DØ SOLENOID UPGRADE PROJECT

Vacuum pumping calculations for the DØ Solenoid

D-ZERO ENGINEERING NOTE # 3823.111- EN-348

August 2, 1993

Russ Rucinski
RD/DØ Mech.

INTRODUCTION

This engineering note documents the calculations done to determine the vacuum pumping speed for the D-Zero solenoid. The raw calculations are attached. A summary of the results are listed below.

RESULTS

The vacuum pumping speed of the solenoid is determined by the conductance of the pumping path. At higher pressure ranges during initial pumpdown, the conductances will be rather high. Calculations were not done for the transient pumpdown period, only the steady state type pumping situation. The pressure is assumed to be on the order of $10E-7$ torr. This is the free molecular flow regime based on Knudsen number. This pressure regime is also where the pumping speed would be least.

The conductances were calculated based on pumping helium gas at a temperature of 300 Kelvin. The total conductance of the pumping path from the solenoid to the inlet of the turbomolecular pump is 11.8 L/s. The effective pumping speed of a 1000 L/s turbo pump attached to this pumping path is 11.7 L/s.

The minimum required pumping speed for design purposes was set at 4.3 L/s. This value was arrived at by assuming a warm leak size ($10E-8$ atm-cc/sec) was not detected during fabrication of the solenoid. It is then assumed that the leak leaks cold liquid helium into the vacuum space. With this leak rate, a 4.3 L/s pumping speed would be able to maintain a $2 \times 10E-7$ torr pressure in the solenoid vacuum jacket. The solenoid would be able to be operated with this small leak with continuous pumping.

CONCLUSION

The effective pumping speed calculated for the solenoid and chimney is greater than that required to keep the solenoid operational even if a small liquid helium leak was leaking into the insulating vacuum space.

EXPLANATION OF ATTACHED CALCULATIONS

Several sets of calculations are attached. They are in chronological order with the most recent calculations first. Each set is described below.

*Calculations dated 8/2/93 thru 8/10/93, Pages 1 thru 5:

These calculations summarize the conductances of the pumping path as described in the August 11, 1993 version of the Design Report. These calculations heavily reference previous calculations. These calculations are the source for the effective pumping speed = 11.7 L/s.

*Calculations dated 5/17/93, Pages 1 thru 6:

These calculations were done before/during the time it was determined that the turbomolecular pump had to be moved. The calculations do contain the latest conductance value calculated for the obround section however. Pages 5 and 6 show the 'new' decision to move the turbo under the control dewar. These calculations also allude to the plan to expand the vacuum jacket from 8" pipe to 10" to get higher pumping speeds.

*Calculations dated 11/13/92, Pages 1 thru 3:

These calculations were done to determine the conductance through the obround chimney section. They determined that the obround should be increased from 3" x 6 3/4" to 3" x 7" to get a much improved conductance.

*Calculations dated 10/7/92 thru 10/13/92, Pages 1 thru 12:

These calculations were the first I did to try to determine whether to use a separate dedicated pumping line or to use the cryo utility transfer line vacuum space. At this date, it was not clear whether the chimney could run vertically from the solenoid or not. The calculations on page 11 conclude that the minimum design pumping speed is 4.3 L/s.

SUBJECT

VACUUM PUMPING CALCULATIONS

NAME

RUSS RUCINSKI

DATE

8-2-93

REVISION DATE

THESE CALCULATIONS BUILD UPON EARLIER CALCULATIONS.
{ REFERENCE 5/17/93 (6 PAGES), 11/13/92 (3 PAGES), 10/7/92 (12 PAGES) }
CALCULATIONS BY ME.

I USE THE OLD CALCULATIONS AS A SOURCE FOR
SOME NUMBERS, PROOF OF FLOW REGIME - FREE MOLECULAR
AND FORMAT OF CONDUCTANCE CALCULATIONS.

CONDUCTANCES OF PUMPING PATH

THE PUMPING PATH HAS BEEN BROKEN DOWN INTO 9 PARTS
AS ITEMIZED ON PAGE 2.

PREVIOUSLY IT HAS BEEN SHOWN (10/7/92, PAGE 3) THAT
FOR THE 2×10^{-5} TORR PRESSURE RANGE, THE
KNUDSEN * IS VERY HIGH MEANING WE ARE IN A
FREE MOLECULAR FLOW REGIME.

ALL CONDUCTANCES WILL BE CALCULATED FOR
PUMPING ON HELIUM GAS AT 300K. I NEGLECT
PUMPING INSIDE LN₂ SHIELDS.

PART ① ELBOW INTO OBROUND

THIS WILL BE MODELED
AS A 90° ELBOW.

THE HYDRAULIC DIAMETER OF THE TUBE PART IS:

$$D_H = D_o - D_i = (4.75 \text{ in.} - 3.50 \text{ in.}) = 1.25 \text{ in.}$$

FOR OBROUND; $D_H = 1.49 \text{ in.}$ { REF 5/17/93, PAGE 2 }

USE 90° ELBOW, I.D. = 1.375 in.
 $r \approx 2.5 \text{ in.}$

$$C = 141 \text{ L/S FROM TK SOLVER}$$

{ REF. TABLE 8.1 FROM
BAMFON, CRYOGENIC
SYSTEM 1985 }

$$C = \left(\frac{29.6 R_u T}{9 \pi M} \right)^{1/2} \frac{D^3}{L}$$

R. RUCINSKI
8/2/93

CHIMNEY CONDUCTANCE ITEMS

FERMILAB
ENGINEERING NOTE

SECTION
RD/DØ

PROJECT
DØ SOLENOID
UPGRADE

SERIAL-CATEGORY
3823-111

PAGE
4

SUBJECT

VACUUM PUMPING CALCULATIONS

NAME

RUSS RUCINSKI

DATE

8-2-93

REVISION DATE

PART ② OBOUND

$$C_{\text{OBOUND}} = 22.9 \text{ L/S} \quad \left\{ \text{REF. 5/17/93 PAGE 2 CALCS.} \right\}$$

PART ③ ELBOW

THE GEOMETRY OF THIS ELBOW IS NOT CLEARLY DEFINED.
MODEL AS A 90° ELBOW.

$$D_{\text{OBOUND}} = 1.49 \quad D_{\text{H}_{8 \times 6}} = D_2 - D_1 = 8.329 - 6.625 = 1.704 \text{ in.}$$

$$\text{USE I.D.} \approx 1.60 \text{ in.} \quad \& \quad r = 4.25 \text{ in.}$$

$$C = 131 \text{ L/S} \quad \text{FROM TK SOLVER}$$

PART ④ 8" PIPE WITH 6" PIPE LN₂ SHIELD

$$C = 113 \text{ L/S} \quad \left\{ \text{REF. 5/17/93 PAGE 2 CALCS.} \right\}$$

PART ⑤ ELBOW

$$\text{USE I.D.} = 1.704 \text{ in.} \quad r = 8 \text{ in}$$

{SHORT RADIUS ELBOW, PIPE FITTER
MANUAL, TUBE TURNS, INC.}

$$C = 84 \text{ L/S} \quad \text{FROM TK SOLVER}$$

PART ⑥ SHORT PIECE OF 8 x 6" PIPE SHIELD

$$L \approx 0.5 \text{ m}$$

$$b/a = .795 \quad K = 1.35$$

$$C = 568 \text{ L/S} \quad \text{FROM TK SOLVER}$$

PART ⑦ 10" PIPE VAC. JACKET, 6" PIPE SHIELD

$$L \approx 3.5 \text{ m}$$

$$a = 10.585 \text{ in.}$$

$$b = 6.625 \text{ in.}$$

$$b/a = .61$$

$$K = 1.207$$

{REF. BARRON
TABLE 8.1
INTERPOLATED}

$$C = 561 \text{ L/S} \quad \text{FROM TK SOLVER}$$

PART ⑧ TEE TO PUMP

LINE TO PUMP WILL BE 6" PIPE, SCH. 10S.

