULAR FLOW AREA $= 120.57\ in^2 - 58.4\ in^2 = 62.17\ in^2$

FLOW AREA AT THE TEE $= 120.57\ in^2 - 58.4\ in^2 - 19.5\ in^2$

$= 42.67\ in^2 = A_1$

1.4. LOSS DUE TO TEE FOR TURBOMOLECULAR PUMP – $K_{12} = 20\ ft$

1.5. SUDDEN EXPANSION WHERE LN_2 SHIELD ENDS –

$K_2 = (1-\beta^2)^2/\beta^4 \qquad \beta^2 = A_1/A_2$

$A_1 \equiv$ SMALLER FLOW AREA $= 42.67\ in^2$
$A_2 \equiv$ LARGER FLOW AREA $= 120.57\ in^2$
$\Big\}\ \beta^2 = \frac{A_1}{A_2} = \frac{42.67}{120.57} = 0.354$

$K_2 = (1-0.354)^2/(0.354)^2 = 3.33$

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1.6 SPACERS FOR LN_2 SHIELD – 4 LOCATIONS

$W = 1700 Y A_1 C \sqrt{\Delta P \rho_1}$ (SAME EQUATION AS 1.3 – MODEL AS AN ORIFICE.)

$A_1 = 120.57 - 58.4 - 2(12.39 - 8.625)(1) = 54.64 \text{ in}^2$

NOTE: SHIELD SUPPORT AT ENTRANCE TO VACUUM VESSEL IS SAME AS SPACER AND IS INCLUDED IN THE FOUR LOCATIONS.

1.7. PARALLEL PLATE RELIEF VENT –

USE K FOR TILTING DISC CHECK VALVE. $K_{12} = 90$ ft

MINIMUM PIPE VELOCITY FOR FULL DISC LIFT $= 30\sqrt{\rho}$ fps

1.8 WHERE:

$L = 34'$

$D_H = 4\frac{A_F}{P_W}$

$A_F = 120.57 \text{ in}^2 - 58.4 \text{ in}^2 = 62.17 \text{ in}^2$

$P_W = \pi(12.39 + 8.625) = 66 \text{ in}$

$D_H = \frac{4(62.17)}{66} = 3.77 \text{ in}$

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2.0 FLOW RATES AND SOURCES FOR THE HELIUM AND NITROGEN COOLING CIRCUITS HAVE NOT BEEN FINALIZED AT THIS TIME. INITIAL CALCULATIONS INDICATE THAT THE COIL REQUIRES A LHe FLOW OF 30 g/s. PUMPS ARE BEING CONSIDERED FOR THE LHe CIRCUIT. THE FOLLOWING RELIEVING CONDITIONS WILL BE ASSUMED TO CALCULATE CHIMNEY PRESSURE DROP:

1) RELIEVING FLOW = FLOW OF FOUR HELIUM PUMPS FROM RUPTURED COOLING TUBE INSIDE THE COIL'S CRYOSTAT.

2) GHe FLOWING TEMP = 300 K. THIS IS A WORSE CASE ASSUMPTION BECAUSE GHe WILL EXIT THE COIL'S CRYOSTAT AT 80K AND THEN WARM UP AS IT FLOWS THROUGH THE CHIMNEY.

2.1 ΔP FOR FLOW OF FOUR HELIUM PUMPS...

FLOW = 4 (30 g/s) = 120 g/s = 953 Lbm/hr

FLOWING TEMP = 80 °F VISCOSITY = 0.0486 Lbm/ft-hr

FLOWING DENSITY = 0.01 Lbm/ft³

FLOW AREA = 62.17 in² = 0.43 ft²

$$\text{VELOCITY} = 953 \frac{\text{Lbm}}{\text{hr}} \times \frac{\text{hr}}{3600\text{s}} \times \frac{\text{ft}^3}{0.01\,\text{Lbm}} \times \frac{1}{0.43\,\text{ft}^2} = 61.6 \text{ fps}$$

$$Re_{D_H} = \frac{V D_H \rho}{\mu} = \frac{61.6 \frac{\text{ft}}{\text{sec}} \times \left(\frac{3.77''}{12}\right)\text{ft} \times 0.01 \frac{\text{Lbm}}{\text{ft}^3} \times 3600 \frac{\text{sec}}{\text{hr}}}{0.0486 \frac{\text{Lbm}}{\text{ft-hr}}}$$

$$= 1.4 \times 10^4 \Rightarrow f = 0.03$$

2.1.1 34' OF ANNULAR FLOW AREA WITH ENTRANCE LOSS...

