D-ZERO CENTRAL CALORIMETER

PRESSURE VESSEL AND VACUUM VESSEL

SAFETY NOTES

R. RUCINSKI

R.LUTHER

October 25, 1990

Revised:

November 19, 1990
September 26, 1991
November 21, 1991

D-ZERO ENGINEERING NOTE 3740. 214 -EN- 263

R. Rucinski 11/19/90

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(revised on 12/6/91 by John Wu)

PRESSURE VESSEL ENGINEERING NOTE
PER MANDATORY STANDARD SD37

Prepared by: R.D. Luther / R.A. RUCINSKI

Preparation date: OCTOBER 15, 1990

Revision dates: 9/26/91, 11/21/91 by John Wu

REVIEWED 12-6-91 RLL

1 Description and Identification

Fill in the label information below:

This vessel conforms to engineering standard SD37

Vessel Title DØ - CC CRYOSTAT INNER VESSEL

Vessel Number RD - 4023

Vessel Drawing Number 3740.214 - ME - 223235

Obtain from Division/Section Safety Officer

Maximum Allowable Working Pressure (MAWP) +15PSIG WITH VACUUM = 30 PSID

Working Temperature Range -300 °F 100 °F

Contents LIQUID ARGON AND CALORIMETER MODULES

Designer/Manufacturer RICHMOND - LOX EQUIPMENT CO.

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

______ PSI, Hydraulic ______ Pneumatic ______

Accepted as conforming to standard by

Peter H Garbincius 25 Jan 91

of Division/Section Research Division

Actual signature required in this space

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

Revision and review accepted

Peter H Garbincius 6 Dec 9

Reviewed by: Richard L Schmitt Date: 1-25-91

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

______ Date: ______

Lab Property Number(s): ______

Lab Location Code: DAB (obtain from Safety Officer)

Purpose of Vessel(s): DØ COLLIDER/DETECTOR CALORIMETER CRYOSTAT

Vessel Capacity/Size: 5000 GAL. LIQUID ARGON Diameter: 16'-1/2" Length: 10'

Normal Operating Pressure (OP) 5 PSIG

MAWP-OP = 10 PSIG

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

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

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

Drawing #	**Location of Original**
3740.214-ME-223235	DØ DWG ARCHIVES
" .220-ME-222256	
" .214-MD-223236	
" " " -223237	
" .210-ME-222361	
" .210-MC-222269	
" .210-ME-223220	
" .214-ME-223683	
" " -MD-223871-873	
" " -MB-223881-884 (883 is AN E SIZE DWG)	
" " -MD-223885	

2 **Design Verification**

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

Staple photo of U stamp plate below.

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

Copy data here:

NAT'L BOARD No. 3688

UHA 51 RT-4

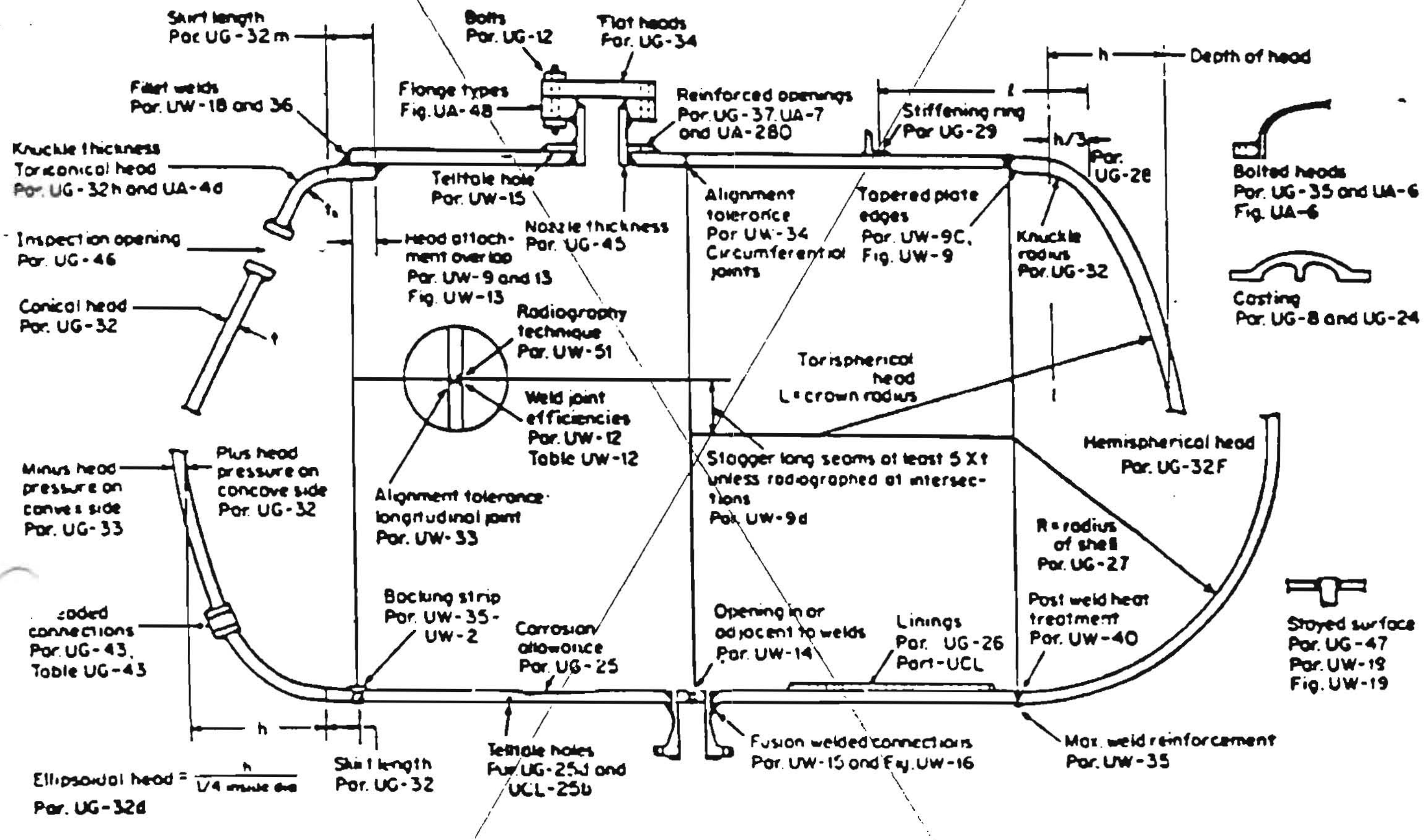
VESSEL DP 15 PSI at -298 IT +100 °F

MFR. SER # 30093 YR BLT 1987

SHELL THK. .625 .375

HEAD THK. .625

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



Summary of ASME Code

Item	Reference ASME Code Section	CALCULATION RESULT (Required thickness or stress level vs. actual thickness or calculated stress level)
		vs.
		vs.
		vs.
		vs.
		vs.

If this vessel is exceptional or had exceptional parts, list their details under 5.6. Yes______ No__________

3 System Venting. Provide the system schematic in the Appendix, if the vessel safety is system sensitive.

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

Yes______ No X

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

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

Yes X No______ Actual setting 13 PSIg
(A no response violates the Standard.)

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

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

Provide test or calculational proof in the Appendix. D0 ENG. NOTE 3740.00-EN-63
(Non-conforming pressure rises violate the Standard.)

List of reliefs and settings:

Manufacturer	Relief	Setting	Flow Rate	Size
ANDERSON-GREENWOOD	RELIEF VALVE	13 PSIG	1018 scfm air	2" x 3"
FIKE	RUPTURE DISK	18 PSIG	2640 scfm, AIR	3"

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

4 Operating Procedure

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

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

5 Welding Information

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

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

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

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

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

Exhibit A-1

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

Prepared By R.D. Luther Date 5/14/87 Div/Sect AD/ESD-D0

Reviewed By R L Schmitt Date 1-28-91 Div/Sect RD/CRYO

Div/Dept Head Peter Garbincus Date 1-28-91 Div/Sect Res Div. Office

I. Identification and Verification of Compliance

Fill in the Fermilab Engineering Conformance Label information below:

This vessel conforms to Engineering Standard SD-41

Vessel Title D0-CC CRYOSTAT OUTER VESSEL (VACUUM JACKET)

Vessel Number RDV-4023

Vessel Drawing Number 3740.214-ME-223235

Working Temperature Range 0 °F 100 °F

Designer/Manufacturer RICHMOND-LOX EQUIPMENT CO.

Date of Manufacture 1987

Acceptance Date

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

Amendment No.:	Reviewed By:	Date:

Exhibit A-2

II. Description of Vessel and Relief System

Laboratory location code DAB

Laboratory property number

Purpose of vessel VACUUM JACKET FOR LIQUID ARGON CALORIMETER

List all pertinent drawings (append copies)

Drawing No.:	Location of Original:
3740.214-ME-223235	D-0 ARCHIVES
-ME-222256	
-ME-222361	
-MC-222269	
-MD-223237	
-ME-223683	
-MB-223871-873	
-MB-223881-885	

Can this vessel be pressurized? No

If yes, to what pressure. ———

Is a testing procedure necessary for the safe acceptance testing (proof testing) of this vessel? No

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

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

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

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

Manufacturer	Relief	Setting	Flow Rate	Size	ASME Stamped Device Yes/No
FERMILAB (PSV-209V)	BLOW-OFF DISC	0.85 psig	>10000 Scfm	10"-150# ANSI FLANGE	No

Welding Information

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

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

⑦

D-ZERO ENGINEERING NOTE
#3740.214-EN-68
December 5, 1986

DESIGN SUMMARY

CC CRYOSTAT VESSELS

By Rick Luther
December 5, 1986

A summary of the design of the CC Cryostat pressure and vacuum vessels is presented on the following pages along with supporting calculations. In the calculations several references are made to an independent review of the design performed by the Battelle Memorial Institute, Columbus Division. This review has been published as D-Zero Engineering Note #3740.510-EN-54.

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DESIGN SUMMARY - CC CRYOSTAT

INNER VESSEL

Design Conditions:

Int. Pressure = 15 psig w/ Full vacuum outside

ΔP = 30 psi

Liquid Head = 16 ft of Liquid Argon
= 10 psig @ the bottom

$\therefore P_{DES})_{Internal}$ = 40 psi

Ext. Design Pressure = 15 psi

Temperature: 90 K (-298 °F) to 100 °F

MATERIAL: SA-240 TYPE 304 STAINLESS STEEL
S = 18800 psi

Radiography: NONE REQD.

Geometry: SHT CCS-4

Criteria: Int. Pressure - ASME Code, Section VIII, Div. 1. (stamped)

Ext Pressure - CGA-341 ($P_{CRITICAL}$ = 30 psi MIN)

Inner Vessel - Cont'd

Design Results:

OUTER Cylinder: $t = 5/8"$

$t_{rqd} = 0.3163$ Int. Press (CCI-1)

$= 0.4375$ Ext. Press PER
ASME CODE
($P_{cr} = 45$psi) (CCI-2)

OUTER KNUCKLE $t = 5/8"$

$t_{rqd} = 0.415$ Int. Pr. (CCI-15)

$= 0.447$ Ext. Pr. (CCI-17)

CROWN: $t = 5/8"$

$t_{rqd} = 0.256$ (CCI-19) Int. Pr.

0.435 (CCI-22) Ext. Pr.

INNER KNUCKLE: $t = 5/8"$

$t_{rqd} \approx 5/8"$ Int & Ext. P.
(CCI-24)

INNER CYLINDER: $t = 3/8"$

$t_{rqd} = 3/8$ Int. Pr. (CCI-26)
$= .098"$ Ext Pr (CCI-26)

Signal Port Nozzle:
(CCI-3)

The min wall required for nozzles
in the inner vessel is 0.2570". For
An OD of 8.625 and allowing ±.030
on the bore diameter yields:

$ID_{min} = 8.625 - 2(t_{min}) - 2(.030)$
$= 8.051$

USE 8.050±.030 FOR BORE ϕ.

DESIGN SUMMARY (CONT'D)

OUTER VESSEL

DESIGN COND'NS

DESIGN PRESSURE = ± 15 psig

TEMP = 100°F

MAT'L: SA-240 TYPE 304 S.S.

$S = 18800$

RADIOGRAPHY: NONE REQ'D

GEOMETRY: SHT CCS - 5

CRITERIA: TENSILE STRESS - ASME CODE

Comp. STRESS - CGA-341 (P_{cr} = 30 psi min)

(Note: In all instances the thicknesses are controlled by comp. stress criteria.)

DESIGN RESULTS

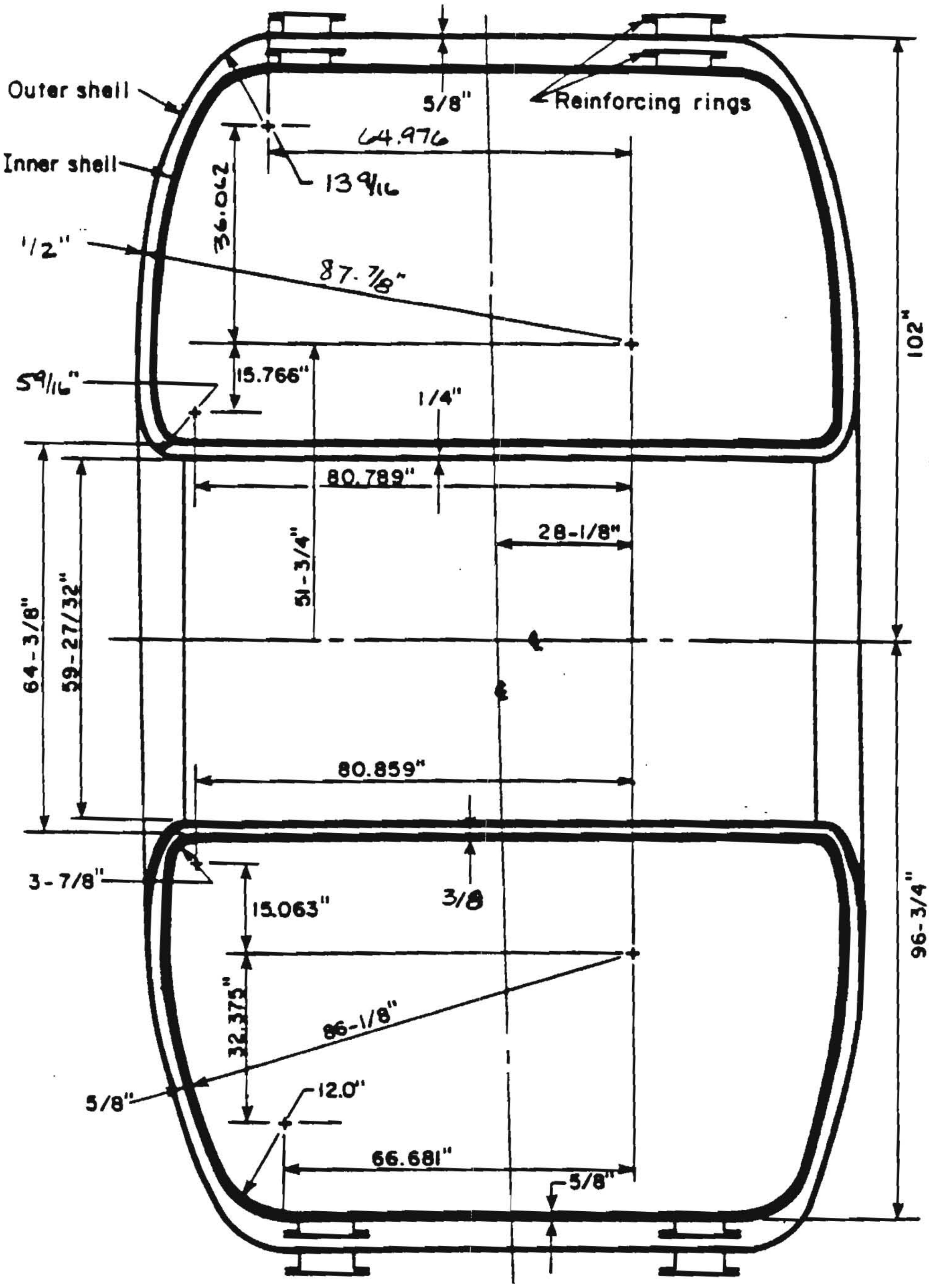
OUTER CYLINDER: $t = 5/8"$; $t_{rqd} = 0.360$ (CCO-3)

INNER CYL: $t = 1/4"$; $t_{rqd} = 0.2"$ (CCO-9)

OUTER KNUCKLE: $t = 1/2"$; $t_{rqd} = 0.404"$ (CCO-11)

CROWN: $t = 1/2"$; $t_{rqd} \approx .361"$ (CCO-12)

INNER KNUCKLE: $t = 1/2"$; $t_{rqd} = .366"$ (CCO-13 & 14)



CENTRAL CALORIMETER VESSEL GEOMETRY

RDC 12/4/86
SHT CCS-4

CCI -

THRU
CCI-4

CC INNER   OUTER CLY.   RDC 6/19/86

DESIGN FOR INT. PRESSURE

$P = 40$ psi

$D_o = 193.5 \quad R_o = 96.75$

$S = 18800$

$$t = \frac{PR_o}{SE + 0.4P}$$

$$= \frac{40(96.75)}{18800E + 0.4(40)}$$

$$= \frac{3870}{18800E + 16}$$

$E = 1.0$

$t = 0.2057$

$E = 0.9$

$t = 0.2285$

$E = 0.85$

$t = 0.2419$

$E = 0.80$

$t = 0.2570$

$E = 0.65$

$\underline{\underline{t = 0.3163}}$ INT. PRES.

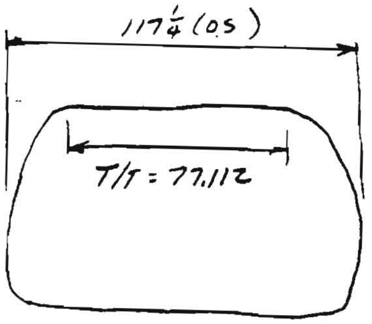
@ $t = 0.625$

$$P_a = \frac{18800(.65)(.625)}{\left(\frac{193.5}{2} - .625\right) + 0.6(.625)}$$

$$= 79.15 \text{ psi}$$

DESIGN FOR EXT PRESSURE

$P = 15$ psi $\quad D_o = 193.5$



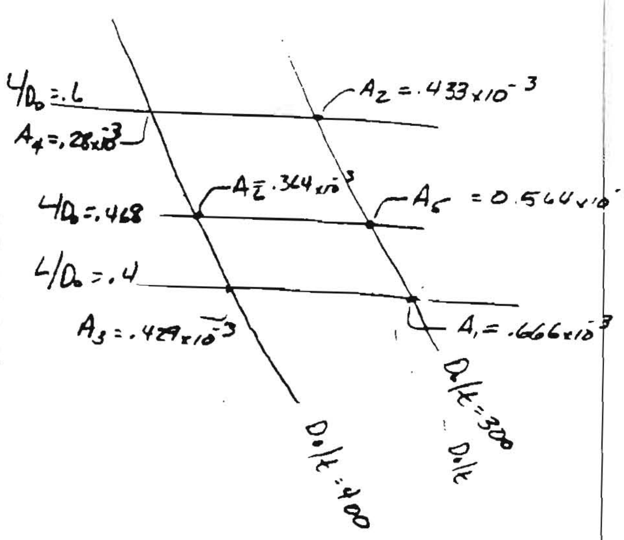
$L = 117.25 - \frac{2}{3}(117.25 - 77.112)$

$L = \underline{90.491}''$

$$L/D_o = \frac{90.491}{193.5} = 0.468$$

$t = 0.625$

$D_o/t = 309.6$



CC, INNER

OUTER CYL
EXT P.

RDC 6/19/86

$$A_5 = A_1\left(\frac{A_2}{A_1}\right)^{\left(\frac{\log(41/.468)}{\log(.41/.6)}\right)}$$

$$= .666\times10^{-3}\left(\frac{.433}{.666}\right)^{\frac{\log(.41/.468)}{\log(.41/.6)}}$$

$$= 0.564\times10^{-3}$$

$$A_6 = A_3\left(\frac{A_4}{A_3}\right)^{\left(\frac{\log(.41/.468)}{\log(41/.6)}\right)}$$

$$= .429\left(\frac{280}{.429}\right)^{\left(\frac{\log .41/.468}{\log .41/.6}\right)}$$

$$= 0.364\times10^{-3}$$

$$A = A_5\left(\frac{A_6}{A_5}\right)^{\left(\frac{\log(300/309.6)}{\log(300/400)}\right)}$$

$$= .564\times10^{-3}\left(\frac{.364}{.564}\right)^{\left(\frac{\log(300/309.6)}{\log(300/400)}\right)}$$

$$= 0.538\times10^{-3}$$

Fig 5-UHA-28.1

$$B = B_1\left(\frac{B_2}{B_1}\right)^{\left(\frac{\log(A_1/A)}{\log(A_1/A_2)}\right)}$$

$A_1 = .463\times10^{-3}$

$B_1 = 6590$

$A_2 = 1.5\times10^{-3}$

$B_2 = 10600$

$$B = 6590\left(\frac{10600}{6590}\right)^{\frac{\log(.463/.538)}{\log(.463/1.50)}}$$

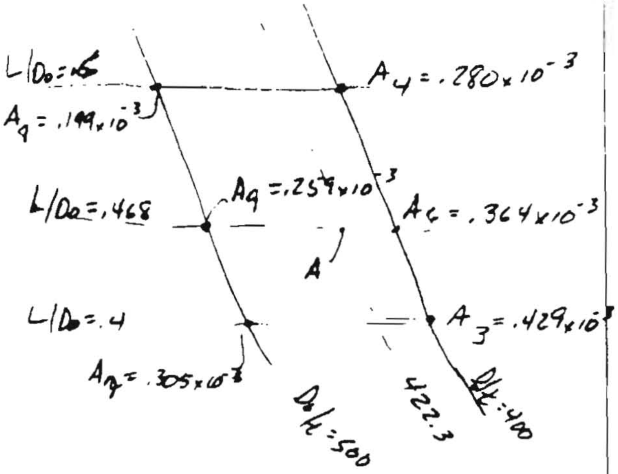
$$= 7002$$

$$P_a = \frac{4}{3}\left(\frac{7002}{309.6}\right) = \underline{30.16 \text{ psi}}$$

try $\underline{t = 0.4375}$

$$D_o/t = 422.3$$

Fig 5-UGO-28.0



$$A_9 = A_7\left(\frac{A_8}{A_7}\right)^{\left(\frac{\log(.41/.468)}{\log(.41/.6)}\right)}$$

$$= .305\times10^{-3}\left(\frac{.199}{.305}\right)^{\left(\frac{\log(.41/.468)}{\log(.41/.6)}\right)}$$

$$= 0.259\times10^{-3}$$

$$A = .364\times10^{-3}\left(\frac{.255}{.364}\right)^{\frac{\log(400/422.3)}{\log(400/500)}}$$

$$= 0.335\times10^{-3}$$

$A_1 = .01\times10^{-3}$ $B_1 = 140$

$A_2 = .463\times10^{-3}$ $B_2 = 6590$

$$B = 140\left(\frac{6590}{140}\right)^{\left(\frac{\log(.01/.335)}{\log(.01/.463)}\right)}$$

$$= 4761.5$$

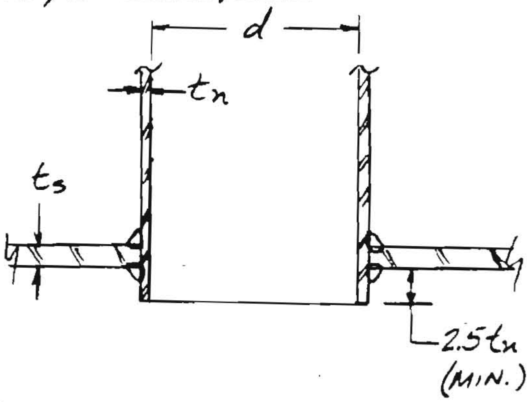
$$P_a = \frac{4}{3}\left(\frac{4761.5}{422.3}\right) = \underline{\underline{15.03 \text{ psi}}}$$

$\underline{\underline{t_r = 0.4375}}$ EXT. PRESSURE

DETERMINE THE MAXIMUM ID FOR THE 8" φ SIGNAL PORTS

Assume steel pipe will be used (8.625" OD) with the bore enlarged to the maximum allowed by the ASME Code. Reinforcement requirements for this geometry will then be determined.

Longitudinal plane



$t_{n_{min}}$ (UG-45)

$E = 1.0$ or 0.85

$$t_n = \frac{PR_o}{SE + 0.4P}$$

$$= \frac{40\left(\frac{19.35}{2}\right)}{18800(1.0) + 0.4(40)}$$

$$= 0.2051$$

$E = 0.65$

$$t_n = \frac{40\left(\frac{19.35}{2}\right)}{18800(.8) + .4(40)}$$

$$t_n = 0.2570"$$

$$d = 8.625 - 2t_n$$

$$= 8.625 - 2(.2570)$$

$$= 8.111" \quad E = .65$$

$$= 8.214" \quad E = 1.0$$

t_r

Int. Pressure

$t_r = 0.2570$ $E = .65$

$t_r = 0.2051$ $E = 1.0$ or $.85$

Ext. Pressure

$t_r = 0.4375$

External Pressure

$$A_{req} = 0.5\, d\, t_r\, F$$

$$= 0.5(8.111)(0.4375)(1.0)$$

$$= 1.774 \text{ in}^2 \quad E = .65$$

$$= 1.796 \text{ in}^2 \quad E = 1.0$$

AREA AVAILABLE IN NOZZLE

OUTSIDE

t_{rn}

Assume $L_{max} \approx 32"$

$$\frac{L}{D_o} = 4.0$$

$t = .050$

$$\frac{d_o}{t} = 172.5$$

$A = .00014$

$$P_a = \frac{2(.00014)(28 \times 10^6)}{3(172.5)}$$

$$P_c = 15.15 \quad \text{OK}$$

$t_{r_n} = 0.050$

$A_2 = (t_n - t_{rn}) 5 t_n$

AREA INSIDE

$A_3 = 2(t_n)(2\frac{1}{2})t_n$

$= 5 t_n^2$

Weld Areas

Assume 1/4" min leg length

$A_w = 2(\text{leg})^2$

$= 2(1/4)^2$

$= 0.125 \text{ in}^2$

AREA EXCLUSIVE OF SHELL.

$A_2 + A_3 + A_w$

E=0.65

$t_n = 0.2570$

$A = (.2570 - .050)(5)(.2570)$

$+ 5(.2570)^2 + .125$

$= .266 + .330 + .125$

$= 0.721 \text{ in}^2$

Area required in shell:

$A_1 = A_{req} - A$

$= 1.774 - 0.721$

$= 1.053 \text{ in}^2$

Reqd. Shell thickness:

$A_1 = 1.053 \leq (t_s - t_r)d$

$1.053 \leq (t_s - .4375)(8.111)$

$\underline{\underline{t_s \geq 0.5673''}}$ (see trans. plane) E=0.65 $t_n = .2570$

For E=1.0

$t_n = 0.2057$

$A = A_2 + A_3 + A_w = (.2057 - .05)5(.2057)$

$+ 5(.2057)^2 + .125$

$= .160 + .212 + .125$

$= 0.497 \text{ in}^2$

$A_1 = 1.796 - .497 = 1.299 \text{ in}^2$

$1.299 \leq (t_s - .4375)(8.214)$

$\underline{\underline{t_s \geq 0.5956 \text{ in}}}$ E: 1.0 or .85 $t_n = .2057''$

See transv. plane

Internal Pressure

$A_{req} = d t_r F$

$= 8.111(0.2570)(1.0)$

$= 2.085 \text{ in}^2$ E=0.65

$= 1.690 \text{ in}^2$ E=1.0

$t_{rn} = \frac{40(8.111/2)}{.8(18800) - .6(40)}$

$= 0.011''$ E=0.65

$= 0.009''$ E=1.0

AREA EXCL. SHELL

$\underline{E = .65}$

$A = (.2570 - .011)(5)(.2570)$
$+ .330 + .125$

$= .316 + .330 + .125$

$= 0.771 \text{ in}^2$

$A_1 = (2085 - 0.771) \leq (t_s - .257)(8.111)$

$t \geq 0.419'' < 0.5673$

$\therefore$ EXT PRESS CONTROLS

$\underline{E = 1.0}$

$A = (.2057 - .009)(5)(.2057)$
$+ .212 + .125$

$= .202 + .212 + .125$

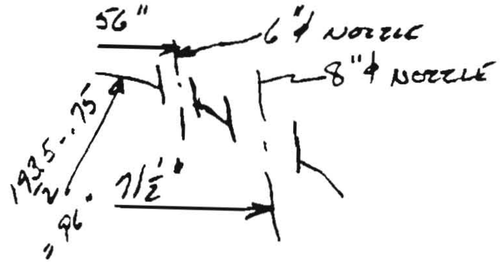
$= .539$

$A_1 = (4690 - .539) \leq (t_s - .2057)(6.214)$

$t_s \geq 0.346 < 0.595$

$\therefore$ EXT P. CONTROLS

TRANSVERSE PLANE



$\alpha_8 = \sin^{-1} \frac{71\frac{1}{2}}{96}$

$= 48.14°$

$d^*_{8''} = \frac{8.111}{\cos 48.14°} = 1.5 \times 8.111$

$= \underline{\underline{12.155''}}$ $E = .65$ $= \underline{\underline{12.309}}$ $E = 1.0$

$d_6 = 6.625 - 2(.2057)$

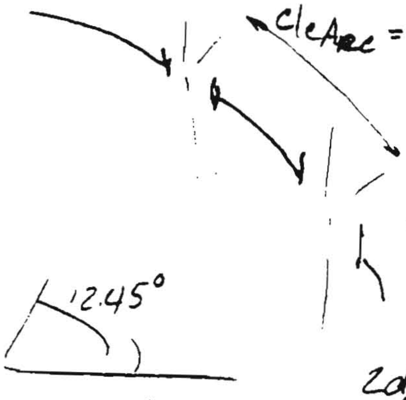
$= 6.214''$

$\alpha_6 = \sin^{-1} \frac{56}{96}$

$= 35.69°$

$d^*_6 = \frac{6.214}{\cos 35.69°} = 1.231 \times 6.214$

$= \underline{7.651}$



C_L ARC $= 96''(12.45)\left(\frac{\pi}{180}\right)$

$= 20.86''$

$d^*_{avg} = \frac{12.155 + 7.651}{2}$

$= 9.903$

$2d^*_{avg} = 19.806$

$19.806 < 20.86$

$\therefore$ LIMITS OF REINF. DO NOT OVERLAP.

TRANS. PLANE (CONT'D)

Integral Reinforcement $F = 0.5$

EXT. PRESS

$$A_{req} = 0.5\, d\, t_r\, F$$
$$= 0.5(12.155)(0.4375)(.5)$$
$$= 1.329\ in^2 \quad E = .65$$
$$= 1.346\ in^2 \quad E = 1.0$$

This area is less than the area reqd for the longitudinal plane in which the limits of reinforcement are smaller. Therefore the logitudinal plane controls.

Int. Pressure

$$A_{req} = d\, t_r\, F$$
$$= 12.155(0.257)(.5)$$
$$= 1.562\ in^2 \quad E = .65$$
$$= 1.260\ in^2 \quad E = 1.0$$

These are less than the corresponding values for the long. plane. Therefore, the lngtdnal plane controls.

Non-Integral Reinforcement $F = 1.0$

Ext Pressure

$$A_{req} = 0.5\, d\, t_r\, F$$
$$= 0.5(12.155)(.4375)(1.0)$$
$$= 2.659\ in^2 \quad E = .65$$
$$= 2.693\ in^2 \quad E = 1.0$$
$$A_1 = A_{req} - (A_2 + A_3 + A_w)$$
$$= 2.659 - 0.721$$
$$= 1.938\ in^2$$

$$1.938 \le (t_s - t_r)d$$
$$1.938 \le (t_s - .4375)(12.155)$$
$$\underline{\underline{t_s \ge 0.5970}} \quad E = 0.65$$
$$t_n = 0.2570$$

$\underline{E = 1.0\ ,\ t_n = .2057}$

$$A_1 = 2.693 - .497 = 2.196\ in^2$$
$$2.196 \le (t_s - .4375)(12.309)$$
$$\underline{\underline{t_s \ge 0.6159}} \quad E = 1.0$$
$$t_n = .2057$$

Int press. values will be smaller (see long. plane).

Summary 8" Signal Ports only

E = 0.65

$t_{n_{min}} = 0.2570"$

$t_{s_{min}} = 0.5673$ Full-penetration nozzle weld

$t_{s_{min}} = 0.5970$ Non-Integral Welds.

E = 1.0

$t_{n_{min}} = 0.2057"$

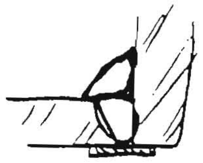
$t_{s_{min}} = 0.596"$ Full-pen. welds

$t_{s_{min}} = 0.616"$ non-int. welds.

NOTE: Internal Projection Required!

Look at 8" nozzle w/o internal projection

(Full pen. weld w/ backing strip)



$t_{n_{min}} = 0.2570$ $(E = .65)$

$= 0.257$ $(E = 1.0)$

Ext. Pressure Controls $t_r = 0.4375$

$A_{req} = 1.774\ in^2$ $E = .65$

$= 1.796$ $E = 1.0$

$t_{rn} = 0.050$

Summary

for nozzles welded from OS only (Full Pen Welds, F=0.5)

$E = 0.65$ $t_{n_{min}} = .2570$

$t_{s_{min}} = 0.616"$

$E = 1.0$ $t_{n_{min}} = 0.25$

$t_{s_{min}} = 0.625")$ approx.

AREA EXCLUDING SHELL

$E = .65$

$A = (.2570 - .050)(5)(.2570)$

$+ (1/4)^2$

$= .266 + .0625$

$= .328$

Shell t Rqd.

$(1.774 - .328) \le (t_s - .4375)(8.111)$

$t_s \geq .616$ $\therefore$ 5/8" OK

$E = 1.0$

$A = (.2057 - .05)(5)(.2057) + .0625$

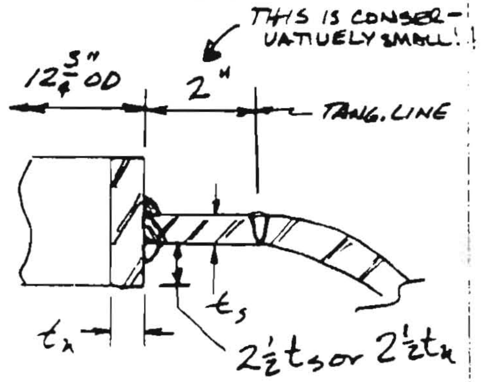
$= 0.223$

$(1.796 - .223) \le (t_s - .4375)(8.214)$

$t_s \geq 0.629$ $\therefore$ Can't use min t nozzle

1/4" wall OK.

12"φ SUPPORT NOZZLES



THESE NOZZLES ARE NOT PRESENT IN FINAL DESIGN!!

AREA AVAILABLE FOR REINFORCEMENT WILL BE CHECKED FOR THIS SIDE.

$t_r = 0.4375$ EXT. PRESSURE

$= 0.2570 \quad E = 0.65$
$= 0.2057 \quad E = 1.0$ } INT. PRESS.

1ST Assume $t_s = t_{r_{ext}} = 0.437$ & size nozzle to provide 100% OF AREA RQD.

Ext Press.

$A_{req} = 0.5\, d\, t_r\, F$
$= 0.5\,(12.75 - t_n)(.4375)(1.0)$

$= 2.789 - .219 t_n$

ONLY 1/2 OF THIS MUST LIE ON EACH SIDE OF THE NOZZLE

$A_{req} = \frac{1}{2}(2.789 - .219 t_n)$
$= 1.395 - .109 t_n$

$A_1 = 0$

A_ω = weld area $= \left(\frac{1}{4}\right)^2 = .0625$ NEGLECT

$A_2 = A_{NECK}$ O.S.

$= (t_n - t_{rn})\, 2.5\, t_s$
or
$= (t_n - t_{rn})\, 2.5\, t_n$ } smaller

Find t_{rn}

Assume $L \approx 12"$

$\frac{L}{D_o} = 1.0$

let $t = .045$

$D_o/t = 283$

$A = .000275 \quad B = 3750$

$P_a = \frac{4}{3}\left(\frac{3750}{283}\right) = 17.5$ psi

OK

$t_{rn} = \underline{\underline{0.045}}$

$A_3 = A_{NECK}$ I.S.