$$L_{\text{EFF}} = L_{\text{AXIAL}} + 1.33 D$$

REF: VACUUM EQUIPMENT &
TECHNIQUES. 1949
GUTHRIE & WAKERLING.
PG. 41. 7

$$L_{\text{EFF}} = 0.5 \text{ m} + 1.33 \left(\overset{\text{KIND OF ARBITRARY}}{6.357''} \overset{\text{I.D. OF 6" PIPE SCH. 10}}{(.0254 \text{ m/in.})} \right)$$

$$= 0.715 \text{ m}$$

$$C = \frac{3.5}{.715} (561 \text{ L/S}) = 2750 \text{ L/S}$$

FERMILAB
ENGINEERING NOTE

SECTION

RD/00

PROJECT

DD SOLENOID
UPGRADE

SERIAL-CATEGORY

3823.111

PAGE

5

SUBJECT

VACUUM PUMPING CALCS.

NAME

RUSS RUCINSKI

DATE

8-10-93

REVISION DATE

PART 9 6" PIPE TO PUMP

$$L \approx 54 \text{ m} \quad L/D = 54/6.357 = 8.5 < 30 \therefore \text{SHORT TUBE.}$$

THERE WILL BE A VACUUM VALVE IN BETWEEN.

$$C_{\text{VACUUM VALVE}} = 9,154 \text{ L/S}$$

REF. AMS CALCULATIONS, PG. 9 OF
SDC DETECTOR SOLENOID DESIGN
NOTE #117. KEPT IN WHIIX
RD/MECH. SUPPORT GROUP.

FOR FIRST HALF $L \approx 27 \text{ m} = .686 \text{ m}$

$$C = 1541 \text{ L/S}$$

FROM TK SOLVER USING BARRON EQ. 8.1

$$C_{\text{PART 9}} = \left\{ \frac{1}{1541} + \frac{1}{9154} + \frac{1}{1541} \right\}^{-1} = \underline{712 \text{ L/S.}}$$

TOTAL CONDUCTANCE, SOLENOID TO PUMP:

$$C_{\text{TOTAL}} = \left\{ \frac{1}{141} + \frac{1}{229} + \frac{1}{131} + \frac{1}{113} + \frac{1}{84} + \frac{1}{568} + \frac{1}{561} + \frac{1}{2750} + \frac{1}{712} \right\}^{-1}$$

$$= \underline{11.8 \text{ L/S}}$$

IF WE USE 1000 L/S TURBO

$$S_{\text{EFF}} = \left\{ \frac{1}{11.8} + \frac{1}{1000} \right\}^{-1} = \underline{11.7 \text{ L/S}}$$

SUBJECT

VACUUM PUMPING FOR SOLENOID
FINAL? ITERATION

NAME

RUSS RUCINSKI

DATE

5/17/93

REVISION DATE

CALCULATE CONDUCTANCES AND PUMPING SPEED FOR
SOLENOID AND CONTROL DEWAR.

{ REFERENCE 10/7/92 & 11-13-92 CALCS
BY RUSS RUCINSKI, VACUUM CALCS. }

PUMPING PATH

CONDUCTANCE

He, 300 K
(FREE MOLECULAR
REGIME)

①	OBROUND CHIMNEY	22.9 L/s
②	N-S CHIMNEY RUN	113.0
③	LOWER INCLINE	482.5
④	VERTICAL TUBE	231.5
⑤	UPPER INCLINE.	52.4

SECTION ①

MODEL AS 2 RECTANGLES + 2 TUBES.

i) RECTANGLES MEASURED ALONG SIDES OF LN₂ SHIELD TO
BE: 0.40625" x 4.50" x L ≈ 9 ft ≈ 2.75 m

USE TK SOLVER $A/8 = .0903 \Rightarrow K = 1.46$ TABLE B.1 OF BARRON, CASE 5

$$C = 4.93 \text{ L/s, } T = 300 \text{ K, He}$$

T	He	N ₂
300	4.93	1.86
90	2.55	1.963

ii) SPACE AT END

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

{ REF. CBI TECHNICAL
BULLETIN 594 }

9

SUBJECT

VACUUM PUMPING

NAME

RUSS RUCINSKI

DATE

5/17/93

REVISION DATE

$$H = 1.3125 - \frac{9}{32} = 1.03125''$$

$$D = 2.625''$$

$$H/D = .393 \Rightarrow \alpha = .364811$$

$$A = \pi \frac{(2.625 \text{ in})^2}{4} \cdot (.364811) = 1.974 \text{ in}^2$$

$$\theta = \sin^{-1} \left(\frac{9/32''}{1.3125 \text{ in}} \right) = 12.3736^\circ$$

$$\phi = 180 - 2\theta = 155.25^\circ = 2.709 \text{ RADIANS}$$

$$S = r\phi = (1.3125 \text{ in})(2.709 \text{ RADIANS}) = 3.556 \text{ in.}$$

$$C = 2 \times 1.3125 \cos \theta - 2(.40625 \text{ in.}) = 1.7515 \text{ in.}$$

$$P = \text{PERIMETER} = S + C = 3.556 + 1.752 \text{ in.} = 5.31 \text{ in.}$$

$$D_H = 4 \times r_H = 4 \times \frac{A}{P} = \frac{4 \times 1.974 \text{ in}^2}{5.31 \text{ in.}} = 1.49 \text{ in.}$$

USE TK SOLVER, LONG TUBE $L/D > 30$, FREE MOLEC.

$$C_{\text{END}} = 6.50 \text{ L/s FOR ONE END}$$

T	He	N ₂
300 K	6.50	2.46 L/s
80 K	3.36	1.27

$$C_{\text{TOTAL OBSERVED}} = 2 \cdot C_{\text{RECT.}} + 2 C_{\text{END}} = 2(4.93 \text{ L/s}) + 2(6.50 \text{ L/s})$$

$$= 22.9 \text{ L/s}$$

T	He	N ₂
300	22.9	8.64
80 K	11.8	4.47

② N-S CHIMNEY RUN

MODEL AS ANNULUS, $D_1 = 8.329 \text{ in.}$, $D_2 = 6.625 \text{ in.}$

$$L = 9.2 \text{ ft} \approx 2.75 \text{ m}$$

$$D_2/D_1 = .795 \Rightarrow K = 1.35$$

T	He	N ₂
300 K	113.0	42.7
80 K	58.4	22.1

SUBJECT

VACUUM PUMPING FOR SOLENOID

NAME

ROSS REICHSER

DATE

5/17/93

REVISION DATE

ATV

- ③ LOWER INCLINE
ANNULUS

$$L = 1.9 \text{ ft} \approx 0.6 \text{ m}$$

T	He	N ₂
300 K	482.5	182.4
80 K	249.2	194.2

- ④ VERTICAL TUBE.