$$\Sigma K_{D_H} = 1 + \frac{0.03\,(34\,\text{ft})}{(3.77/12)\,\text{ft}}$$

$$= 1 + 3.25 = 4.25$$

$$\Delta P_{D_H} = \frac{K v^2}{2g}\frac{\gamma}{144} = 4.25\,(61.6)^2 \frac{\text{ft}^2}{\text{sec}^2}\; 0.01 \frac{\text{Lb}}{\text{ft}^3}\; \frac{1}{2}\; 32.2 \frac{\text{sec}^2}{\text{ft}}\; \frac{\text{ft}^2}{144\,\text{in}^2}$$

$$= \underline{0.02 \text{ psi}}$$

2.1.2 LOSS AT TEE TO CHIMNEY BAYONET BOX ...

RESTRICTION LOSS:

$$\left(\frac{W}{1700\,Y A_1 C}\right)^2 \frac{1}{\rho_1} = \Delta P$$

DETERMINE C —

$$\beta = \frac{d_1}{d_2} \qquad A = \frac{\pi d^2}{4} \Rightarrow d = \sqrt{\frac{4A}{\pi}}$$

$$\beta = \frac{\sqrt{\frac{4A_1}{\pi}}}{\sqrt{\frac{4A_2}{\pi}}} = \sqrt{\frac{A_1}{A_2}}$$

$A_1 \equiv$ FLOW AREA AT RESTRICTION $= 42.67\ in^2$

$A_2 \equiv$ UNRESTRICTED FLOW AREA $= 62.17\ in^2$

$$\left.\begin{array}{l} \beta = \sqrt{\frac{42.67}{62.17}} = 0.83 \\ Re_{DH} = 1.4 \times 10^4 \end{array}\right\} \Rightarrow C = 0.9$$

DETERMINE Y —

$K_{He} = 1.6$

THE ΔP SHOULD BE FAIRLY SMALL. IF SO, THEN $\Delta P / P_1'$ WILL BE SMALL SINCE $P_1' = 14.7$ PSIA AND Y WILL BE CLOSE TO 1.

$\therefore$ SET $Y = 1$.

SUBSTITUTE VALUES INTO ΔP EQUATION —

$$\left(\frac{953}{1{,}700(1)(42.67)(0.9)}\right)^2 \frac{1}{0.01} = \Delta P = 0.021\ psi$$

K_{DH} LOSS:

$$\Sigma K_{DH} = 20 f_T + \frac{fL}{D_H} = 20(0.018) + \frac{0.03(2)}{(3.77/12)} = 0.36 + 0.19 = 0.55$$

$$\Delta P = \frac{K v^2}{2g}\frac{\gamma}{144} = \frac{0.55(61.6)^2}{2(32.2)}\frac{0.01}{144} = 0.002\ psi$$

CHECK: $\frac{\Delta P}{P_1'} = \frac{0.002}{14.7} = 0.00014 \Rightarrow Y \doteq 1$ OK

$$\Sigma \Delta P = 0.021 + 0.002 = 0.023\ psi$$

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2.1.3 LOSS DUE TO TEE FOR TURBOMOLECULAR PUMP

$K_{12} = 20 f_t = 20\,(0.013) = 0.26$

$$\text{VELOCITY} = 953\,\frac{\cancel{Lbm}}{\cancel{hr}}\;\frac{\cancel{hr}}{3600\,s} * \frac{ft^3}{0.01\,\cancel{Lbm}} * \frac{1}{0.8373\,\cancel{ft^2}} = 31.62\ fps$$

FLOW AREA OF 12" SCH 10S PIPE (120.57 in^2)

$$\Delta P = \frac{0.26\,(31.62)^2}{2\,(32.2)}\;\frac{0.01}{144} = \underline{0.0003\ psi}$$