$= 2.5\, t_n^2$
or
$2.5\, t_n t_s$ } smaller

Assume $t_s < t_n \qquad t_s = .4375$

$1.395 - .109 t_n = (t_n - .045)\, 2.5(.4375) + 2.5 t_n(.4375)$

$1.395 - .109 t_n = 2.1875 t_n - .049$

$2.2965 t_n = 1.346$

$\boxed{t_n = 0.5861}$ > t_s OK

RQD NOZZLE t FOR $t_s = t_r$

Check int pressure w/ $t_s = .4375$
(E = .65 ONLY)

$A_{req} = d t_r F$

$= (12.75 - t_n)(.2570)(1.0)$

$= 3.277 - .257 t_n$

One Side:

$A_{req} = 1.638 - .129 t_n$

$A_1 = (0.4375 - .257)(2.0 + t_n)$

$= .361 + .181 t_n$

$t_{rn} = \dfrac{40(6.1)}{.8(18800) - .6(40)}$ assume r = 6.1

$= .016''$

$A_2 = (t_n - t_{rn})\, 2\tfrac{1}{2} t_s$

$= 1.094 t_n - .018$

$A_3 = 2.5 t_n t_s$

$= 1.094 t_n$

$A_{req} = A_1 + A_2 + A_3$

$1.638 - .129 t_n = .361 + .181 t_n$

$+ 1.094 t_n - .018$

$+ 1.094 t_n$

$2.498 t_n = 1.295$

$\underline{t_n = 0.518}$

Ext. P controls

Sched 80S

Assume 12"φ Sched 80S pipe for nozzle & determine rqd. Shell thickness for self-reinforcement.

$d = 11.750 \quad t_n = 0.5''$

Ext Pressure

$A_{req} = \tfrac{1}{2}[0.5 d t_r F]$

$= .5(.5)(11.75)(.4375)(1.0)$

$= \underline{1.285 \text{ in}^2}$ (ONE SIDE)

$A_1 = (t_s - t_r)(\overset{4.681 + .5}{\cancel{2}} + t_n)$

$= (t_s - .4375)(\overset{5.181}{\cancel{2.5}})$

$= \overset{5.181}{\cancel{2.5}} t_s - \overset{2.267}{\cancel{1.094}}$

4.681 is dist to tan line in later design!!

$A_2 = (t_n - t_{rn})\, 2\tfrac{1}{2} t_n$

$= (.5 - .045)(2.5)(.5)$

$= 0.569 \text{ in}^2$

$A_3 = 2.5 t_n^2$

$= 2.5(.5)^2$

$= 0.625 \text{ in}^2$

$A_1 + A_2 + A_3 \geq A_{req}$

$\overset{5.151}{\cancel{2.5}} t_s - \overset{2.267}{\cancel{1.094}} + .569 + .625 \geq 1.285$

$\underline{t_s \geq \overset{0.455}{\cancel{0.474}}''}$

Sched 80S (cont'd)

Int. Press. $E = 0.65$

$A_{req} = \frac{1}{2}(d\, t_r F)$ (one side)

$= \frac{1}{2}(11.75)(.257)(1.0)$

$= 1.510 \text{ in}^2$

$A_1 = (t_s - t_r)(2 + t_n)$

$= (t_s - .257)(2.5)$

$= 2.5 t_s - .643$

$A_2 = (t_n - t_{rn})\, 2.5 t_n$

$= (.5 - .016)(2.5)(.5)$

$= .609 \text{ in}^2$

$A_3 = 2.5(t_n)^2$

$= .625 \text{ in}^2$

$A_1 + A_2 + A_3 \geq A_{req}$

$2.5 t_s - .643 + .609 + .625 \geq 1.510$

$t_s \geq 0.368''$

Ext Press. Controls

For Sched 80S pipe

$t_s = 0.\cancel{474}$ min

0.455 for actual T.L.

Check Sched 40S

$d = 12.0 \quad t_n = 0.375$

Ext Press

$A_{req} = \frac{1}{2}(.5 d\, t_r F)$

$= .5(.5)(12)(.4375)(1.0)$

$= 1.3125 \text{ in}^2$

$A_1 = (t_s - .4375)(\overset{\overset{5.056}{4.691+.375}}{\cancel{2.375}})$

$= \overset{5.056}{\cancel{2.375}} t_s - \overset{2.212}{\cancel{1.039}}$

$A_2 = (.375 - .045)(2.5)(.375)$

$= .272 \text{ in}^2$

$A_3 = 2.5(.375)^2$

$= .352 \text{ in}^2$

$\overset{5.056}{\cancel{2.375}} t_s - \overset{2.212}{\cancel{1.039}} + .272 + .352$
≥ 1.3125

$t_s \geq \overset{0.574}{\cancel{0.7274}}$ in

Int Press

$A_{req} = 1.542$

$A_1 = 2.375 t_s - 2.375(.257)$

$= 2.375 t_s - 0.610$

$A_2 = (.375 - .016)(2.5)(.375)$

$= 0.337$

$A_3 = 2.5(.375)^2$

$= 0.352$

$2.375 t_s - .61 + .337 + .352 \geq 1.542$

$t_s \geq 0.616 \quad \therefore$ Ext P. Controls

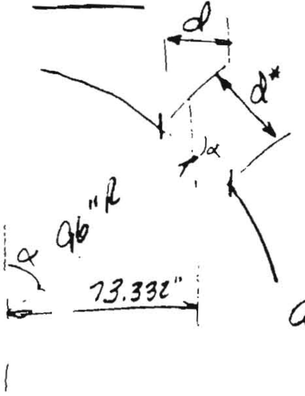
For Sched 40S Pipe

~~$t_s = 0.727$~~" MIN

$t_s = 0.574$ for actual tank

12"φ Support Nozzle. Cont'd

Check Sched 80S for Transverse Plane



$d = 11.75$

$t_n = 0.5"$

$\alpha = \sin^{-1}\frac{73.332}{96}$

$= 49.807°$

$d^* = \frac{d}{\cos\alpha} = \frac{11.75}{\cos 49.8°}$

$= 1.550(11.75)$

$= 18.207"$

Ext. Pressure

$t_r = 0.4375$

$t_{rn} = 0.045$

For consistency check one side of nozzle:

$A_{req} = 0.5(0.5) t_r d F$

$F = 0.5$ (Full Pen. Welds)

$= .5(.5)(18.207)(.4375)(.5)$

$= 0.9955$

This is less than the area rqd for the longitudinal plane. ∴ longit. controls, this is also true for Int. pressure.

Summary

Nozzle neck	Shell Thickness*
Sched 40S (.375)	0.~~727~~" 0.574
" 80S (.500)	~~0.474~~ 0.455"
0.586"	0.4375 (=tr)
0.423"	0.625"

* Full Penetration welds and Internal Projection Rqd.

NOTE: These nozzles are not present in final FNAL design.

find nozzle thickness allowed for $t_s = 0.625$

$d = 12.75 - 2t_n$

<u>Ext. Press</u>

$$A_{req} = \tfrac{1}{2}(.5\,d\,t_r\,F)$$
$$= \tfrac{1}{2}(.5)(12.75 - 2t_n)(.4375)(1.0)$$
$$= 1.395 - .219\,t_n$$

$$A_1 = (.625 - .4375)\overset{4.68'}{(2 + t_n)}$$
$$= \overset{.478}{\cancel{.375}} + .1875\,t_n$$

$$A_2 = (t_n - .045)\,2.5(t_n)$$
$$= 2.5t_n^2 - .1125\,t_n$$

$$A_3 = 2.5t_n^2$$

$$A_1 + A_2 + A_3 = A_{req}$$
$$\overset{.478}{\cancel{.375}} + .1875t_n + 2.5t_n^2 - .1125t_n + 2.5t_n^2 = 1.395 - .219t_n$$

$$5t_n^2 + .294t_n \overset{-.517}{\cancel{-.602}} = 0$$

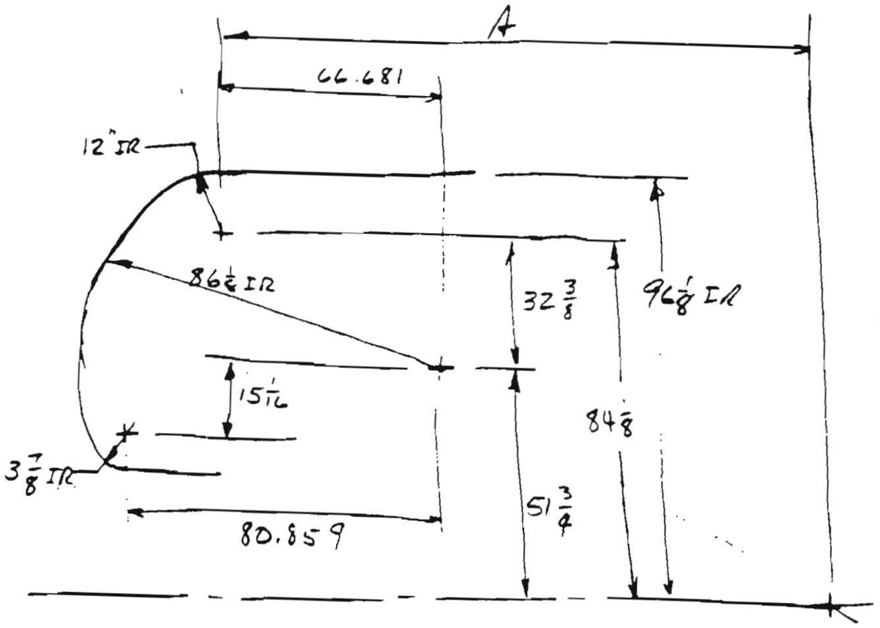
$$t_n^2 + .0588\,t_n \overset{-.103}{\cancel{-.204}} = 0$$

$$t_n = \frac{-.0588 \pm \sqrt{.0588^2 + 4(.204)}}{2}$$
$$= \frac{-.0588 + \overset{.645}{.9052}}{2}$$

$$t_n = \overset{.293"}{\cancel{0.423}}"$$

for $t_s = 0.625"$

Smaller nozzles probably OK since a larger portion of the area will be available in the nozzle neck. If necessary, reinforcing pads can be accommodated at other locations.



$$\frac{A}{84\frac{1}{8}} = \frac{66.681}{32\frac{3}{8}}$$

$$A = 173.268$$

$$L = 12" + \left[A^2 + (84\tfrac{1}{8})^2\right]^{\frac{1}{2}}$$

$$= 12 + \left[(173.268)^2 + (84\tfrac{1}{8})^2\right]^{\frac{1}{2}}$$

$$= 12 + 192.610$$

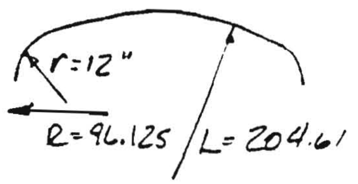
$$= 204.610"$$

72
24.
106
213.

72
30.75
102.75
205.5

7
10
202

CHECK AS A REG. TORISPHERICAL HEAD PER DIV. 1 RULES:



INT P   P=40 psi   E=0.65

$$\frac{r}{L} = 0.0586 = 6\%$$

NO X-RAY

$$t = \frac{0.885PL}{SE - 0.1P} = \frac{.885(40)(204.61)}{18800(.65) - .1(40)} = 0.593"$$

SPOT OR FULL X-RAY HEAD; NO X-RAY ON ATTACH WELD (E=0.80)

$t = 0.482$ (E=0.80)

SPOT OR FULL X-RAY HEAD, SPOT X-RAY ATTACH. WELD (E=.85)

$t = 0.453$ (E=0.85)

FULL X-RAY HEAD & ATTACH WELD (E=1.0)

$t: 0.385$ (E=1.0)

Because the inner cylinder will carry a portion of the axial pressure load, the outer knuckle is not a highly stressed as a std F&D knuckle would be. The magnitude of the load in the knuckle is estimated below.

COMPARE STRESSES IN CC KNUCKLES w/ EC KNUCKLES:
(using results from Battelle NONLYN Runs.)

<u>CC</u>

HOOP MEMB = -14550
HOOP BEND = -4650 (OS)
MER. MEMB. = 2900

MER BEND. = -15850 (OS)

<u>EC</u>

HOOP MEMB. = -20000
HOOP BEND = -7300 (OS)
MER. MEMB. = 4300

MER. BEND. = -25000 (OS)

COMPARISONS:

HOOP MEMB : $\frac{14530}{20000} = \boxed{0.727}$

MER MEMB : $\frac{2900}{4300} = \boxed{0.674}$

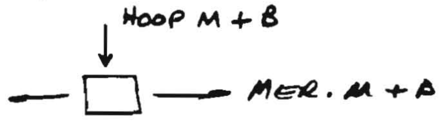
MER. BEND : $\frac{15850}{25000} = \boxed{0.634}$

<u>SUMMARY</u>

RATIOS VARY FROM 63 TO 73%: HENCE, A 40 PSI PRESSURE IN CC PRODUCES STRESSES IN THE KNUCKLE EQUIVALENT TO A PRESSURE OF ABOUT 27 psi. SINCE PLASTIC COLLAPSE WILL PROBABLY CONTROL THE DESIGN, AND PLASTIC COLLAPSE IS RELATED TO MERIDIONAL BENDING STRESSES FOR WHICH THE RATIOS ARE ALL LESS THAN 70%. AN EQUIVALENT PRESSURE OF 0.7x40 = <u>28 PSI</u> WILL BE USED TO SIZE THE KNUCKLE FOR INT. PRESS

STRESS INTENSITIES:

INSIDE SURF



<u>CC</u> S.I. = (MER M+B) - (HOOP M+B)

= (2900 + 15850) - (-4650 - 14530)

= 18750 + 19180

= 37930

<u>EC</u> SI = (4300 + 25000) - (-7300 - 20000)

= 29300 + 27300

= 56600

RATIO = $\frac{37930}{56600} = \boxed{0.670}$

DETERMINE RQD t FOR INT. PRESSURE OF 28 PSI

PER UG-32:

$R = 96.125 \quad L = 204.61 \quad r = 12 \quad P = 28 \quad E = \text{VARIES}$

$S = 18800$

$\frac{r}{L} = 0.06$

$$t = \frac{0.885\,PL}{SE - 0.1P} = \frac{.885(28)204.61}{18800E - .1(28)}$$

$$\boxed{t = 0.415 \quad E = .65}$$

$t = 0.337 \quad E = 0.80$

$t = 0.317 \quad E = 0.85$

$t = 0.270 \quad E = 1.0$

Because the heads are relatively thin ($D/t = 193/.625 = 310$) there is a possibility of buckling or collapse of the knuckle under internal pressure. This is checked on the following pages for operating and test equivalent pressure

CHECK OUTER KNUCKLE
FOR BUCKLING:

Ref.: Galletly, G.D., Buckling and Collapse of Thin Internally-Pressurized Dished Ends, Proc. Instn. Civ. Engrs., Part 2, 1979, 67, Sept., pp 607-626

Elastic Buckling

$$P_{cr} = 100\,E\left[3.7\frac{r}{D} + 0.68\right]\left(\frac{t}{D}\right)^{2.45}$$

$R_s = D_o = 205.0$ $\quad r = 12.625$

$\frac{r}{D} = 0.06$

let $t = 0.415$ $\quad \frac{t}{D} = .00202$ $\quad \frac{D}{t} = 494$

$$P_{cr} = 100\,(28\times10^6)\left[3.7(.06) + .68\right](.00202)^{2.45}$$

$= 632$ psi

For a factor of safety of 4.0

$P_a = \frac{632}{4} = 158$ psi $\gg 42$ OK

Elastic-Plastic — No Strain Hardening

$$P_{cr} = \sigma_{yp}\,\frac{285\left(1 - 125\frac{\sigma_y}{E}\right)\left(r/D\right)^{.84}}{(D/t)^{1.53}(R_s/D)^{1.1}}$$

$\sigma_y = 30$ ksi

$R_s/D = \frac{205.2}{193.5} = 1.06$

$$= \frac{30000\,(285)\left(1 - \frac{125(30)}{28000}\right)(.06)^{.84}}{(494)^{1.53}(1.06)^{1.1}}$$

$= 49.4$ psi

F.S	P
4	12.35
1.18	42
1.76	28

FIND THICKNESSES REQD FOR VARIOUS FACTORS OF SAFETY:

F.S.	REQD P_{cr}	t
4xOPN	114	0.717
3xOPN	84	0.587
1.5xTST	63	0.486

Plastic Collapse

$$P_{cr} = \frac{12.6\sigma_y\left(1+\frac{240\sigma_y}{E}\right)(r/D)^{1.04}}{(D/t)^{1.09}\,(R_s/D)^{.79}}$$

for $\underline{\underline{t=0.625}}$ $D_o/t = 328.3$

$$P_{cr} = \frac{12.6(30000)\left(1+\frac{240(30)}{28000}\right)(.06)^{1.04}}{(328.3)^{1.09}\,(1.06)^{1.1}}$$

$= \underline{\underline{43.21 \text{ psi}}}$

$F.S. = \frac{43.21}{28.}$ $\underline{\underline{1.54}}$ OPN.

$\underline{\text{TEST } P} = 1.5 \times 30 + \frac{17}{34}(14.7) = 52.5$ psi

$F.S. = \frac{43.21}{28\left(\frac{52.5}{40}\right)} = \underline{\underline{1.18}}$ $\underline{\underline{\text{OK}}}$

Check $t=0.415$

$D/t = 494$

$P_c = 27.68$ psi

∴ F.S. = 1.0 ON OPERATING. !!

FIND t RQD FOR RQD F.S.

F.S.	P_{cr} RQD	t
4.0 ON OPN	112	1.50
3.0×OPN	84	1.15
2.0×OPN	56	0.792
1.5×TST	63	0.883
	30	0.447

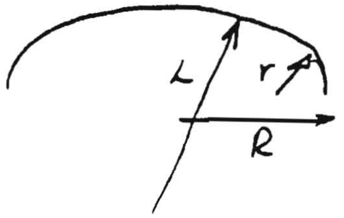
USE 5/8" OUTER KNUCKLE

SIZE HEAD BY DIV. 2 RULES

$P = P_{op} = 28$ psi

$P_{TEST} = 1.5 \times 30 + \frac{17}{34}(14.7) = 52.5$

$P_{Teq} = 28\left(\frac{52.5}{40}\right) = 36.75$



$L = 204.6$

$r = 12$

$D = 192.25$

S = membrane stress intensity limit

Use S from Div. 1 multiplied by the joint efficiency, E.

$SE = 18800\,E$

$= 18800\,(.65)$

$= 12220$ psi

Per A-433

$P/S = \frac{28}{12220} = .002291$ OPN.

$= \frac{36.75}{1.25(12220)} = .002411$ TEST

Test Controls

$y = \log(P/S) = -2.6187;$ ①

$y^2 = 6.8577$ ②

$x = \frac{r}{D} = \frac{12}{192.25} = .06242$ ③

$x^2 = .0038961$ ④

$$A = a_1 + a_2 x + a_3 x^2 + (b_1 + b_2 x + b_3 x^2) y + (c_1 + c_2 x + c_3 x^2) y^2$$

$A = -2.4513$

$\frac{t}{L} = 10^A$

$t = L(10)^A$

$= 204.6(10)^{-2.4513}$

$= \underline{0.7238"}$

Check Opn.

$P/S = \frac{28}{12220} = .002291$

$y = \log(P/S) = -2.6399$ ①

$y^2 = 6.9691$ ②

$x = .06242$ ③

$x^2 = .0038961$ ④

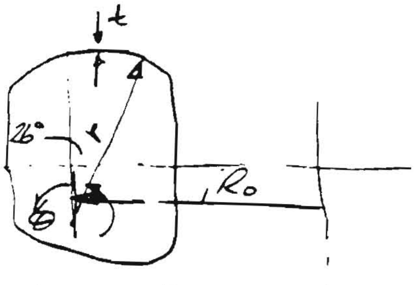
$A = -2.4685$

$t = 204.6(10)^{-2.4685}$

$= \underline{0.697"}$ CLOSE ∴ 5/8" OK

CROWN - INT. PRESSURE

Under internal pressure the crown behaves like a torus. The hoop stress in a torus can be calculated by:



$$\sigma = \frac{Pr}{2t}\ \frac{2R_0 + r\sin\theta}{R_0 + r\sin\theta}$$

$$\sigma = \frac{40(86.75)}{2t}\ \frac{(2)(51.75)-37.85)}{51.75-37.85}$$

$$= \frac{40(86.75)}{2t}\ (4.72) < 0.65(18800)$$

$r = 86\frac{3}{4}$

$R_0 = 51\frac{3}{4}$

$\theta = 360 - 26° = 334°$

$r\sin\theta = 37.85$

$$t = \frac{40(86.75)\ \ (4.72)}{2(.65)(18800)}$$

$$= 0.670''$$

This formula appears to be overly conservative based on BATTELLE's STRESS RESULTS which indicate that membrane hoop and meridional stresses are both on the order of 5000 psi. The required thickness can be estimated by allowing these stresses to approach SE, the basic Div. I allowable.

$$\frac{Pr}{2t} = 5000 \qquad \frac{Pr}{2t_{req}} < 18800(.65) = 12220$$

$$t_r = t\left(\frac{5000}{12220}\right)$$

$$= 0.625\left(\frac{5000}{12220}\right)$$

$$= 0.256''$$

Check Per 1-6(g) for dished heads:

$$t = \frac{5PL}{6S} = \frac{5(40)(88)}{6(18800)} = 0.156.$$

$\therefore$ $\boxed{t_r = 0.256'' \text{ For Int. Pressure}}$ Check for 15 psi Ext. Pressure.

CROWN - EXTERNAL PRESSURE.

The most likely mode of failure of the heads under external pressure is asymmetric buckling. Per WRC Bulletins 119 and 227 (below) this mode of failure is related to knuckle stresses and deformations. Table 7 of WRC-227 indicates that an equivalent torispherical head ($D_o = 193.5$, $t = 5/8"$, $L = 204"$, $r/L = 0.06$) would probably collapse at the onset of yielding in the knuckle region. The Bulletin uses the Von Mises criterion. For convenience we will use the maximum shear stress theory which will be slightly conservative.

From the Battelle report (Table 5, p18) the maximum stress intensity in either knuckle is 38.5 ksi for an internal pressure of 40 psi. Assuming linearity, the external pressure required to produce yielding in the knuckle ($S.I. = 30$ ksi $= S_y$) is:

$$P_{ext} = 40\left(\frac{30}{38.5}\right) = 31.2 \text{ ksi} = \text{Critical Buckling Pressure.}$$

Note that this collapse pressure is less than that predicted by Equation 8 of WRC-227 when a value of $L = 206"$ is used:

$$P_c = 30000 \cdot 10^{\left(1.188 - 1.437 \log \frac{1}{.0031} + .355 \log .06\right)}$$

$$= 42.8 \text{ psi}$$

The minimum critical pressure is greater than 30 psi which is the lab minimum for safety. Therefore, a knuckle thickness of 5/8" will ensure that yielding does not occur at 30 psi, preventing asymmetric buckling of the crown. The crown must also be sized to prevent collapse of the crown assuming a clamped edge. This is done in Battelle's report on sheet D0-CC-04 where a critical pressure of ≈80 psi is determined. Since there appears to be some excess thickness in the crown, Battelle's procedure

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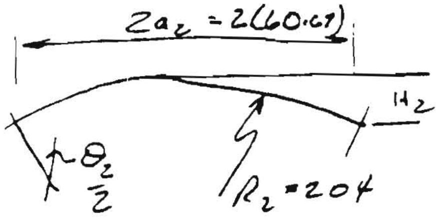
WRC-119 - Stemper, R.J., and Washington, C.E., "Interpretations of Experimental Data on Pressure Vessel Heads Convex to Pressure."

WRC-227 - Washington, C.E., et al, "Tests of Torispherical Pressure Vessel Heads Convex to Pressure", June, 1977 will be used to minimize the crown thickness:

(Ref. Huang, N-C, "Unsymmetrical Buckling of Thin Shallow Spherical Shells," ASME Transactions, Journal of Applied Mechanics, 1964.



$$2a_2 = 60.67(2) = 121.3''$$

$$\frac{\theta_2}{2} = \sin^{-1}\frac{2a_2}{2R_2} = \sin^{-1}\left[\frac{121.3}{2(204)}\right] = 17.3°$$

$$H_2 = R_2\left(1-\cos\frac{\theta_2}{2}\right) = 204(1-\cos 17.3)$$
$$= 9.23''$$

$$\lambda_2 = 2\left[3(1-\nu^2)\right]^{1/4}\left(\frac{H}{t}\right)^{1/2}$$
$$= \underset{2.5708}{2\left[3(.91)\right]^{.25}}\sqrt{\frac{9.23}{t}}$$

$$q_0 = \frac{2Et^2}{R^2\sqrt{3(1-\nu^2)}} = \frac{2(28\times10^6)\,t^2}{(204)^2\sqrt{3(.91)}}$$
$$= 814.4\,t^2$$

try $t = 0.256$

$\lambda_2 = 15.43$ Too large., $\frac{q_{cr}}{q_0} \approx .15$

$$q_{cr} = .15(814.4)(.256)^2$$
$$= 8.0 \text{ psi}$$ No Good

$t = 0.375$

$\lambda_2 = 12.75$ $\frac{q_{cr}}{q_0} \approx 0.2$

$$q_{cr} = 0.2(814.4)(.375)^2$$
$$= 23 \text{ psi} < 30 \text{ psi}$$ No Good

$t = 0.4375$

$\lambda_2 = 11.8$ $\frac{q_{cr}}{q_0} \approx 0.25$

$$q_{cr} = 0.25(814.4)(.4375)^2$$
$$= 40 \text{ psi}$$ OK > 30 psi

Also check per ASME for spherical shell.

App. D of the Code states that the critical buckling pressure for a spherical shell is equal to:

$$\sigma_{cr} = \frac{P_{cr} R_o}{2t} = 0.125 \frac{Et}{R_o}$$

$R_o = 204.6$

$E = 28 \times 10^6$

for $P_{cr} = 30$ psi, solve for t

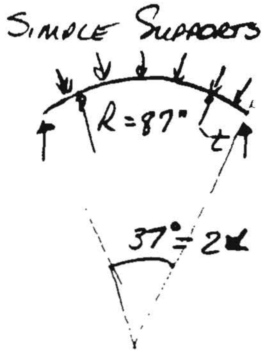
$$\frac{30(204)}{2t} = .125 \frac{(28\times10^6)\,t}{204}$$

$$t^2 = \frac{30(204)^2}{2(.125)(28\times10^6)}$$

$$t = 0.422''$$

Check stability of a curved panel:

(Ref: Roarke, 4th Ed, p.354, case 33. Based on Timoshenko, "Theory of Elastic Stability", McGraw-Hill, 1936.)



$$p_{cr} = \frac{Et^3\left(\frac{\pi^2}{\alpha^2}-1\right)}{12r^3(1-\nu^2)} \geq 30\text{psi}$$

$$t = \left[\frac{30(12)(87)^3(1-.3^2)}{28\times10^6\left(\frac{\pi^2}{(.323)^2}-1\right)}\right]^{\frac{1}{3}}$$

$$\alpha = \frac{37^\circ}{2} = 0.323 \text{ RAD}$$

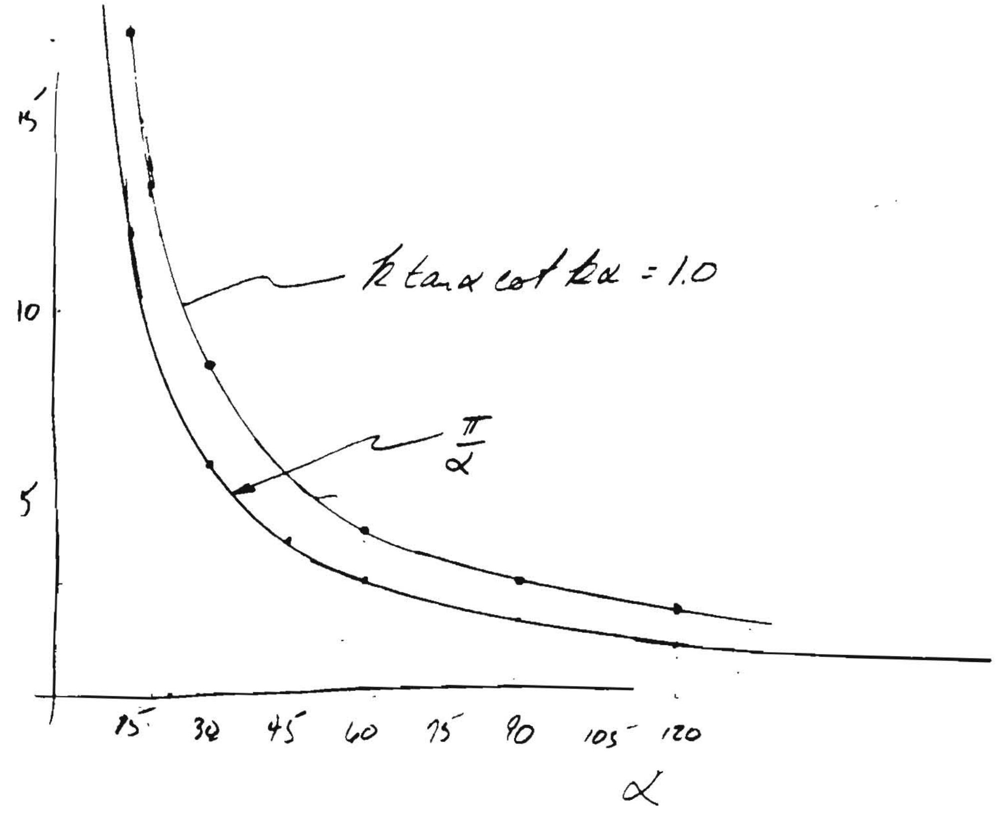
$$\underline{\underline{t = 0.435''}}$$

for a Safety Factor of 4.0 (ASME), $P_{cr} = 4(15) = 60$

$t = 0.563''$

use 5/8" CROWN.

Check a clamped curved panel (Roarke, case 34):



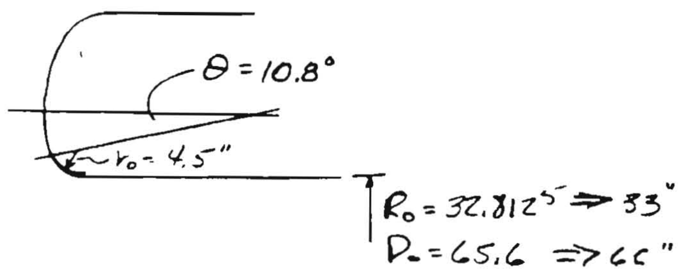
α = 18.5°	k	k tan α cot kα
	13.2	2.135
	10	36.91
	13.5	1.667
	13.8	1.21
	14.0	.91
20°	12	25
	13	.833
	12.[illegible]	[illegible]
	[illegible]	[illegible]

$$\frac{\overset{28\times10^6}{\cancel{E}}\, t^3(13.8^2-1)}{12(87)^3(.91)} = 30$$

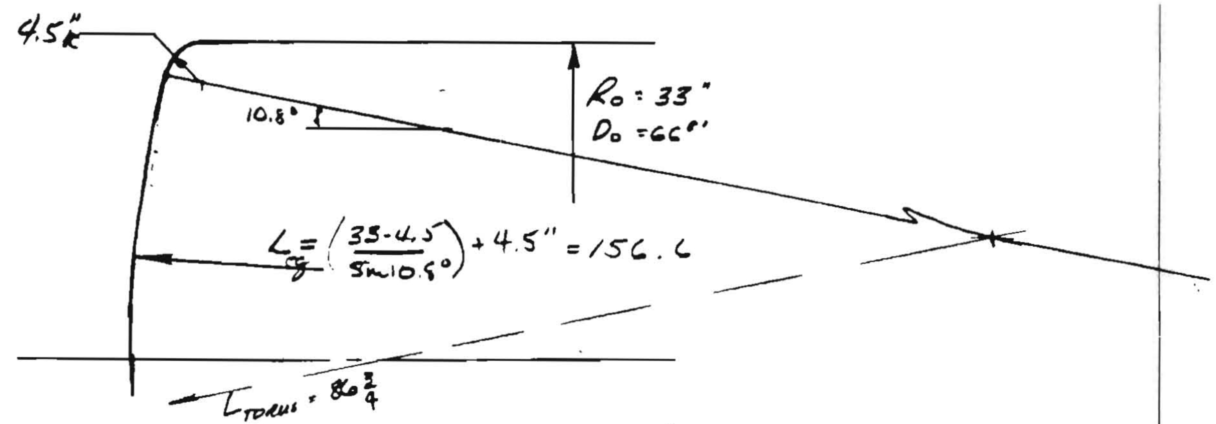
$$t^3 = \frac{30(12)(87)^3(.91)}{28\times10^6(13.8^2-1)}$$

$$t = 0.344''$$

Since the knuckles will allow a fair amount of edge rotation, the critical pressure will likely be closer to the hinged case. Therefore, the min t for the crown will be set at 7/16".



Equivalent torispherical shell



$\frac{r}{L} = \frac{4.5}{156.6} = 0.029 \Rightarrow$ 2.9% Knuckle → Very Sharp.

for $\frac{t}{L} = .008$, $t = 1\frac{1}{4}"$ $\qquad \frac{r}{D_o} = \frac{4.5}{66} = .068 \qquad \frac{t}{L} = \frac{.625}{156.6} = .0040$

The knuckle is very sharp which will lead to high bending and circumferential stresses. Battelle's stress results show a max. stress intensity of 38.5 ksi in the knuckle for an internal pressure of 40 psi. This value is less than the quantities 4SE (4(.65)(18.8) = 48.9 ksi) and 3Sm (3(20) = 60 ksi) and is considered acceptable. The maximum membrane stress intensity (which is equal to the max membrane stress in this instance) from Battelle's Report is about 18 ksi (hoop tension) which is less than 1.5SE (18.3 ksi) and is also acceptable. Since both values are close to the Div. 1 allowables (especially the membrane stress) it does not appear that reducing the thickness of this knuckle is advisable.

For external pressure it was shown above that the critical pressure for buckling of the crown is not at the pressure at which the knuckle yields. For the 5/8" knuckle this was shown to be 31.2 psi which is just above the minimum critical p of 30 psi required by the Lab.

Buckling of the inner knuckle will be checked using Drucker's formula. First the equivalent pressure for the fictitious head (shown on the previous page) must be determined.

From Battelle's Report the axial stress in the inner cylinder under 40 psi internal pressure is 2200 psi. The axial force in the inner cylinder under 15 psi external pressure would be:

$$N_\phi = 2200 \frac{lb}{in^2} \times \frac{7}{16}(in)\left(\frac{-15}{40}\right)$$

$$= -361 \frac{lb}{in}$$

The equivalent internal pressure in the fictitious cylinder is:

$$P_{eq} R_{eq} = N_\phi$$

$$P_{eq} = \frac{361}{33} = 10.94 \text{ psi} \quad \text{use } 11 \text{ psi}$$

Drucker's Formula:

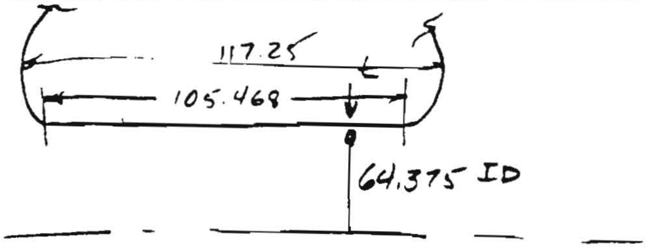
$$n P_{eq}^{D} = 30000\left[(1.33 + 5.5(.068)).004 + 28(1 - 22(.068))(.004)^2 - .0006\right]$$

$$n P_{eq}^{D} = 78 \text{ psi}$$

The corresponding external collapse pressure for the torus knuckle is:

$$n P^{D} = 78\left(\frac{15}{11}\right) = \underline{\underline{106 \text{ psi}}}$$

$$n = \text{factor of safety} = \frac{106}{15} = \underline{\underline{7.1}} \quad \underline{\underline{OK}}$$



TAN LENGTH = 2(80.959 - 29.125)
= 105.468

$L = 105.468 + \frac{1}{3}(117.25 - 105.468)$

$= 109.395$

Pressure @ bottom of cyl.