FREE TO CHOOSE PIPE SIZE

TRY 6" PIPE, SCH. 10S $\rightarrow$ I.D. = 6.357"

$$L = 15 \text{ ft. to } 20 \text{ ft} \approx 6 \text{ m}$$

$$L/D = \frac{20 \text{ ft} \times 12 \text{ in/ft}}{6.357} = 37.8 > 30 \therefore \text{LONG TUBE}$$

T	He	N ₂
300 K	231.5	87.5 L/s
80 K	119.5	45.2

- ⑤ UPPER INCLINE $L \approx 20 \text{ ft}, 6 \text{ m}$

T	He	N ₂
300	52.4	19.8
80	27.1	10.2

MISCELLANEOUS:

{ PER AMS
10/2/90
SDC CALCS.
SDC DESIGN
NOTE #117 }

6" SCH. 10S LONG RADIUS ELBOW, 90°

$$C = 2374 \text{ L/s}$$

300 K, He GAS

4" SCH. 10S LONG RADIUS 90° $C = 1,100 \text{ L/s}$

ENGINEERING NOTE

SECTION

RD-107

PROJECT

D6 SOLENOID
UPGRADE

SERIAL CATEGORY

3823.111

PAGE

2

SUBJECT

VACUUM PUMPING FOR SOLENOID

NAME

RUSS RUCINSKI

DATE

5/17/93

REVISION DATE

TOTAL CONDUCTANCES,

A) PUMP TO SOLENOID

$$C_{TOTAL} = \left[\frac{1}{22.9} + \frac{1}{113.0} + \frac{1}{482.5} + \frac{1}{231.5} + \frac{4}{1000} \right]^{-1}$$

ESTIMATED ELBOWS

$$= 15.9 \text{ L/s}$$

300 K, He

B) PUMP TO CONTROL DEWAR

$$C_{TOTAL} = \left[\frac{1}{52.4} + \frac{1}{231.5} + \frac{2}{1000} \right]^{-1} = 39.4 \text{ L/s}$$

SELECTION OF PUMP SPEED

$$S_{EFF} = \left[\frac{1}{C_{TOTAL}} + \frac{1}{S_{NOM}} \right]^{-1}$$

TURBO PUMP SPEED	S_{EFF} SOLENOID	S_{EFF} CONTROL DEWAR
135 L/s	14.2	30.5
380 L/s	15.3	35.7 ←
440	15.3(5)	36.2
620	15.5	37.0
1000	15.6(5)	37.9

IF WE PUMP ON SOLENOID THRU CHIMNEY UP TO CONTROL DEWAR LOCATION $C_{TOTAL} = 12.9 \text{ L/s}$

CAN'T PUT TURBO IN MUON TRUSS DUE TO STRAY MAGNETIC FIELD. RUGI SAYS B ≈ 200 GAUSS.

WILL MOVE TURBO ONTO LOWER PLATFORM.

FERMILAB ENGINEERING NOTE		SECTION RD/106	PROJECT Solenoid Upgrade	SERIAL-CATEGORY 3323-111	PAGE 5
SUBJECT VACUUM PUMPING FOR SOLENOID			NAME Russ Robinson		
DATE 5/17/93			REVISION DATE		

NEW ARRANGEMENT

CONDUCTANCE OF (3)';

WHAT IF LN₂ SHIELD IS REDUCED TO 5" O.D.?

$$b/a = \frac{4.875 \text{ in}}{8.329 \text{ in}} = .5853 \quad K \approx 1.20$$

$$L \approx 12 \text{ ft} = 3.7 \text{ m}$$

$$C = 267.7 \text{ L/s} \quad 300\text{K, He gas.}$$

SECTION (2)'; L = 2.75, 5" O.D. SHIELD

$$C = 356.4 \text{ L/s}$$

SECTION (4)'; 6" PIPE, L = 1 m

SHORT TUBE CONDUCTANCE

$$C = 1142.8 \text{ L/s}$$

TOTAL CONDUCTANCES;

A) PUMP TO SOLENOID

$$C_{\text{TOTAL}} = \left[\frac{1}{22.9} + \frac{1}{356.4} + \frac{1}{267.7} + \frac{1}{1142.8} + \frac{4}{1000} \right]^{-1} = 18.1(5) \text{ L/s}$$

B) PUMP TO CONTROL DEWAR (5' = 2')

$$C_{\text{TOTAL}} = \left[\frac{1}{356.4} + \frac{1}{1142.8} + \frac{3}{1000} \right]^{-1} = 149.7 \text{ L/s}$$

FERMILAB ENGINEERING NOTE		SECTION RD/DO	PROJECT DO SOLENOID UPGRADE	SERIAL-CATEGORY	PAGE 6
SUBJECT VACUUM PUMPING FOR SOLENOID.			NAME RUSS RUCINSKI		REVISION DATE
			DATE 5/17/93		

PRELIMINARY SELECTION OF PUMP.

TURBO PUMP SPEED	SEFF SOLENOID	SEFF CONTROL DEWITT
380 L/S	17.3	107.4
440	17.4	111.7
620	17.6	120.6
1000 L/S	17.8	130.2

GO WITH 1000 L/S TURBO PUMP,
LEYBOLD MODEL TMP1000 WOULD BE SUITABLE.

DECIDED AGAINST REDUCING SHIELD SIZE TO 5" O.D.
MIGHT BE TOO CRAMPED.

WILL PLAN ON EXPANDING VACUUM JACKET
TO 10" PIPE FOR INCLINE PORTION OF CHIMNEY.
WILL NEED TO REDO CALCS.

SUBJECT:

DØ: SOLENOID CHIMNEY

VACUUM

NAME: RUSS RUCINSKI

DATE: NOV-13, 1992

REVISION DATE

CONDUCTANCE CALCULATIONS / PUMPING SPEED.

- ESTIMATE CONDUCTANCE OF 3" x 6 3/4" OBOUND SECTION

TRY TO MODEL AS A
CIRCULAR ANNULUS.

$$\text{FLOW AREA} = \frac{\pi (2.625 \text{ in.})^2}{4} + (3.75 \text{ in.})(2.625 \text{ in.}) - (2 \text{ in.})(4.5 \text{ in.}) = 6.2556 \text{ in.}^2$$

$$\text{WETTED PERIMETER} = \pi (2.625 \text{ in.}) + 2(3.75 \text{ in.}) + 2(4.5 \text{ in.} + 2 \text{ in.}) = 28.747 \text{ in.}$$

$$r_H = \frac{A}{P} = \frac{6.2556 \text{ in.}^2}{28.747 \text{ in.}} = 0.2176 \text{ in.}$$

$$D_H = 4r_H = .87 \text{ in.}$$

$$\text{FOR AN ANNULUS: } r_H = \frac{\frac{1}{4} [\pi D_1^2 - \pi D_2^2]}{\pi D_1 + \pi D_2}$$

D₁ - LARGER DIA.
D₂ - SMALLER DIA.

$$r_H = \frac{1}{4} (D_1 - D_2) \quad \text{OR} \quad D_{H \text{ ANNULUS}} = D_1 - D_2$$

THE CONDUCTANCE EQN FOR ANNULUS IS:

BAKON.