2.1.4 SUDDEN EXPANSION WHERE LN_2 SHIELD ENDS...

$$\Delta P = \frac{3.33\,(31.62)^2}{2\,(32.2)}\;\frac{0.01}{144} = \underline{0.0036\ psi}$$

2.1.5 LOSS DUE TO LN_2 SHIELD SPACERS...

$$\left(\frac{W}{1700\,Y\,A_1 C}\right)^2 \frac{1}{\rho_1} = \Delta P \text{ FOR EACH OF 4 LOCATIONS.}$$

DETERMINE C –

$A_1 = 54.64\ in^2$ $\qquad$ $A_2 = 62.17\ in^2$

$$\left.\begin{aligned} \beta &= \sqrt{\frac{A_1}{A_2}} = \sqrt{\frac{54.64}{62.17}} = 0.94 \\ Re_{D_H} &= 1.4 \times 10^4 \end{aligned}\right\} \Rightarrow C = 0.95$$

DETERMINE Y –
SET Y = 1 AS DONE IN 2.1.2
SOLVE FOR PRESSURE DROP AT ALL 4 LOCATIONS –

$$\Delta P = (4)\left(\frac{953}{1{,}700(1)\,54.64\,(0.95)}\right)^2 \frac{1}{0.01} = \underline{0.047\,psi}$$

2.1.6 LOSS DUE TO PARALLEL PLATE RELIEF VENT —

$K_{12} = 90 f_T = 90(0.013) = 1.17$

VELOCITY = 31.62 fps SAME AS IN 2.1.3

CHECK VELOCITY FOR FULL DISC LIFT:

$$V_L = 30\sqrt{P} = 30\sqrt{0.01} = 3 \text{ fps} < 31.62 \text{ fps} \quad \underline{\underline{OK}}$$

$$\Delta P = \frac{1.17(31.62)^2}{2(32.2)} \frac{0.01}{144} = \underline{0.0013 \text{ psi}}$$

2.1.7 ΔP SUMMARY:

SUBSECTION No.	DESCRIPTION	ΔP (PSI)
2.1.1	34' OF ANNULAR PIPE WITH ENTRANCE LOSS	0.02
2.1.2	TEE FOR CHIMNEY BAYONET BOX	0.023
2.1.3	TEE FOR TURBOMOLECULAR PUMP	0.0003
2.1.4	SUDDEN EXPANSION WHERE LN_2 SHIELD ENDS	0.0036
2.1.5	LN_2 SHIELD SPACERS	0.047
2.1.6	PARALLEL PLATE RELIEF	0.0013
	$\Sigma =$	0.0952

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SUBJECT: VACUUM VESSEL PRESSURE DURING PRESSURE RELIEF

NAME: AMS

DATE: 9/25/90

REVISION DATE:

1. CALCULATE PRESSURE AT ENTRANCE TO CHIMNEY.

ASSUME INCOMPRESSIBLE FLOW.

INCLUDE COMPRESSIBILITY FOR ELEVATION CHANGE.

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2 + h_f$$

1 - INSIDE VACUUM VESSEL

2 - PARALLEL PLATE RELIEF VENT EXIT

h_f - PRESSURE LOSS = 0.0952 psi

$V_1 = 0$

$z_1 = 0$

$$\therefore \frac{p_1}{\gamma} = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2 + h_f$$

$$p_1 = \frac{V_2^2}{2g}\gamma + p_2 + \gamma z_2 + \gamma h_f$$

$$\frac{V_2^2}{2g}\gamma = 61.6^2 \frac{\cancel{ft}}{\cancel{sec^2}} \frac{\cancel{sec^2}}{2(32.2\,ft)} * 0.01 \frac{Lb}{\cancel{ft^3}} * \frac{\cancel{ft^2}}{144\,in^2} = 0.0041 \text{ psi}$$