$P = 15 + \text{head} + 15$

$= 30 + \text{head}$

$\text{head} = \frac{(1\,\text{sq in}) \times \text{depth} \times \gamma \times 62.4}{1728}$

$= \frac{(1)\left(\frac{193.5}{2} + \frac{64.375}{2}\right)(1.4)(62.4)}{1728}$

$= \frac{128.94''(1.4)(62.4)}{1728}$

$= 6.52\,\text{psi} \Rightarrow 7\,\text{psi}$

$P = 37\,\text{psi}$

Int P.
$t = \frac{37(32.19)}{13800(.65) - .6(37)}$
$= .098''$

~~try $t = 3/8''$~~

$\frac{L}{D_o} = \frac{109.395}{64.375 + .375} = 1.689$

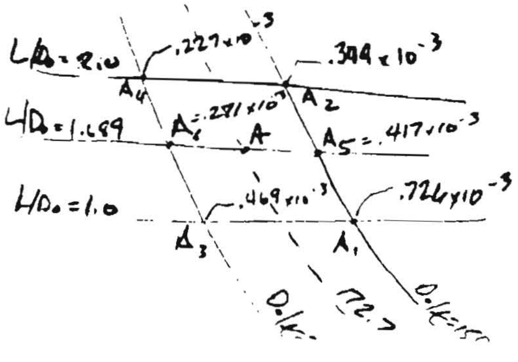
$\frac{D_o}{t} = \frac{64.75}{.375} = 172.7$

$A = .00033$

$B = 4700$

$P_a = \frac{4(4700)}{3(172.7)} = 36.3$

TRY ANALYTICAL INTERPOLATION



$A_5 = A_1\left(\frac{A_2}{A_1}\right)^{\left(\frac{\log 1/1.689}{\log 1/2}\right)}$

$= .726\times10^{-3}\left(\frac{.349}{.726}\right)^{\left(\frac{\log 1/1.689}{\log 1/2}\right)}$

$= 0.417\times10^{-3}$

$A_6 = .469\times10^{-3}\left(\frac{.227}{.469}\right)^{\left(\frac{\log(1/1.689)}{\log 1/2}\right)}$

$= 0.271\times10^{-3}$

$A = .417\times10^{-3}\left(\frac{.271}{.417}\right)^{\frac{\log(150/172.7)}{\log(150/200)}}$

$= 0.338\times10^{3}$

$A_1 = .01\times10^{-3}$ $B_1 = 140$
$A_2 = .463\times10^{-3}$ $B_2 = 6590$

$B = 140\left(\frac{6590}{140}\right)^{\frac{\log .01/.338}{\log .01/.463}}$

$= 4804$

$P_a = \frac{4}{3}\frac{(4804)}{(172.7)}$

$= 37.1\,\text{psi} > 37$ OK

Check axial comp under ext press.
$\sigma = \frac{PR_o}{2t} = \frac{15(33)}{2(.375)} = 660\,\text{psi}$

$A = \frac{.125t}{R_o} = .00142$

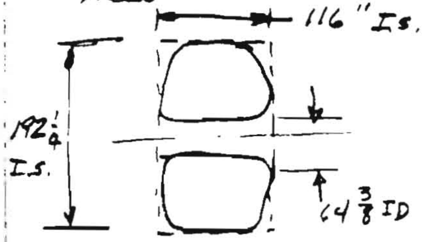
$B = 10000 >> 660$ OK

3/8" PLATE OK

WTS

CC INNER VESSEL - 23000 (E.N. 39)

ARGON



$$Vol = \frac{\pi}{4}\frac{(192\tfrac{1}{4}^2 - 64.375^2)116}{1728} = 1730\ ft^3$$

$$wt = \gamma \times Vol = 1.4(62.4)(1730)$$

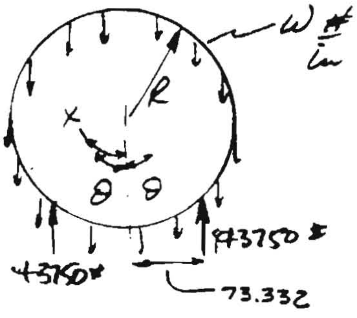
$$= 151100\ \#$$

TOTAL WT:

shell	23000
Argon	151000
Insul. etc.	1000
	175000 #

Look at the stiffening rings with a length of shell. Most of the load is transferred into the ring from the remainder of the vessel by shear. Initially (and conservatively) look at a ring loaded by its own weight (Ref. Roarke, 4th Ed, p 176 Case 19): (SUBSEQUENT ANALYSES INDICATED THAT RESULTS FOR BY SHEAR RATHER THAN WEIGHT (ROARKE, CASE 25) ARE ONLY A FEW PERCENT LOWER.)

For each of 2 rings:



$$w\ \frac{\#}{in} = \frac{175000\ \#}{2\pi R\ (2)}$$

$$= \frac{175000}{2\pi(96.125)(2)}$$

$$= 144.9\ \frac{\#}{in}$$

$$\theta = \sin^{-1}\frac{73.332}{R}$$

$$\theta = 49.72° = 0.868\ RAD$$

$s = \sin\theta = 0.763$

$c = \cos\theta = 0.647$

$z = \sin x \quad u = \cos x$

$$R = \frac{192.25}{2} = 96.125$$

$$M_1 = M_{x=0} = wR^2(\tfrac{1}{2} + c + \theta s - \pi s + s^2) \quad -.005582$$

$$T_1 = wR(s^2 - \tfrac{1}{2})$$

Previous work showed that max values occur at the load and at about 93°.

$$M_x = M_1 - T_1R(1-u) + wR^2(xz + u - 1 - \pi z + \pi s) \qquad \underbrace{-s^2 - us^2 + \tfrac{1}{2}u - \tfrac{1}{2}}$$

$$= wR^2\left[\tfrac{1}{2} + c + \theta s - \pi s + s^2 + xz + u - 1 - \pi z + \pi s\right] - wR^2(1-u)(s^2 - \tfrac{1}{2})$$

$$= wR^2\left[c + \theta s + xz - \pi z + \tfrac{1}{2}u + us^2\right]$$

$$M_x = wR^2\left[c + \tfrac{1}{2}u + xz - \pi z + \theta s + us^2\right]$$

$$= wR^2\left[.647 + \tfrac{1}{2}(\cos x) + x\sin x - \pi\sin x + .662 + .582\cos x\right]$$

$$= wR^2\left\{1.309 + 1.082\cos x - (\pi - x)\sin x\right]$$

<u>at load</u> $(x = \theta)$

$$M = wR^2(1.309 + 1.082(.647) - (\pi - .868)(.763))$$

$$= wR^2(0.2743)$$

@ $x = 93° = 1.623$ RAD.

$$M = wR^2(1.309 + 1.082\cos 93° - (\pi - 1.623)\sin 93°)$$

$$= wR^2(-.2641)$$

@ $x = 0°$

$$M = M_1 = wR^2(\tfrac{1}{2} + .647 + .868(.763) - \pi(.763) + (.763)^2)$$

$$= wR^2(-.00558)$$

<u>AXIAL LOADS</u>

$$T = wR\left[u(s^2 - \tfrac{1}{2}) - (\pi - x)z\right]$$

$$= wR\left[.082\cos x - (\pi - x)\sin x\right]$$

@ load $x = 49.72°$

$T = wR(-1.682)$

@ $x = 93°$

$T = wR(-1.521)$

@ $x = 0°$

$T = T_1 = wR(.082)$

For $w = 144.9$
$R = 97.625$

$x = 49.72$
$T = -23793$ #

$x = 93°$
$T = -21516$ #

$x = 0$
$T = 1160$ #

For the supports, internal pressure is likely to be the controlling condition since the vessel will be empty when it is evacuated.

The membrane hoop stress in the cylinder due to pressure is:

$$\sigma_p = \frac{PR}{t} = \frac{40(96.125+.3125)}{.625} = 6172 \text{ psi}$$

At nozzle locations the stress is higher due to dilation of the opening. Since the Code design attempts to limit local stresses to 1.5S, assume that the hoop stress at openings is 1.5 x 6172 = 9260 psi. The allowable membrane hoop stress is given in U6-23(E) as S. In addition the weld joint efficiency must be considered. Since the stress will vary significantly around the circumference, the value of E used will be dependent on the location. At Category A welds a value of SE = 18800 x .65* = 12200 psi will be used. At other locations away from openings a value of 18800 x .80* = 15040 psi will be used. At openings the stress will be considered to be local and the allowable value will be taken as 1.5 x 18800 x .8 = 22560 psi. Allowable stresses for the support loads only will be equal to the above values less the membrane pressure stress:

	MEMB. HOOP ALLOW. STRESS.	
LOCATION	PRESS + SUPPORT	SUPPORT ONLY
NOZZLES	22560	22560 - 9260 = 13300
SHELL	15040	15040 - 6180 = 8860
CAT. A. WELD	12200	12200 - 6200 = 6000

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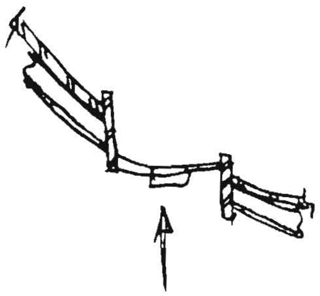
* These values reflect no radiography.

AT THE SUPPORT NOZZLE



THE MOMENT IS SUCH THAT THE SHELL SIDE IS IN TENSION. THEREFORE, THE INCREASED MEMBRANE STRESS IN THE SHELL MUST BE LESS THAN

22560 − 9260 = 13300 PSI.

$$\frac{M}{S} \le 13300 \text{ PSI}$$

$$S > \frac{wR^2(.2743)}{13300}$$

$w = 144.9$ #/in

$R = 96.125 + 1.5$ (conservative)
$= 97.625$

$$S_{SH} \geq \frac{144.9(97.625)^2(.2743)}{13300}$$

$$S_{SH} \geq \frac{378805}{13300}$$

$$\underline{\underline{S_{SH} \geq 28.5 \text{ in}^3}}$$

Cover PLATE:

Stress in the cover plate due to bending will be limited to 0.66Fy per AISC: .66(30) = 20 ksi less 1200 psi to = 18.8 ksi acct for axial comp. (see next sh.

$$S_C \geq \frac{M}{S} = \frac{378805}{18800} = \underline{\underline{20.15 \text{ in}^3}}$$

In order to use this allowable stress the width/thickness ratio for the compression flange (cover plate) must be less than $190/\sqrt{F_y}$ (sec. 1.5.1.4.1 of AISC)

$$\frac{w}{t} < \frac{190}{\sqrt{F_y}}\ ; \quad t \geq \frac{15.75\sqrt{30}}{190}$$

$$t \geq 0.454$$

∴ 1/2" cover plate req'd near support NOZZLES.

<u>at $x = 93°$</u> ($M = Max$) $M = .2641\, wR^2$

The moment is such that the shell side is in compression. Hence, the stress will be maximized when the internal pressure is zero. The resulting shell allowable stress will be <u>15040 psi</u>.

$$M = 0.2641\, \omega R^2$$

$$= .2641(144.9)(97.625)^2$$

$$= 364720 \text{ in-lb}$$

$$S_{SH} \geq \frac{364720}{15040}$$

$$S_{SH} \geq 24.25 \text{ in}^3 \quad (\text{See below})$$

For <u>The Cover Plate</u>. $S_{allow.} = .66(30) = 20 ksi$

$$S_e \geq \frac{364720}{20000}$$

$$\underline{\geq 18.24 \text{ in}^3}$$

Assuming An Area For the stiffener of 21 in^2

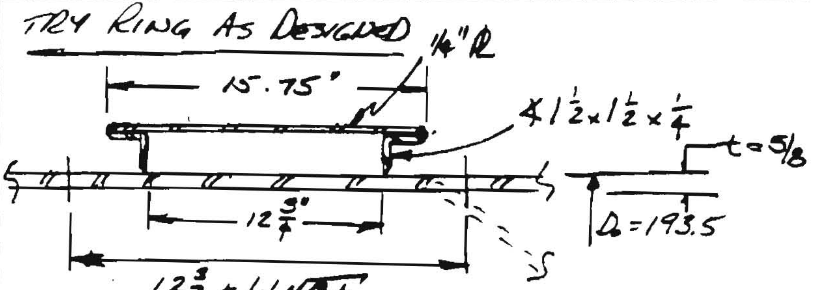
$$f_a = \frac{T}{A} = \frac{-21516}{21} = -1025 \text{ psi}$$

Since this is compressive it acts to reduce the stress in the cover plate and increase the stress in the shell.

$$S_H = \frac{364720}{15040 - 1025}$$

$$\underline{= 26.02 \text{ in}^3 \text{ RQD}}$$

TRY RING AS DESIGNED



$12\frac{3}{4} + 1.1\sqrt{D_o t}$

$= 12.75 + 12.1$

$= 24.85$

(Note that the additional stiffness provided by the head knuckle has not been considered except in that the shell has been assumed to extend beyond the joint for the calculations below.)

	A	y	Ay	Ad²	Io
shell	15.53	.3125	4.854	3.213	.506
Angle webs	.75	1.375	1.031	0.381	.141
" Flanges	.625	2.0	1.25	1.899	—
Cover ℞	3.938	2.25	8.859	8.657	.021
	20.843		15.994	I = 14.816 in⁴	

$\bar{y} = \frac{15.994}{20.843} = 0.767$

$S_1 = \frac{14.816}{.767} = 19.317$ (Shell SIDE)

$S_2 = \frac{14.816}{(2.375 - .767)} = 9.214$ (Cover ℞ SIDE)

No Good .!!

TRY 1/2" Cover plate

	A	y	Ay	Ad²	Io
SHELL	15.53	.3125	4.854	8.280	.506
ANGLE WEBS	.75	1.375	1.031	.083	.141
" FL.	.625	2.0	1.25	.573	—
Cover PL	7.875	2.375	18.703	13.978	.164
	24.780		25.838	I = 23.725	

$\bar{y} = \frac{25.838}{24.780} = 1.0427$

$c_{SHELL} = 1.0427 - \frac{.625}{2} = .7302$

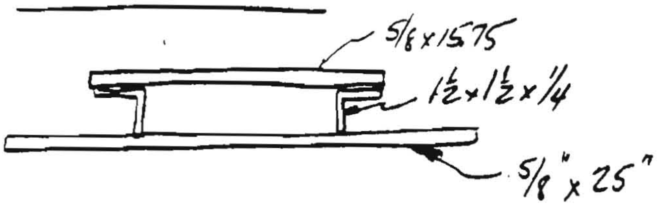
for membrane shell stress

$S_{SH} = \frac{23.725}{.7302} = 32.49\ in^3$ OK

$S_C = \frac{23.725}{2.625 - 1.0427} = 14.99\ in^3$

No Good

TRY 5/8" Cover R.



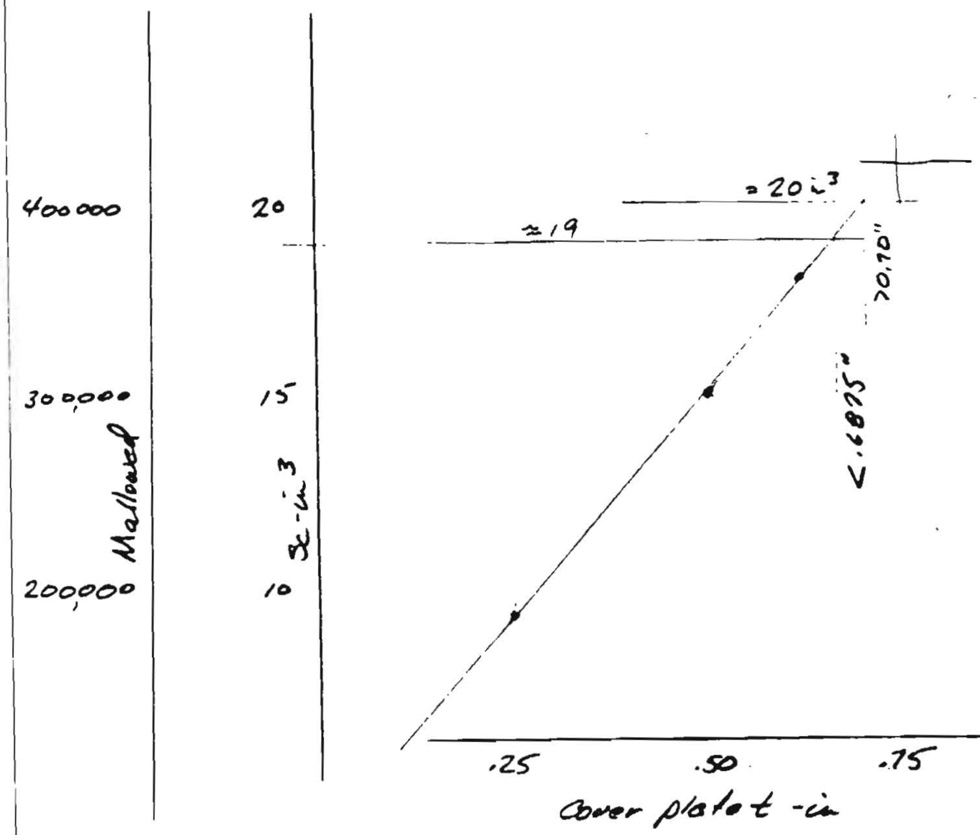
	A	y	Ay	Ad^2	I_o
SHELL	15.625	.3125	4.883	11.242	.5
WEBS	.75	1.375	1.031	.034	—
FLANGES	.625	2.0	1.25	.440	—
Cover R.	9.844	2.438	23994	16.060	.3
	26.844		31.158		

$I = 28.576$

$\bar{y} = \frac{31.158}{26.844} = 1.1607$

$S_{SH} = \frac{28.576}{1.1607 - .3125} = 33.69$ OK

$S_c = \frac{28.576}{2.75 - 1.1607} = 17.98$



3/4" WILL HAVE $S \approx 21\ in^3$

∴ use 3/4" Cover R
in area of support
nozzle and around
to a point above the
equator at which
a ¼" R is adequate.
(See next page)

PLOT MOMENTS VS. CIRC. ANGLE TO DETERMINE COVER PL THICKNESS POINTS:

$0 \leq x \leq \theta$ $\quad M_x = 144(97.625)^2\left[1.082\cos x + x\sin x - 1.088\right]$

$\theta \leq x \leq \pi$ $\quad M_x = 144.9(97.625)^2\left[1.309 + 1.082\cos x - (\pi - x)\sin x\right]$

x	M	x	M	x	M
0	-8240	55	196790	120	-191820
5	-3447	60	50000	125	-135250
10	10800	65	-72920	130	-75950
15	34160	70	-172650	135	-15810
20	66060	75	-250110	140	43350
25	105720	80	-306480	145	99850
30	152120	85	-343110	150	152130
35	204078	90	-361540	155	198830
40	260225	93	-364560	160	238725
45	319020	95	-363460	165	270825
49.72	375440	100	-350690	170	294330
50	368890	105	-325140	175	308670
		110	-288790	180	313490
		115	-243670		

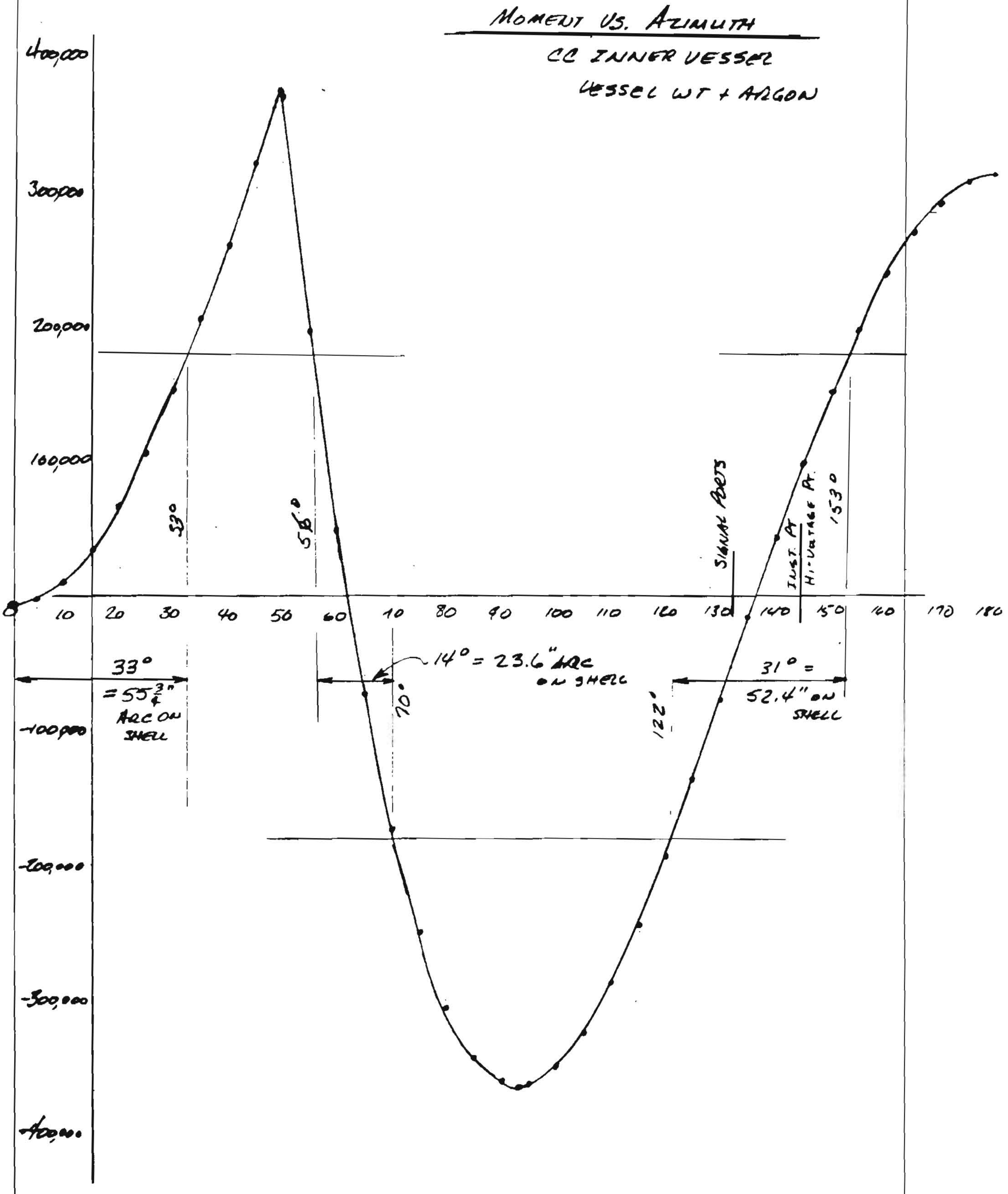
(PLOTTED ON NEXT PAGE)

FOR A 1/4" COVER PL $S \approx 9.0$

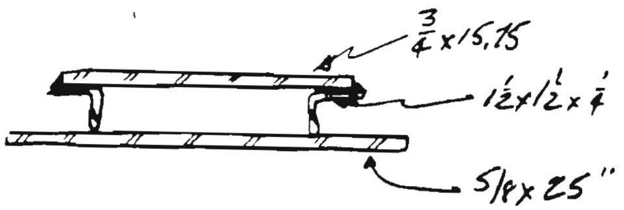
$$20000 \geq \frac{M}{9.0}$$

$$M \leq 180{,}000$$

PLOT ON NEXT PAGE SHOWS THAT THE 1/4" COVER PLATE COULD BE USED ON SMALL AREAS ONLY. THEREFORE, THE COVER PLATE WILL BE THE SAME THICKNESS ALL AROUND.


MOMENT VS. AZIMUTH
CC INNER VESSEL
VESSEL WT + ARGON
400,000
300,000
200,000
100,000
0
-100,000
-200,000
-300,000
-400,000
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
33°
58°
SIGNAL PORTS
INST. PT.
HI-VOLTAGE PT.
153°
33° = 55 3/4" ARC ON SHELL
14° = 23.6" ARC ON SHELL
70°
122°
31° = 52.4" ON SHELL

USE 3/4" COVER PLATE.



	A	y	Ay	Ad²	I₀
SHELL	15.625	.3125	4.883	14.433	.5
WEBS	.75	1.375	1.031	.008	—
FL.	.625	2.0	1.25	.330	—
COVER PL	11.813	2.50	29.533	17.767	.55
	28.813		36.697	I = 33.588	

$\bar{y} = \frac{36.697}{28.813} = 1.2736$

$R = 96.125 + 1.274$
$= 97.4"$

$S_{SHELL} = \frac{33.588}{1.2736 - .3125} = \underline{\underline{34.95}}\ in^3$ (MEMB. STRESS IN SHELL)

$S_{COVER} = \frac{33.588}{2.875 - 1.2736} = \underline{\underline{20.97\ in^3}}$

$\underline{\underline{OK}}$

<u>CHECK SHEAR</u>

The maximum shear occurs @ the load.
$x = \theta$

$$V = -T_1 z + wR(xu - \pi u)$$
$$= -wR(s^2 - 1/2)z + wR(xu - \pi u)$$
$$= wR\left[(\theta - \pi)\cos\theta - \sin\theta(\sin^2\theta - \tfrac{1}{2})\right]$$
$$= wR(-1.534)$$
$$= 144.9(96.125 + 1.274)(-1.534)$$
$$= -21650\ \#$$

$$f_v = \frac{-21650}{2(1/4)(2.875)} = 15100\ psi$$

ALLOWABLE SHEAR:
$V = 12000(2)(.25)(2.875)$
$= 17250$

$F_v = 0.4F_y = 0.4(30000) = 12000 < 15100$ No Good!

Find width Rqd:

$$w = \frac{21560}{2(2.875)(12000)} = 0.3125 \Rightarrow 5/16$$

PLOT THE VARIATION OF THE SHEAR FORCE & DETERMINE WHERE DESIGN IS GOOD.

PLOT SHEAR

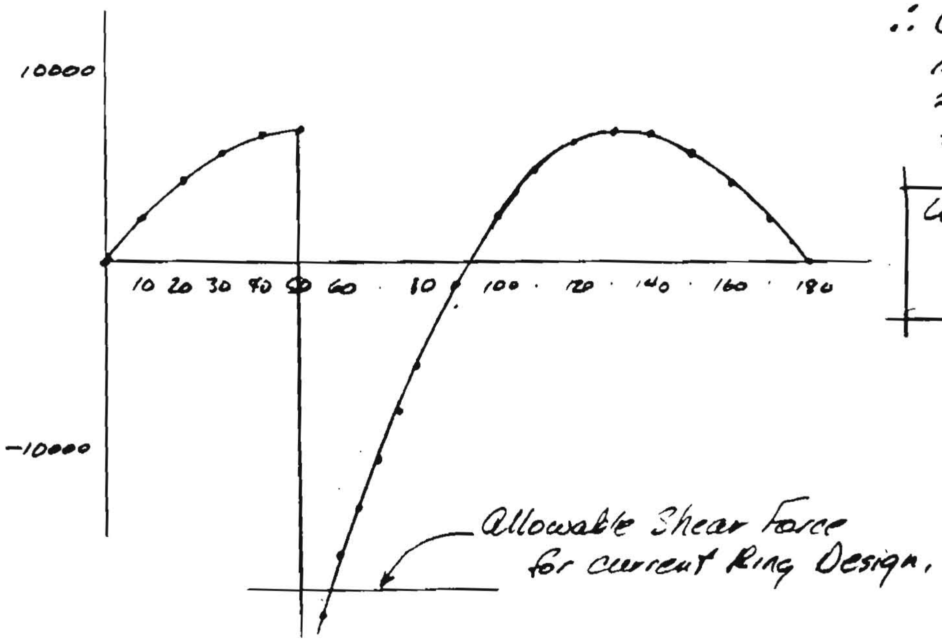
$0 \le x \le \theta$

$$V = wR\left(xu - z\left(s^2 - \tfrac{1}{2}\right)\right)$$
$$= wR\left(x\cos x - \sin x\left(\sin^2\theta - \tfrac{1}{2}\right)\right)$$
$$= wR(x\cos x - .082\sin x)$$
$$= (144.9)(96.125 + 1.25)(x\cos x - .082\sin x)$$

$\theta \le x \le \pi$

$$V = wR\left[(xu - \pi u) - z\left(s^2 - \tfrac{1}{2}\right)\right]$$
$$= wR\left[(x - \pi)\cos x - .082\sin x\right]$$
$$= (144.9)(96.125 + 1.25)\left((x - \pi)\cos x - .082\sin x\right)$$

x	V	x	V	x	V
0	0	65	-13017	135	7018
5	1126	70	-10352	140	6802
10	2224	75	-7810	145	6397
15	3269	80	-5416	150	5820
20	4232	85	-3192	155	5091
25	5091	90	-1157	160	4232
30	5820	95	672	165	3269
35	6397	100	2282	170	2224
40	6802	105	3663	175	1126
45	7018	110	4809	180	0
49.72	7033 -21625	115	5716		
50	-21464	120	6386		
55	-18604	125	6821		
60	-15778	130	7028		



∴ Additional Strength is required only for ≈ 10° (≈18") above the support nozzle.

USE THICKER COVER PL FOR 18-24" ABOVE THE SUPPORT NOZZLES

CHECK WELD SIZE FOR COVER R.

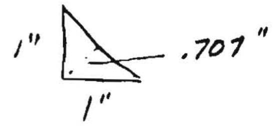
Allowable weld size per AISC

$\tau_{allow} = 0.3 \times$ Nom. Tensile Strength of the weld metal

or

$\tau_{allow} = 0.4 F_y$ of base metal.

for a 1" fillet

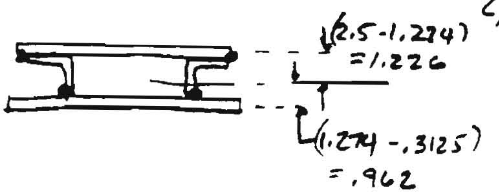


$\tau_{Throat} = \dfrac{\text{SHEAR FORCE}}{0.707 \times \text{length}} < 0.3\ T.S.$

for E308/E309 welds - MTS = 80 ksi

SHEAR < .707(.3)(80)(length)

< 17 K



$\tau_{Base\,Metal} = \dfrac{\text{SHEAR}}{1'' \times \text{length}} < 0.4(30)$

SHEAR < 12 ksi Controls

f = 12.0 K per in per in of weld size

$W = \dfrac{VQ}{nI}$

TOP

$W = \dfrac{21.650(3/4)(15.75)(2.226)}{(2)(33.59)}$

= 4.67 K/in

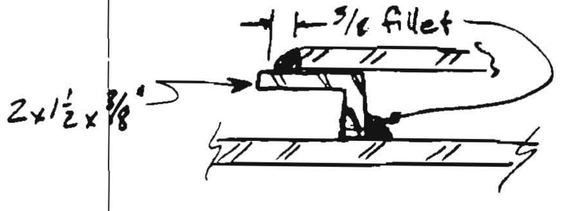
$w = \dfrac{4.67}{12} = 0.389''$

Shell

$W = \dfrac{21.65(5/8)(25)(.962)}{(2)(33.59)}$

= 4.84

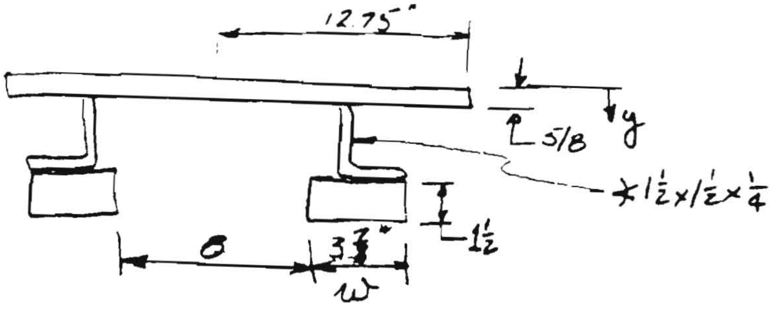
$w = \dfrac{4.84}{12} = 0.404$



USE 3/8" fillets since welds need not be larger than the attached pieces.

Away from the support nozzle the loads are never more than 1/3 as large as these. Therefore use 3/16" cont. fillets elsewhere.

SIZE STIFF. RING FOR STANCHION WHICH DOES NOT PIERCE INNER VESSEL:



2285

	A	y	Ay	Ad²	I_o
SHELL	7.97	5/16	2.49	9.202	0.26
ANGLE WEBS	.313	.391	.122	.311	.07
" FLANGES	.375	2.0	.75	.141	–
COVER PL	5.8125	2.875	16.71	12.870	1.09
	14.47		20.07		

$I_{a/2} = 23.943$

$\bar{y} = \frac{20.07}{14.47} = 1.387$

$I = 47.89\ in^4$

$S_{SHELL} = \frac{47.89}{1.387} = 34.5\ in^3 > 28.5$ OK

$S_{CP} = \frac{47.89}{3.625 - 1.387} = 21.40\ in^3 > 20.15$ OK

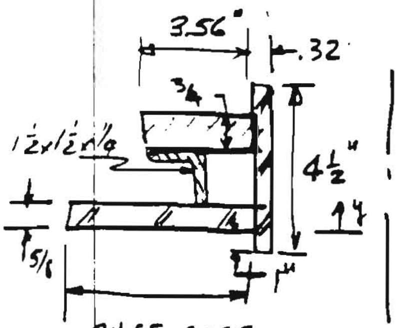
CHECK SHEAR

$V = 22^k$

$f_s = \frac{V}{A} = \frac{22}{2(3.625)(.25)} = 12.1\ ksi$ $F_s = 0.4 F_y = 12\ ksi \therefore$ OK

USE 8" ϕ BAR. MUST BE WELDED TO SHELL & COVER PLATE TO PREVENT OVER-STRESSING SHELL. IF BAR IS SEGMENTED, USE 4" ϕ EXTENSION TO TRANSFER SHEAR.

CHECK RINGS AT SIGNAL PORTS



$\frac{24.85-9.625}{2}$

$= 8.11"$

	A	y	Ay	Ad²	I₀
Shell	5.07	.3125	1.58	3.36	.16
Neck	1.44	1.25	1.8	.02	2.43
Angle Web	.325	1.375	.43	.02	.07
" Fl.	.313	2.0	.63	.24	—
Cover Pl.	2.67	2.5	6.68	5.04	.13
	9.868		11.11		

$\bar{y} = \frac{11.11}{9.868} = 1.126"$

$I = 11.47\ in^4$

ONE SIDE ONLY!

$I_{TOT} = 22.94\ in^4$

$S_{SHELL} = \frac{22.94}{1.126} = 20.37\ in^3$

$S_{COVER} = \frac{22.94}{2.875-1.126} = 13.12\ in^3$

FROM SN 22 THE STRESS LIMIT IN THE SHELL IS 13300 psi.

$\frac{M}{S} < 13300$

$M < 13300(20.4)$

$M < 271000$ in-lb

OK

THIS MOMENT IS WELL IN EXCESS OF MOMENTS IN THE REGION OF THE SIGNAL PORTS. (SEE SN 28)

FROM SN. 28 THE STRESS LIMIT IN COVER PLATE IS 18800 psi.

$M < 18800(13.12)$

$M < 247000$ in-lb

OK

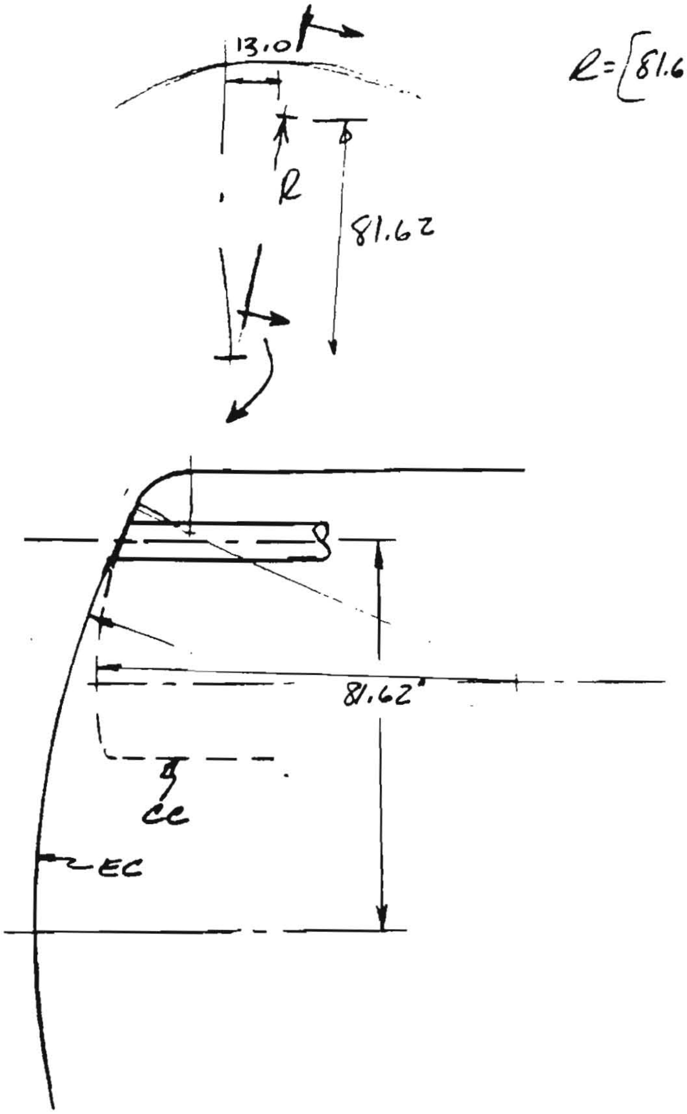
THIS ALSO EXCEEDS THE MOMENT IN THE AREA OF THE NOZZLES.

OTHER NOZZLES

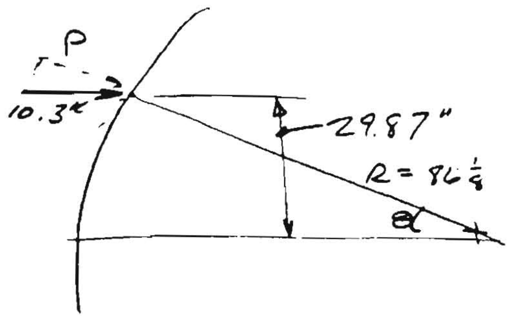
FOR THE SMALLER NOZZLES THE SECTION MODULUS WILL BE SUBSTANTIALLY LARGER AND ARE DEEMED OK BY INSPECTION.