$$C = \left[\frac{\pi g_c R_u T}{18 M} \right]^{1/2} \frac{(D_1 - D_2)^2 (D_1 + D_2) K}{L + 4/3 (D_1 - D_2)}$$

TRY TO GET AN EQUIVALENT D₁ & D₂

$$\pi D_1 = \pi (2.625) + 2(3.75) \Rightarrow D_1 = 5.0123 \text{ in.}$$

$$\pi D_2 = 13 \text{ in.} \Rightarrow D_2 = 4.138 \text{ in.}$$

$$D_1 - D_2 = 5.0123 \text{ in.} - 4.138 \text{ in.} = .8743 \text{ in.}$$

A GOOD MATCH!

$$L \approx 7 \text{ ft.} = 2.134 \text{ m}$$

$$D_2/D_1 = .825569 \Rightarrow K = 1.385$$

USING TK SOLVER,

$$C = 24.2 \text{ L/S}$$

T = 300K, M = 4

FREE MOLECULAR REGIME

SUBJECT

DØ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

11-13-92

REVISION DATE

TRY TO MODEL AS PARALLEL PATHS OF 4 RECTANGLES

RECTANGLE #1:
(x 2)

$$a = .3125 \text{ in.}$$

$$b = 4.5 \text{ in.}$$

$$a/b = .0694 \Rightarrow K = 1.5122$$

RECTANGLE #2:
(x 2)

$$a = .9375 \text{ in.}$$

$$b = 2.0 \text{ in.}$$

$$a/b = .4688 \Rightarrow K = 1.1598$$

$L = 2.134 \text{ m}$, $T = 300 \text{ K}$, $M = 4$ MOLECULAR FLOW REGIME

$$C = \left(\frac{32gc R_u T}{9\pi M} \right)^{1/2} \frac{a^2 b^2 K}{(a+b)L + 8/3 ab}$$

USE TK SOLVER ALREADY
SET UP.

$$C_{\text{RECT. \#1}} = 3.97 \text{ L/s}$$

$$C_{\text{RECT. \#2}} = 8.78 \text{ L/s}$$

$$C_{\text{TOTAL}} = 2C_{\text{RECT. \#1}} + 2C_{\text{RECT. \#2}} = 25.68 \text{ L/s} = \underline{25.7 \text{ L/s}}^*$$

THE ANNULUS MODEL & THIS RECTANGULAR MODEL AGREE WITHIN 6%.

CHECK CONDUCTANCE OF ANNULUS IN RESPECT OF TRANSFER LINE.

ASSUME 8" SCH. 10 VACUUM JACKET & 6.25 IN. O.D. RADIATION
SHIELD. ASSUME LENGTH TO BE 18 FT. = 5.48 m

$$D_1 = 8.329 \text{ in.}$$

$$D_2 = 6.25 \text{ in.}$$

$$D_2/D_1 = \frac{6.25}{8.329} = 0.750 \Rightarrow K = 1.3016$$

$$C = 79.8 \text{ L/s}^* \text{ FREE MOLECULAR, } T = 300 \text{ K, } M = 4$$

* THIS NEGLECTS PUMPING INSIDE OF
RADIATION SHIELD.

FERMILAB

ENGINEERING NOTE

SECTION

R0/D0

PROJECT

SOLENOID
UPGRADE

SERIAL CATEGORY

3323.111

PAGE

33

SUBJECT

D0 SOLENOID CHIMNEY

NAME

RUSS RUCINSKI

DATE

11-13-92

REVISION DATE

VACUUM

HOW MUCH IMPROVEMENT IN THE CONDUCTANCE FOR THE
OROUND PART IF WE INCREASE 6.375 IN TO 6.875 IN?

→ MODEL AS RECTANGLES AS ON PAGE 2.

RECT. #1 SAME: $C_{RECT. \#1} = 3.97 \text{ L/s}$

RECT. #2 $a = .9375 + .25 \text{ in.} = 1.1875 \text{ in.}$

$b = 2.125 \text{ in.}$

$a/b = .5588 \Rightarrow K = 1.142$

$C_{RECT. \#2} = 13.83 \text{ L/s}$

$C_{TOTAL} = 2(3.97) + 2(13.83) = 35.6 \text{ L/s}$ ← QUITE AN IMPROVEMENT.

WHAT IF WE MOVE THE LN₂ RAD SHIELD BY 1/2" TO SIDE ALSO?

RECT. #1 SAME: $C_{RECT. \#1} = 3.97 \text{ L/s}$ (x 2)

RECT. #2 $.9375 \times 2 \Rightarrow C_{RECT. \#2} = 8.78$

RECT. #3 $a = .9375 + .5 \text{ in.} = 1.4375 \text{ in.}$

$b = 2.25 \text{ in.}$

$a/b = \frac{1.4375}{2.25} = .6389$

$K = 1.1468$

$C_{RECT. \#3} = 15.0 \text{ L/s}$

$C_{TOTAL} = 2(3.97) + 8.78 + 15 = 31.7 \text{ L/s}$ ← IT IS BETTER TO KEEP
LN₂ SHIELD CENTRATED
IN VACUUM JACKET.

SUBJECT

DØ SOLENOID CHIMNEY.

VACUUM

NAME

RUSS RUCINSKI

DATE

10/7/92

REVISION DATE

⇒ DETERMINE WHAT SIZE PUMPING LINE IS REQUIRED.

- LOOK @
- RECTANGULAR DUCT
 - ANNULAR
 - CIRCULAR

CDF
EXPERIENCE

COIL OPERATING VACUUM MUST BE 10^{-7} TORR OR LESS.

10^{-6} TORR CAUSES SIGNIFICANT HEAT LOADS & PROBLEMS

4×10^{-6} TORR CAUSES QUENCH (GAUGE READING) 2.2×10^{-5} TORR (HE ENVIRONMENT)

2×10^{-5} TORR DURING QUENCH (ASSUME GAUGE READING)

REFERENCE: SSC SDC DESIGN NOTE #117 ENTITLED "HIGH VACUUM PUMPING OF A HELIUM OR NITROGEN LEAK IN THE SDC SOLENOID VACUUM VESSEL" BY A.M. STEFANIK, 10-15-90

METHOD:

- FIND FLOW REGIME FOR DIFFERENT SIZES & SHAPES
- CALCULATE CONDUCTANCES FOR DIFFERENT SIZES & SHAPES
- CHOOSE SHAPE & CONFIGURATION OF PUMPING SYSTEM FROM CHIMNEY TO PUMP. CALCULATE CONDUCTANCE
- CALCULATE THROUGHPUT FOR A GIVEN SIZE PUMP AND THE DIFFERENT SIZE & SHAPES.
- REACH CONCLUSION ON FIRST ITERATION.

SIZES & SHAPES

A) RECTANGULAR

i) $2.5" \times 9.5" = 6.35 \text{ cm} \times 24.13 \text{ cm}$

ii) $2.5" \times 5" = 6.35 \times 12.7 \text{ cm}$

B) ANNULAR

i) $a = 2.75"$, $b = 2"$

$a = 2.75"$ $b = 2.5"$

C) CIRCULAR

i) $2.75" \text{ I.D.}$

ii) $1" \text{ I.D.}$

SUBJECT

DØ SOLENOID CHIMNEY.