$p_2 = 14.7$ psia

$$z_2 = 34' + \frac{30'' + 10''}{12} = 37.4 \text{ ft}$$

$$z_2\big|_{INCOMP} = 37.4\,\cancel{ft} * 0.01 \frac{Lb}{\cancel{ft^3}} * \frac{\cancel{ft^2}}{144\,in^2} = 0.0026 \text{ psi}$$

$$\Delta P = P_0 - P_0 \exp\left(-\frac{y - y_0}{P_0/(P_0 g/g_0)}\right)$$

$$= 14.7 - 14.7 \exp\left[\frac{-37.4\,\cancel{ft}}{14.7 \frac{\cancel{Lbf}}{\cancel{in^2}} * 144 \frac{\cancel{in^2}}{\cancel{ft^2}} * \frac{\cancel{ft^3}}{0.01\,\cancel{Lbm}} * \frac{\cancel{sec^2}}{32.2\,\cancel{ft}} \frac{32.174\,\cancel{Lbm}}{\cancel{Lbf\text{-}sec^2}}}\right]$$

$= 0.0026$ psi $\Rightarrow$ COMPRESSIBILITY IS NEGLIGIBLE WITH THIS DENSITY AND ELEVATION

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SUBSTITUTE INTO EQN:

$P_1 = 0.0041 + 14.7 + 0.0026 + 0.0952$

$P_1 = 14.8019$ psia $= 0.1019$ psig = PRESSURE IN THE VACUUM VESSEL AT ENTRANCE TO THE CHIMNEY.

2. CALCULATE ΔP FROM ONE END OF THE COIL'S VACUUM VESSEL TO THE OTHER END, ASSUMING THE RUPTURED LH_e COOLING TUBE AT ONE END AND THE CHIMNEY AT THE OTHER END.

THE VACUUM VESSEL HAS AN ANNULAR FLOW AREA.

IR = 2014 mm = 79.3", SUPPORT CYLINDER OUTER RADIUS

OR = 2133 mm = 84", OUTER LN_2 SHIELD INNER RADIUS

LENGTH = 9000 mm = 354.33" = 29.53', USE 30 FT

FLOW AREA $= \pi (OR^2 - IR^2) = \pi (84^2 - 79.3^2) = 2{,}411.2\ in^2$

$A_F = 16.74\ ft^2$

$$D_H = \frac{4 A_F}{P_W}$$

$P_W = 2\pi (84 + 79.3)'' = 1{,}026'' = 85.5$ ft

$$D_H = \frac{4 (16.74\ ft^2)}{85.5\ ft} = 0.783\ ft = 9.4''$$

FLOW = 953 Lbm/hr FLOWING TEMP = 80°F

DENSITY = 0.01 Lbm/ft³ VISCOSITY = 0.0486 Lbm/ft-hr

$$\text{VELOCITY} = 953 \frac{Lbm}{hr} * \frac{hr}{3600\ s} * \frac{ft^3}{0.01\ Lbm} * \frac{1}{16.74\ ft^2} = 1.6\ \text{fps}$$

$$Re_{D_H} = \frac{V D_H \rho}{\mu} = \frac{1.6 \frac{ft}{sec} * 0.783\ ft * 0.01 \frac{Lbm}{ft^3} * 3600 \frac{sec}{hr}}{0.0486\ Lbm/ft\text{-}hr}$$

$= 928 \Rightarrow$ LAMINAR FLOW, $f = 64/Re$

$f = 64/928 = 0.07$

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$$h_f = \frac{fL}{D}\frac{v^2}{2g}$$

$$= 0.07\,\frac{(30\,\cancel{ft})}{0.783\,\cancel{ft}} \times (1.6)^2\,\frac{ft^2}{\cancel{sec^2}} \times \frac{1}{2} \times \frac{\cancel{sec^2}}{32.2\,\cancel{ft}} = 0.107\,ft$$

$$\Delta P = 0.107\,\cancel{ft} \times 0.01\,\frac{Lb}{\cancel{ft^3}} \times \frac{\cancel{ft^2}}{144\,in^2} = \underline{7.4\times10^{-6}\,psi.}$$

∴ VACUUM VESSEL ΔP IS NEGLIGIBLE.