AN ANSYS MODEL OF CC ARGON VESSEL WAS RUN FOR INTERNAL PRESSURE. ELEMENT 2147 WAS A BEAM ELEMENT BETWEEN NODES 999 AND 3534. THE RESULTING AXIAL FORCE IN THE BEAM IS 10225#.

$$R = \left[81.62^2 + 13^2\right]^{\frac{1}{2}} = 82.65''$$



CC



$\theta = \sin^{-1} \frac{29.87}{86 \, 1/4} = 20.3°$

$P = 10.3^K \cos 20.3°$

$= 9.67^K$

use 10^K

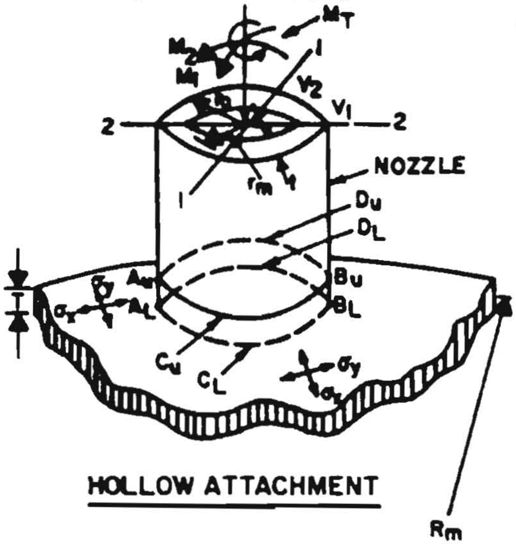
$V = 10.3 \sin 20.3$

$= 3.6^K$

The table on the following page (from WRC-107) demonstrates that shell stresses at the bypass tube are not excessive.

Table 3—Computation Sheet for Local Stresses in Spherical Shells (Hollow Attachment)

COJ-4.



1. **Applied Loads***
   - Radial Load, P = 10000 lb.
   - Shear Load, V_1 = 3600 lb.
   - Shear Load, V_2 = — lb.
   - Overturning Moment, M_1 = — in. lb.
   - Overturning Moment, M_2 = — in. lb.
   - Torsional Moment, M_T = — in. lb.

2. **Geometry**
   - Vessel Thickness, T = 5/8 in.
   - Vessel Mean Radius, Rm = 86 1/2 in.
   - Nozzle Thickness, t = .322 in.
   - Nozzle Mean Radius, r_m = 4.152 in.
   - Nozzle Outside Radius, r_o = 4.313 in.

3. **Geometric Parameters**
   - T $\frac{r_m}{t}$ = 12.89
   - ρ $\frac{T}{t}$ = 1.94
   - U $\frac{r_o}{\sqrt{R_mT}}$ = 0.587

4. **Stress Concentration Factors** due to:
   - membrane load, K_n = ______
   - bending load, K_b = ______

NOTE: Enter all force values in accordance with sign convention

From Fig.	Read curves for	Compute absolute values of stress and enter result ·	STRESSES – if load is opposite that shown, reverse signs shown							
			Au	AL	Bu	BL	Cu	CL	Du	DL
SP-1 to 10	$\frac{N_xT}{P}$ = .046	$K_n\left(\frac{N_xT}{P}\right)\cdot\frac{P}{T^2}$ = 1178	−1.2	−1.2	—	—	—	—	—	—
↓	$\frac{M_x}{P}$ = .053	$K_b\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2}$ = 8220	−8.2	+9.2	−	+	−	+	−	+
SM-1 to 10	$\frac{N_xT\sqrt{R_mT}}{M_1}$ =	$K_n\left(\frac{N_xT\sqrt{R_mT}}{M_1}\right)\cdot\frac{M_1}{T^2\sqrt{R_mT}}$ =	▨	▨	▨	▨	−	−	+	+
	$\frac{M_x\sqrt{R_mT}}{M_1}$ =	$K_b\left(\frac{M_x\sqrt{R_mT}}{M_1}\right)\cdot\frac{6M_1}{T^2\sqrt{R_mT}}$ =	▨	▨	▨	▨	−	+	+	−
	$\frac{N_xT\sqrt{R_mT}}{M_2}$ =	$K_n\left(\frac{N_xT\sqrt{R_mT}}{M_2}\right)\cdot\frac{M_2}{T^2\sqrt{R_mT}}$ =	−	−	+	+	▨	▨	▨	▨
↓	$\frac{M_x\sqrt{R_mT}}{M_2}$ =	$K_b\left(\frac{M_x\sqrt{R_mT}}{M_2}\right)\cdot\frac{6M_2}{T^2\sqrt{R_mT}}$ =	−	+	+	−	▨	▨	▨	▨
Add algebraically for summation of σ_x =			−9.4	+7.0						
SP-1 to 10	$\frac{N_yT}{P}$ = 0.2	$K_n\left(\frac{N_yT}{P}\right)\cdot\frac{P}{T^2}$ = 5120	−5.1	−5.1	—	—	—	—	—	—
↓	$\frac{M_y}{P}$ = .045	$K_b\left(\frac{M_y}{P}\right)\cdot\frac{6P}{T^2}$ = 6910	−6.9	+6.9	−	+	−	+	−	+
SM-1 to 10	$\frac{N_yT\sqrt{R_mT}}{M_1}$ =	$K_n\left(\frac{N_yT\sqrt{R_mT}}{M_1}\right)\cdot\frac{M_1}{T^2\sqrt{R_mT}}$ =	▨	▨	▨	▨	−	−	+	+
	$\frac{M_y\sqrt{R_mT}}{M_1}$ =	$K_b\left(\frac{M_y\sqrt{R_mT}}{M_1}\right)\cdot\frac{6M_1}{T^2\sqrt{R_mT}}$ =	▨	▨	▨	▨	−	+	+	−
	$\frac{N_yT\sqrt{R_mT}}{M_2}$ =	$K_n\left(\frac{N_yT\sqrt{R_mT}}{M_2}\right)\cdot\frac{M_2}{T^2\sqrt{R_mT}}$ =	−	−	+	+	▨	▨	▨	▨
↓	$\frac{M_y\sqrt{R_mT}}{M_2}$ =	$K_b\left(\frac{M_y\sqrt{R_mT}}{M_2}\right)\cdot\frac{6M_2}{T^2\sqrt{R_mT}}$ =	−	+	+	−	▨	▨	▨	▨
Add algebraically for summation of σ_y =			−12.0	+1.8						
Shear stress due to load, V_1		$\tau_1 = \frac{V_1}{\pi r_o T}$ = 425	▨	▨	▨	▨	−	−	+	+
Shear stress due to load, V_2		$\tau_2 = \frac{V_2}{\pi r_o T}$ = 425	+.4	+	−	−	▨	▨	▨	▨
Shear stress due to torsion, M_T		$\tau_1 = \tau_2 = \frac{M_T}{2\pi r_o^2 T}$ =	+	+	+	+	+	+	+	+
Add algebraically for summation of τ, =										

COMBINED STRESS INTENSITY - S

1) When $\tau \neq 0$, S = largest absolute magnitude of either
$S = 1/2\left[\sigma_x + \sigma_y \pm \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}\right]$ or $\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}$.

2) When $\tau = 0$, S = largest absolute magnitude of either
$S = \sigma_x, \sigma_y$ or $(\sigma_x - \sigma_y)$.

= 12.0 OK

CC Shipping Trunion

LIMIT BENDING STRESSES
TO 1.5(18800) = 28200psi

Bending in Cover Plate

$$\sigma = \frac{\beta M}{a t^2}$$ (Roark p 368 # 20)

$b = 2.75''$ $\beta = .2.062$

$a = 6.1''$ $t = 2$

$M = 11380 \times 9.7 \times 2 = 220772$ (2g) (275480 $\Rightarrow$ EC

$$\sigma = \frac{2.062\,(220772)}{6.1\,(2)^2} = 18657$$ (23280 $\Rightarrow$ EC)

Bending in Shell

Using equations from attached sheet:

$r_0 = 5''$ $\beta = .875\left(\frac{5}{102}\right) = .0429$

$R_m = 102''$

$T = .625''$ $\gamma = \frac{102}{.625} = 163.2$

From curve 3-B

FACTOR = 16 $M_L = 11380 \times 5.25 \times 2 = 119490$

(149100 $\Rightarrow$ EC

$$\sigma = \frac{16\,(119490)}{(102)^2(.0429)(.625)} = 6853$$ (8552 $\Rightarrow$ EC)

From curve 1-B

FACTOR = .05

$$\sigma = \frac{(.05)(6)(119490)}{(102)(.0429)(.625)^2} = 20,972$$ (26169 $\Rightarrow$ EC

Bending in Pipe Section

$11380 \times 2 \times 9.7 = 220772 = M$ (275480 ⇒ EC)

$\sigma = \frac{M}{S} \Rightarrow .66(36000) = \frac{220772}{S}$

MIN $S = 9.29$ (11.59 ⇒ EC)

Bending in Retaining Collar

$M = \frac{-Wa}{C_8}\left(\frac{R_0 C_9}{b} - L_9\right)$ (Roark p 338 #11 & p 332:333)

$a = 4''$

$b = 2.75''$

$R_0 = 2.7925''$

$\nu = .3$

$W = 11380$

$C_9 = \frac{b}{a}\left\{\frac{1+\nu}{2}\ln\frac{a}{b} + \frac{1-\nu}{4}\left[1-\left(\frac{b}{a}\right)^2\right]\right\} = .23$

$C_8 = \frac{1}{2}\left[1+\nu+(1-\nu)\left(\frac{b}{a}\right)^2\right] = .8154$

$L_9 = \frac{R_0}{a}\left\{\frac{1+\nu}{2}\ln\frac{a}{R_0} + \frac{1-\nu}{4}\left[1-\left(\frac{R_0}{a}\right)^2\right]\right\} = .2$

$M = \frac{-11380(4)}{.8154}\left(\frac{2.7925(.2309)}{2.75} - .2257\right) = 490$ (611 ⇒

$\sigma = \frac{6M}{t^2}$ $\sigma_{max} = .66(36000) = 23760$

$t^2 = \frac{6(490)}{23760} = .35''$ (.39'' ⇒ EC)

CCI-46

Table 5—Computation Sheet for Local Stresses in Cylindrical Shells

1. Applied Loads*

Radial load, P = ——— lb.
Circ. Moment, M_c = ——— in. lb.
Long. Moments, M_L = ——— in. lb.
Torsion Moment, M_T = ——— in. lb.
Shear Load, V_c = ——— lb.
Shear Load, V_L = ——— lb.

2. Geometry

Vessel thickness, T = ——— in.
Attachment radius, r_o = ——— in.
Vessel radius, R_m = ——— in.

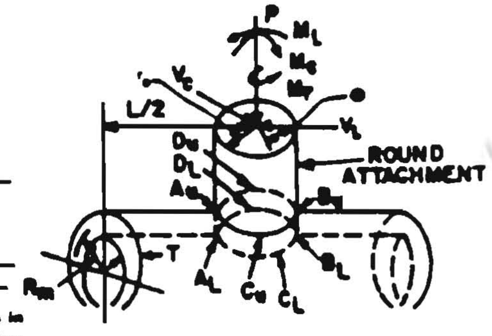
3. Geometric Parameters

$\gamma \quad \frac{R_m}{T}$ = ———

$\beta \quad (0.875)\frac{r_o}{R_m}$ = ———

Stress Concentration due to:
a) membrane load, K_n ———
b) bending load, K_b ———

*NOTE: Enter all force values in accordance with sign convention



CYLINDRICAL SHELL

From Fig.	Read curves for	Compute absolute values of stress and enter result·	STRESSES – if load is opposite that shown, reverse signs shown							
			A_u	A_L	B_u	B_L	C_u	C_L	D_u	D_L
3C or 4C	$\frac{N\phi}{P/R_m}$ =	$K_n\left(\frac{N\phi}{P/R_m}\right)\cdot\frac{P}{R_mT}$ =	−	−	−	−	−	−	−	−
1C or 2C-1	$\frac{M\phi}{P}$ =	$K_b\left(\frac{M\phi}{P}\right)\cdot\frac{6P}{T^2}$ =	−	+	−	+	−	+	−	+
3A	$\frac{N\phi}{M_c/R_m^2\beta}$ =	$K_n\left(\frac{N\phi}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =	▨	▨	▨	▨	−	−	+	+
1A	$\frac{M\phi}{M_c/R_m\beta}$ =	$K_b\left(\frac{M\phi}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =	▨	▨	▨	▨	−	+	+	−
3B	$\frac{N\phi}{M_L/R_m^2\beta}$ =	$K_n\left(\frac{N\phi}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+	▨	▨	▨	▨
1B or 1B-1	$\frac{M\phi}{M_L/R_m\beta}$ =	$K_b\left(\frac{M\phi}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−	▨	▨	▨	▨
Add algebraically for summation of ϕ stresses, σ_ϕ =										
3C or 4C	$\frac{N_x}{P/R_m}$ =	$K_n\left(\frac{N_x}{P/R_m}\right)\cdot\frac{P}{R_mT}$ =	−	−	−	−	−	−	−	−
1C-1 or 2C	$\frac{M_x}{P}$ =	$K_b\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2}$ =	−	+	−	+	−	+	−	+
4A	$\frac{N_x}{M_c/R_m^2\beta}$ =	$K_n\left(\frac{N_x}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =	▨	▨	▨	▨	−	−	+	+
2A	$\frac{M_x}{M_c/R_m\beta}$ =	$K_b\left(\frac{M_x}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =	▨	▨	▨	▨	−	+	+	−
4B	$\frac{N_x}{M_L/R_m^2\beta}$ =	$K_n\left(\frac{N_x}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+	▨	▨	▨	▨
2B or 2B-1	$\frac{M_x}{M_L/R_m\beta}$ =	$K_b\left(\frac{M_x}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−	▨	▨	▨	▨
Add algebraically for summation of X stresses, σ_x =										
Shear stress due to Torsion, M_T		$\tau_{\phi x} = \tau_{x\phi} = \frac{M_T}{2\pi r_o^2 T}$	+	+	+	+	+	+	+	+
Shear stress due to load, V_c		$\tau_{x\phi} = \frac{V_c}{\pi r_o T}$	+	+	−	−	▨	▨	▨	▨
Shear stress due to load, V_L		$\tau_{x\phi} = \frac{V_L}{\pi r_o T}$	▨	▨	▨	▨	−	−	+	+
Add Algebraically for summation of shear stresses, τ =										

COMBINED STRESS INTENSITY - S

1) When $\tau \neq 0$, S = largest absolute magnitude of either
$S = 1/2\left[\sigma_x + \sigma_\phi \pm \sqrt{(\sigma_x - \sigma_\phi)^2 + 4\tau^2}\right]$ or $\sqrt{(\sigma_x - \sigma_\phi)^2 + 4\tau^2}$.

2) When $\tau = 0$, S = largest absolute magnitude of either
$S = \sigma_x$, σ_ϕ or $(\sigma_x - \sigma_\phi)$.

$N_i/(M_L/R_m^2\beta)$ so determined by (C_L) from Table 8 (see para. 4.3).

4.2.2.5.2: When considering bending moment (M_L): $\beta = K_L\sqrt[3]{\beta_1\beta_2^2}$ where K_L is given in Table 8.

4.3 Calculation of Stresses

4.3.1 STRESSES RESULTING FROM RADIAL L P.

4.3.1.1 Circumferential Stresses (σ_ϕ):

Step 1. Using the applicable values of β and γ

CCI-4

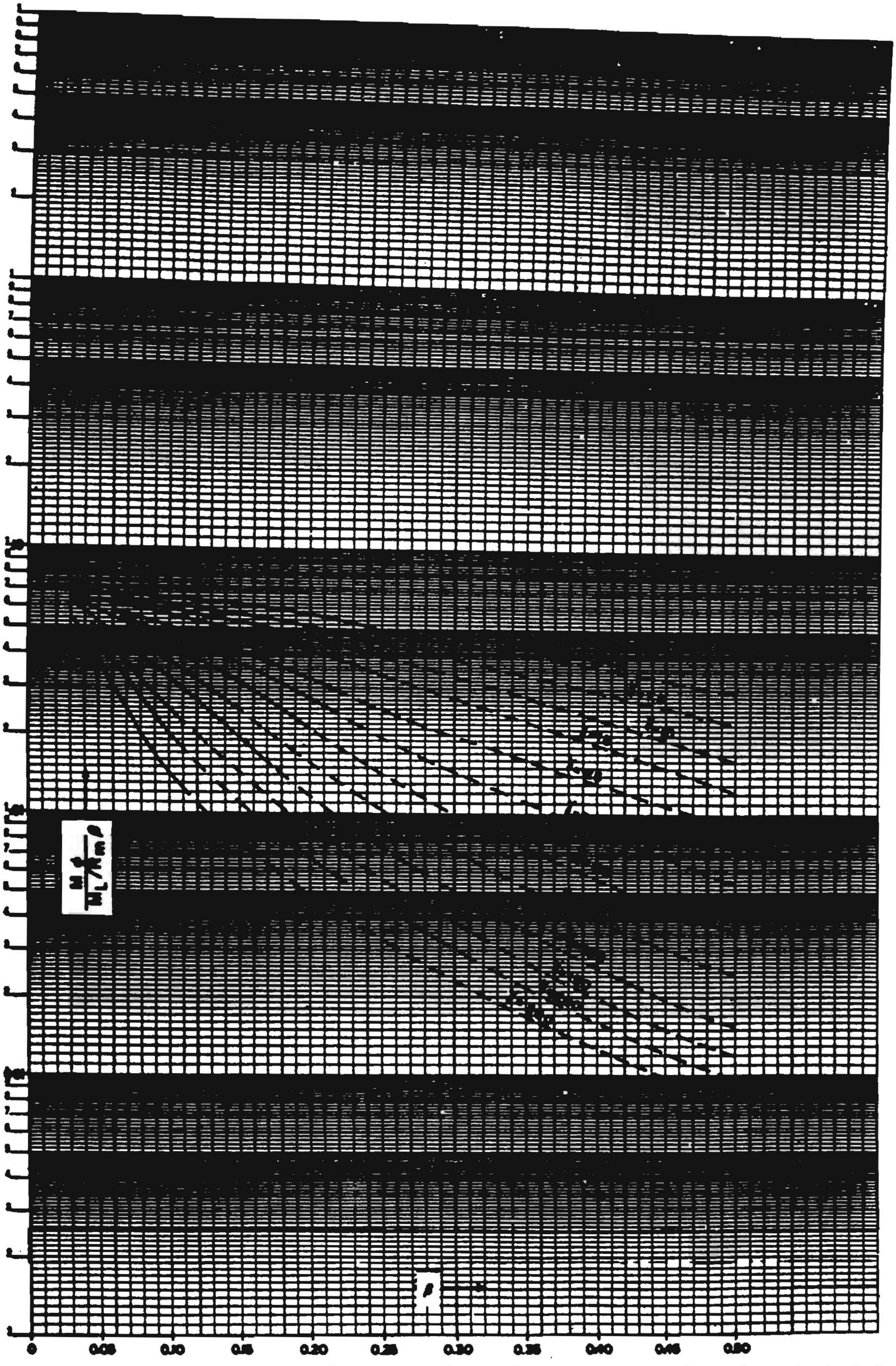
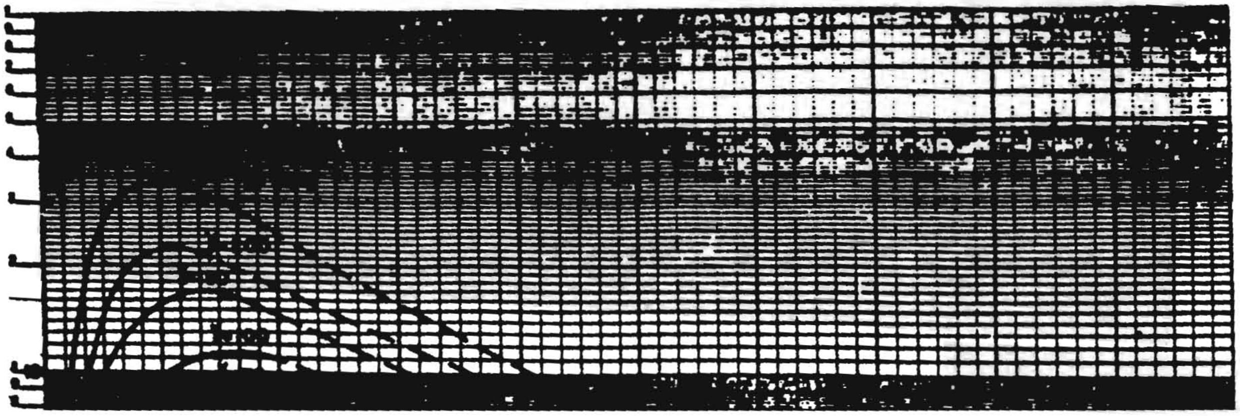


Fig. 1B—Moment $M_\phi/(M_L/R_m\beta)$ due to an external longitudinal moment M_L on a circular cylinder (Stress on the longitudinal plane of symmetry)

CCI-48
END



cc/o-2

CC OUTER

OUTER CYL.

RDL 6/19/86

$$B = 6590\left(\frac{10600}{6590}\right)^{\frac{\log(.463/.531)}{\log(.463/1.50)}}$$

$= 6965$

$$P_a = \frac{4}{3}\left(\frac{6965}{326.4}\right) = 28.5 \text{ psi}$$

try $\underline{t = 0.450}$

$D_o/t = 453.3$

$$A_q = .305\times10^{-3}\left(\frac{.199}{.305}\right)^{\frac{\log .4/.439}{\log .4/.6}}$$

$= 0.276\times10^{-3}$

$$A = .390\times10^{-3}\left(\frac{.276}{.390}\right)^{\frac{\log(400/453.3)}{\log(400/500)}}$$

$= 0.321\times10^{-3}$

$$B = 140\left(\frac{6590}{140}\right)^{\frac{\log .01/.321}{\log .01/.463}}$$

$= 4562$

$$P_a = \frac{4}{3}\left(\frac{4562}{453.3}\right) = 13.42 < 15$$

No Good

try $\underline{t = 0.475}$

$D_o/t = 429.5$

$$A = 0.390\times10^{-3}\left(\frac{.276}{.390}\right)^{\frac{\log(400/429.5)}{\log(400/500)}}$$

$= 0.349\times10^{-3}$

$$B = 140\left(\frac{6590}{140}\right)^{\frac{\log .01/.349}{\log .01/.463}}$$

$= 4961$

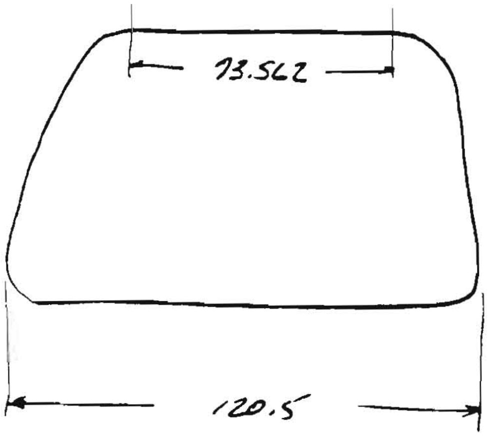
$$P_a = \frac{4}{3}\left(\frac{4961}{429.5}\right) = \underline{15.4 \text{ psi}}$$

$$\underline{t_r = 0.475}$$

ASME
VIII - Div. 1.

FERMILAB ALLOWS VACUUM VESSELS TO BE DESIGNED IN ACCORDANCE WITH COMPRESSED GAS ASSOCIATION (CGA) STD #341.

SIZE IN ACCORDANCE WITH CGA-341. (FACTOR OF SAFETY OF 2 vs. 4 FOR ASME.) SPECIFICALLY, USE ASME RULES FOR A VACUUM OF 7.5 psi.



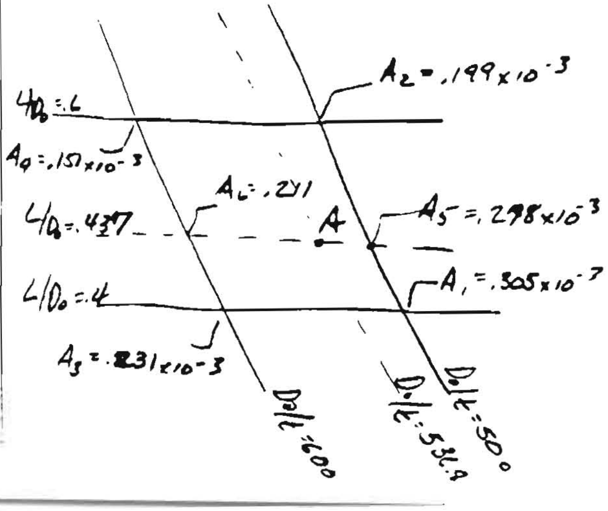
$L = 120.5 - \frac{2}{3}(120.5 - 73.562)$

$= 89.208$

$L/D_o = \frac{89.208}{204} = 0.437$

let $t = 0.380$

$D_o/t = \frac{204}{.380} = 536.8$



$$A_5 = A_1\left(\frac{A_2}{A_1}\right)^{\left(\frac{\log .4/.437}{\log .4/.6}\right)}$$

$$= .305 \times 10^{-3}\left(\frac{.199}{.305}\right)^{\frac{\log .4/.437}{\log .4/.6}}$$

$$= 0.278 \times 10^{-3}$$

$$A_6 = .231 \times 10^{-3}\left(\frac{.151}{.231}\right)^{\frac{\log .4/.437}{\log .4/.6}}$$

$$= 0.211 \times 10^{-3}$$

$$A = .278 \times 10^{-3}\left(\frac{.211}{.278}\right)^{\frac{\log 500/536.8}{\log 500/600}}$$

$$= 0.250 \times 10^{-3}$$

$B = 3500$ (Inspection)

$$P_a = \frac{4}{3}\left(\frac{3500}{536.8}\right) = 8.7 \text{ psi}$$

$t = 0.360$

$D_o/t = 566.7$

$$A = .278 \times 10^{-3}\left(\frac{.211}{.278}\right)^{\frac{\log 500/566.7}{\log 500/600}}$$

$$= 0.230$$

$$B = 140\left(\frac{6590}{140}\right)^{\frac{\log .01/.23}{\log .01/.463}}$$

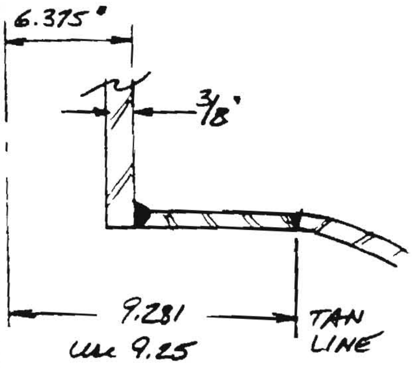
$$= 3264$$

$$P_a = \frac{4}{3}\left(\frac{3264}{566.7}\right) = 7.68$$

$$tr_{ext} = 0.360$$

CGA-341

Assume 12"φ Sch 40S pipe with full penetration welds and no internal projection:



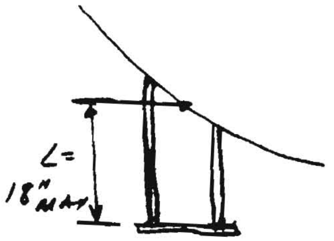
$d = 12.0"$ $t_r = 0.360"$ (CGA-341)

$A_{req} = 0.5(12.0)(.36)(1.0)$
$= 2.160 \text{ in}^2$

ONLY 1/2 IS RQD ON EACH SIDE:

$A_{req} = \frac{2.16}{2} = 1.08 \text{ in}^2$

Find t_{rn}



$L/D_o = \frac{18}{12.75} = 1.412$

$t = .050"$ $D_o/t = 255$

$A = .00022$ $B = 3100$

$P_a = \frac{4}{3}\left(\frac{3100}{255}\right) = 16.2$ <u>OK</u>

$t_{rn} = 0.05"$

Area in nozzle neck:

$A_2 = 2.5(.360)(.375-.050)$
$= 0.2925 \text{ in}^2 < A_{req}$.

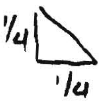
Therefore, additional thickness rqd in shell:

$A_{SHELL} = A_{req} - A_2$
$= 1.080 - .2925$
$= .7875 \text{ in}^2$

$0.788 = (t_s - t_r)(9.25 - 6.0)$

$t_s = \frac{.788}{3.25} + .360$
$= 0.242 + .360$
$= 0.602" \rightarrow \underline{\underline{5/8"}}$

Add the area due to the weld



$A = \frac{1}{2}(1/4)^2 = .0208"$

SIDE WELD TO ALLOW USE OF 1/2" Shell.

$A_{req} = A_{SHELL} + A_{NOZZ} + A_{WELD}$

$1.080 = (.5 - .36)(3.281) + .293 + .5(leg)^2$

$\underline{leg = 0.810}$

Find nozzle t to minimize shell. (1/4" fillet)

$1.080 = 2.5(.36)(t_n - .05) + \frac{1}{2}(1/4)^2$

$\underline{t_n = 1.215" \text{ TOO LARGE}}$

See if stiff. rings can serve as ASME stiffeners ($P = 7.5$ psi) in which case area replacement will not be necessary as long as the required section is provided at the nozzle.

first, if rings OK $L = 2(27.5) = 55''$ for the vessel:

$L/D_o = 55/204 = 0.27$

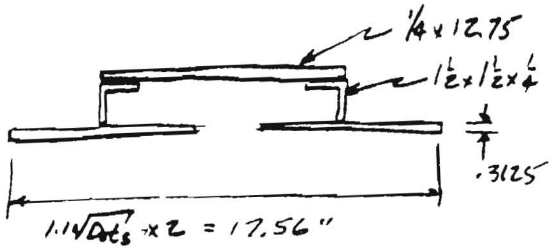
let $t = 0.3125$

$D_o/t = \frac{204}{.3125} = 653$

$A = .00030$

$B = 4262$

$P_a = \frac{4}{3}\left(\frac{4262}{653}\right) = 8.7$ OK (CGA-341)



	A	y	Ay	Ad^2	I_o
SHELL	5.49	.156	.867	2.98	—
ANGLE	.75	1.688	1.266	.49	.141
PLATE	3.188	1.938	6.177	3.57	—
	9.428		8.30	$I' = 7.08$ in^4	

$\bar{y} = \frac{8.30}{9.428} = 0.880$

$S_{SH} = \frac{7.08}{.88} = 8.05$

$S_{cp} = \frac{7.08}{2.0625 - .88} = 6.0$

$L_s = 27.5 + (36.781 - 27.5) + \frac{1}{3}\left(\frac{120.5}{2} - 36.781\right)$

$= 44.604''$

$t + \frac{A_s}{L_s} = .3125 + \frac{9.428}{44.604} = 0.524$

$B = \frac{3}{4}\left(\frac{7.5(204)}{.524}\right) = 2190$

$A = .00016$

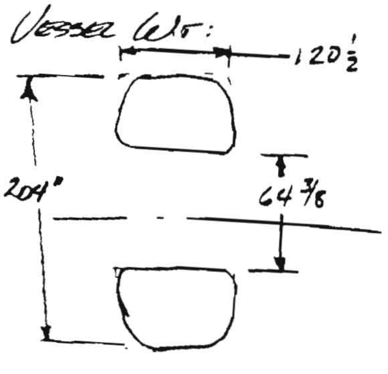
$I_s' = \left[\frac{(204)^2(44.604)(.524)(.00016)}{10.9}\right]$

$= 14.3$ in$^4 > I'$

∴ <u>NO GOOD</u> AS VESSEL STIFFENER

SIZE STIFFENER FOR SUPPORT LOADS & RECHECK.

Vessel Wt:



W_T = Vol x density

$= \pi\left(\frac{204+64\frac{3}{8}}{2}\right)(2)\left(120.5+\left(\frac{204-64\frac{3}{8}}{2}\right)\right) t \times \frac{500\ \#/ft^3}{1728\ in^3/ft^3}$

$= 46430\ t$ (lb)

t (in)	wt (#)
1/4	11607
5/16	14510
3/8	17410
1/2	23214
5/8	29020

Assume 3/8" walls except inner cyl = 1/4".
Calculate per DØ Eng Note 39 (Rev. 4/28/86)

Heads: $13280 \times \frac{3/8}{5/8}$ = 7970 #

Outer cyl.: $8500 \times \frac{3/8}{5/8}$ = 5100 #

Inner cyl. $1550\ \frac{1/4}{1/4}$ = $\underline{1550}$

14620 #

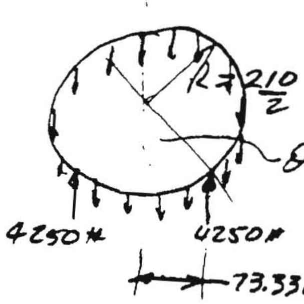
Rings 1/4 x 12.75 + 2 ∠ 1½ x 1½ x 1/4
- length = $\pi(204+3) = 650$ in

$wt = \frac{1}{4}(19)(650)\left(\frac{500}{1728}\right)$
= 900 #

use 1800 # for conservatism

SHELL	14620
RINGS	1800
NOZZLES etc	500
	16920

⇒ $\underline{\underline{17000\ \#}}$ use 8500 #/ring



$R = \frac{210"}{2} = 105$

$\theta = \sin^{-1}\frac{73.332}{105} = \sin^{-1}.698$

$= 44.30° = 0.773$ RAD

$\theta = .773$

$c = \cos\theta = .716$

$s = \sin\theta = .698$

$z = \sin x$ $u = \cos x$

$w = \frac{8500}{\pi(210)} = 12.9\ \#/in$

use $\underline{\underline{13\ \#/in}}$

(Roarke, 4th Ed, p176 case 15)

$M_1 = wR^2(\frac{1}{2} + c + \theta s - \pi s + s^2)$

$= wR^2(.5 + .716 + (.773 - \pi)(.698) + .698^2)$

$= .0499\, wR^2$

$= .0499(13)(105)^2$

$= 7156$ in-lb;

$T_1 = wR(s^2 - 1/2)$

$= wR(.698^2 - 1/2)$

$= -.0128(13)(105)$

$= -17.5$ #

At $x = \theta$

$M_x = M_1 - T_1 R(1-u) + wR^2(xz + u - 1 - \pi z + \pi s)$

$u = c,\ z = s$

$M_x = wR^2(.0499) - (-.0128)wR^2(1 - .716) + wR^2\underbrace{(.716 - 1 + .773(.698))}_{.2556}$

$= .309\, wR^2$

$= .309(13)(105)^2$

$= 44290$ in-lb

$x \approx 90°$

$M_x = .0499\, wR^2 + .0128\, wR^2(1 - \cos x) + wR^2(x\sin x + \cos x - 1 - \pi\sin x + \pi\sin\theta)$

$= wR^2((.0627 \cancel{-1}) + (1 - .0128)\cos x - (\cancel{\pi} - x)\sin x + 2.193)$

$= wR^2(1.255 + .987\cos x - (\pi - x)\sin x)$

x	C	Mx
90° = 1.571 RAD	-.3158	-45260
91° = 1.588 RAD	-.315	
89° = 1.553 RAD	-.3158	-45260
89.5° = 1.562	-.31585	-45270

use $M_{MAX} = 46000$ in-lb

pressure stress:

$\sigma = \frac{PR}{t} = \frac{15(102)}{.375} = 4080$ psi

assume near openings $\sigma = 1.5\sigma_p$

$\sigma = 1.5(4100) = 6150$ psi

Assuming the longitudinal welds will not be located near high stress areas, the shell stress will be limited to $0.8 \times S = .8(18800) = 15040$ psi

Subtracting the pressure stress:

$\sigma_{allow.} = 15040 - 4080$
$= 10960$ psi

$S_{SH} = \frac{M}{\sigma} = \frac{46000}{10960} = 4.198\ in^3$

For cover plate $f_b < .6F_y$
$< .6(30) = 18$ ksi

$S_{CP} = \frac{46000}{18000} = 2.6\ in^3$

∴ Ring is adequate for support. (See cc10-5)

Check deflection of shell w/o heads:

$w \approx \frac{7500}{2(210\pi)} = 5.7$ #/in

use 6.0

$\Delta R = \frac{6(105)^4}{28\times10^6(7.08)}(.3832 - .5708(.716 + .773(.698)) + .5(.698)^2)$

$= \frac{6(105)^4(-.0899)}{28\times10^6(7.08)}$

$= -.3306"$

FAIRLY LARGE
BUT OK. (CONS. CALC.)

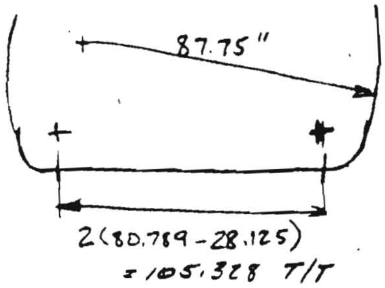
Two designs are viable. These are:

1 Use an outer shell thickness of 5/8". This is adequate to ensure self-reinforcement of all properly spaced nozzles. The heads can be 1/8" thinner than the shell — 5/8 - 1/8 = 1/2" — and still be attached without a tapered transition. The stiffener rings are adequate with 1/4" cover plates.