VACUUM

NAME

RUSS RUCINSKI

DATE

10/7/97

REVISION DATE

• FLOW REGIME; CHARACTERIZE BY KNUDSEN $Kn = \lambda / D$

LOW (ROUGH VACUUM) & VISCOUS FLOW $Kn < 10^{-2}$

MEDIUM VACUUM & INTERMEDIATE FLOW $10^{-2} < Kn < 0.5$

HIGH/ULTRA HIGH VACUUM & MOLECULAR FLOW $Kn > 0.5$

$$Kn = \lambda / D$$

λ - MEAN FREE PATH

$$\lambda = \frac{1}{\sqrt{2} n d_0^2}$$

REF. A USER'S GUIDE
TO VACUUM TECHNOLOGY
BY JOHN O'HANLON

d_0 IS THE MOLECULAR DIAMETER (m)

n IS GAS DENSITY (MOLECULES/m³)

FOR He; $d_0 = .218 \text{ nm} = .218 \times 10^{-9} \text{ m}$

FOR N₂; $d_0 = .375 \text{ nm} = .375 \times 10^{-9} \text{ m}$

IDEAL GAS LAW: $P = nKT$

P - PRESSURE IN (Pa)

n - MOLECULES/m³

K - BOLTZ. CONST. J/K

T - TEMP. (K)

$$K = 1.3804 \times 10^{-23} \text{ J/K}$$

$$n = \frac{P}{KT}$$

$$\text{FOR } P = 2.2 \times 10^{-5} \text{ Torr} = 2.2 \times 10^{-5} \text{ Torr} \times 133.32 \frac{\text{Pa}}{\text{Torr}} = 2.93 \times 10^{-3} \text{ Pa}$$

$$T = 80 \text{ K}$$

$$n = \frac{2.93 \times 10^{-3} \text{ Pa}}{(1.3804 \times 10^{-23} \text{ J/K})(80 \text{ K})} = 2.653 \times 10^{18} \text{ m}^{-3}$$

$$\lambda_{N_2} = \frac{1}{\sqrt{2} (.375 \times 10^{-9})^2 (2.653 \times 10^{18})} = 1.895 = 1.9 \text{ m}$$

$$\lambda_{He} = \frac{1}{\sqrt{2} (.218 \times 10^{-9})^2 (2.653 \times 10^{18})} = 5.6 \text{ m}$$

IN CALCULATING Kn USE THE HYDRAULIC DIAMETER = $4 \times \frac{\text{AREA}}{\text{PERIMETER}}$

A) RECTANGULAR i) 2.5" x 4.5" $Kn = 56.3$ FOR He
19. FOR N₂

SEE TABLE 1 FOR THESE & OTHER
SHAPE/SIZE RESULTS.

SUBJECT

DØ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

10/7/92

REVISION DATE

TABLE 1 - KNUDSEN #'S & OTHER INFORMATION

SIZE	AREA	PERIMETER	D_h	K_n (He/N ₂) (80K)
RECTANGLE A _i 2.5" x 9.5"	.0145 m ²	.5842 m	.0994 m ^{3.911"}	56.3 m / 19.3 m
RECTANGLE A _{ii} 2.5" x 5"	.0081 m ²	.381 m	.0847 m ^{3.33"}	66.1 m / 22.4 m
ANNULAR B _i 2.75" x 2"	.0018 m ²	.379 m	.01905 m ^{.75"}	294 m / 100 m
ANNULAR B _{ii} 2.75" x 2.5"	.000665 m ²	.4189 m	.00635 m ^{.25"}	882 m / 299 m
CIRCULAR C _i 2.75" Ø	.00383 m ²	.2194 m	.06985 m ^{2.75"}	80.2 / 27.2 m
CIRCULAR C _{ii} 1" Ø	.000507 m ²	.080 m	.0254 m ^{1"}	220 m / 74.8 m

⇒ IN ALL CASES $K_n > 0.5$ ∴ WE ARE IN THE HIGH/ULTRA HIGH VACUUM & MOLECULAR FLOW REGIME.

{NOTE AT T=300K, $\pi \uparrow$, $z \downarrow$, $K_n \uparrow$ ∴ @ 300K K_n IS EVEN HIGHER}

• CONDUCTANCES

RECTANGULAR TUBE:

$$C = \left(\frac{32 g_c R_u T}{9 \pi \mu} \right)^{1/2} \frac{a^2 b^2 K}{(a+b)L + 8/3 ab}$$

$a/b \leq 1$ FOR A_i; $a/b = 2.5/9.5 = .263$ $K \approx 1.25$

A_{ii}; $a/b = 0.50$ $K = 1.151$

(REF. BARRON TABLE B.1 2nd EDITION pg. 434-435)

$g_c = 1$

$R_u = 8.314 \times 10^{-2} \text{ m}^3 \cdot \text{bar} / \text{kmol} \cdot \text{K}$

$T = 300 \text{ K}$

$L = 1.84 \text{ m}$

$$C_{A_i}^{300K} = \left(\frac{32(1)(8.314 \times 10^{-2} \text{ m}^3 \cdot \text{bar} / \text{kmol} \cdot \text{K})(300 \text{ K})}{9 \pi (4 \text{ kg} / \text{kmol})} \right)^{1/2} \frac{(4.03 \times 10^{-3} \text{ m}^2)(5.823 \times 10^{-2})}{(3.048 \times 10^{-1} \text{ m})(1.84 \text{ m}) + 8/3(1.5)(2 \times 10^{-1})}$$

$$C_{A_i}^{300K} = (7.0571 \frac{\text{m}^3 \cdot \text{bar}}{\text{kg}})^{1/2} (4.88 \times 10^{-4} \text{ m}^2)$$

20

SUBJECT

DØ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

10/7/92

REVISION DATE

$$C_{A, 300K} = \left(7.0571 \frac{\text{m}^3 \cdot \text{bar}}{\text{kg}} \times \frac{10^5 \text{ N/m}^2}{1 \text{ bar}} \times \frac{1 \frac{\text{kg}}{\text{m}^3}}{1 \text{ N}} \right)^{1/2} (4.88 \times 10^{-4} \text{ m}^2)$$

$$= 0.4095 \text{ m}^3/\text{s} \times \frac{1000 \text{ L}}{1 \text{ m}^3} = 409.5 \text{ L/s} = 410 \text{ L/s}$$

I SET THIS UP IN TK SOLVER (MAC. APPLICATION) TO DO THE CALCULATIONS FOR THIS AND OTHER RECTANGULAR SIZE/CONDITIONS. SEE TABLE 2 FOR RESULTS.

ANNULAR TUBE: (REF. SAME; BARRON TABLE 8.1)

$$C = \left(\frac{\pi g_c R_u T}{18 M} \right)^{1/2} \frac{(D_1 - D_2)^2 (D_1 - D_2) K}{L + (4/3)(D_1 - D_2)}$$

WHERE K IS READ OFF OF TABLE

D₁ IS BIG DIA.

D₂ IS SMALL DIA.