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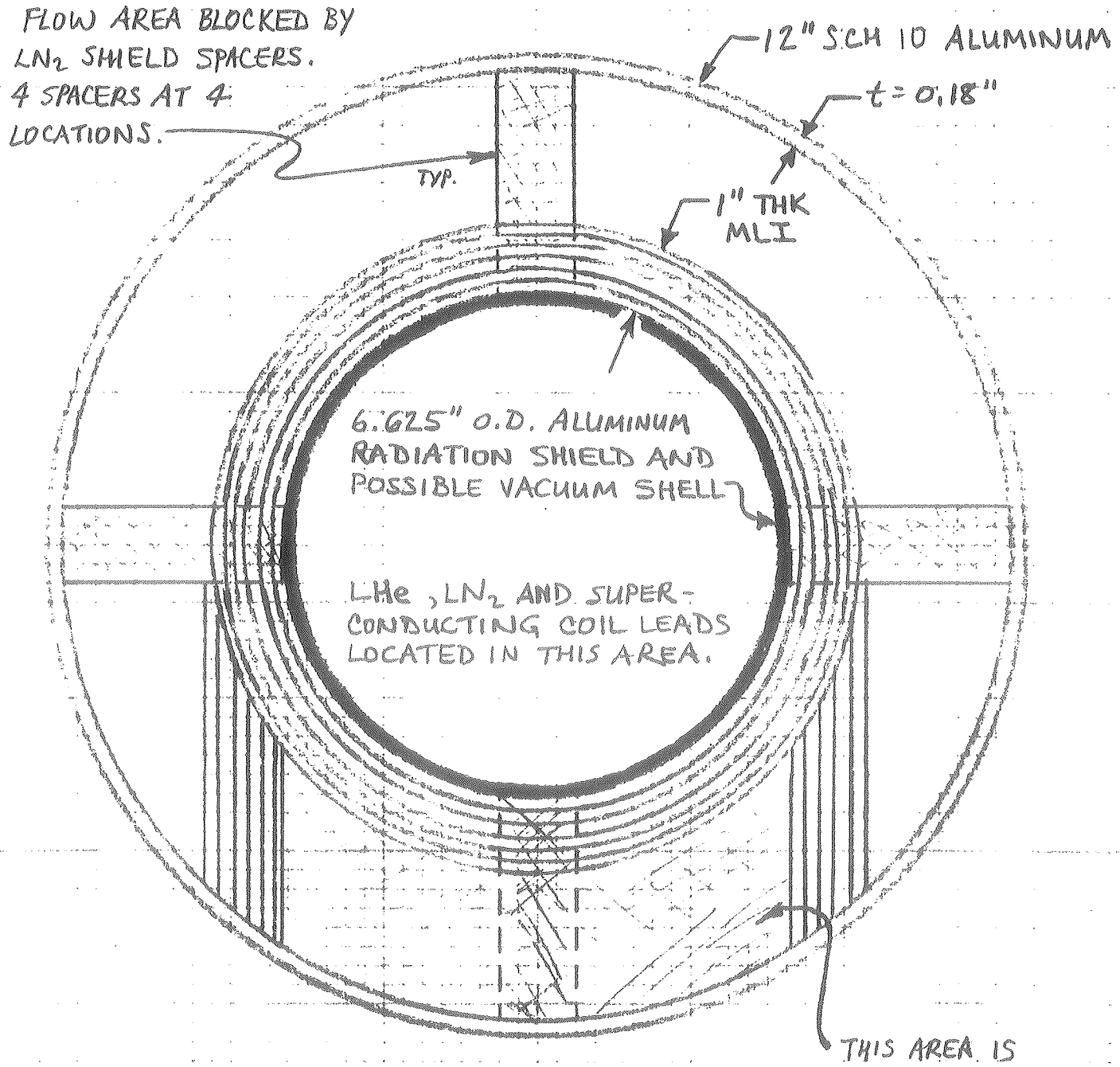
	DATE 9/18/90	REVISION DATE

CROSS SECTION



NOTE: THE MLI SHALL BE SECURED SO THE VENTING GAS WILL NOT RIP IT OFF THE LN_2 SHIELD. FOR EXAMPLE, WRAP THE MLI WITH A FABRIC, I.E. NYLON, COVER SHEET AND SECURE THE FABRIC WITH NYLON OR STEEL (CHICKEN WIRE TYPE) MESH, OR ENCLOSE THE MLI WITH A THIN ALUMINUM JACKET.