Approach Chosen For Design

2. Minimize the outer shell thickness — use 3/8" material. Additional material will be required at nozzles for area replacement. Thickened cylinders preferable to pad plates in stiffener ring area. Stiffener rings adequate with 1/4" cover plates. Heads can be 5/16" thick. ⊛ This will provide a savings in weight on the order of 8000 #. 12"φ nozzles will have to be about 1 1/4" thick to provide adequate area.

⊛ 5/16" thickness must be shown to be adequate for internal and external pressures (Subsequent calcs indicate that 7/16" outer knuckle and crown are required to resist collapse loads. Therefore, expected weight savings will not be completely realized.



$L = 105.328 + 2\left(\frac{1}{3}\right)(87.75 - 80.789)$

$= 105.328 + 4.641$

$= 109.969$

use $L = 110"$

$D_o \Rightarrow$ use 60.5"

$\underline{t = 0.25"}$

$D_o/t = 242 \quad L/D_o = 1.82$

$A = .000195$

$B = 2765$

$P_a = \frac{4}{3}\frac{(2765)}{(242)} = \underline{\underline{15.2 \text{ psi}}}$

$\underline{\underline{t_r = 0.25 \text{ ASME}}}$

$\underline{\underline{\text{OK}}}$

$\underline{\text{CGA}}$ $P_{ez} = 1.5$ psi

try 3/16

$D_o/t = 323 \quad L/D_o = 1.82$

$A = .00012$

$B =$ —

$P_e = \frac{2(.00012)\,29\times10^6}{3(323)}$

$= 6.9$ psi

No Good

For $\underline{\underline{t = 0.2}}$

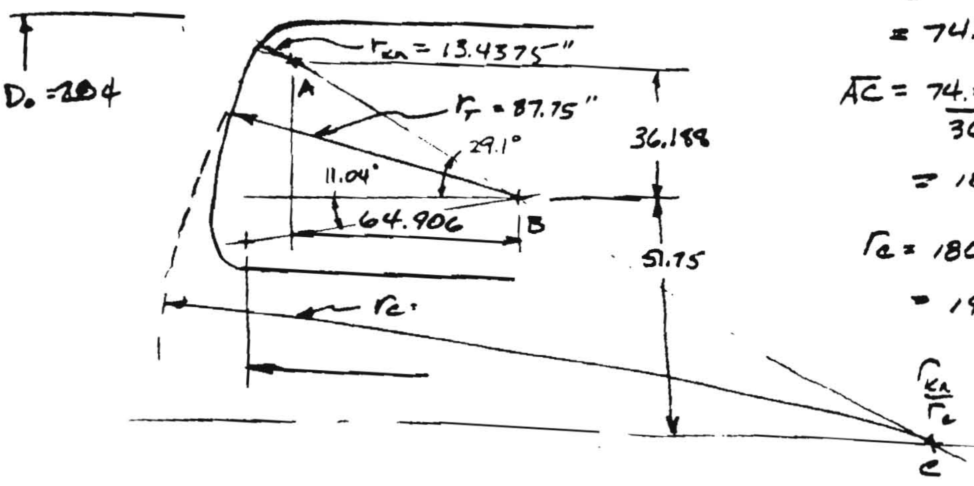
$D_o/t = 303$

$A = .00013$

$P_a = 8.0$ $\underline{\underline{\text{OK}}}$

$\underline{\underline{t_r = 0.2"}}$ $\underline{\underline{\text{CGA}}}$

USE 1/4" for inner cylinder.



$\overline{AB} = \left[(64.906)^2 + (36.188)^2\right]^{\frac{1}{2}}$

$= 74.3126"$

$\overline{AC} = \frac{74.3126}{36.188}(36.188 + 51.75)$

$= 180.582$

$r_c = 180.582 + 13.4375$

$= 194.019 < D_o$ OK

$\frac{r_{kn}}{r_c} = \frac{13.4375}{194.019} = .069 > .06$ OK

Check outer knuckle by assuming geometry is equivalent to a torispherical head of 204" OD

$L = 194.02$, $r = 13.4375$

$S = 18800$ $E = 0.65$ (Cons.)

Internal Pressure $P = 15$ psi
(1-4, Div. 1)

$t = \frac{PLM}{2SE - 0.2P}$

$\frac{L}{r} = 14.44$ $M = 1.70$

$t = \frac{15(1.7)(194.02)}{2(18800)(.65) - 0.2(15)}$

$= 0.202"$ $E = .65$

$= 0.165"$ $E = 0.80$

$= 0.132"$ $E = 1.0$

Note: these values are conservative since it was demonstrated in the CC/Inner calcs that the equivalent pressure on the knuckle is ≈ 70% of the actual pressure in the torus.

$0.7 \times 0.202 = \underline{\underline{0.141"}}$ $E = 0.65$.

Int. pressure is unlikely to control design.

External Pressure $P = 7.5$ psi (CGA)

$R_o = r_c + 194.020 + 0.625$

$= 194.645$

let $\underline{t = 0.132}$

$R_o/t = 1475$

$A = \frac{.125}{1475} = .000085$

$P_a = \frac{.0625(28 \times 10^6)}{(1475)^2}$

$= 0.804$ psi No Good

try $\underline{t = 3/8"}$

$R_o/t = 519$ $A = .00024$

$B = 3300$ $P_a = \frac{3300}{519} = \underline{6.36}$

$\underline{t = 0.4}$

$R_o/t = 487$ $A = .000257$

$B = 3500$ $P_a = \frac{3500}{487} = \underline{\underline{7.2}}$

$\underline{t = 0.4375}$

$R_o/t = 445$ $A = .000281$

$B = 4000$ $P_a = \frac{4000}{445} = \underline{\underline{9.0}}$

This thickness is excessive since the equivalent pressure is less that 7.5 psi. by 30%. Check collapse of knuckle.

Check the outer knuckle for plastic collapse per Shield & Drucker: (Limit collapse pressure to 30 psi per CGA-341)

$$P_{cr} = 30000\left[\left(.33+5.5\left(\frac{r}{D}\right)\right)\frac{t}{L}+28\left(1-2.2\left(\frac{r}{D}\right)\right)\left(\frac{t}{L}\right)^2-.0006\right]$$

$$r/D = \frac{13.44}{204} = .066 \qquad \frac{t}{L}=\frac{t}{194} \text{ use } \frac{t}{204}$$

$$P_{cr_{eq}} = 101.82\,t + 17.259\,t^2 - 18$$

let $P_{cr_{eq}} = 30 \times .7 = 21$

$$17.259\,t^2 + 101.82\,t - 39 = 0$$

$$t_r = \frac{-101.82 + \sqrt{(101.82)^2 - 4(17.259)(-39)}}{2(17.259)}$$

$$t_r = 0.361''$$

for $t = 5/8$

$P_{cr_{eq}} = 52.4$ psi

$P_{cr} = \frac{52.4}{0.7} = 75$ psi

$F.S. = \frac{75}{15} = 5.0$

$t = 1/2$

$P_{cr_{eq}} = 37.225$

$P_{cr} = \frac{37.225}{0.7} = 53.2$ psi

$F.S. = \frac{53.2}{15} = 3.5$

Determine t required to prevent yielding in the knuckle at 30 psi. From the Battelle report, the max stress intensity in the knuckle @ 15 psi pressure is 12100 psi ($t = 5/8''$, $S_m = 6650$ psi, $S_b = 5425$ psi)

$$t_{yeild} = (5/8)\left(\frac{6650}{30000}+\sqrt{\frac{5425}{30000}}\right) = .404''$$

∴ Yeilding will not occur in a knuckle which is 0.404" thick.

USE 1/2" OUTER KNUCKLE FOR FIT-UP TO 5/8" OUTER CYL.

CROWN

Limit stresses (Membrane) in the crown to SE using Battelle's results.

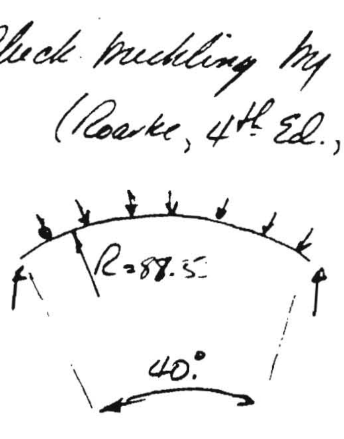
From Battelle's report, @ 15 psi the max. membrane stress in the crown is 5500 psi. (Note that although high bending stresses exist in the crown, these are adjacent to the knuckles and can be classified as secondary.)

$$t_r = t_{BATTELLE}\left(\frac{5500}{SE}\right)$$

$$= 5/8\left(\frac{5500}{18800(.65)}\right)$$

$$= 0.281''$$

Check buckling by modeling as a curved panel:
(Roarke, 4th Ed., p354 case 33)



$$P_{cr} = \frac{Et^3\left(\frac{\pi}{\alpha^2}-1\right)}{12r^3(1-\nu^2)} \geq 30 \text{ psi}$$

$$t = \left[\frac{30(12)(87)^3(.91)}{28\times10^6\left(\frac{\pi^2}{(.349)^2}-1\right)}\right]^{\frac{1}{3}}$$

$\alpha = \frac{40°}{2} = 20° = 0.349$ Rad

$$t_r = \underline{\underline{0.438}}'' < 1/2''$$

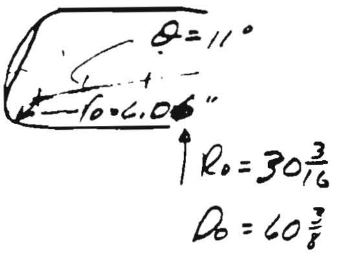
$F.S. = \frac{.5}{.438} \times \frac{30}{15} = \underline{\underline{2.2}}$

For clamped edges: ($k = 12.85$)

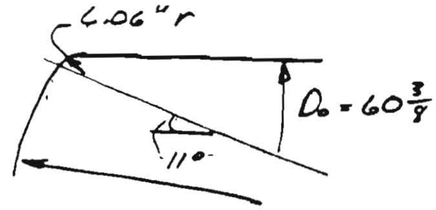
$$t = \left[\frac{30(12)(87)^3(.91)}{29\times10^6(12.85^2-1)}\right]^{\frac{1}{3}} = \underline{0.361}$$

Since edges will be at least partially clamped let $\underline{\underline{t = 1/2''}}$. $\boxed{\text{use } 1/2'' \text{ Crown}}$

Actual Geo.



Equiv. Geo.



L_{TORUS} ←
= 87.75"

$$L_{eq} = \left(\frac{30.188 - 6.06}{\sin 11°}\right) + 6.06 = 132.5''$$

$$\frac{r}{L} = \frac{6.06}{132.5} = .046 \Rightarrow 4\tfrac{1}{2}\% \text{ Knuckle}$$

$$\frac{r}{D_o} = \frac{6.06}{60\,3/8} = 0.100 \qquad \frac{t}{L} = \frac{.625}{132.5} = .0047$$

Stress Results ($t_{BATTELLE} = 5/8"$)

From Battelle's Report the largest meridional bending stress is 9.1 ksi (memb + bending) which is substantially lower than the Div. I allowable of 4SE = 48.9 ksi. The maximum hoop membrane stress is 6.7 ksi which also is less than the allowable of 1.5SE = 18.3 ksi. The maximum stress intensity is 10.3 ksi (@S=211° in Battelle Nonlin Run CCUU1B). This value will be limited to yield (30 ksi) to avoid initiating buckling in the crown.

Using these stresses to determine an allowable thickness:

	$\sigma_{BATTELLE}$	ALLOWABLE	$t_r = t_{BATTELLE}\overset{(=5/8")}{}\left(\frac{\sigma_{BATTELLE}}{\text{ALLOWABLE}}\right)$
MEMB.	6.7	18.3	0.229"
BEND	9.1	48.9	$\left(\frac{.442}{48.9} + \sqrt{\frac{7.71}{48.9}}\right)\left(\frac{5}{8}\right) = 0.266''$
S.I.	10.3	30.0	$\left(\frac{10.3}{30.0}\right)^{\frac{1}{2}}(5/8) = .366''$ ← CONTROLS (CONSERVATIVE)

Buckling of the inner knuckle: (Ref. Shield & Drucker, 1961)

First the equivalent internal pressure must be determined:

From Battelle's report for 15 psi:

$$\sigma_{INNERCYL} = 1750 \text{ psi}$$ (Mer. Membrane stress NONLIN CCUV10)

$$N_\phi = 1750(.25) = 438 \ \#/in = \frac{P_{eq} \times R}{2}$$

$$P_{eq} = \frac{2(438)}{\left(\frac{60\,3/8}{2}\right)} = 29.0 \text{ psi} \Rightarrow \text{use } 30 \text{ psi}$$

Use Drucker's Formula to find the min. thickness required for a collapse pressure of 2×30 = 60 psi

$$\frac{60}{\sigma_y} = \left(.33 + 5.5\left(\frac{r}{D}\right)\right)\frac{t}{L} + 28\left(1 - 2.2\frac{r}{D}\right)\left(\frac{t}{L}\right)^2 - .0006$$

$$\frac{60}{30000} = \left(.33 + 5.5(.1)\right)\frac{t}{132.5} + 28\left(1 - 2.2(.1)\right)\left(\frac{t^2}{(132.5)^2}\right) - .0006$$

$$199.24t + 37.32t^2 - 78 = 0$$

$$t = \frac{-199.24 + \sqrt{(199.24)^2 + 4(37.32)(78)}}{2(37.32)}$$

$$= \underline{0.366''}$$

∴ A 3/8" knuckle is adequate. However, it is possible that the heads will be formed from a single 1/2" plate. The resulting minimum knuckle thickness would be > 7/16". The corresponding factor of safety for buckling would be:

$$FS. \ \frac{P_{cr}}{15} = \frac{30\left(\frac{7/16}{.366}\right)}{15} = 2.4$$

The factor of safety on yielding of the knuckle is:

$$FS. = \frac{7/16}{.366} = 1.19$$

If a separate knuckle plate is used, limit the nom t to 3/8" to ensure smooth transitions.

Look At Vac. Vessel Bypass tube for buckling:

Assume:

6" Sched 40s PIPE

$ID = 6.065$ $\quad I = 28.14\ in^4$

$t = .280$ $\quad r = 2.245"$

$A = 5.58$ $\quad S = 8.50\ in^3$

Force = 1/2 of force from ANSYS analysis of argon vessel.

$$= \tfrac{1}{2}(10.3^k)$$

$$= \underline{\underline{5.2^k}}$$

$$\text{Moment} = \left[2238^2 + 14030^2\right]^{\frac{1}{2}}$$

$$= 14200\ in\text{-}lb$$

$$f_a = \frac{5.2^k}{5.58} = 0.93\,ksi$$

$$\frac{Kl}{r} = \frac{1.0(2(52.6))}{2.245} = 46.9$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y = (30ksi)}} = 136 \qquad \frac{\frac{Kl}{r}}{C_c} = 0.345$$

$$F_a = \frac{\left[1 - \frac{(.345)^2}{2}\right] F_y}{\frac{5}{3} + \frac{3}{8}(.345) - \frac{1}{8}(.345)^3} = \frac{(.940)F_y}{1.791} = 0.52\,F_y$$

$$= .52(30) = 15.6\ ksi$$

$$\frac{f_a}{F_a} = \frac{.93}{15.6} = 0.06$$

$$\therefore \frac{f_b}{F_b} < 1 - .06 = .94$$

END

$$f_b = \frac{14200}{8.5} = 1671 \text{ psi}$$

$$\frac{d}{t} = \frac{1}{.28} = 25$$

$$\frac{3300}{F_y} = \frac{3300}{30} = 110 > 25$$

$$\therefore F_b = 0.66 F_y = 20 \text{ ksi}$$

$$\frac{f_b}{F_b} = \frac{1.7}{20} = 0.085 < .94 \quad \underline{\underline{OK}}$$

Sch 5S $\quad A = 2.23 \text{ in}^2 \quad r = 2.304$

$$f_a = \frac{5.2}{2.23} = 2.33 \text{ ksi}$$

$$\frac{Kl}{r} = \frac{1.0(2(52.6))}{2.304} = 45.7$$

$$F_a \approx 15 \text{ ksi}$$

$$\frac{f_a}{F_a} = \frac{2.33}{15} = 0.16$$

$$f_b = \frac{14200}{3.6} = 3.9 \text{ ksi}$$

$$F_b = 20$$

$$\frac{f_b}{F_b} = \frac{3.9}{20} = 0.20$$

$$.16 + .2 = .36 < 1.0 \quad OK$$

Sched 5S OK

Code Ext P.

$$\frac{L}{D_o} = \frac{105}{6} = 17.5$$

$$\frac{D_o}{t} = \frac{6.625}{.109} = 61$$

$$A = .0003$$

$$B = 4200$$

$$P_a = \frac{4(4200)}{3(61)} = 92 \quad \underline{\underline{OK}}$$

PRESSURE RELIEF CALCULATION SUMMARY PAGE

CONDITION	REQUIRED FLOW CAPACITY (SCFM, air)	REFERENCE
1. Fire Condition	264	EN-6, pg. 5
2. Loss of Vacuum	139	EN-6, pg. 5
3. LN2 Condenser coil rupture	443	Cooling loop calcs, pg. 5
4. Maximum Pressure Building Rate		EN-321, appended
5. Overpressure from LAr storage dewar		EN-321, appended

CONCLUSION: The relief valve and relief piping capacity was calculated to be 908 scfm air. This exceeds all relieving conditions. The vessel also has a rupture disc with a 2640 scfm air stamped capacity.

Explanation of conditions 4 and 5:

Revised, 9/26/91: Pressure building in the CC is accomplished by supplying gaseous argon from the argon storage dewar. The argon storage dewar will be at a relieving pressure of 20 psig when argon transfer between the storage dewar and CC can take place. 116 percent of the CC MAWP is 34.7 psid or 19.7 psig, therefore, in order to prevent overpressure from the argon dewar, the maximum temperature of the modules within the cryostat before filling with argon was determined in EN-321 to be 218 K. The operating procedures will ensure that the module temperature is below this temperature before filling the cryostat with argon. EN-321 has been appended to this note at the end.

Revised, 11/21/91: EN-323 contains calculations of the maximum module temperature allowable when filling the ECN from various sources. The maximum temperature is 155 K for filling the ECN from the CC. The ECN is the worst case cryostat, therefore, the operating procedures will require a temperature below that calculated for the ECN. A section entitled "Determine Worst Case Cryostat to Fill" has been appended to this note to show that the ECN is a worse case than the CC.

D-ZERO COOLING LOOP INFORMATION

Recently there has been concern at the laboratory about the safety concerns of vessels having internal cooling loops in them. I will address these concerns.

Piping flexibility:

The annular space piping was analyzed and found to be safe. It is documented in D-Zero engineering note number 25. The cover sheet which includes a summary of this note is included in the appendix.

Inside the vessel, the inlet and exhaust ports are only 18.4" and 20.2" apart on the shell. The shortest length of piping between these ports is about 175" which includes no less than six 90 degree turns. A quick rough calculation shows that clearly there is enough flexibility to take up the 0.06" contraction.

Condenser Rupture:

A very worst case was considered to do the quickest most conservative case. The maximum LN2 mass flow rate was calculated. This maximum flow rate was 252 g/s.

Assumption for relief conditions:

1. LN2 of 100 percent quality delivered to the CC at 252 g/s.
2. Condenser piping is completely severed.
3. CC is warm at 300 K.
4. The LN2 is vaporized to 300 K.

From Anderson Greenwood, to convert mass flow rate to volumetric flow rate;

$V = (W*6.32)/M$

Where: V = Required capacity in scfm
W= Required capacity in lbs/hr
M = Molecular weight of flowing gas

Converting the mass flow rate from g/s to lbs/hr gives,

W= 1996 lbm/hr, N2 gas at 300K

Using M= 28.013 and substituting into the A & G equation,

V= (1996*6.32)/28.013 = 450 scfm, N2.

Converting to scfm, air,

V (air) = 450*SQRT[28.018/28.97] = 443 scfm, air

The above required flow rate is less than the 908 scfm flow capacity of the relief valve and piping on the CC. In addition to the relief valve, the CC also has a 2640 scfm stamped air capacity rupture disc.

FERMILAB
ENGINEERING NOTE

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SUBJECT: CC MAX LN_2 FLOW

NAME: R. RUCINSKI

DATE: 10-18-90

REVISION DATE: 11/16/90

CALCULATE THE EQUIVALENT LENGTH OF THE PIPING FROM THE LN_2 DEWAR TO THE INNER VESSEL OF THE CC.

DEWAR TO CRYOCORNER:

30' + 48' + 29' + 49' + 9' = 165 ft, 1½" SCH. 10

ELBOWS : 11

TEES : 1 THRU 1 BRANCH

CRYOCORNER TO VALVE BOX:

9' (JUMPER) + 5' + 40' + 20' + 20' = 94 ft, 1½" SCH. 10

ELBOWS : 8

TEES : 3 THRU

VALVE BOX TO INSIDE CC:

30 ft, 1½" SCH. 10

ELBOWS: 14

TEES : 1 THRU

VALVES, LN_2 DEWAR TO INSIDE OF CC:

PV-513N, $C_v = 34$ 1½" CRYOLAB CV159Q

MV-543N, $C_v = 34$ 1½" CRYOLAB CV8 SERIES

MV-477N, $C_v = 12$ 3/4" CRYOLAB CV8-86-5WPY-2

MV-491N, $C_v = 34$ 1½"

PV-201-N, $C_v = 1.25$ 1½" CRYOLAB CV8 SERIES

↑ CUSTOM TRIM ORDERED FROM BADGER. INSTALLED BY J. URBIN

FERMILAB
ENGINEERING NOTE

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SUBJECT
CC MAX LN_2 FLOW.

NAME
R. RUCINSKI

DATE
10-18-90

REVISION DATE

CONVERT ELBOWS, TEES, VALVES INTO EQUIVALENT LENGTHS OF PIPE.

[REFERENCE CRANE TECHNICAL PAPER No. 410]

ELBOWS: PG. A-26 & A-29, CRANE

$K = 20 f_t$ WHERE: K = RESISTANCE COEFFICIENT
f_t = TURBULENT FRICTION FACTOR
D = INTERNAL PIPE DIA., Ft
L = LENGTH OF PIPE, Ft

ALSO $L_{EQ} = \frac{KD}{f}$

$f = f_t$ SO,

$L_{EQ} = 20D \times n$ WHERE: n = # OF ELBOWS

$L_{EQ} = 20\left(\frac{1.77}{12}\text{ Ft.}\right) \times 33$ ELBOWS $= 97$ Ft, $1\frac{1}{2}$ SCH. 10

TEES: PG. A26 & A-29, CRANE

FLOW THRU BRANCH $K = 60 f_t$
FLOW THRU RUN $K = 20 f_t$

$L_{EQ} = 20D \times n_{THRU} + 60D \times n_{BRANCH}$

WHERE:
n_{THRU} = # THRU TEES
n_{BRANCH} = # BRANCH TEES

$L_{EQ} = 20\left(\frac{1.77}{12}\text{ Ft}\right) \times 5 + 60\left(\frac{1.77}{12}\text{ Ft}\right) \times 1 = 24$ Ft, $1\frac{1}{2}''$ SCH. 10

VALVES: PG. 2-10 CRANE

$C_v = \frac{29.9\, d^2}{\sqrt{K}}$ [EQ. 2-6 CRANE] WHERE: d = INTERNAL PIPE DIA., IN.
C_v = FLOW COEFFICIENT

REARRANGING,

$K = \left[\frac{29.9\, d^2}{C_v}\right]^2$

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
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SUBJECT: CC MAX LN_2 FLOW

NAME: RUSS RUCINSKI

DATE: 10-18-90

REVISION DATE:

EQUIVALENT LENGTHS OF VALVES (cont.)

- PV-513-N, $C_v = 34$ $d = 1.77$ INCHES

$$K_{1\frac{1}{2}, SCH.10} = \left[\frac{29.9\,(1.77)^2}{34}\right]^2 = 7.59$$

$$L_{EQ} = \frac{KD}{f} = 7.59\left(\frac{1.77}{12}\text{ ft}\right)/.021 = 53 \text{ ft}, 1\tfrac{1}{2}''\text{ SCH. 10}$$

- MV-543-N, SAME CALCULATION AS ABOVE, $L_{EQ} = 53$ ft.

- MV-477-N, $C_v = 12$ $d = .884$ INCHES

$$K_{3/4'' SCH.10} = \left[\frac{29.9\,(.884)^2}{12}\right]^2 = 3.79$$

FROM PAGE 2-10, CRANE

$$K_a = K_b\left(\frac{d_a}{d_b}\right)^4 \quad \left[\text{EQN. 2-5 CRANE}\right] \quad \text{TO CONVERT TO } 1\tfrac{1}{2} \text{ SCH. 10}$$

$$K_{1\frac{1}{2}\, SCH.10} = K_{3/4''\, SCH.10}\left[\frac{d_{1\frac{1}{2}}}{d_{3/4}}\right]^4$$

$$K_{1\frac{1}{2}\, SCH.10} = 3.79\left[\frac{1.77}{.884}\right]^4 = 60.9$$

$$L_{EQ} = \frac{KD}{f} = 60.9\left(\frac{1.77}{12}\text{ ft}\right)/.021 = 428 \text{ ft}, 1\tfrac{1}{2}''\text{ SCH. 10}$$

- MV-491-N, $C_v = 34$ SAME AS MV-543 & PV 513N

$$L_{EQ} = 53 \text{ ft}, 1\tfrac{1}{2}''\text{ SCH. 10}$$

- PV-201-N, $C_v = 1.25$ $d = 1.77$ INCHES

$$K_{1\frac{1}{2}\, SCH.10} = \left[\frac{29.9\,(1.77)^2}{1.25}\right]^2 = 5616$$

$$L_{EQ.} = \frac{KD}{f} = 5616\left(\frac{1.77}{12}\text{ ft}\right)/.021 = 39{,}440 \text{ ft}, 1\tfrac{1}{2}\text{ SCH. 10}$$

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SUBJECT
CC MAX LN_2 FLOW

NAME	
RUSS RUCINSKI	
DATE	REVISION DATE
10-18-90	11/19/90

FROM COMPARING EQUIVALENT LENGTHS, IT IS CLEAR THAT ALMOST ALL PRESSURE DROP WILL OCCUR ACROSS PV-201N. PV-201-N WITH $C_V = 1.25$ WILL LIMIT LN_2 FLOW.

DRIVING PRESSURE

DURING COOLDOWN THE LN_2 DEWAR PRESSURE IS 70 PSIA [REFERENCE CC CRYOSTAT PROCEDURES PAR. 7.4.1]

HEAD DUE TO ELEVATION

℄ ELEVATION LN_2 DEWAR ⇒ 749'-0"

DIA. OF LN_2 DEWAR = 8.3 Ft

ELEVATION TOP OF LN_2 IN DEWAR IS	753'-2"
ELEVATION OF CC CONDENSING COILS IS	731'-2"
	22 Ft.

CONVERT THIS HEAD TO PSI

$$22\text{ Ft} \times \rho_{LN_2}(\text{PRESS}= 44\text{ PSIA}) = 22\text{ Ft}\cdot\left(47.2\ \frac{\text{lbm}}{\text{Ft}^3}\right)\left(\frac{1\text{ Ft}^2}{144\text{ IN}^2}\right)$$

$$= 7.2\text{ PSI}$$

$$\text{DRIVING PRESSURE} = (LN_2\text{ DEWAR PRESS.}) + (\text{HEAD}) - [\text{CC MANF} + 3\text{ PSI}]$$

$$= (70\text{ PSIA}) + (7.2\text{ PSI}) - [30\text{ PSIA} + 3\text{ PSI}]$$

$$\boxed{\Delta P_{MAX} = 44.2\text{ PSI}}$$

522703

SUBJECT
CC MAX. LN_2 FLOW

NAME
RUSS RUCINSKI

DATE
11/19/90

REVISION
SUPERSEDED 10/18/90

CALCULATE MAXIMUM FLOW

ASSUMPTIONS:

1) CONDENSOR COMPLETELY SEVERS
2) NEGLECT HEAT LEAK IN TRANSFER LINE
3) PRESSURE DROP THRU LINE IS NEGLIGIBLE (CONSERVATIVE). ie/ PV-201-N LIMITS FLOW
4) SATURATED LN_2

REFERENCE: FLOW EQUATIONS FOR SIZING CONTROL VALVES
ISA STANDARD * ISA-S75.01-1985

SECTION 5 APPLIES, INCOMPRESSIBLE FLUID – CHOKED FLOW OF VAPORIZING LIQUID (FLASHING ACROSS PV-201-N)

$$q_{max} = N_1 F_L C_V \sqrt{\frac{P_1 - F_F P_V}{G_F}}$$

WHERE N_1 = Numerical constant
$N_1 = 1.00$ FOR q = gpm & p = psia

F_L = LIQ. PRESS. RECOVER
P_1 = UPSTREAM PRESSURE, PSIA.
P_2 = DOWNSTREAM PRESSURE, PSIA
P_V = ABS. VAPOR PRESSURE AT INLET
P_c = ABSOLUTE CRITICAL PRESSURE
G_F = SPECIFIC GRAVITY

$F_L = 0.9$ APPENDIX D, GLOBE VALVE

$P_{VC} = F_F P_V$

$F_F = 0.96 - 0.28\left(\frac{P_V}{P_c}\right)^{1/2}$ APPENDIX G.

SOLUTION

$P_1 = 77.2$ PSIA $P_2 = 33$ PSIA. $P_V = 70$ PSIA $C_V = 1.25$
$P_c = 493.13$ PSIA

$$F_F = 0.96 - 0.28\left(\frac{70}{493.13}\right)^{1/2} = .8545$$

$$P_{VC} = F_F P_V = .8545\,(70\text{ PSIA}) = 59.815\text{ PSIA}$$

$$q_{max} = (1.0)(.9)(1.25)\sqrt{\frac{77.2 - .8545(70)}{\frac{.727\ g/cc}{.998\ g/cc}}} = 5.50\text{ gpm}$$

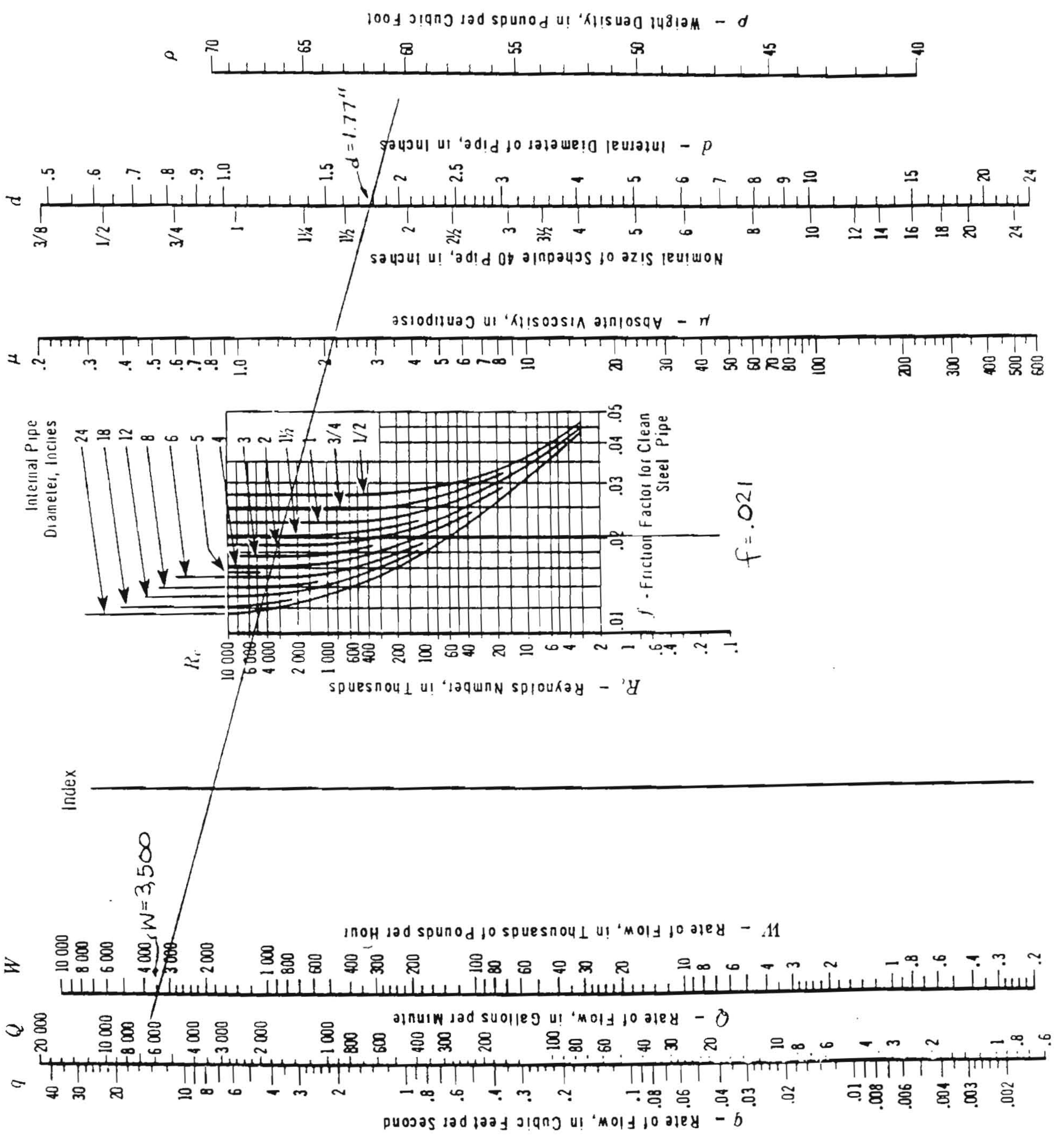
CONVERTING TO g/s;

$$q_{max} = 5.50\ \frac{gal}{MIN} \times .727\ \frac{g}{cm^3} \times \frac{1\ min}{60\ s.} \times \frac{3785.4\ cm^3}{1\ gal} = \boxed{252\ g/s}$$

PAGE 6

Reynolds Number for Liquid Flow Friction Factor for Clean Steel Pipe

(continued)



FERMILAB **ENGINEERING NOTE**	SECTION	PROJECT	SERIAL-CATEGORY	PAGE 7

SUBJECT CC RELIEF PIPING	NAME RUSS RUCINSKI	
	DATE 10-19-90	REVISION DATE 11/20/90

THESE CALCULATIONS ARE TO DETERMINE THE PRESSURE DROPS IN THE CC RELIEF PIPING. THE CALCULATED PRESSURE DROPS CAN THEN BE COMPARED TO ACCEPTABLE VALUES ALLOWED BY ASME CODE SECTION VIII.

THE RELIEF PIPING WILL BE BROKEN DOWN INTO THE FOLLOWING SECTIONS;

1) CC INNER VESSEL TO INLET OF RELIEF VALVE

2) OUTLET OF RELIEF VALVE TO PLATFORM BAYONET

3) PLATFORM BAYONET TO EXHAUST POINT OUTSIDE BUILDING

SECTION 1

CC INNER VESSEL TO INLET OF RELIEF VALVE.
THE RELIEF VALVE IS MOUNTED ON NOZZLE NUMBER N4V. PER DRG. 3740.210-ME-222361, CC CRYOSTAT ARGON VESSEL PIPING, THE PIPING CONSISTS OF;
2 1/2" SCH. 40 CONSTRUCTION, 304 S.S.

1 ~ 90° MITRED ELBOW
1 ~ 90° LONG RADIUS B.W. ELBOW
2 ~ 90° BENDS WITH A 6" ℄ RADIUS
1 ~ 59° LONG RADIUS ELBOW CUT FROM A STANDARD 90° LONG RADIUS ELBOW

120.5 INCHES OF 2 1/2" SCH. 40 PIPE

AN INLET LOSS

522703

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE 8

SUBJECT: CC RELIEF PIPING

NAME: RUSS RUCINSKI

DATE: 10-19-90

REVISION DATE: 11/20/90

SECTION 1 (CONT)

I WILL CONVERT THE ELBOWS TO EQUIVALENT LENGTHS OF 2½" SCH. 40 PIPE.