FROM COMPARISON TO AN "OLD" VERSION OF THIS EQ'N IN BARRON 1ST EDITION, I CONCLUDE THAT THERE IS A MISPRINT IN THE FORMULA. THE "CORRECT" FORMULA SHOULD BE:

$$C = \left(\frac{\pi g_c R_u T}{18 M} \right)^{1/2} \frac{(D_1 - D_2)^2 (D_1 + D_2) K}{L + (4/3)(D_1 - D_2)}$$

OLD FORMULA EQ. 1 WAS;

$$C = \left(\frac{\pi g_c R_u T}{18 M} \right)^{1/2} \frac{(D_1 - D_2)^2 (D_1 + D_2)}{L} K$$

DO 2.75" Ø & 2" Ø

$$C = \left(\frac{\pi (1) (8314 \frac{\text{J}}{\text{kmol} \cdot \text{K}}) (300 \text{ K})}{18 (4 \frac{\text{kg}}{\text{mol}})} \right)^{1/2} \frac{(.01905 \text{ m})^2 (.12065 \text{ m}) (1.276)}{(1.84 \text{ m} + 4/3 (.01905 \text{ m}))} = .00988 \text{ m}^3/\text{s}$$

$$D_2/D_1 = \frac{2}{2.75} = .727 \Rightarrow K = 1.276$$

$$C = 9.9 \text{ L/s}$$

I SET THIS UP IN TK SOLVER, SEE TABLE 2 FOR RESULTS OF OTHER SIZES, TEMP, GAS.

FOR 2.75" Ø & 2.5" Ø, $D_2/D_1 = .909 \rightarrow K = 1.536$

CIRCULAR TUBE:

$$C = \left(\frac{\pi g_c R_u T}{18 M} \right)^{1/2} \frac{D^3}{L}$$

BARRON 2ND - TABLE 8.1

CDF

$$D_2/D_1 = .798 \quad K = 1.3547 \quad L \approx 3.48 \text{ m}$$

SDC

REFERENCE A. STEFANK CALC, SDC DESIGN NOTE 117

BIGGEST CONTRIBUTION IN C, ANNULAR FLOW PATH, 34' LG, 12.4" Ø & 8.7" Ø.

FERMILAB
ENGINEERING NOTE

SECTION

RD/DØ

PROJECT

DØ
SOLENOID
UPGRADE

SERIAL-CATEGORY

PAGE

5

SUBJECT

DØ SOLENOID CHIMNEY
VACUUM

NAME

RUSS RUCINSKI

DATE

10/8/92

REVISION DATE

TABLE 2 - CONDUCTANCE OF DIFFERENT SHAPES & SIZES.
($L = 1.84\text{ m}$, FREE MOLECULAR FLOW, TEMP. & GAS NOTED)

SIZE	$C_{300K}(\text{He})$	$C_{300K}(\text{N}_2)$	$C_{80K}(\text{He})$	$C_{80K}(\text{N}_2)$
RECTANGLE A i 2.5" x 9.5"	410 L/s	155 L/s	212 L/s	80 L/s
RECTANGLE A ii 2.5" x 5"	169	64	87	33
ANNULAR B i 2.75" x 2"	9.9	3.7	5.1	1.9
ANNULAR B ii 2.75" x 2.5"	1.5	0.6	0.8	0.3
CIRCULAR 2.75" Ø	61	23	32	12
CIRCULAR 1" Ø	2.9	1.1	1.5	0.6
ANNULAR (CDF) 0.203 m Ø x 162 m Ø 3.48 m LONG	78	29	40	15
SDC COMPLETE LINE 6" Ø TO PUMP	141	53	73	27
SDC COMPLETE LINE 4" Ø TO PUMP	125	47	65	24

IF DØ IS TO ACHIEVE PUMPING SPEEDS COMPARABLE TO CDF OR THOSE AVAILABLE FOR SDC, IT LOOKS CLEAR FROM THE ABOVE TABLE THAT DØ WILL REQUIRE A SEPARATE PUMPING LINE OR EMPLOY SOME OTHER "TRICK" LIKE PLACING A PUMP CLOSER TO THE SOLENOID.

SUBJECT

DØ SOLENOID CHAMBER.

VACUUM

NAME: RUSS RUCINSKI

DATE: 10/9/92

REVISION DATE

→ LOOK AT THROUGHPUT / PUMPING SPEED

ONCE THE PUMPING PATH IS OUT OF THE 'CRACK', ASSUME WE CAN RUN A 4" SCH. 5 PIPE TO THE PUMP.

IMAGINE PUMP IS LOCATED NEAR CONTROL DEWAR.

RUN WOULD CONTAIN: ABOUT 35' OF 4" SCH. 5 PIPE
5 ELBOWS (SHORT RADIUS)
1 GATE VALVES.

DO ALL CALCS FOR $T=300K$ $M=4$ (He), $P=2.2 \times 10^{-5}$ TORR ^{FREE MOLECULAR}

PIPE: 4" SCH. 5, I.D. = $4.5" - 2(0.083") = 4.33"$

$L/D = 30$ CUT-OFF PLU FORMULAS

$L > 30D$ LONG TUBE

$L > 10.8'$ LONG TUBE FORMULA

$L < 10.8'$ SHORT TUBE FORMULA.

B-FE. PIPE, SHORT TUBE $L = 2.438m$

$$C = \left(\frac{\pi g_c R T}{18 M} \right)^{1/2} \left(\frac{L}{D} + \frac{4}{3} \right)^{-1} D^2 = 169.8 = 170 \text{ L/s}$$

Z-FE PIPE, SHORT TUBE $L = 0.6096m$

$$C = 580 \text{ L/s}$$

20 FT PIPE, LONG TUBE $L = 6.096m$

$$C = 72 \text{ L/s}$$

5 FT. PIPE, SHORT TUBE $L = 1.524m$

$$C = 263 \text{ L/s}$$

ELBOW BECAUSE OF SPACE LIMITATIONS ASSUME SHORT RADIUS.

$$d = 4.33" \quad r/d = \frac{4}{4.33} \approx 1 \Rightarrow K = 0.05$$

$$C = \left(\frac{2 g_c R T}{9 \pi M} \right)^{1/2} \frac{D^3}{r}$$

$$C = \left(\frac{2 (8314) (300)}{9 \pi (4)} \right)^{1/2} \frac{(0.10998)^3}{(0.1016)} = 2.75 \text{ m}^3/\text{s} \times \frac{1000 \text{ L}}{1 \text{ m}^3} = 2750 \text{ L/s}$$

23

SUBJECT

~~DO~~ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

10/9/92

REVISION DATE

GATE VALVE: HIGH VALVUM GATE VALVE, 4" { REF. A. STEFANIK SRC }
DESIGN NOTE #117

$$C = 2,960 \text{ L/s} \quad \text{FREE MOLECULAR FLOW}$$

$$\frac{1}{C_{\text{EXTERNAL LINE TO PUMP}}} = \sum \frac{1}{C_i} = \frac{5}{2750 \text{ L/s}} + \frac{1}{170} + \frac{1}{580} + \frac{1}{72} + \frac{1}{263}$$

$$C_{\text{EXTERNAL LINE TO PUMP}} = 36.9 \text{ L/s} \approx \underline{37 \text{ L/s}} \quad (4" \text{ PIPE SIZE})$$

FOR AN EXAMPLE CONSIDER USING A TMP361 LEYBOLD TURBO PUMP.
W/ 4" ASA FLANGE

$$S = 380 \text{ L/s} \quad \text{HR.}$$

→ EFFECTIVE PUMPING SPEED;

$$\frac{1}{S_{\text{EFF}}} = \frac{1}{S_{\text{PUMP}}} + \frac{1}{C_{\text{EXTERNAL LINE TO PUMP}}} + \frac{1}{C_{\text{CHIMNEY}}}$$

USING THE ABOVE EQUATION AND DATA IN TABLE 2, WE CAN
CONSTRUCT TABLE 3.