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PLAN

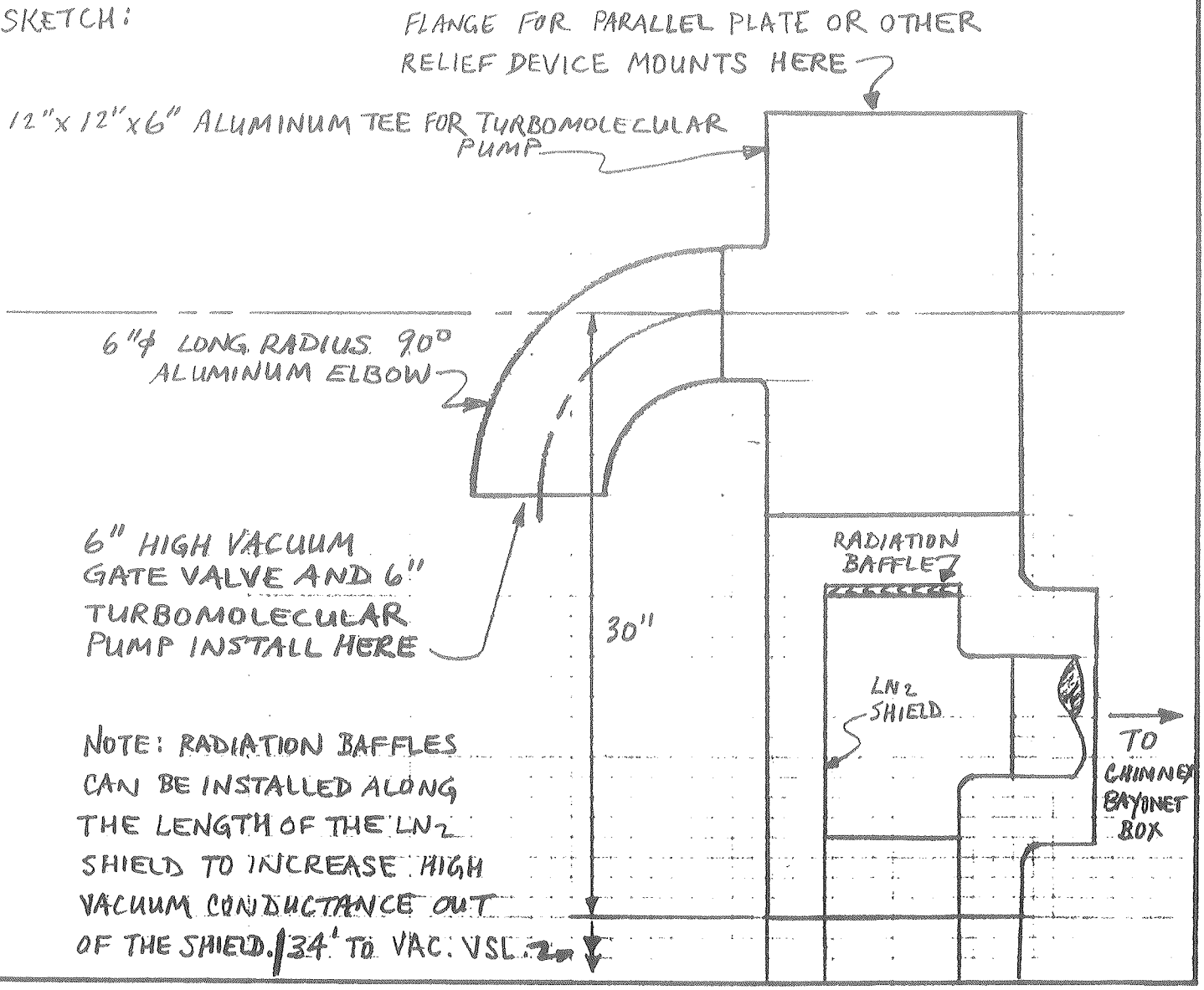
CHIMNEY LENGTH THROUGH THE DETECTOR $= 11{,}315 - \frac{2{,}200}{2} = 10{,}215$ mm

$= 33.5$ ft

ASSUME THE CHIMNEY EXTENDS 6" PAST THE DETECTOR BEFORE THE TEE IS ATTACHED.

∴ STRAIGHT PIPE LENGTH $= 33.5' + 0.5'$
$= 34'$

SKETCH:



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