- 90° MITRED ELBOW, REF. CRANE PAGE A-29, MITRED BENDS $\alpha = 90°$

$$K = 60\, f_t$$

$$L_{EQ} = \frac{KD}{f} = 60D = 60\left(\frac{2.469}{12}\text{ ft}\right) = 12.345\text{ ft.},\ 2\tfrac{1}{2}\text{ SCH. 40}$$

- 90° LONG RADIUS ELBOW, REF. CRANE PAGE A-29

$$r/d = 3.75/2.469 = 1.52 \Rightarrow K = 14\, f_t$$

$$L_{EQ} = 14D = 14\left(\frac{2.469}{12}\text{ ft}\right) = 2.88\text{ Ft},\ 2\tfrac{1}{2}''\text{ SCH. 40}$$

- 2 ~ 90° BENDS W/ 6" ℄ RADIUS

$$r/d = 6/2.469 = 2.43 \Rightarrow K = 12\, f_t$$

$$L_{EQ} = 12D \times n = 12\left(\frac{2.469}{12}\text{ Ft}\right) \times 2 = 4.94\text{ Ft},\ 2\tfrac{1}{2}''\text{ SCH. 40}$$

- 1 ~ 59° ELBOW

$$L_{EQ.} = 2.88\text{ Ft} \times \frac{59}{90} = 1.89\text{ Ft},\ 2\tfrac{1}{2}''\text{ SCH. 40}$$

- INLET LOSS

DUE TO SUDDEN CONTRACTION,

$$K_1 = 0.5\left(1 - \frac{d_1^2}{d_2^2}\right)^{\to 0} \quad \text{EQN. 2-10 CRANE}$$

$$K_{2\frac{1}{2}''\text{ SCH-40}} = 0.5$$

$$L = \frac{KD}{f} = \frac{0.5\left(\frac{2.469}{12}\right)}{.018} = 5.71\text{ Ft.},\ 2\tfrac{1}{2}''\text{ SCH. 40 PIPE}$$

<u>TOTAL EQUIVALENT LENGTH SECTION 1</u>

$$L_{EQ\ \text{TOTAL SECTION 1}} = 12.35' + 2.88' + 4.94' + 1.89\text{ Ft} + 5.7' + \frac{120.5'}{12} = 37.8'\ 2\tfrac{1}{2}''\text{ SCH. 40}$$

FERMILAB
ENGINEERING NOTE

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SUBJECT: CC RELIEF PIPING

NAME: RUSS RUCINSKI

DATE: 10-22-90

REVISION DATE:

SECTION 2

OUTLET OF RELIEF VALVE TO PLATFORM BAYONET

- DESCRIPTION OF PIPING AND FITTINGS:

PIPE, 3" SCH. 10 × 6 3/8" LG.
2 ~ 3" SCH. 10 SHORT RADIUS ELBOWS
EXPANSION INTO A 4" SCH. 10 TEE
PIPE, 4" SCH. 10 × 19" LG.
FLEX HOSE, 4" I.D. × 11½" LG.
8 ~ 4" SCH. 10 ELBOWS, 90°
1 ~ 4" SCH. 10 TEE, BRANCH →

1 ~ 4" SCH. 10, 45° ELBOW
2 ~ 4" SCH. 10 TEE, THRU
PIPE, 4" SCH. 10, 92'-3½" LG. (SUM OF SECTIONS)

- I WILL DETERMINE THE EQUIVALENT LENGTHS OF THE PIPE AND FITTINGS IN TERMS OF 4" SCH. 10 PIPE.

– 3" PIPE

$$K_{3"sch.10} = \frac{L_{3"} f_{3"}}{D_{3"}} = \frac{\frac{6.375'}{12}(.018)}{\frac{3.26'}{12}} = .0352$$

$$K_{4"sch.10} = K_{3"sch.10} \cdot \left(\frac{d_{4"}}{d_{3"}}\right)^4 = (.0352)\left(\frac{4.26}{3.26}\right)^4 = .10264$$

$$L_{EQ,\,4"sch.10} = \frac{K_{4"sch.10}\, D_{4"sch.10}}{f_{4"}} = \frac{.10264\left(\frac{4.26}{12}\right)}{.017} = 2.14 \text{ ft., } 4" \text{ sch. } 10$$

– 3" ELBOWS (REF. CRANE A-29)

$$r/d = \frac{3}{3.26} \approx 1 \Rightarrow K = 20 f_T$$

$$L_{EQ} = \frac{KD}{f} = \frac{20 f_T (D)}{f} = 20D = 20\left(\frac{3.26}{12}\right) = 5.43 \text{ ft, } 3" \text{ sch. } 10$$

$$K_{3"sch.10} = .360 \Rightarrow K_{4"sch.10} = 1.0497$$

$$L_{EQ,\,4"sch.10} = 21.9 \text{ ft.} \times 2 \text{ ELBOWS} = 43.84 \text{ ft., } 4" \text{ SCH } 10$$

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE 10

SUBJECT: CC RELIEF PIPING

NAME: Russ Rucinski

DATE: 10-22-90

REVISION DATE:

- EXPANSION (REF. CRANE PG. 2-11)

$d_1 = 3.26''$ $d_2 = 4.26''$ $\theta = 180°$

$K_1 = \left(1 - \frac{d_1^2}{d_2^2}\right)^2 = \left(1 - \frac{3.26^2}{4.26^2}\right)^2 = .1717$

L_{EQ} 4" = .1717 (60.8) = 10.44 ft, 4" SCH. 10

↑ FACTOR DEDUCED FROM PREVIOUS TWO CALCULATIONS

- 4" I.D. FLEX HOSE

$L_{EQ\ 4''\text{I.D. TUBE}} = 11\frac{1}{2}'' \times \frac{1\,ft}{12''} \times 3 = 2.875$ ft, 4" I.D. TUBE

$K_{4''\text{I.D. TUBE}} = \frac{Lf}{D} = \frac{2.875\,(.017)}{\frac{4.00}{12}} = .14663$

$K_{4''\text{SCH.10}} = (.14663)\left(\frac{4.26}{4.0}\right)^4 = .18863$

$L_{EQ\ 4''\text{SCH.10}} = \frac{KD}{f} = \frac{.18863\left(\frac{4.26}{12}\right)}{.017} = 3.94$ ft, 4" SCH. 10

- 4" SCH. 10 ELBOWS

$r/d = 4/4.26 \approx 1 \Rightarrow K = 20 f_T$

$L_{EQ} = 20 D \times n$ WHERE: D = PIPE DIA. IN FEET
n = # OF ELBOWS

$L_{EQ} = 20\left(\frac{4.26}{12}\right)(8.5) = 60.35$ ft., 4" SCH. 10

↑ 8 ~ 90° + 1 ~ 45°

- 4" SCH. 10 TEES

THRU BRANCH, $K = 60 f_T$
THRU RUN, $K = 20 f_T$

$L_{EQ} = \left[20 \times n_{THRU} + 60 \times n_{BRANCH}\right] \times D$

$= \left[20 \times 2 + 60 \times 1\right]\left(\frac{4.26}{12}\right) = 35.5$ ft, 4" SCH. 10

TOTAL EQUIVALENT LENGTH SECTION 2

$L_{EQ\ TOTAL} = 2.14' + 43.84' + 10.44' + 1.58' + 3.94' + 60.35' + 35.5' + 92.29'$

$\boxed{L_{EQ\ TOTAL} = 250 \text{ ft., } 4'' \text{ SCH. } 10}$

RELIEF VALVE OUTLET
TO BAYONET ON PLATFORM

SECTION 3

PLATFORM BAYONET TO EXHAUST POINT OUTSIDE BUILDING.
(REFERENCE: DRG. 3740.512-MC-222952 FOR PIPING LAYOUT)

PIPING DESCRIPTION;

2 ~ 4" SCH.10 ELBOWS, 90°, SHORT RADIUS
PIPE, 4" SCH.10 × 5 Ft.
1 ~ 4 × 6" EXPANSION BY A REDUCER
8 ~ 6" SCH.10 ELBOWS
2 ~ 6" SCH.10 TEES (THRU BRANCH)
PIPE, 6" SCH.10 × 156 Ft.
PIPE EXIT

I WILL CONVERT THE ABOVE TO EQUIVALENT LENGTHS OF 6" SCH.10 PIPE.

– 4" ELBOWS

$$K_{4'\ \text{ELBOW}} = 20 f_t = 20.(.017) = .34$$

$$K_{6''\ \text{SCH.10}} = (.34)\left(\frac{6.357}{4.26}\right)^4 = 1.686$$

f = .018 FROM CRANE, A-25

$$L_{\substack{\text{EQ}\\ 6''\text{SCH.10}}} = \frac{KD}{f} \times n_{\text{ELBOWS}} = \frac{1.686\left(\frac{6.357}{12}\right)}{.018} \times 2 = 99.2\ \text{Ft, } 6''\ \text{SCH.10}$$

– 4" PIPE

FROM PG. 6 CALCS

$$K_{4''\ \text{SCH 10}} = \frac{L_{4''\text{SCH.10}}\, f_{4''}}{D_4} = \frac{(5\ \text{Ft})(.019)}{\left(\frac{4.26}{12}\text{Ft}\right)} = .2676$$

$$K_{6''\text{SCH.10}} = .2676\left(\frac{6.357}{4.26}\right)^4 = 1.327$$

$$L_{\text{EQ}\ 6''\text{SCH.10}} = \frac{KD}{f} = \frac{1.327\left(\frac{6.357}{12}\right)}{.018} = 39.1\ \text{Ft, } 6''\ \text{SCH.10}$$

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SUBJECT
CC RELIEF PIPING

NAME
RUSS RUCINSKI

DATE
10-22-90

REVISION DATE
11/20/90

- 4"×6" EXPANSION (REF. PG. 2-11 CRANE)

$$K_1 = \left(1 - \frac{d_1^2}{d_2^2}\right)^2 \qquad d_1 = 4.26 \qquad d_2 = 6.357$$

$$K_{4''\,sch.\,10} = \left(1 - \frac{4.26^2}{6.357^2}\right)^2 = .3035$$

← RATIO, PREVIOUS CALC.

$$L_{EQ.\,6''\,sch.\,10} = .3035 \times \left(\frac{39.1}{.2676}\right) = 44.3 \text{ Ft } 6''\text{ SCH. 10}$$

- 6" ELBOWS

$$r/d \sim 1 \rightarrow K_{\underset{ELBOW}{6''\,SCH.10}} = 20 f_t$$

$$L_{EQ} = 20 \cdot D \times n_{ELBOWS} = 20 \cdot \left(\frac{6.357}{12} \text{ Ft}\right) \times 8 = 84.76 \text{ Ft, } 6''\text{ SCH. 10}$$

- 6" TEES

$$L_{EQ} = 60 \times D \times n_{TEES} = 60 \left(\frac{6.357}{12} \text{ Ft}\right) \times 2 = 63.57 \text{ Ft, } 6''\text{ SCH. 10}$$

- PIPE EXIT

$$K_1 = \left(1 - d_1^2/d_2^2\right)^2 \longrightarrow \lim_{d_2 \to \infty} K_1 = 1.0 \Rightarrow L = \frac{KD}{f} = 29.5 \text{ Ft, } 6''\text{ SCH. 10}$$

TOTAL EQUIVALENT LENGTH, SECTION 3

$$L_{TOTAL}^{EQ} = 99.2' + 39.1' + 44.3' + 84.8' + 63.6' + 29.5' + 156' = \boxed{516.5 \text{ Ft } 6''\text{ SCH. 10}}$$

TO GET AN EQUIVALENT LENGTH, RELIEF VALVE OUTLET TO EXHAUST, I WILL COMBINE SECTIONS 2 & 3

SECTION 2 $L_{EQ.}$ = 250 Ft., 4" SCH. 10

SECTION 3 $L_{EQ.}$ = 517 Ft., 6" SCH. 10

CONVERTING SECTION 2 LENGTH TO 6" SCH. 10 EQUIVALENT,

$$K_{4''\,SCH\,10} = \frac{LF}{D} = \frac{(250 \text{ Ft})(.019)}{\left(\frac{4.26}{12}\right)} = 13.38$$

$$K_{6''\,SCH.10} = 13.38 \left(\frac{6.357}{4.26}\right)^4 = 66.35$$

$$L_{EQ\,6''\,SCH.10} = \frac{KD}{F} = \frac{66.35 \cdot \left(\frac{6.357}{12} \text{ Ft}\right)}{.018} = 1{,}953 \text{ Ft, } 6''\text{ SCH. 10}$$

$L_{EQ.}$ = 2470 Ft, 6" SCH. 10, RELIEF OUTLET TO EXHAUST POINT.

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SUBJECT	NAME	
CC RELIEF PIPING	RUSS RUCINSKI	
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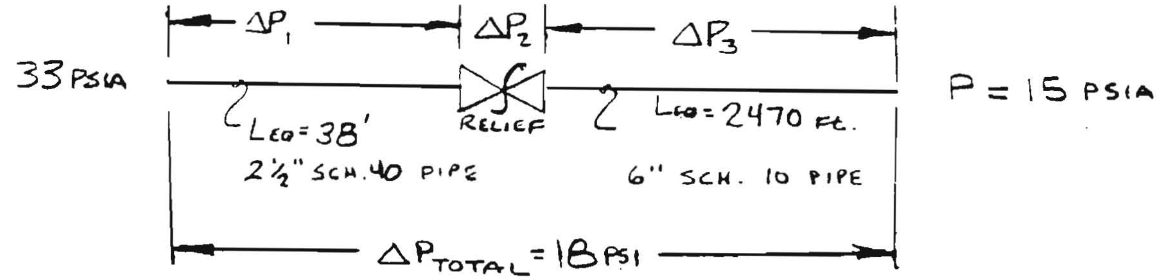
PROBLEM: DETERMINE THE MAXIMUM FLOW RATE THROUGH RELIEF PIPING.

GIVEN: EQUIVALENT LENGTHS OF PIPING
AVAILABLE ΔP
EQUATIONS OF FLOW FOR RELIEF VALVE

ASSUME: ARGON GAS AS FLUID
TEMPERATURE OF FLUID IS 95K

SKETCH OF PROBLEM:



METHOD FOR SOLUTION:

1. PICK A FLOW RATE
2. CALCULATE ΔP_1
3. CALCULATE ΔP_3
4. CALCULATE $\Delta P_2 = 18\text{ PSI} - \Delta P_1 - \Delta P_3$
5. CALCULATE FLOW RATE THRU RELIEF
6. COMPARE CALCULATED FLOW RATE WITH PICKED FLOW RATE
7. KEEP ITERATING 1. THRU 6 UNTIL THE CALCULATED FLOW RATE THRU RELIEF MATCHES PICKED FLOW RATE. THIS IS THE MAXIMUM FLOW RATE THRU THE RELIEF PIPING.

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SUBJECT	NAME	
CC RELIEF PIPING	RUSS RUCINSKI	
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TRY A FLOW RATE OF 10,000 lb/hr SATURATED ARGON GAS.

$$\Delta P = 3.36\times10^{-6}\ \frac{fLW^2}{\rho d^5}$$ FROM CRANE PG. 3-2, COMPRESSIBLE FLOW

- DETERMINE ΔP_1.

$L = 32$ ft $\quad \rho\,(P = 31\text{ PSIA}) = .716\ \text{lb}/\text{ft}^3 \quad d = 2.469$ IN.

CRANE EQN. 3-3 } $Re = 6.31\ \frac{W}{d\mu}$ $\quad \mu = 79.1\times10^{-4}$ centipoise

$$Re = 6.31\ \frac{10{,}000}{2.47\,(79.1\times10^{-4})} = 3.23\times10^{6} \Rightarrow f = 0.018$$ CRANE PG. 3-19

$$\Delta P_1 = 3.36\times10^{-6}\ \frac{(.018)(38)(10{,}000)^2}{(.716)(2.469)^5} = 3.5 \text{ PSI}$$

- DETERMINE ΔP_3

$L = 2470$ ft $\quad d = 6.357 \quad \rho\,(P = 15\text{ PSIA}) = .365\ \text{lb}/\text{ft}^3$

$$Re = 6.31\ \frac{W}{d\mu} = 6.31\ \frac{(10{,}000)}{(6.357)(72.6\times10^{-4}\text{ cp})} = 1.37\times10^{6}$$

$f = .0155$

$$\Delta P_3 = 3.36\times10^{-6}\ \frac{(.0155)(2470)(10{,}000)^2}{(.365)(6.357)^5} = 3.4 \text{ PSI}$$

- DETERMINE FLOW THRU RELIEF VALUE (SUB-SONIC FLOW) FROM AGCO CATALOG,

$$W = 735\ A\ K_d\ P_1\ F' \sqrt{\frac{M}{TZ}}$$

WHERE $$F' = \left\{\left(\frac{k}{k-1}\right)\left[\left(\frac{P_2'}{P_1}\right)^{2/k} - \left(\frac{P_2'}{P_1}\right)^{\frac{k+1}{k}}\right]\right\}^{1/2}$$

AND $$\frac{P_2'}{P_1} = \frac{P_1 - 0.55(P_1 - P_2)^{.96}}{P_1}$$

M = molec. wt = 40 g/mol

P_1 = INLET PRESSURE

P_2 = OUTLET PRESSURE

K = RATIO C_p/C_v = 1.74
↑ AT P = 24 PSIA

T = FLOWING TEMPERATURE AT INLET

A = 2.29 IN^2 ORIFICE AREA

K_d = DISCHARGE COEFF. = .939

Z = COMPRESS. FACTOR = 1.0

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SUBJECT	NAME
CC RELIEF PIPING	RUSS RUCINSKI
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FLOW IS SUBSONIC IF $P_2 \geq P_{CF}$

$$P_{CF}' = P_1 \left(\frac{2}{K+1}\right)^{K/K-1} = 30 \text{ PSIA} \left(\frac{2}{2.74}\right)^{\frac{1.74}{.74}} = 14.3 \text{ PSIA}$$

P_2 WILL ALWAYS BE GREATER THAN P_{CF} $\therefore$ SUBSONIC FLOW IS CORRECT.

$P_1 = 29.5$ PSIA , $P_2 = 18.4$ PSIA $\rightarrow$ $\frac{P_2'}{P_1'} = .81$

$F' = 0.40$ $T\,(P_{SAT} = 30\text{ PSIA}) = 170°R$

SUBSTITUTE INTO FLOW EQUATION,

$$W = 735\,(2.29)(.939)(29.5)(0.40)\sqrt{\frac{40}{170\,(1.0)}} = 9{,}046 \text{ lb/hr}$$

- COMPARISON

PICKED A FLOW RATE = 10,000 lb/hr

CALCULATED $\Delta P_1 = 3.5$ psi , $\Delta P_2 = 11.1$ PSI , $\Delta P_3 = 3.4$ PSI

CALCULATED RELIEF RATE = 9046 lb/hr

TRY A FLOW RATE OF 9,500 lb/hr SATURATED ARGON GAS

- DETERMINE ΔP_1

$$\Delta P_1 = 3.36 \times 10^{-6} \frac{(.018)(38)(9{,}500)^2}{(.716)(2.469)^5} = 3.2 \text{ PSI}$$

- DETERMINE ΔP_3

USE $\rho\,(P = \frac{17.4+15}{2} = 16.2 \text{ PSIA}) = .38775 \text{ lb/ft}^3$

$$\Delta P_3 = 3.36 \times 10^{-6} \frac{(.0155)(2740)(9{,}500)^2}{(.38775)(6.357)^5} = 3.2 \text{ PSI}$$

- DETERMINE FLOW THRU RELIEF VALVE

$P_1 = 29.8$ PSIA $P_2 = 18.2$ PSIA $P_2'/P_1 = .81$ $F' = 0.40$

$$W = 735\,(2.29)(.939)(29.8)(0.40)\sqrt{\frac{40}{170\,(1.0)}} = 9{,}138 \text{ lb/hr}$$

- COMPARISON

PICKED A FLOW RATE = 9500 lb/hr

CALCULATED $\Delta P_1 = 3.2$ PSI , $\Delta P_2' = 11.6$ PSI , $\Delta P_3 = 3.2$ PSI

CALCULATED FLOW RATE = 9138 lb/hr

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ENGINEERING NOTE

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PAGE 16

SUBJECT: CC RELIEF PIPING

NAME: RUSS RUCINSKI

DATE: 10-25-90

REVISION DATE: 11/20/90

TRY A FLOW RATE OF 9250 lb/hr SATURATED Argon gas

- $\Delta P_1 = 3.0$ PSI
- $\Delta P_3 = 3.0$ PSI
- DETERMINE FLOW THRU RELIEF

$P_1 = 30$ PSIA $P_2 = 18$ PSIA $P_2'/P_1 = .80$ $F' = .41$

$$W = 735(2.29)(.939)(30.0)(.41)\sqrt{\frac{40}{170(1.0)}} = 9{,}430 \text{ lb/hr}$$

FROM THE ITERATIONS DONE AND ACCURACIES INVOLVED I FEEL IT IS SAFE TO SAY THE ACTUAL RELIEF CAPACITY OF THE RELIEF VALVE/PIPING IS

$$W_{CAPACITY} = 9250 \text{ lb/hr} \quad \text{SATURATED ARGON}$$

- CONVERT THIS TO AN EQUIVALENT AIR FLOW RATE

FROM ASME APPENDIX 11 CAPACITY CONVERSIONS,

$$W = CKAP\sqrt{\frac{M}{T}} \quad \text{FOR ANY GAS OR VAPOR}$$

FOR THE SATURATED ARGON CASE,

$$KAP = \frac{W}{C}\sqrt{\frac{T}{M}}$$

$W = 9250$ lb/hr
$C =$ FUNCTION OF $K = 1.74 \Rightarrow 385$
$M = 40$ g/mol
$T =$ ABS. TEMP AT INLET °R $= 170$ °R

$$KAP = \frac{9250}{385}\sqrt{\frac{170}{40}} = 49.53$$

RATING IN AIR IS,

$$W_a = CKAP\sqrt{\frac{M}{T}} = 356(49.53)\sqrt{\frac{28.97}{520°R}} = 4162 \text{ lb/hr}$$

CAPACITY IN SCFM AIR IS,

$$V = 6.32\frac{W}{M} = 6.32\frac{(4162 \text{ lb/hr})}{28.97} = \boxed{908 \text{ scfm air}}$$

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ENGINEERING NOTE

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SUBJECT	NAME
CC RELIEF PIPING	RUSS RUCINSKI
	DATE 10-25-90 REVISION DATE 11/20/90

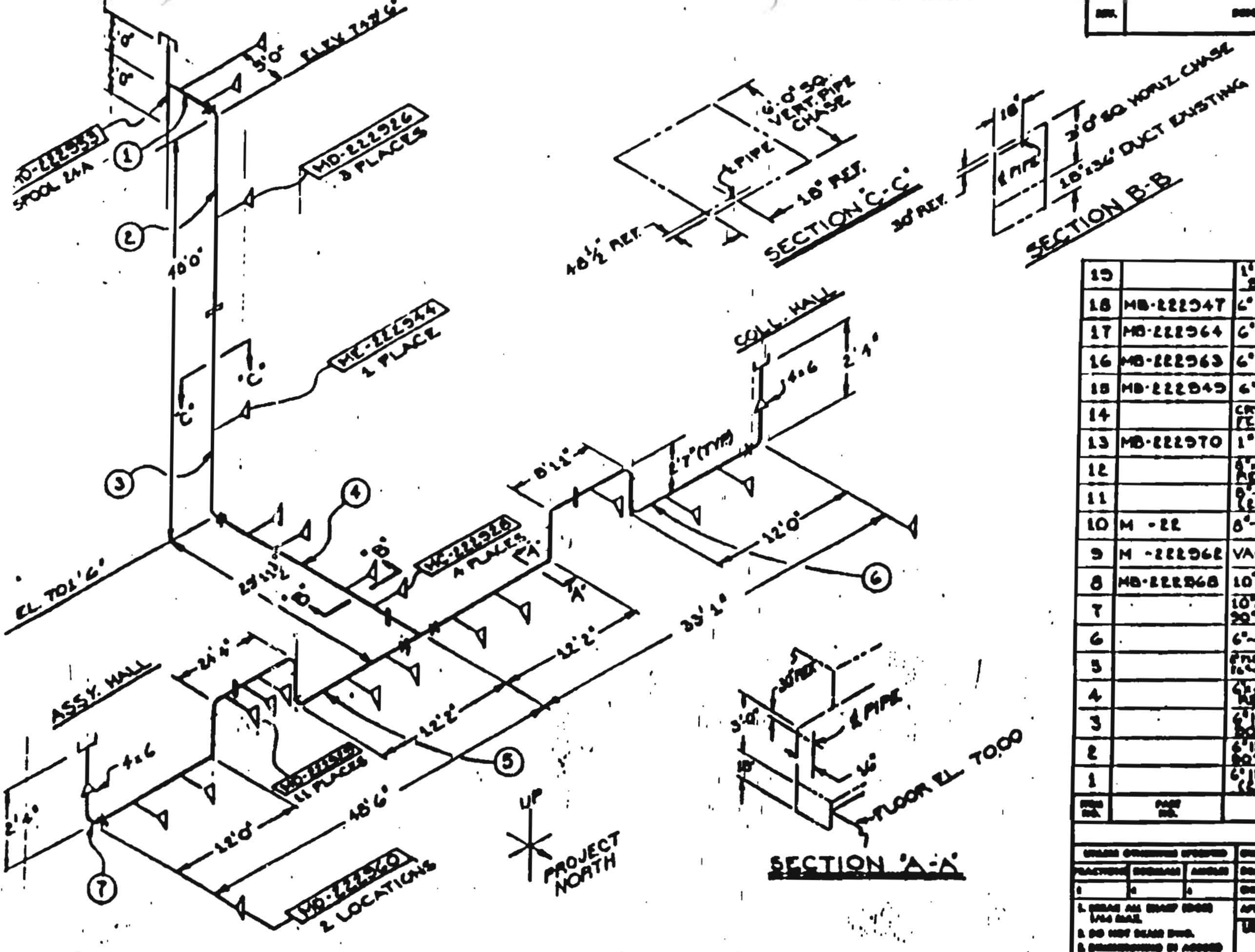
SUMMARY

THE RELIEF CAPACITY OF THE RELIEF PIPING AND VALVE IS 908 SCFM, AIR.

THE PRESSURE DROP IN THE PIPING UP TO THE VALVE IS 3.0 PSI. THE PRESSURE DROP IN THE PIPING AFTER THE VALUE IS 3.0 PSI.

THE INLET PIPING LOSS IS 23% OF THE SET PRESSURE WHICH EXCEEDS THE API LIMIT OF 3% SET PRESSURE. THE RELIEF PILOT SENSING LINE HOWEVER IS TIED INTO A PRESSURE SENSING LINE WHICH WILL NOT SEE FLOW DURING THE OCCURENCE OF THE RELIEF VALVE RELIEVING. THIS MEASURE MEETS THE INTENT OF API RP520, PART II PAR. 2.2.

REV.	DESCRIPTION	DRAWN	DATE
		APPR.	DATE



ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY.
19		1"~CVI 1046 VACUUM SEAL OFF VALVE	4
18	MB-222947	6" SPIDER RETAINING BAND	60
17	MB-222964	6"8¼" TRAVEL SPIDER	12
16	MB-222963	6" CONCENTRIC SPIDER	18
15	MB-222949	6" CLAMSHELL	6
14		CRYOLAB CCB-8-1-BWM-4" FEMALE BAYONET	2
13	MB-222970	1" VACUUM NIPPLE	2
12		8"x6"~SCH. 10s CONCENTRIC REDUCER~SS304	2
11		8"~SCH. 10s PIPE (20'-0" LG.)~SS304	11
10	M -22	8"-SCH. 10s~45° MITER SECT.	11
9	M -222962	VACUUM BREAK	3
8	MB-222968	10"x8" ADAPTER PLATE	2
7		10"~SCH. 10s PIPE 90° S.R. BW ELBOW~SS304	1
6		6"~SCH. 10s~TEE SS 304	1
5		[illegible]	4
4		6"x4"~SCH. 10s CONCENTRIC REDUCER~SS304	2
3		6" IPS~SCH. 10s PIPE 90° S.R. BW ELBOW~SS304	1
2		6" IPS~SCH. 10s PIPE 90° S.R. BW ELBOW~SS304	11
1		6" IPS~SCH. 10s PIPE (20'-0" LG.)~SS304	9

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTIONS	DECIMALS	ANGLES	DRAWN	18d	6/92
±	±	±	CHECKED		
[illegible]			APPROVED		
			USED ON		
			MATERIAL		

NOTES:

1) SEE ME-222906 FOR OVERALL PIPING ASSY.
2) FABRICATE AND TEST PER SPEC. NO. 3740.510-ES-222972
3) ALL DIM'S ARE ℄ TO ℄ OF 8" VACUUM PIPE @ 70°F.

SYMBOLS

- PIPE SUPPORT
- DENOTES FIELD WELD SPOOL CONN.
- VACUUM BREAK
- BAYONET CONN.

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

D-Ø DETECTOR
6x8 Ar/N₂ VENT
LINE-6x8-4017-E SPOOL #24

18

SCALE	FILMED	DRAWING NUMBER	REV.
~/		3740.512-MC-222952	

SHEET 1 OF 3

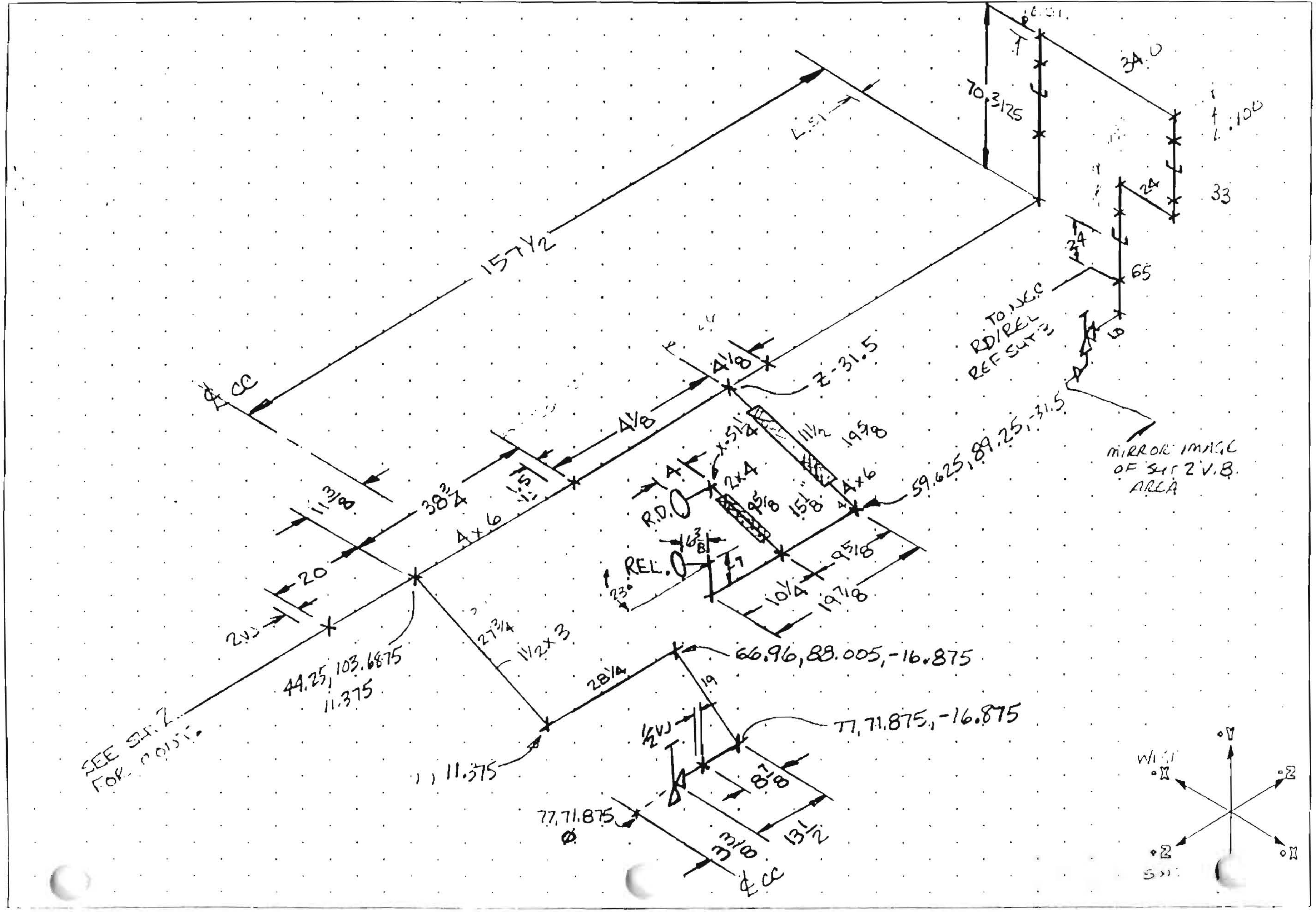
SKETCHPIPE.DWG
USE WITH CREATEPIPE.PRG

○ - POINT NUMBER
□ - PIPE/ELEMENT NUMBER
⬡ - PIPE DIR
⬭ - ELDIR

TONY PARKER JULY 5, 1989

D-0 4x6 Ar/N_2 Vent

REV. 2/12/90



SHEET 2 OF 3

SKETCHPIPE.DWG

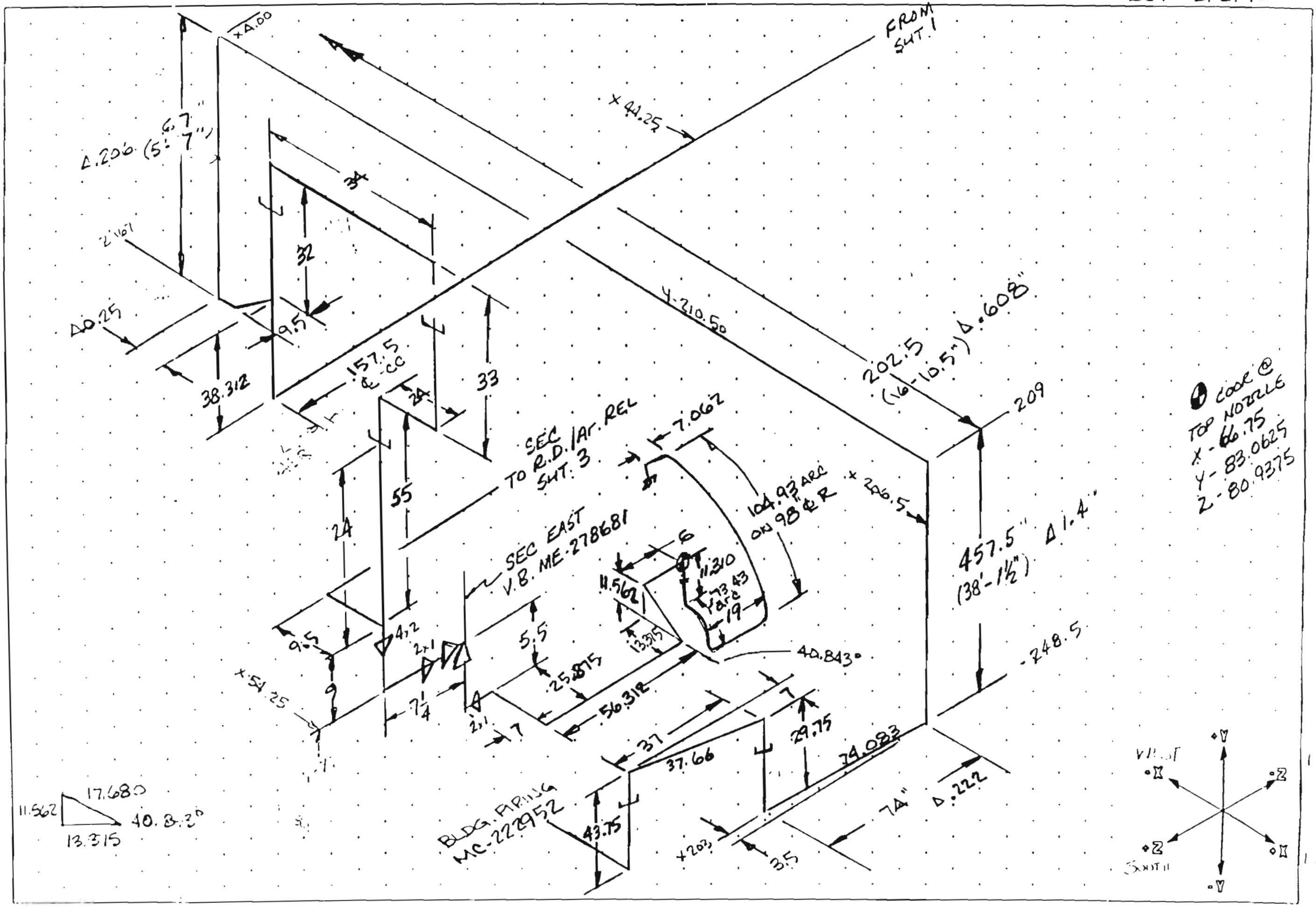
USE WITH CREATEPIPE.PRG

○ - POINT NUMBER
□ - PIPE/ELEMENT NUMBER
⬡ - PIPE DIR
○ - ELDIR

TONY PARKER JULY 5,1989

D-0 4×6 AR/N2 VENT

REV 2/2/90



revision 11/18/91

John Wu

Determine Worst Case
Cryostat to Fill

DØ Engineering Note 3740.224-EN-323, "ECN Pressure and Vacuum Vessel Engineering Notes," contains calculations to determine the maximum ECN relief capacity (p.5-14), and the maximum module temperature when filling the ECN from the CC (p.15-24). The ECN is the worst case cryostat to fill. DØ Engineering Note 3740.224-EN-329 compares the ECS to the ECN to show that the ECN is a worse case. This section compares the CC to the ECN. The CC differs from the ECN in that the CC has a much shorter equivalent length of vent piping, and also a shorter equivalent length of piping from the LAr dewar to the CC. To determine the worst case cryostat, both the fill capacity and the vent capacity are compared.