RUNNING THRU THE FIRST SIZE & SHAPE, AL

$$\frac{1}{S_{\text{EFF}}} = \frac{1}{380} + \frac{1}{37} + \frac{1}{410} \Rightarrow S_{\text{EFF}} = 31.1 \text{ L/s} = \underline{31 \text{ L/s}}$$

FROM THE DATA IN TABLE 3, IT IS OBVIOUS THAT THE
EXTERNAL LINE CONDUCTANCE (37 L/s) NEEDS TO
BE IMPROVED.

Table 3 - Pumping speed comparison

Size/Shape	Chimney Conductance (l/s)	External line Conductance (4" pipe size)(l/s)	Nominal Pump speed (l/s)	Effective pump Speed @ coil (l/s)
Rect. 2.5" x 9.5"	410	37	380	31
Rect. 2.5" x 5"	169	37	380	28
Annular, 2.75" ϕ x 2" ϕ	10	37	380	8
Annular, 2.75" ϕ x 2.5" ϕ	2	37	380	1
Circular, 1" ϕ	3	37	380	3
Circular, 2.75" ϕ	61	37	380	22
Circular, 3" O.D. x .065" wall	69	37	380	23
CDF, both pumps on				59
CDF, control dewar pump only				42
SDC 4" ϕ to pump	total 125		390	95

Required pump speed to keep the coil at 2.2×10^{-7} Torr with a warm 10^{-8} atm-cc/sec leak leaking cold LHe is $4 \frac{1}{2}$

Temperature used in calculations is 300K.

Assumed pumping helium gas.

Conductances are for free molecular flow regime.

SUBJECT

DØ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

10-12-92

REVISION DATE

- ESTIMATE PUMPING SPEED REQUIRED.

$$P_{\text{WH}} = Q_i / S_s$$

$$\text{VOLUME OF VACUUM CHAMBER} = \pi(r_o^2 - r_i^2)L = \pi(.71\text{ m}^2 - .575\text{ m}^2)(2.7\text{ m})$$

$$= 1.47\text{ m}^3$$

SAY ABOUT 1/2 OF THAT VOLUME IS CONDUCTOR, BOBBIN etc.

$$V_{\text{EMPTY}} = 0.7\text{ m}^3 \times \frac{1000\text{ L}}{1\text{ m}^3} = 700\text{ LITRES}$$

$$P_{\text{WH}} = 2.2 \times 10^{-7}\text{ TORR.}$$

GUESS Q_i , SOLVE FOR S_s , EFFECTIVE PUMP SPEED REQ'D. Q_i - INLEAK RATE DUE TO VIRTUAL LEAKS, REAL LEAKS, AND OUTGASSING.

ASSUME THAT DURING FABRICATION & LEAK CHECKING, A LEAK IN THE HELIUM CIRCUIT OF SIZE $1 \times 10^{-10}\text{ ATM-CC/SEC HE}$ GOES UNNOTICED. HOW MUCH LEAK IS THAT WHEN LIQUID HE FLOWS THROUGH THE LINE & VACUUM SPACE IS @ VACUUM?

MINIMUM DETECTABLE LEAK $\approx 10^{-9}\text{ Pa-L/S}$ { REF. A USER'S GUIDE TO VACUUM TECHNOLOGY }

$$Q_{\text{LEAK MIN}} = 10^{-9} \frac{\text{Pa} \cdot \text{L}}{\text{S}} \times \frac{760\text{ TORR}}{1.013 \times 10^5\text{ Pa}} = 7.5 \times 10^{-12} \frac{\text{TORR} \cdot \text{L}}{\text{S}}$$

$$Q_{\text{ASSUMED LEAK}} = 1 \times 10^{-10} \frac{\text{ATM-CC}}{\text{SEC}} \times \frac{760\text{ TORR}}{1\text{ ATM}} \times \frac{1\text{ L}}{1000\text{ CC}} = 7.6 \times 10^{-11} \frac{\text{TORR} \cdot \text{L}}{\text{S}} \quad \text{ROOM TEMP HE}$$

→ USE ASSUMED LEAK

MODEL THE 'LEAK' AS CHOKED FLOW. THAT IS GAS FLOWS AT IT'S SONIC VELOCITY THRU THE HOLE/PATH

$$V_s|_{\text{He}} = 1100\text{ m/s} \quad \rho_{\text{He}} = .1625 \frac{\text{kg}}{\text{m}^3} \quad \text{300K}$$

$$\dot{m} = \rho VA$$

$$\dot{m}|_{\text{max}} = 1 \times 10^{-10} \frac{\text{ATM-CC}}{\text{SEC}} \times \rho = 1 \times 10^{-10} \frac{\text{cm}^3}{\text{SEC}} \times .1625 \frac{\text{kg}}{\text{m}^3} \times \frac{1\text{ K}}{1000\text{ cm}^3} \times \frac{1}{1000\text{ L}} \times 10^3$$

$$= 1.625 \times 10^{-17} \frac{\text{kg}}{\text{S}} \times \frac{1000\text{g}}{1\text{ kg}}$$

26

$$\dot{m}|_{\text{max}} = 1.625 \times 10^{-14} \text{ g/s}$$

SUBJECT

DØ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

10-12-92

REVISION DATE

SOLVING FOR A THEORETICAL A_s

$$A = \frac{\dot{m}}{\rho V_s} = \frac{1.625 \times 10^{-14} \text{ g/s}}{.1625 \frac{\text{kg}}{\text{m}^3} (1100 \text{ m/s})} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 9.09 \times 10^{-20} \text{ m}^2$$

DETERMINE LIQUID FLOW RATE AT 'COLD' RUNNING CONDITION.

$$\dot{m} = \rho V_s A = \left(124.9 \frac{\text{kg}}{\text{m}^3} \right) (177 \text{ m/s}) (9.09 \times 10^{-20} \text{ m}^2) \times \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right)$$

LHC

$$= 2.0 \times 10^{-12} \text{ g/s}$$

THIS COLD MASS FLOW RATE WILL BE WARMED UP TO 300K.

CONVERTING THE COLD MASS FLOW RATE TO WARM PUMP LOAD UNITS;

$$Q_{\text{LEAK}} = 2.0 \times 10^{-12} \frac{\text{g}}{\text{s}} \times \frac{1 \times 10^{-10} \frac{\text{ATM-CC}}{\text{SEC}}}{1.625 \times 10^{-14} \frac{\text{g}}{\text{s}}} = 1.24 \times 10^{-8} \frac{\text{ATM-CC}}{\text{SEC}}$$

$$= 1.24 \times 10^{-8} \frac{\text{ATM-CC}}{\text{SEC}} \times \frac{760 \text{ TORR}}{1 \text{ ATM}} \times \frac{1 \text{ L}}{1000 \text{ CC}} = 9.4 \times 10^{-9} \frac{\text{TORR-L}}{\text{SEC}}$$

OUTGASSING:

EVENTUALLY OUTGASSING ISN'T A FACTOR SINCE IT DECREASES EXPONENTIALLY W/ TIME

$$q_n = q_0 e^{-\alpha n}$$

n - IN HOURS.