Venting capacity

Reference: DØ Engineering Note 3740.224-EN-323, ECN Pressure and Vacuum Vessel Engineering Notes.

The first spreadsheet in EN-323 (p.8-14) calculates the ECN relief flow capacity. In the section, "ΔP Across Relief Valve", line 108 shows the maximum theoretical flow through the relief valve. In the section, "ΔP Across Rupture Disk", line 181 shows the maximum theoretical flow through the rupture disk. Therefore, the total mass flow can be calculated as:

$$\rho\left(q_{rel}^{ECN}\right)_{max} = 7740\,\frac{lb_m}{hr}\,(\text{relief valve}) + 7458\,\frac{lb_m}{hr}\,(\text{rupture disk}) = 15{,}198\,\frac{lb_m}{hr}$$

Note that q here represents the flow through the relief piping, <u>out</u> of the ECN.

revision 11/18/91

John Wu

The calculation of the venting capacity of the ECS was done in DØ Engineering Note 3740.224-EN-329. The only difference in the relief piping of the ECS is that the equivalent length of the common outlet (just to the platform bayonet) is 238 ft. The ECN has an equivalent length of 273 ft. The CC equivalent length can be determined from drawings of the Ar/N2 vent line as follows:

Relief Common Outlet to Platform Bayonet

Reference: Drawings from Tony Parker of 4" x 6" Ar/N2 vent lint.

$d = 4.260$ in $= 0.355$ ft (inside diameter of 4" pipe)

There is no rotary bayonet assembly for the CC vent line.

$$L_{piping} = 4 + 27.5 + 157.5 + 38 + 10 + 40 + 67 + 210.5 + 457.5 + 74 + 16$$
$$L_{piping} = 1102 \text{ in} = 91.83 \text{ ft}$$

\# els, 90° = 6
\# els, 45° = 1
\# tees, thru = 1
\# tees, branch = 2

Using K factors for standard elbows and tees as a conservative estimate,

$$L_{eq} = 91.83 + 0.355\,[6(30) + 1(16) + 1(20) + 2(60)] = 204 \text{ ft}$$

In EN-329, the total mass flow for the ECS was calculated to be 16,815 lbm/hr. The ECN and ECS relief piping flowrates were then compared:

$$\frac{q_{rel}^{ECS}}{q_{rel}^{ECN}} = \frac{\rho q_{rel}^{ECS}}{\rho q_{rel}^{ECN}} = \frac{16{,}815\,\frac{lb_m}{hr}}{15{,}198\,\frac{lb_m}{hr}} = 1.106$$

The maximum relief outlet flow from the ECS is greater than the maximum relief outlet flow from the ECN by about 10%. The CC has an even shorter equivalent length of vent piping than the ECN or ECS. Therefore, the maximum relief outlet flow from the CC would be greater than that of the ECN by more than 10%.

Fill capacity

Reference: ECN numbers taken from DØ Engineering Note 3740.512-EN-321, Cryostat Filling Limitations for Proposed Ar Dewar Pressure Increase, in the section "Calculation of Max. Flowrate from LAr Dewar to ECN".

There are two cases to consider for the CC, filling from the LAr dewar, and filling from one of the EC's. Note that the equivalent lengths of piping from the ECN and the ECS will be approximately the same. Looking at the ECN, since the CC has a higher venting capacity than the ECN, it would be worse to fill the ECN from the CC, than the CC from the ECN (or the ECS). The case of filling the ECN from the CC is covered in EN-323. Filling from the LAr dewar is considered next.

$$\left(q_{fill}^{ECN}\right)_{max} = 12.3 \text{ gpm}$$

Note that q here represents the flow through the inlet fill piping, into the ECN.

$$\Sigma K^{ECN} = 90.05$$

$$\Sigma K^{CC} = \Sigma K^{ECN} - \frac{f(L_{eq})}{d} \cong 90.05 - \frac{(0.022)(30\text{ ft})}{0.1402\text{ ft}} = 85.34$$

The CC has a smaller resistance coefficient because it has a shorter equivalent length of piping from the argon dewar. Therefore, the same driving pressure from the dewar will produce a larger inlet flow to the CC than to the ECN (Note the ECS is the worst case in this respect). The flowrate is inversely proportional to the square root of the resistance coefficient:

$$q^{\text{cryostat}} \propto \frac{1}{\sqrt{\Sigma K^{\text{cryostat}}}}$$

Therefore, the flowrates of the CC and ECN can be compared as follows:

$$\frac{q_{\text{fill}}^{\text{CC}}}{q_{\text{fill}}^{\text{ECN}}} = \frac{\sqrt{\Sigma K^{\text{ECN}}}}{\sqrt{\Sigma K^{\text{CC}}}} = \frac{\sqrt{90.05}}{\sqrt{85.34}} = 1.027$$

The maximum inlet flow to the ECS is greater than the maximum inlet flow to the ECN by about 3%.

Conclusion

The CC has a higher venting capacity than the ECN (and the ECS). The only situation where the CC also has a higher inlet flow is the case of filling the CC from the LAr dewar. Since, in this case, the flowrate <u>out</u> of the CC relative to the flowrate <u>out</u> of the ECN (more than 1.106 times ECN) is greater than the flowrate <u>into</u> the CC relative to the flowrate <u>into</u> the ECN (1.027 times ECN), the ECN is the flowrate limiting vessel. Therefore, the calculations in EN-323 for the ECN are also valid for the CC, specifically, the maximum module temperature before filling any cryostat with argon is determined by the worst case of the CC filling the ECN.

7.0 CC CRYOSTAT

These procedures describe the operation of the cryostat on the platform. Refer to the cryogenic flow diagram, 3740-ME-222394, revision W for platform operations.

Only subsequent changes or modifications which affect the safety of the vessel will be updated in the CC Cryostat Engineering Note and in DØ Note #3740.EN-263.

7.1.0 Inner Vessel Pump and Purge

The following assumes that the platform piping has been installed, leak checked, and pressure tested as required, the connections to the CC cryostat have been made, helium has been provided to the cold valve (PV219A), I/A (open MV1400I/1401I) and GN2 purge are connected and flowing to the platform , all valves have been stroked and are operational, EC cryostat and UV branches are properly capped or (welded) closed if required, and the cryocorner jumpers have been fabricated and tested, and are ready to install. Note that the u-tubes that connect the storage dewar to the cryostat must be removed at this time; the cryostat must be isolated from the LAr dewar when not in operation. If it is necessary to have the LAr fill/drain u-tube (440LA) installed at this point, then the key lock for I/PX18A shall be in the DISABLE position and the key secured in the lock box.

7.1.1 Install the cryocorner jumper lines in order according to their designations; 406V, 416E, 430LA, 424UV, 421GA, and 411LN, in strict accordance with **10.2** of the special procedures.

7.1.2 Start pumping down the CC insulating jacket according to **3.5**. This operation is independent of the pressure vessel and may be performed in parallel with those that follow.

7.1.3 To Pump and Purge the Inner Vessel CLOSE:

Cryostat
_ mv205A(test)
_ PV215UV
_ PV219A
_ MV241A(sample)
_ PV214A
_ mv217N
_ PV228A(vent)
_ MV243A(sample)

Pump room
_ PV706V
_ MV712UV(vent)
_ MV727N
_ PV707UV
_ EV714UV
_ MV722A

Note: the liquid sample valves, MV241A and MV243A, are closed to eliminate the long lines to the Cryocorner. Those lines must be separately pumped and purged at the Sample panel in the cryocorner before either of the sample valves are opened or a sample attempted, see Appendix S for the LAr Sample Procedure .

7.1.4 To Pump and Purge the Inner Vessel OPEN:

Cryostat	_ mv203A _ MV244A	_ mv224A (outer) _ mv245A
Cryocorner	_ MV454UV	
Pump Room	_ MV705UV _ mv729UV	_ mv728UV _ mv734UV

7.1.5 Backfill the UV manifold with GN_2 to 1 psi as read on PI716UV (PT717UV) by opening MV727N and EV714N. Close EV714N.

7.1.6 Vent any inner vessel positive pressure greater than 1 psi through PV215UV by opening the vent valve, MV712UV, and then closing it tightly. Note: PV215UV is interlocked CLOSED and will have to be temporarily overridden to release the pressure. Close PV215UV. Check MV712UV tightly closed before proceeding.

7.1.7 Start the utility roughing pump and begin pumping on the inner vessel by opening PV707UV to the manifold and PV215UV to the cryostat.

7.1.8 If there is an unacceptable cryostat vacuum due to bakeable outgassing components, the warm-up heaters may be used to bake out the detector according to the procedures in **10.5**. UNDER NO CIRCUMSTANCES SHOULD THE HEATERS BE OPERATED AT ANY LEVEL WHILE THE CRYOSTAT IS UNDER VACUUM.

7.1.9 Continue pumping the pressure vessel until the pressure reaches at least 100 μ as read on TG258A. This process may take several days to weeks for a tight system, depending on the cryostat pump history and the current rate of outgassing of the contents. Open all trapped (capped) volumes to the vessel while pumped down and until back filled. Do not include these volumes in any long term pumping or in ROR measurements, and be sure to leave them closed at the procedures end. Indicate completion of the opening of the trapped volumes; mv205A, MV241, and MV243. Please be careful not to inadvertently open any of the VPT charging valves; mv253, 254, or 255.

7.1.10 Isolate the UV pump from the header, close PV707UV.

7.1.11 Check the ROR of the inner vessel for one hour or a 50 μ rise, and record the data in the logbook.

7.1.12 Check PI742N to ensure that the supply pressure from PRV725N is between 2 and 3 psig. Start backfilling the cryostat with GN_2 by opening EV714N.

7.1.13 Continue to fill the cryostat with nitrogen gas. When the pressure in the cryostat reaches 1 psig as read by PT717UV and checked with PI716UV, close MV727N.

7.1.14 Open PV707UV and pump the cryostat to at least 100 µ once again.

7.1.15 If the condenser outlet overflow switch, TS232E, has not been tested *in situ*, special permission should be obtained from the safety panel if necessary in order to flood the condenser with LN2 in an attempt to trip the temperature switch. If the switch has been tested *in situ* recently, continue to 7.1.20.

7.1.16 Once the necessary safety approval has been granted, install the LN2 dewar/cryostat jumper at the storage dewar and pump and purge the nitrogen transfer line as described in 7.2.3 through 7.2.7.

7.1.17 Ensure that PV513N is closed and MV535N, MV493N are closed and locked. Open or check open all valves from the N2 storage dewar through the condenser steady state cooling coil and into the condenser exhaust. Specifically, OPEN

_ MV543N _ MV477N _ MV491N
_ PV202N@100% _ PV210N@100%

7.1.18 Open PV513N, cool down the transfer line and flood the condenser. The condenser outlet overflow switch, TS232E, should open when liquid flows past PV210N. If TS232E fails to open when there has been a reasonable amount of time allotted to flood the condenser, then the switch must be repaired and the "flood test" repeated until reasonable confidence is attained with this device.

7.1.19 When the testing is complete, close PV513N and allow the boil off in the transfer line and loops to vent out of the building. The remaining liquid may be flushed out by connecting the utility vacuum at MV535N and using 3 psig nitrogen gas.

7.1.20 Backfill with GN_2 a second time, following the same procedure described in 7.1.10-7.1.13. Close MV727N.

7.1.21 Open PV707UV and pump the inner vessel to at least 100 µ a third time prior to backfilling with GAr.

7.1.22 Open EV714N and pump out the small volume from the UV manifold to MV727N and MV722A to at least 150 µ, then close PV707UV. Check that the output of PRV818A is set and locked at 150 psig and the PRV822A is set between 2 and 3 psig.

7.1.23 Continue to backfill with argon gas until the pressure in the cryostat reaches 1.5 psig (compare PT204A and PT230A), and then close MV722A.

7.1.24 Open PV228A, disconnect the air supply from the solenoid, and mechanically secure the main relief vent manifold block valve in the OPEN position by switching the position of the rack stop (drg. no. 3740.512-MC-295020). Checkthat the PV228A position switch indicates open in the control system software graphic and is armed, but not "in alarm". Record all these actions in the log book.

7.1.25 Close PV215UV. Activate the interlock and, redundantly, "lock" PV215UV closed. Close MV454UV. Note that MV454UV redundantly closes downstream of PV215UV.

7.1.26 Pump down the UV manifold to 20 μ to demonstrate the UV manifold isolation valve, MV454UV, is tight.

7.2.0 Transfer Line Pump and Purge

The following assumes that the necessary safety approval has been granted in order to allow the u-tubes which connect the storage dewars to the cryostats to be installed. All platform piping is assumed to have been pressure tested, leak checked, and UV and EC cryostat branches capped or (welded) closed if necessary. All building piping is assumed to have been pressure tested, leak checked, the alternate cryocorner connections and purge valves are closed and/or capped. and both helium and air supplies to pneumatic valves are fully functional.

7.2.1 Lock MV617A, the argon dewar relief selector 3-way valve, in the OPERATION (16 psi relief valve) position at the argon storage dewar. Note that this operation limits the pressure of the LAr dewar and insures the safe operation of the CC cryostat. Record this action in the logbook.

7.2.2 Using a portable vacuum pump with monitoring hardware, ensure that all insulating vacua of the following lines are 30 μ or less:

_ LN2 to cryostat withdrawal stub at N2 dewar
_ LN2, N2 dewar to cryostat u-tube, 443LN
_ LN2, N2 dewar to cryocorner manifold, 412LN, 4 vac. spaces
_ LN2, cryocorner to platform u-tube, 411LN
_ LN2 platform manifold, 409LN, 2 vac. spaces
_ LAr withdrawal stub at Ar storage dewar
_ LAr, Ar storage dewar to cryostat u-tube, 440LA
_ LAr, Ar storage dewar to cryocorner, 427LA, 4 vac. spaces
_ LAr, cryocorner to platform u-tube, 430LA,
_ LAr platform manifold, 429LA
_ GAr withdrawal stub at Ar storage dewar
_ GAr, Ar storage dewar to cryostat u-tube, 441GA
_ GAr, Ar storage dewar to cryocorner, 422GA, 4 vac. spaces
_ GAr, cryocorner to platform u-tube, 421GA
_ GAr platform manifold, 419GA, 2 vac. spaces
_ GAr/GN2 platform manifold, 414E, 2 vac. spaces
_ GAr/GN2 platform to cryocorner u-tube, 416E
_ GAr/GN2 cryocorner to outdoor manifold, 417E, 5 vac. spaces

(Note that the installed EC female bayonets/connectors are closed with vacuum-insulated/PO-equipped males. Those insulating vacua and POs should be checked as well.)

Record all the data in the Cryo Logbook.

7.2.3 Install the jumper and line up the valves in the following order to pump and purge the liquid nitrogen piping. The pumped line here is between the LN2 dewar, PV513N, and the outlet of the cooling loops, PV210N. Install the jumper line 443LN in strict accordance with **10.2.**

GN$_2$ P&P	CLOSED	OPEN
N2 dewar	_ PV513N	_ MV543N
	_ mv559N (bypass)	_ mv559N (shut-offs)
	_ mv535N	
Cryocorner	_ mv439N	_ MV477N
	_ mv481N (bypass)	_ mv481N (shut-offs)
	_ mv485N (bypass)	_ mv485N (shut-offs)
	_ MV493N	_ MV491N
Cryostat	_ PV210N	_ PV201N
	_ mv217N	_ PV202N
		_ mv216N
	_ PV1403N	_ mv493N (capped)

7.2.4 Run the flex-line from the utility vacuum header to the pres/vac fitting at MV535N outside, near the LN2 dewar. Unlock and open MV535N and MV573UV and pump on the nitrogen piping from the N2 storage dewar (PV513N) to the cryostat condenser outlet valve, PV210N. Attain a minimum of 20 μ in order to eliminate the water. Tighten packings, flanges as necessary. If 20 μ can not be attained, close MV491N at the cryocorner and pump on the nitrogen piping upstream of MV491N to 20 μ. The piping downstream of MV491N may have to be flow purged because of small flow-through leaks in the cooling loop control valves.

7.2.5 Unlock and cycle the capped MV493N and pumpout the trapped volume.

7.2.6 After valving off the pump, measure the ROR, and record it in the log book. Then backfill with GN2 to 1 psig as read on PT717UV (and checked with PI716UV) through EV714UV by opening MV727N. Close MV727N.

7.2.7 Pump the line again to 20 μ and backfill to 1 psig, close and lock MV535N, and MV493N, place a cap on pres/vac flange, and cap and secure the flex-line end.

7.2.8 Install the jumper and line up the valves in the following order to pump and purge the liquid argon piping. The pumped line here is between the LAr dewar, PV638A, and the cryostat cold valve, PV219A. Install the jumper line 440LA in strict accordance with **10.2**.

LAr P&P	CLOSED	OPEN
Ar dewar	_ PV638A _ MV658A _ MV678UV _ mv667A (bypass) _ mv668A (bypass)	_ MV660A _ MV661A (capped) _ mv667A (shut-offs) _ mv668A (shut-offs)
Cryocorner	_ mv437A (capped)	_ MV476A
Cryostat/ Platform	_ PV219A _ mv237A (bypass) _ mv494A (capped)	_ PV218A* _ mv237A (shut-offs)

* The I/P218A enable/disable key switch will have to be temporarily set to the ENABLE position for the duration of the pump and purge process.

7.2.9 Run the flex-line from the utility vacuum header to the pres/vac fitting at MV658A in the argon dewar room. Unlock and open MV658A, and MV678UV and pump on the liquid argon piping from the Ar storage dewar (PV638A) to the cryostat argon cold valve, PV219A. Attain a minimum of 20 μ in order to eliminate the water. Tighten packings, flanges as necessary.

7.2.10 Unlock and cycle the capped valves, MV661A and MV494A on the LAr line, to pumpout the trapped volumes. Cycle MV643A (capped), mv667A(bypass), mv668A (bypass), and mv237A(bypass), as well.

7.2.11 After valving off the pump, test the ROR and record it in the log book. Backfill with GAr to 1 psig as read on PT717UV through EV714UV by opening MV722A. Close MV722A.

7.2.12 Pump the line to 20 μ again and backfill to 1 psig, lock closed MV658A, MV661A,and MV494A and place a cap on pres/vac flange and secure the flex-line. The enable/disable key lock for I/P218A shall now be switched back to the DISABLE position and the key returned to the lock box.

7.2.13 Install the jumper and line up the valves in the following order to pump and purge the gaseous argon piping. Install the jumper line 441GA in strict accordance with **10.2**.

GAr P&P	CLOSED	OPEN
Argon dewar	_ PV611A	_ MV646A (capped)
	CLOSED	OPEN

	_ MV643A _ mv677A (bypass)	_ MV648A _ mv677A (shut-offs)
Cryocorner	_ mv435A (capped)	_ MV474A
Cryostat/ Platform	_ PV214A	_ MV483A (capped)

7.2.14 Run the flex-line from the utility vacuum header, MV678UV, to the pres/vac fitting at MV643A in the argon dewar room. Unlock and open MV643A and pump on the gaseous argon piping from the Ar storage dewar (PV611A) to the GAr control valve, PV214A, at the cryostat by opening MV678UV. Attain a minimum of 20 μ in order to eliminate the water. Tighten packings, flanges as necessary.

7.2.15 Unlock and cycle the capped MV646A and mv483A to pumpout the trapped volumes.

7.2.16 Valve off the pump, measure a ROR, and record it in the log book. Backfill with GAr to 1 psig as read on PT717UV through EV714UV by opening MV722A. Close MV722A.

7.2.17 Pump the line again to 20 μ and argon backfill to 1 psig, lock closed MV643A, MV646A, and mv483A, place cap on pres/vac flange and secure the flex-line.

7.3.0 Cooldown

The following procedures assume that both sections **7.1**, Inner Vessel Pump and Purge, and **7.2**, Transfer Line Pump and Purge, have been successfully completed. Additionally: all the safety approvals necessary to bring cryogens into the assembly building high bay have been granted, EF7 ventilation fan (4,500 cfm) is running and EF6 (13,000 cfm) is operational and in standby, all trough bellows/ducting is installed and sealed as appropriate, the ODH monitoring and warning system is fully commissioned, the nitrogen warming purge is connected and flowing into the vent line (open MV498N), the overflow switch (TS232E) is operational and interlocked to the condenser inlet valves, the I/P218A key lock switch is in the DISABLE position, and the nitrogen dewar is at or near its maximum fill level of 14000 gallons.

7.3.1 At the nitrogen dewar check MV510N open and set the back pressure regulator, PRV530N, to vent the nitrogen dewar at 45 psig (60 psia) Turning the adjusting screw in, increases the set pressure. Raise the dewar pressure as required to make this adjustment. Put the LN2 dewar pressure build control loop, PV501N, in automatic at 40 psig (55 psia) The pressure build loop will normally be active during this period supplying the large amounts of nitrogen required by the cooldown of the CC Cryostat. Watch the dewar pressure, PT501N, to ensure that the proper operation of the pressure build circuit, and that the regulator venting and pressure build operations are mutually exclusive. The LN2 dewar pressure should not exceed 60 psia or fall below 55 psia.

7.3.2 Set the argon storage dewar condenser inlet controller, PIC612N, to a dewar pressure of 25 psia, and the condenser outlet controller; PIC615N, to maintain this loop pressure at 45 psia. Check MV610A and MV664A open to the pressure building coil and raise and set PIC601A to 20 psia. Watch the dewar pressure, PT653A, to ensure that the vaporizer circuit is functioning properly and that the condensing and vaporizing operations are mutually exclusive. The LAr dewar pressure should not exceed 25 psia or fall below 20 psia.

7.3.3 Confirm that the valve positions in 7.2.3, 7.2.8, and 7.2.13 have not changed with the following exceptions: CLOSE MV646A, MV661A, mv483A, and mv494A. Check and record that the inner line pumpout valves, MV535N, MV643A, and MV658A are closed and the adjacent pres/vac fittings are capped and securely locked. Set the manual valves on the nitrogen flow meter to the cryostats to their "cooldown" positions. The valve positions are now arranged to support the CC Cooldown.

7.3.4 Change PIC214A (makeup/vent) to MAKE-UP (reverse acting: no) mode, the clamped SP limit; low to 17 psia, and the clamped SP limit; high to 25 psia on the PLC loop page for cooldown. Set PIC214A in automatic at 20 psia. Set ML611A to 100% open, and check the pressures of the cryostat, PT230A, and the dewar, PT653A, to ensure that argon storage dewar gas is pressurizing the cryostat. As the cooldown proceeds and the temperatures fall, PV214A will open as necessary to provide the gas needed to keep the cryostat pressure approximately constant as the gas density increases.

7.3.5 Adjust the low clamped set points on PIC201 and 202N to 24 psia and PIC210N to 16 psia. This will help to avoid sub-atmospheric cryostat pressures and frozen argon on the fins of the condenser coils. Place both PIC201N and 202N in automatic and adjust their set points to 60 psia. The condenser inlets are now set to cool the gas within the cryostat without condensing it.

7.3.6 Open the LN2 dewar to the cryostat cooling loops by setting ML513N to 100%. Set PIC210N to automatically control the cryostat pressure at 18 psia. The transfer line is probably warm and it will take several minutes before liquid will enter the condenser. A decreasing pressure trend should be observed in the cryostat; recheck valves, pressures and line up if this is not the case.

7.3.7 Throughout the cooldown, the temperature gradients within the cryostat shall be closely watched and maintained within the limits summarized in table 1. In order to decrease the cooling, INCREASE the setpoint(s) of PIC210N, PIC201N and/or PIC202N. Some trial and error will be required to determine what the best combination of setpoints is for various phases of the cooldown. Conversely, if more cooling is required, DECREASE the setpoint(s) of PIC210N, PIC201N and/or PIC202N. Take additional care when the condenser pressure is set below 50 psia since condensation will occur on the cooling coil surfaces and large temperature gradients on the module skins will develop rapidly. Avoid subatmospheric pressures and pressures greater than 13 psig, the cryostat relief valve setting. Note that control of the cooldown rate is a constantly monitored function; the concern is excessive temperature gradients due to a high cooldown rate, this rate can be slowed to zero nearly instantaneously. Alarms may be provided to aid in monitoring, but the cooldown must not be left to proceed unattended.

TABLE 1. Temperature Gradient Limits

LOCATION	QUALIFIER	MAXIMUM DELTA T	REMARKS
Intra-module	CH	100K	within a module
	FH	100K	within a module
	EM	50K	within a module
Module end plates	any two	100K	each type; CH, FH, EM,
	any adjacent	20K	each type; CH, FH, EM
Module-Beam	nearest Beam	25K	modulskin avg.nearest beam-beam avg.
Beam-Cryostat shell	nearest Beam	20K	shell avg. nearest beam-beam avg.

7.3.8 Activate the pressure, temperature, and level alarms and set up the historical trending of these cryostat parameters and the flow through the nitrogen line using the monitoring software.

7.3.9 Make daily checks of the delta p across the filters on the LN2 lines to the cryostat and storage dewar condensers, and most importantly, the filter on the GAr line to the cryostat and record the data in the log book. If the delta p exceeds 1 psid on the argon filters and 5 psid on the nitrogen filters, plans should be made to have the line isolated, warmed, and the filter element inspected and cleaned/replaced.

7.3.10 When the detector structural components reach an average temperature of 100K (10K above equilibrium temperature) and the temperature gradient limits of Table 1. can be maintained, the cryostat LAr is "fill ready".

7.4.0 Filling the Cryostat

This procedure assumes the cryostat is free of contaminants and cold, and must be preceded by section **7.2**, Transfer Line Pump and Purge and **7.3**, Cooldown, or, if recently disconnected and moved, by section **7.2**, Transfer Line Pump and Purge. If there is any question of the tightness of the transfer lines it should be verified by repeating section **7.2**.
The cryostat internal temperatures should be checked prior to LAr filling and the cryostat convection cooled, as necessary, before filling until the temperatures are

below those specified as "fill ready" in 7.3.10.
There should be a minimum of 5200 gallons of LAr in the storage dewar that has been tested for purity according to section **6.0** just prior to filling the cryostat. If the argon is deemed to be unacceptable, it will have to be pressure transferred back to a ground level trailer transport (see **5.5**).

7.4.1 Valve positions and control settings to fill the cryostat are as follows:

Fill LAr	**CLOSED**	**OPEN**
N2 dewar	_ MV535N (capped) _ MV546N (capped)	_ PIC501N@45 psia _ PV513N _ PRV530N@50 psia _ MV543N _ MV544N _ PV548N
Ar dewar	_ PV625A _ MV638A _ MV646A (capped) _ MV658A (capped) _ MV661A (capped) _ MV663A (capped) _ MV683N	_ PIC601A@20 psia _ PV611A _ PIC612N@25 psia _ PIC615N@45 psia _ MV648A _ MV686N, 694N (SS pos.)

Ensure that MV617A is locked open to the low pressure relief side (PSV620A, RD621A)

Cryocorner	_ mv435A (capped) _ mv437A (capped) _ mv439A (capped) _ MV483A (capped) _ MV493A (capped) _ MV494A (capped)	_ MV474A _ MV476A _ MV477N _ EV480N, 487N (CD pos.) _ MV491N
Platform/ Cryostat	_ PV201N _ PV219A	_ PIC202N@60 psia _ PIC210N@18 psia
		OPEN
		_ PIC214A@20 psia _ PV218A

7.4.2 Set the cooling loops, PIC201N to 40 psia in automatic. Set the cryostat pressure controller, PIC210N, to 18 psia in automatic. This will enable the heat exchanger to condense LAr at a pressure slightly above atmospheric - OPERATION BELOW THIS POINT MAY LEAD TO A NEGATIVE PRESSURE DIFFERENTIAL AND ARGON CONTAMINATION. Flow through the condenser is automatically governed by the pressure in the cryostat.

7.4.3 Increase the set points of PIC612N, dewar condenser inlet valve controller, to 33 psia and PIC601A, the vaporizer controller, to 32 psia. The set point of PSV620A is approximately 34.5 psia. Check that the vaporizer and condenser are not running concurrently, and that the relief is not weeping. The pressure differential should be sufficient to fill the cryostat 3/4 full at a reasonable rate. When initially filling the cryostat the modules (avg. temp. approx. 100) heat capacity will limit the transfer rate to that determined by the condenser capacity.

7.4.4 Place PIC214A in the MAKE-UP (reverse acting: no) mode and set the controller to make-up gas at 17 psia; this will protect the cryostat from experiencing a subatmospheric pressure by flowing gas from the dewar if the pressure decreases below 17 psia. Verify that the SP limits, high and low, of 7.3.4, 7.3.5, 7.3.6, and 7.3.7 are in place on the respective loop pages before proceeding.

7.4.5 Open the cold valve, PV219A, and open PV218A after turning the key lock switch for I/P218A to the ENABLE position (NOTE: THIS SWITCH MAY BE ENABLED ONLY IF THE AVG. DETECTOR MODULE TEMPERATURE IS BELOW 164 K). Open the LAr dewar outlet valve, PV638A, initially to 5% and increase the opening SLOWLY while observing the cryostat pressure from PT230A is being maintained at its setpoint. Make adjustments to the PID loops if necessary. The cryostat pressure should increase rapidly at first due to the surge of warm gas resulting from the warm transfer line.

7.4.6 As liquid starts to accumulate in the cryostat, the level can be read from the fill level LEDs, EI250A, and level transmitter, DPT222A, that are monitored and recorded by the PLC. Record LED voltages every hour or so in the Cryo Logbook throughout the duration of the fill. Vapor pressure can be read using PT233A (upper), PT234A (lower) and PT240A (middle). The relative fill rate and an estimate of the instantaneous value can be obtained from the flow meter FM671A at the argon storage dewar.

7.4.7 If the cryostat was recently drained (still very cold) the cryostat will initially fill at a relatively rapid rate. The fill rate will slow as the liquid level rises due to the decrease in transfer pressure caused by the static head in the cryostat. The filling rate can be slowed by decreasing the setting of LAr dewar pressure, PIC601A, or for more immediate results, close down on LAr dewar outlet, PV638A.

7.4.8 After the liquid level reaches about 8 psid, the liquid flow from the storage dewar will seriously slow or stop due to the loss of a sufficient transfer pressure between the storage dewar and cryostat. At this point, close PV219A and then close PV218A after 15 minutes. The rest of the liquid will have to be condensed into the cryostat.

7.4.9 Set the cooling loops,, PIC201N and PIC202N, to control at 26 psia in the automatic mode. Increase the PIC210N setting to 20 psia.

7.4.10 Ensure that PIC214A is still in the direct acting mode and set it in auto to supply the cryostat to a pressure of 22 psia. The dewar is now supplying gas to the cryostat where it is being condensed by the condenser coils to build liquid level.

7.4.11 During this final phase of the fill, close PV214A and tune the PID loops for PI201N,PI202N, and PI210N if necessary to minimize the pressure fluctuations in the cryostat. As the ullage volume in the cryostat decreases, the effects of this loop will be increasingly faster.

7.4.12 As the level approaches its final operational height, between the 8th and 12th LEDs (one inch above the top of the CH endplate) on the top level probe or 9.33 psid on DPT222A, compare the argon liquid temperatures as read from the VPTs, with the saturated temperature associated with the cryostat operating pressure (90.3 K @ 20 psia). This will should indicate the direction and magnitude of the volumetric changes toward the steady state, i.e. indicate whether the liquid will shrink or swell after filling.

7.4.13 Stop condensing at a level either slightly above or below the final operating height depending on the temperature of the liquid. A final level adjustment may have to be made to compensate for the shrinking/swelling of the liquid. Condense into the cryostat or vent gas to the storage dewar until the temperature equilibrium operating level is achieved.

7.4.14 Record the cryostat vapor pressure temperatures and final level in the Cryo Logbook.

7.5.0 Steady State Operations

7.5.1 In steady state operation, the argon storage dewar will be prepared to accept gaseous argon from the cryostat should the need arise. Reduce the settings of the dewar vaporizer, PIC601A, to 15.5 psia, the dewar pressure, PIC612N, to 17 psia, and the condenser pressure, PIC615N, to 44 psia. Change PIC214A to the VENT (reverse acting) mode (increasing cryostat pressure increases the valve opening) on the PLC, and set it to vent the CC cryostat to the storage dewar at 22 psia in automatic.

7.5.2 PIC210N should be controlling the cryostat pressure at 20 psia and PIC202N/PIC202N controlling the condenser pressure at 26 psia. Adjustments to the condenser pressure change the LN2-LAr temperature difference and the wetted area directly.

7.5.3 The level in the cryostat should continue to be carefully watched immediately after being filled. Relatively small changes in fluid temperature toward the steady state value will measurably change the level. Make level adjustments as required after an equilibrium is clearly demonstrated. Activate low liquid level alarm as indicated by the operating level probe.

7.5.4 Less flashing of the liquid nitrogen across the inlet valve, PV202N, will occur if the liquid nitrogen storage dewar pressure is reduced. Set the nitrogen dewar vaporizer pressure, PIC501N, to 40 psia and adjust PRV530N to vent the dewar pressure at 45 psia.

7.5.5 At the cryocorner, close MV477N and switch the positions of manual shutoff valves to FM478N and 479N to the OPERATE mode. The nitrogen flow meter, FM479N, is now in its lower range to monitor the steady state, operate, flow.

7.5.6 Check PS471N, the GN_2 purge manifold pressure switch, to confirm that the nitrogen warming purge is flowing through the restricting orifice to the vent line.

7.5.7 The nitrogen manifold subcooling valve, PV1403N, position should be adjusted to 60% open in manual to assure a subcooled source to cooling loop inlet valves.

7.5.8 The argon in the cryostat should be checked periodically for purity as in **6.0.**

7.6.0 Emptying and Warming the Cryostat

7.6.1 Maintain the same original steady state PIC settings as in 7.5.1 and 7.5.2, i.e.;

Controller	PV	SP
PIC612N	LAr dewar pressure	17 psia
PIC615N	LAr dewar condenser pressure	44 psia
PIC214N	Cryostat GAr vent	22 psia
PIC202N/202N	Cryostat condenser pressure	26 psia
PIC210N	Cryostat pressure	20 psia

7.6.2 Check that the valves in the cryostat fill/drain line are in the following positions:

Draining LAR

OPEN:

_ mv203A
_ MV476A

CLOSE:

_ PV214A
_ PV219A
_ mv437A (capped)
_ MV494A (capped)
_ MV638A
_ MV658A (capped)
_ MV660A
_ MV661A (capped)

7.6.3 Check that the LAr dewar pressure is 17 psia , the cryostat pressure is 20 psia, and open MV638A and MV660A to connect the LAr dewar to the outlet of PV218A. Open the cold valve, PV219A, and then open PV218A in 5% increments;

gradually increase the opening as the storage dewar condenser demonstrates it can maintain a pressure less than 25 psia. Note that the liquid head 0.6 psi/ft, or about 10 psi, provides all the initial transfer pressure difference required. The current PIC615N (condenser pressure controller) setting ensures that the pressure in the storage dewar will not drop below one atmosphere.

7.6.4 Check the LAr dewar gas phase valve, PV611A, open, and change the PLC, if necessary, to assure that PIC214A is in the MAKEUP (direct acting) mode. Set the pressure on PIC214A to 17 psia. This will put the cryostat and dewar at approximately the same pressure, leaving the head (about 10 psi) as the transfer pressure difference. Set the cryostat pressure controller, PIC202N to 25 psia to allow higher pressure cryostat operation as the cryostat empties.

7.6.5 The LAr drain flow rate can be obtained from FM671A on the PLC. The flow rate will be relatively large at first and decrease as the static head in the cryostat decreases. Flow can be increased by raising the VENT pressure set point of PIC214A to compensate for the loss of head. Flow can be decreased at anytime by reducing the opening of PV638A.

7.6.6 Since the bottom of the cryostat is only 14 in. above the centerline of the dewar, it will be necessary to make adjustments to maintain a transfer pressure difference. The normal heat leak is just about that required to maintain the cryostat pressure as it empties. If it is is necessary, or significantly faster, the heaters at the bottom of the cryostat can be energized to pressure transfer the remaining liquid. Heater operation is described in **10.5**. If the incipient heat leak is sufficient proceed to 7.6.9.

7.6.7 Set PIC214A to 25 psia. Set EH220A power to zero and turn on. SLOWLY increase power until the pressure in the cryostat is maintained at a constant level below 25 psia, the condenser controlling pressure.

7.6.8 When the cryostat is empty (cryostat and LAr dewar pressure difference disappears, flow drops to zero), close PV218A and after an hour, close PV219A. Turn the I/P218A key lock switch to the DISABLE position and return the key to the lock box. Maintain the cryostat pressure with PIC214A set to VENT (reverse acting) at 20 psia. Secure the cooling loop flow, close PV513N.

7.6.9 If the cryostat is to be moved to the collision hall at this point, then proceed to chapter, **10.3**, Moving the Platform.