$$\text{SURFACE AREA OF SHELL} = 2\pi(r_o + r_i)L + \pi(r_o^2 - r_i^2)$$

SPN. ALUM.

$$A_{\text{SHELL}} = 2\pi(.71\text{m} + .575\text{m})(2.7\text{m}) + \pi(.71\text{m}^2 - .575\text{m}^2) = 22.3 \text{ m}^2$$

$$A_{\text{DOBBIN}} = 2\pi(.66\text{m} + .61\text{m})(2.7\text{m}) = 21.5 \text{ m}^2 \quad (\text{AL 5083})$$

$$A_{\text{CHIMNEY}} = \pi D L = \pi(4.33 \text{ IN.})(15\text{m}) \left(\frac{.0254 \text{ m}}{1 \text{ IN.}} \right) = 5.2 \text{ m}^2$$

FX-PER LINE

$$Q_{\text{S.S.}} = 1 \times 10^{-10} \frac{\text{TORR-L}}{\text{S-CM}^2} = 1 \times 10^{-6} \frac{\text{TORR-L}}{\text{S-M}^2}$$

$$Q_{\text{AL}} = 2 \times 10^{-10} \frac{\text{TORR-L}}{\text{S-CM}^2} = 2 \times 10^{-6} \frac{\text{TORR-L}}{\text{S-M}^2}$$

$$Q_{\text{MYLAR}} = 7 \times 10^{-9} \frac{\text{TORR-L}}{\text{S-CM}^2} = 7 \times 10^{-5} \frac{\text{TORR-L}}{\text{S-M}^2}$$

REF - VACUUM TECHNOLOGY
HANDBOOK
FROM COURSE NOT
AVG. VALUES FROM
OVER 50 REFERENCES
H.G. PATTON 1/87

27

↑ EXPOSED TO VACUUM > 24 HRS

SUBJECT

DØ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

10-12-92

REVISION DATE

$$A_{MYLAR} \approx 8 \text{ LAYERS} \times 22 \text{ m}^2/\text{LAYER} = 176 \text{ m}^2 \approx 180 \text{ m}^2$$

$$Q_{OUTGASS} = \sum q_i A_i = (1 \times 10^{-6} \frac{\text{TORR-L}}{\text{s-m}^2})(5.2 \text{ m}^2) + (2 \times 10^{-6} \frac{\text{TORR-L}}{\text{s-m}^2})(44 \text{ m}^2) \\ + (7 \times 10^{-5} \frac{\text{TORR-L}}{\text{s-m}^2})(180 \text{ m}^2) \\ = .0127 \frac{\text{TORR-L}}{\text{s}}$$

← 6 ORDERS OF MAGNITUDE LARGER
THAN LEAK!

COMPARISON NOTE: CDF LEAK RATE W/ LIQUID HELIUM WAS

$$1.5 \times 10^{-7} \frac{\text{ATM-CC}}{\text{SEC}} = 1.1 \times 10^{-7} \frac{\text{TORR-L}}{\text{SEC}}$$

{ REFERENCE
AMS DESIGN
NOTE 117 }

AFTER CONFERENCE W/ KURT KAGMPETE WE CONCLUDE OUTGASSING LOAD
WILL BE CRYO PUMPED. I WILL THEREFORE ONLY WORRY ABOUT POSSIBLE LHE
LEAKS.

FOR CALCULATION OF REQ'D PUMPING SPEED ASSUME TECHNICIAN
MISSES A $1 \times 10^{-8} \text{ ATM-CC/SEC}$ LEAK (SEE PG. 9 & 10 FOR $1 \times 10^{-10} \text{ ATM-CC/SEC}$)

$$Q_{LEAK} = 1.24 \times 10^{-8} \frac{\text{ATM-CC}}{\text{SEC}} = 9.4 \times 10^{-7} \frac{\text{TORR-L}}{\text{SEC}}$$

$$S_s = \frac{Q_i}{P_{\text{lit.}}} = \frac{9.4 \times 10^{-7} \frac{\text{TORR-L}}{\text{SEC}}}{2.2 \times 10^{-7} \text{ TORR}} = \boxed{4.3 \text{ L/s}}$$

COMPARISON NOTE: CDF EFFECTIVE PUMPING SPEED (ON COIL)
FREE MOLECULAR FLOW REGIME IS:

$$S_{S_{CDF}} = 59 \text{ L/s} \quad \text{FOR BOTH PUMPS PUMPING} \\ = 42 \text{ L/s} \quad \text{FOR CONTROL DEWAR PUMP ON ONLY}$$

{ REFERENCE BRUCE SQUIRES PHONE CONVERSATION
10/12/92 }

WE SHOULD BE SHOOTING FOR $4 \text{ L/s} < S_s < 50 \text{ L/s}$

SUBJECT

DØ SOLENOID CHIMNEY

VACUUM

NAME

RUSS RUCINSKI

DATE

10-13-92

REVISION DATE

FOR THE 'CRACK' PART OF THE CHIMNEY WE COULD
USE 3" O.D. x 0.065" WALL TUBING.

$$I.D. = 2.87"$$

CONDUCTANCE CALCULATES TO BE $69.45 \approx 69$ L/s FOR 300 K
& He
 $L = 1.84$ m.

FROM DESIGN CHART OF LONG VACUUM PIPES MIN. WALL
THICKNESS FOR F.S. = 2 FOR 3" DIA. IS .031". THIS
APPLIES ONLY TO TRUE CIRCULAR SHAPES. SINCE OUR PIPE WILL
BE SHORTER HOWEVER & FIXED AT THE ENDS THE OUT OF
ROUNDNESS / CURVED SHAPE EFFECT WILL PROBABLY
NOT INCREASE THE REQ'D THICKNESS.

THE EXTERNAL PUMPING LINE WILL HAVE TO BE IMPROVED
FROM 4" PIPE.

NOTE: THE FOLLOWING EQUATIONS HOLD FOR THE VACUUM SYSTEM.

$$S_p = Q/P_i$$

$$S_s = Q/P$$

$$C_0 = Q/(P - P_i)$$

$$1/S_s = 1/S_p + 1/C_0$$

where S_p - NOMINAL PUMP SPEED
 S_s - SYSTEM PUMPING SPEED OR EFFECTIVE PUMP SPEED
 C_0 - CONDUCTANCE LINE
 P_i - PRESS. INLET OF PUMP
 P - PRESS. VAC. CHAMBER

$$\text{FOR } S_p = 380 \text{ L/s, } C_0 = 24 \text{ L/s} = \left(\frac{1}{69} + \frac{1}{37} \right)^{-1}$$

$$P = 2.2 \times 10^{-7} \text{ TORR}$$

WE SOLVE THE EQUATIONS TO SHOW

$$P_i = 1.3 \times 10^{-8} \text{ TORR, } S_s = 22.6 \text{ L/s} \approx 23 \text{ L/s AS SHOWN IN TABLE 3}$$

$$Q = 5 \times 10^{-6} \text{ TORR-L/S}$$

$$\text{FOR TMP361, } P_{\text{out}} = < 10^{-10} \text{ mbar} = < 7.5 \times 10^{-11} \text{ TORR}$$

IN GENERAL FOR CONDUCTANCE RANGE WE'RE IN PRESSURE AT
THE SOLENOID WILL BE ONE ORDER OF MAGNITUDE HIGHER
THAN AT THE PUMP.