7.6.10 If the cryostat and contents are to be warmed, continue to follow the rest of the procedures in this section. Heater operating procedures are found in **10.5**.

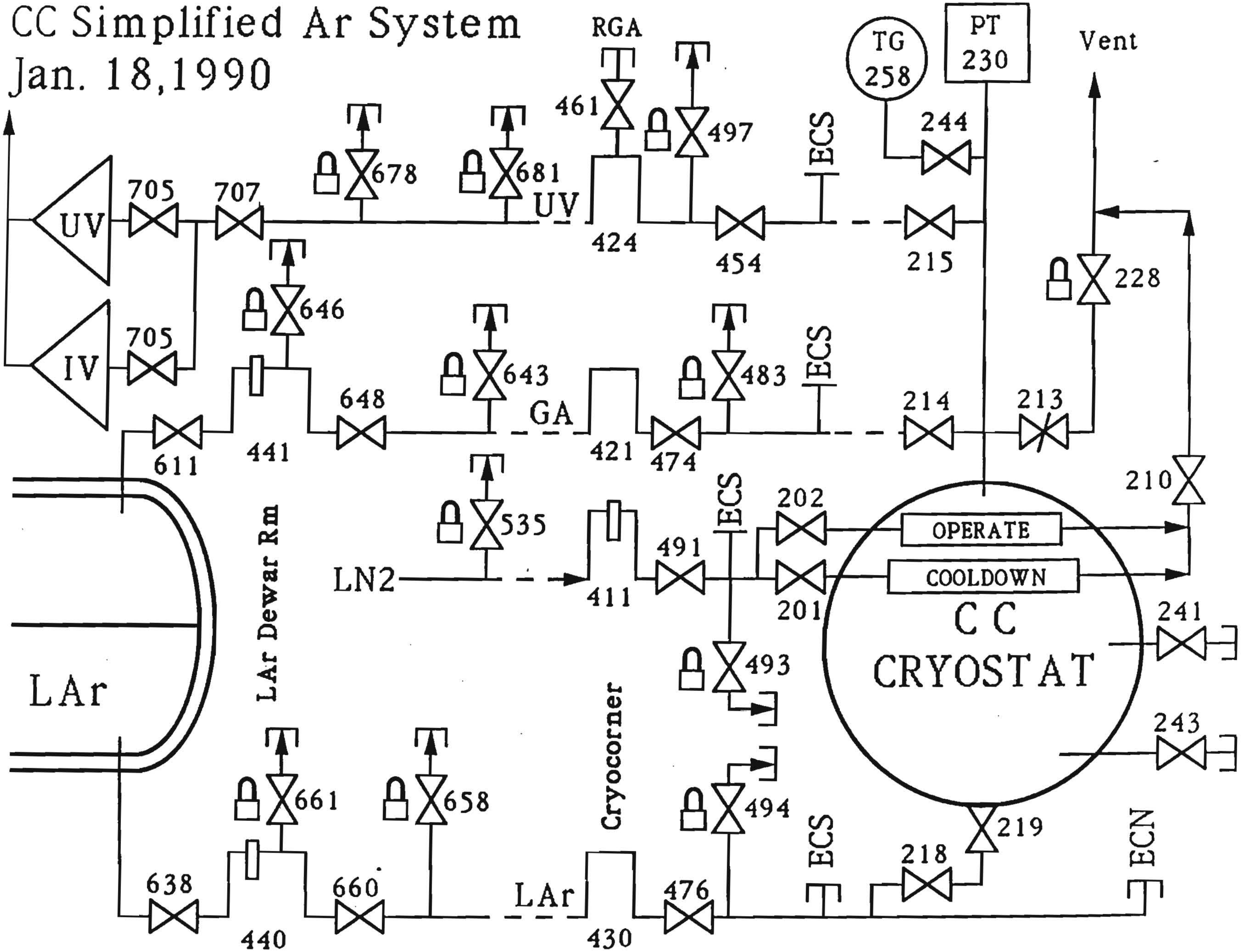
7.6.11 Follow all required safety guidelines related to the use of 208/480VAC power. Increase EH220A power to about. 10 kW in small steps. The temperature gradients limits of 7.3.7, Table 1. must be observed just as they were on cooldown. The gas generated in the warming process, about 1300 scft, will be driven toward the storage dewar and condensed at 17 psia.

7.6.12 Temperatures within the cryostat MUST be continually monitored while making adjustments to the heater power. The anticipated limiting concerns are the skin temperatures just above the heater locations, see dwg. # 3740.510-ME-255523, and the beam-cryostat shell delta T. Under no circumstances should the warm up proceed unmonitored.

7.6.13 The diffusion pump may be secured by closing the inlet valve, PV225V, and securing power to the DP heater. After 30 minutes, close PV221V.

7.6.14 When the average temperature of the modules in the cryostat reaches the temperature specification, the heater EH220A is secured according to**10.5**.

CC Simplified Ar System
Jan. 18,1990



Not shown are subcool valve, most instrument valving, LN2 outside jumpers, and ECN spigots not yet installed.

R. Rucinski 11/8/90

U FORMS AND R-1 INFORMATION PAGES

The ASME U-1, U-2, and U-4 forms are included as part of an D-Zero Engineering note number 3740.214-EN-265. This engineering note is included in it's entirety in the following pages.

The R-1 form and documentation regarding the reattachment of the CC Cryostat heads is included in D-Zero Engineering note number 3740.214-EN-266. It is entitled "Data Report Documenting the Reattachment of the CC Cryostat Heads" originated by Rick Luther. Due to it's length, only the title page, R-1 form and Certificate of compliance are included in this document. These pages follow the copy of EN-265. The entire engineering note EN-266 can be found in the D-Zero engineering note file.

ASME Code Data Report for the CC Cryostat

Engineering Note # 3740.214-EN-265

Issued: November 6, 1990

Originator: Rick Luther

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510

November 11, 1987

Mr. Joe R. Sloan
CBI Na-Con, Incorporated
24137 111th Street
Plainfield, Illinois 60544

SUBJECT: ASME Code Documentation
CC Cryostat Head Removal and Replacement
CBI Na-Con Contract C70708
Fermilab Contract 938570

Dear Joe:

Attached per your request are the ASME Code Data Reports for the CC Cryostat. Included are:

- Form U-1 for the inner vessel of the Cryostat.
- Rubbings of the Code nameplate and the duplicate nameplate located on the top of the outer vessel.
- Forms U-2 for the heads for both vessels (inner and outer).

If you need any additional documentation please let me know.

Very truly yours,

Richard D. Luther
DØ Cryogenics Engineering
Mail Station 357
(312) 840-2322

RDL/hs

cc: Mulholland
Luther/File: CC Head Removal/Replacement

FORM U-1 MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS

As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by Richmond-Lox Equipment Company, Hwy 25 South, Delphi, IN 46923 (Name and address of manufacturer)

2. Manufactured for Fermi National Accelerator Lab, P.O. Box 500, Batavia, IL 60510 (Name and address of purchaser)

3. Location of installation Same (Name and address)

4. Type Horiz.Jackt.Torus (Horiz. or vert. tank) 30093 (Mfgr's serial No.) ____ (CRN) D87-0058 (Drawing No.) 3688 (Nat'l Bd No.) 1987 (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME Boiler and Pressure Vessel Code. The design construction, and workmanship conform to ASME Rules, Section VIII, Division 1 Winter, 1986 (Year)

Winter 1986 (Addenda (date)) ____ (Code Case No.) ____ (Special service per UG 120(d))

Items 6–11 incl. to be completed for single wall vessels, jackets of jacketed vessels, or sheets of heat exchangers

6. Shell: Non-Code (Mat'l. (Spec. No., Grade)) ____ (Nom. Thk. (in.)) ____ (Corr. Allow. (in.)) ____ (Diam. I.D. (ft & in.)) ____ (Length (Overall) (ft & in.))

7. Seams: ____ (Long. (Dbl., Sngl.)) ____ (R.T. (Spot or Full)) ____ (Eff. (%)) ____ (H.T. Temp. (°F))

____ (Time) ____ (Girth (Dbl., Sngl.)) ____ (R.T. (Spot, Partial or Full)) ____ (No. of Courses)

8. Heads: (a) Matl. ____ (Spec. No., Grade) (b) Matl. ____ (Spec. No. Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)										
(b)										

If removable, bolts used (describe other fastenings) ____ (Matl. Spec. No. Gr. Size. No.)

9. Type of Jacket ____ Proof Test ____

10. Jacket Closure ____ (Describe as ogee & weld, bar, etc.) If bar, give dimensions ____ If bolted, describe or sketch

11. MAWP ____ psi at max. temp. ____ °F. Min. temp. (when less than -20°F) ____ °F

Hydro., pneu., or comb. tes press. ____ psi.

Items 12 and 13 to be completed for tube sections

12. Tubesheets: ____ (Stationary Matl. (Spec. No. Gr.)) ____ (Diam. (in.) (Subject to pressure)) ____ (Nom. Thk. (in.)) ____ (Corr. Allow. (in.)) ____ (Attach. (Welded, Bolted))

____ (Floating Matl. (Spec. No. Gr.)) ____ (Diam. (in.)) ____ (Nom. Thk. (in.)) ____ (Corr. Allow. (in.)) ____ (Attach.)

13. Tubes: ____ (Matl. (Spec. No. Gr.)) ____ (O.D. (in.)) ____ (Nom. Thk. (in. or Gauge)) ____ (Number) ____ (Type (Straight or U))

Items 14–17 incl. to be completed for inner chambers of jacketed vessels or channels of heat exchangers

14. Shell: SA240 304 (Matl. (Spec. No., Grade)) .625 (Nom. Thk. (in.)) 0 (Corr. Allow. (in.)) 16' ¼" (Diam. I.D. (ft & in.)) 6' 7/8" (Length (Overall) (ft & in.))

15. Seams: Dbl Butt (Long. (Dbl., Sngl.)) None (R.T. (Spot or Full)) 70% (Eff. (%)) ____ (H.T. Temp. (°F))

____ (Time) Sngl Butt (Girth (Dbl., Sngl.)) None (R.T. (Spot, Partial or Full)) 1 (No. of Courses)

16. Heads: (a) Matl. SA240 304 (Spec. No., Grade) (b) Matl. ____ (Spec. No. Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	Ends	Nom 5/8"	-	7' 2 1/8" 1'0" &;3' 7/8"					-	
(b)										

If removable, bolts used (describe other fastenings) ____ (Matl. Spec. No. Gr. Size. No.)

17. MAWP 30 psi at max. temp. 100 °F. Min. temp. (when less than -20 °F) -320

~~Hydr~~o., pneu., o~~r comb.~~ test press. 50 psi

(12/82) This form (E00108) may be obtained from the Order Dept., ASME, 345 E. 47th St., New York, N.Y. 100

FORM U-2 MANUFACTURER'S PARTIAL DATA REPORT

A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by The Stacey Mfg. Co., 259 Township Ave., Cincinnati, Ohio 45216 (Name and address of manufacturer)

2. Manufactured for Richmond-Lox Equipment Co., Delphi, Indiana 46923 (Name and address of purchaser)

3. Location of installation Not known (Name and address)

4. Type Horizontal Tank (Horiz. or vert., tank) 6308A (Mfgr's serial No. of Part) (CRN) 0-43A53 R.2 (Drawing No.) - (Nat'l. Bd. No.) 1987 (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 1986 (Year)

December 31, 1986 (Addenda (Date)) - (Code Case No.) - (Special service per UG-120(d))

6. (a) Drawing prepared by The Stacey Mfg. Co. (b) Description of part inspected 16'11-3/4" OD Half Torus*

7. Postweld heat treatment: Temp. - °F Time -

Items 8-13 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers

8. Shell: - (Matl. (Spec. No., Grade)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

9. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R. T. (Spot, Partial, or Full)) - (No. of Courses)

10. Heads: (a) Matl. SA240-304* (Spec. No., Grade) (b) Matl. (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	End	Nom. 1/2"	-	7'3-7/8"	1'1-9/16"	& 5-9/16"*	-	-	-	Concave
(b)	-	-	-	-	-	-	-	-	-	-

If removable, bolts used (describe other fastenings) - (Matl., Spec. No., Gr., Size, No.)

11. Type of Jacket - Proof Test -

12. Jacket Closure - (Describe as ogee & weld, bar, etc.) If bar, give dimensions -

If bolted, describe or sketch.

13. MAWP - psi at max. temp. - °F. Min. temp. (when less than -20°F) - °F.

Hydro., pneu., or comb. test press. - psi.

Items 14 and 15 to be completed for tube sections

14. Tubesheets: - (Stationary Matl. (Spec. No., Gr.)) - (Diam. (in.) (Subject to pressure)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach. (Wld., Bolted))

- (Floating Matl. (Spec. No., Gr.)) - (Diam. (in.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach.)

15. Tubes: - (Matl. (Spec. No., Grade)) - (O.D. (in.)) - (Nom. Thk. (in. or gauge)) - (No.) - (Type (straight or "U"))

Items 16-18 incl. to be completed for inner chambers of jacketed vessels or channels of heat exchangers

16. Shell: - (Matl. (Spec. No., Gr.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

17. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot, Partial, or Full)) - (No. of Courses)

18. Heads: (a) Matl. - (Spec. No., Grade) (b) Matl. (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	-	-	-	-	-	-	-	-	-	-
(b)	-	-	-	-	-	-	-	-	-	-

If removable, bolts used (describe other fastenings) -

(12/82) This form (E00110) may be obtained from the Order Dept., ASME, 345 E. 47

FORM U-2 MANUFACTURER'S PARTIAL DATA REPORT
A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by The Stacey Mfg. Co., 259 Township Ave., Cincinnati, Ohio 45216 (Name and address of manufacturer)

2. Manufactured for Richmond-Lox Equipment Co., Delphi, Indiana 46923 (Name and address of purchaser)

3. Location of installation Not known (Name and address)

4. Type Horizontal Tank (Horiz. or vert., tank) 6308B (Mfgr's serial No. of Part) (CRN) 0-43A53 R.2 (Drawing No.) - (Nat'l. Bd. No.) 1987 (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 1986 (Year)

December 31, 1986 (Addenda (Date)) - (Code Case No.) - (Special service per UG-120(d))

6. (a) Drawing prepared by The Stacey Mfg. Co. (b) Description of part inspected 16'11-3/4" OD Half Torus*

7. Postweld heat treatment: Temp. - °F Time -

Items 8-13 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers

8. Shell: - (Matl. (Spec. No., Grade)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

9. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R. T. (Spot, Partial, or Full)) - (No. of Courses)

10. Heads: (a) Matl. SA240-304* (Spec. No., Grade) (b) Matl. - (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	End	Nom. 1/2"		7'3-7/8"	1'1-9/16"	&5-9/16"*				Concave
)										

If removable, bolts used (describe other fastenings) - (Matl., Spec. No., Gr., Size, No.)

11. Type of Jacket - Proof Test -

12. Jacket Closure - (Describe as ogee & weld, bar, etc.) If bar, give dimensions -

If bolted, describe or sketch.

13. MAWP - psi at max. temp. - °F. Min. temp. (when less than -20° F) - °F.

Hydro., pneu., or comb. test press. - psi.

Items 14 and 15 to be completed for tube sections

14. Tubesheets: - (Stationary Matl. (Spec. No., Gr.)) - (Diam. (in.) (Subject to pressure)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach. (Wld., Bolted))

- (Floating Matl. (Spec. No., Gr.)) - (Diam. (in.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach.)

15. Tubes: - (Matl. (Spec. No., Grade)) - (O.D. (in.)) - (Nom. Thk. (in. or gauge)) - (No.) - (Type (straight or "U"))

Items 16-18 incl. to be completed for inner chambers of jacketed vessels or channels of heat exchangers

16. Shell: - (Matl. (Spec. No., Gr.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

17. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot, Partial, or Full)) - (No. of Courses)

18. Heads: (a) Matl. - (Spec. No., Grade) (b) Matl. - (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-

If removable, bolts used (describe other fastenings) - (Matl., Spec. No., Grade, Size, No.)

This form (E00110) may be obtained from the Order Dept., ASME, 345 E. 47th St., New 1001

5CC75 I. V. Hea
Checked 4-14-87
CEW

FORM U-2 MANUFACTURER'S PARTIAL DATA REPORT

A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by The Stacey Mfg. Co., 259 Township Ave., Cincinnati, Ohio 45216 (Name and address of manufacturer)

2. Manufactured for Richmond-Lox Equipment Co., Delphi, Indiana 46923 (Name and address of purchaser)

3. Location of installation Not known (Name and address)

4. Type Horizontal Tank (Horiz. or vert., tank) 6309A (Mfgr's serial No. of Part) (CRN) 0-44-A53 Rev.2 (Drawing No.) - (Nat'l. Bd. No.) 1987 (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 1986 (Year)

December 31, 1986 (Addenda (Date)) - (Code Case No.) - (Special service per UG-120(d))

6. (a) Drawing prepared by The Stacey Mfg. Co. (b) Description of part inspected 16'1-1/2" OD Half Torus*

7. Postweld heat treatment: Temp. - °F Time -

Items 8-13 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers

8. Shell: - (Matl. (Spec. No., Grade)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

9. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R. T. (Spot, Partial, or Full)) - (No. of Courses)

10. Heads: (a) Matl. - (Spec. No., Grade) (b) Matl. - (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	-	-	-	-	-	-	-	-	-	-
(b)	-	-	-	-	-	-	-	-	-	-

If removable, bolts used (describe other fastenings) - (Matl., Spec. No., Gr., Size, No.)

11. Type of Jacket - Proof Test -

12. Jacket Closure - (Describe as ogee & weld, bar, etc.) If bar, give dimensions -

If bolted, describe or sketch.

13. MAWP - psi at max. temp. - °F. Min. temp. (when less than -20°F) - °F.

Hydro., pneu., or comb. test press. - psi.

Items 14 and 15 to be completed for tube sections

14. Tubesheets: - (Stationary Matl. (Spec. No., Gr.)) - (Diam. (in.) (Subject to pressure)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach. (Wld., Bolted))

- (Floating Matl. (Spec. No., Gr.)) - (Diam. (in.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach.)

15. Tubes: - (Matl. (Spec. No., Grade)) - (O.D. (in.)) - (Nom. Thk. (in. or gauge)) - (No.) - (Type (straight or "U"))

Items 16-18 incl. to be completed for inner chambers of jacketed vessels or channels of heat exchangers

16. Shell: - (Matl. (Spec. No., Gr.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

17. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot, Partial, or Full)) - (No. of Courses)

18. Heads: (a) Matl. SA240-304* (Spec. No., Grade) (b) Matl. - (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	End	Nom. 5/8"	-	7'2-1/8"	1'0" & 3-7/8"*	-	-	-	-	-
(b)	-	-	-	-	-	-	-	-	-	-

If removable, bolts used (describe other fastenings) - (Matl., Spec. No., Grade, Size, No.)

FORM U-2 MANUFACTURER'S PARTIAL DATA REPORT

A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by The Stacey Mfg. Co., 259 Township Ave., Cincinnati, Ohio 45216 (Name and address of manufacturer)

2. Manufactured for Richmond-Lox Equipment Co., Delphi, Indiana 46923 (Name and address of purchaser)

3. Location of installation Not known (Name and address)

4. Type Horizontal Tank (Horiz. or vert. tank) 6309B (Mfgr's serial No. of Part) (CRN) 0-44-A53 Rev. 2 (Drawing No.) - (Nat'l Bd. No.) 1987 (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 1986 (Year)

December 31, 1986 (Addenda (Date)) - (Code Case No.) - (Special service per UG 120(d))

6. (a) Drawing prepared by The Stacey Mfg. Co. (b) Description of part inspected 16'1-1/2" OD Half Torus*

7. Postweld heat treatment: Temp. - °F Time -

Items 8-13 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers

8. Shell: - (Matl. (Spec. No., Grade)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

9. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot, Partial, or Full)) - (No. of Courses)

10. Heads: (a) Matl. - (Spec. No., Grade) (b) Matl. - (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	-	-	-	-	-	-	-	-	-	-
(b)	-	-	-	-	-	-	-	-	-	-

If removable, bolts used (describe other fastenings) - (Matl., Spec. No., Gr., Size, No.)

11. Type of Jacket - Proof Test -

12. Jacket Closure - (Describe as ogee & weld, bar, etc.) If bar, give dimensions -
If bolted, describe or sketch.

13. MAWP - psi at max. temp. - °F. Min. temp. (when less than -20 °F) - °F
Hydro., pneu., or comb. test press. - psi.

Items 14 and 15 to be completed for tube sections

14. Tubesheets: - (Stationary Matl. (Spec. No., Gr.)) - (Diam. (in.) (Subject to pressure)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach. (Wld., Bolted))
- (Floating Matl. (Spec. No., Gr.)) - (Diam. (in.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Attach.)

15. Tubes: - (Matl. (Spec. No., Grade)) - (O.D. (in.)) - (Nom. Thk. (in. or gauge)) - (No.) - (Type (straight or "U"))

Items 16-18 incl. to be completed for inner chambers of jacketed vessels or channels of heat exchangers

16. Shell: - (Matl. (Spec. No., Gr.)) - (Nom. Thk. (in.)) - (Corr. Allow. (in.)) - (Diam. I.D. (ft & in.)) - (Length (overall) (ft & in.))

17. Seams: - (Long. (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot or Full)) - (Eff. (%)) - (H.T. Temp. (°F)) - (Time) - (Girth (Wld., Dbl., Sngl., Lap, Butt)) - (R.T. (Spot, Partial, or Full)) - (No. of Courses)

18. Heads: (a) Matl. SA240-304* (Spec. No., Grade) (b) Matl. - (Spec. No., Grade)

Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
End	Nom; 5/8"	-	7'2-1/8"	1'0"&3-7/8"*	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-

If removable, bolts used (describe other fastenings) -

Form U-2 (Back)

MAWP – psi at max. temp. – °F. Min. temp. (when less than -20°F) – °F

Hydro., pneu., or comb. test press. – psi.

Items below to be completed for all vessels where applicable

20. Nozzles, Inspection and Safety Valve Openings:

Purpose (Inlet, Outlet, Drain, etc.)	No.	Diam. or Size	Type	Mat'l.	Nom. Thk.	Reinforcement Mat'l.	How Attached	Location
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
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–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–

21. Supports: Skirt – (Yes or no) Lugs – (No.) Legs – (No.) Other – (Describe) Attached – (Where and how)

Remarks: Neither design nor hydrostatic testing were performed by The Stacey Mfg. Co. *This half section of 16'1-1/2" OD X 5'11-3/4" ID Torus is a ten-piece construction and consists of one (1) latitudinal double butt-welded joint at reverse 0'3-7/8" IKR tangent point jointing 7'2-1/8" IR donut portion, four (4) meridinal double butt-welded joints at 5'11-3/4" ID reverse 0'3-7/8" inside knuckle portion & twelve (12) meridinal double butt-welded joints at 7'2-1/8" IR donut with 1'0" IKR portion. All welding - Full R.T.

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1.

"U" Certificate of Authorization No. 1830 expires March 30, 19 88

Date 3 31 88 Co. name The Stacey Mfg. Co. (Manufacturer) Signed H.C. Ling (Representative)

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of Ohio and employed by H.S.B.I. & I Co. of Hartford, Conn. have inspected the pressure vessel described in this Manufacturer's Partial Data Report on 3 31, 19 88, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this part in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this Manufacturers' Partial Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 3 31 Signed (Authorized Inspector) Commissions NB-3643 Ohio Comm (Nat'l Board (incl. endorsements) State)

30093

FORM U-4 MANUFACTURER'S DATA REPORT SUPPLEMENTARY SHEET

As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by Richmond-Lox Equipment Company, Hwy 25 South, Delphi, IN 46923

2. Manufactured for Fermi National Accelerator Lab, P.O. Box 500, Batavia, IL 60510

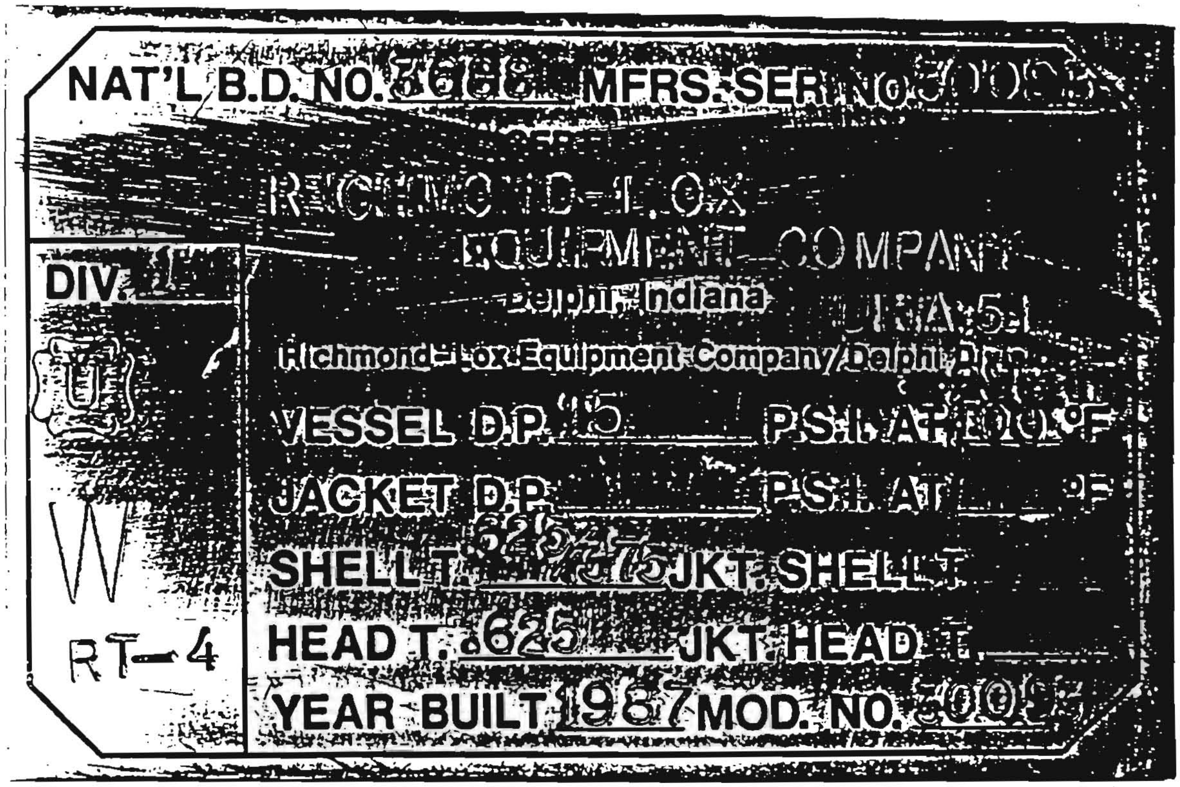
3. Location of installation Same

4. Type Horiz.Jackt.Torus 30093 (CRN) D87-0058 3688 1987

Data Report Item Number	Remarks
14	Inner shell description (During operation, this shell will be subjected to external pressure.)
	SA240 304 .375 0 5' - 4 3/8" 8' - 8½"
15	Inner Shell

Date July 24, 1987 Richmond-Lox Equipment Co. C. E. Whitaker

Date July 24, 1987 Greene N.B. 7917, IND.911



NAT'L B.D. NO. 3668 MFRS. SER. No. 500[illegible]

RICHMOND-LOX
EQUIPMENT COMPANY
Delphi, Indiana U.S.A.

Richmond-Lox Equipment Company/Delphi [illegible]

DIV. 1

U

W

RT-4

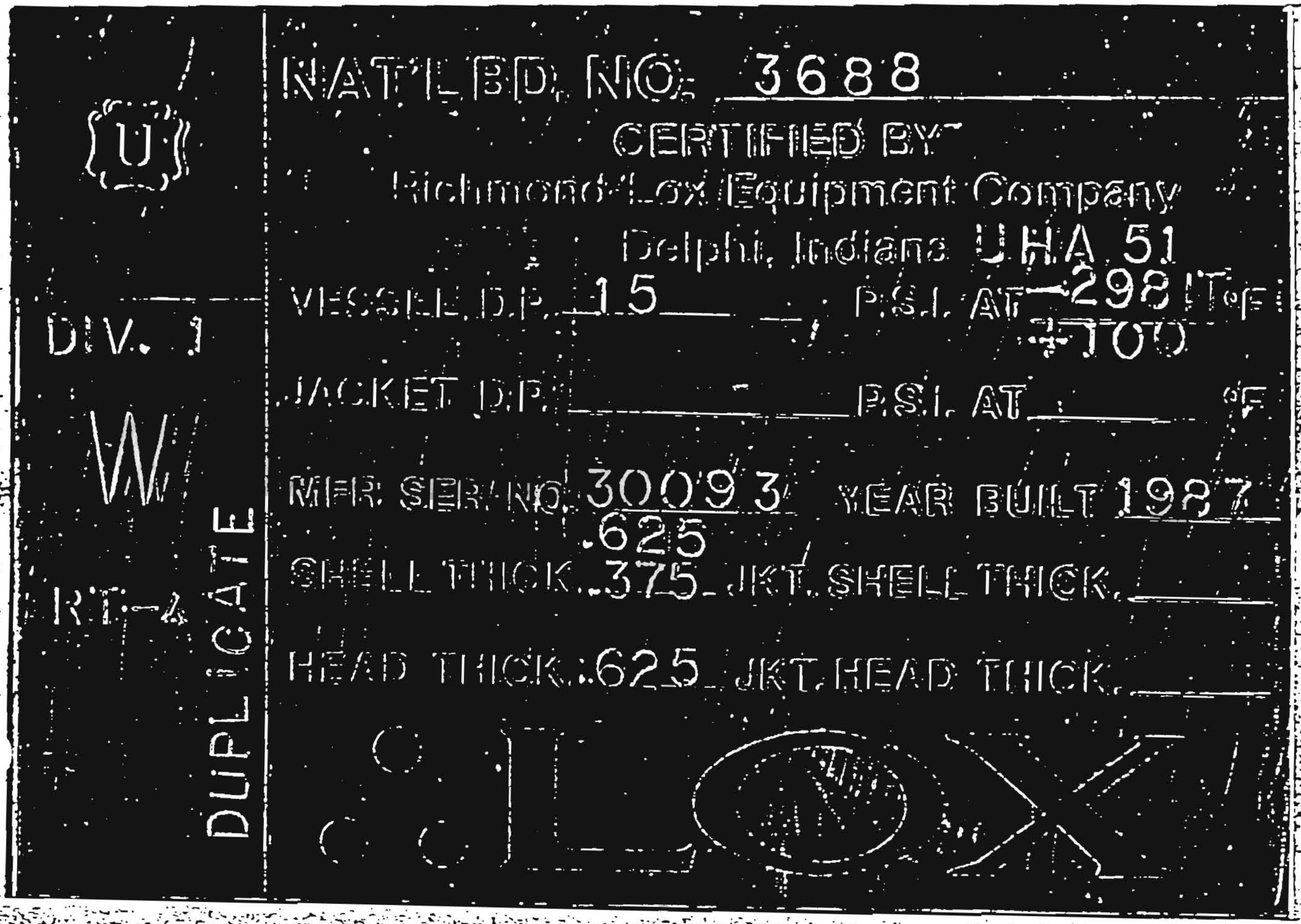
VESSEL D.P. 15 P.S.I. AT 100 °F

JACKET D.P. ______ P.S.I. AT ______ °F

SHELL T. .625 .375 JKT. SHELL T. ______

HEAD T. .625 JKT. HEAD T. ______

YEAR BUILT 1987 MOD. NO. 500[illegible]



U

DIV. 1

W

RT-4

DUPLICATE

NAT'L BD. NO. 3688

CERTIFIED BY

Richmond-Lox Equipment Company

Delphi, Indiana UHA 51

VESSEL D.P. 15 P.S.I. AT -298 °F
+100

JACKET D.P. ______ P.S.I. AT ______ °F

MFR. SER. NO. 30093 YEAR BUILT 1987

SHELL THICK. .375 .625 JKT. SHELL THICK. ______

HEAD THICK. .625 JKT. HEAD THICK. ______

LOX

P.O. Box 1
Baltimore, 203

EASTERN STAINLESS STEEL COMPANY

DIVISION OF Eastmet CORPORATION
THINK FIRST . . . THINK EASTERN

CUSTOMER COPY

CERTIFIED MATERIAL TEST REPORT

We certify that all of the test results and the statements of performed operations recorded here are in compliance with the ordered material specifications and the applicable material requirements.

J E Bongardt

MANIFEST
6877
DATE 19
01/XX 7
CUST. NO
9648
MILL ORDE.
B6364

SHIP TO:
STACEY MFG
259 TOWNSHIP AVE
CINCINNATI OH 45216

MAIL TO: DIRECT ✓
WILLIAMS AND COMPANY INC.
901 PENNSYLVANIA AVENUE
PITTSBURGH PA 15233

CUSTOMER ORDER NO.	LOC.	SHIPPED VIA	SHIP MODE	B/L NUMBER	CAR NUMBER	COLLECT ☐	RLS DT
M316810306	NP	UNIVERSAL AM-CAN	T	2698			01/24/87

ITEM		T NO.	COIL NO.	M.P.O. NO.	GAUGE	SIZE	FINISH CODE	DESCRIPTION	COUPON	W-LOC	BNDL CODE	PLATES COILS SHEETS	GROSS	TARE	NET	PK	GP	FA	WS
01	F	648		92027	0.6250	77.5000 X 267.5000	17	304 HRAP				1	3863		3863	01148			
01	F	648		92028	0.6250	77.5000 X 267.5000	17	304 HRAP				1	3863		3863	01148			
01	F	648		92029	0.6250	77.5000 X 267.5000	17	304 HRAP				1	3863		3863	01148			
01	F	648		92030	0.6250	77.5000 X 267.5000	17	304? HRAP				1	3863		3863	01148			
												4	15452	0	15452				

Q16036-6309
1/29/87
Ob.

6309

ECS ASTM A240-84A ASME SA240 SECT II S85 ADD

EE FR KNOWN CONTACT WITH MERCURY

MINIMUM SOLUTION ANNEALING TEMPERATURE 1900 F

AT NO.	C % ✓	MN % ✓	P % ✓	S % ✓	SI % ✓	CR % ✓	NI % ✓	CU %	TI %	CB+TA %	MO %	CO %	N %
0648	.048	1.68	.029	.007	.51	18.16	8.11	.36			.27	.14	.078
0648	.048	1.68	.029	.007	.51	18.16	8.11	.36			.27	.14	.078
0648	.048	1.68	.029	.007	.51	18.16	8.11	.36			.27	.14	.078
0648	.048	1.68	.029	.007	.51	18.16	8.11	.36			.27	.14	.078

CORROSION TEST CODES

- A. ASTM A262-'A'
- B ASTM A262-'B'
- C ASTM A262-'C'
- D. ASTM A262-'E'
- E QQS-766 (CUS04)

		TRANSVERSE OR FRONT						LONGITUDINAL OR BACK								CORROSION TEST		MAG PERM	SOLUTION ANNEAL	
AT NO		TENSILE PSI ✓	YIELD PSI ✓	ELONG % ✓	HARDNESS ✓	BEND	R/A %	TENSILE PSI	YIELD PSI	ELONG %	HARDNESS	BEND	R/A %	GR	C	CODE	RESULT	TEST	TIME MINUTES	TEMP. °F
0648	27	91.6	44.8	58	HB167		64													
0648	28	92.0	45.5	58	HB170	G	64													
0648	29	92.0	45.5	58	HB170	G	64													
0648	30	92.0	45.5	58	HB170	G	64													

CAUTION: PROCESSING THAT MAKES FUMES, DUST OR SOLUTIONS MAY

STACEY MFG. QUALITY CONTROL DEPARTMENT:

Material on this MTR was ordered from:

Williams & Co. on

P.O. #Q16036-6309 Item #. 1

This material applies to Stacey MFG.

S.O. # 6309

MK. # 1-1

This MTR. has been checked against

ASME. spec. SA-240 T304

By: Date: 1/22/87

ESSOP STEEL COMPANY

Washington, Pennsylvania 15301

AN ATHLONE Company

CERTIFICATE OF TEST

OUR ORDER NO. 71611-99- -06
YOUR ORDER NO. 42534
MEMO NO. 10/06/86
DATE
SALESMAN NO. Saleman no. 080

AUTHORIZED SIGNATURE

DECLARED TO UNDER OATH BEFORE ME

THIS ____________ DAY OF ____________

JESSOP STEEL COMPANY

BY

BILL TO
Ship to:
WILLIAMS & CO
7640 REINHOLD DR
CINCINNATI OH
45237

SHIP TO
Bill to:
WILLIAMS & COMPANY INC
901 PENNSYLVANIA AVE
PITTSBURGH PA
15233

ATTN W C CLERK

JESS T 304 STAINLESS HRAP
ASME -240-86 AMS 5513D ASTM A240-85a ASTM A167-84a
COMP ASTM A312-85 ; COMPOSITION & MECHANICAL PROPERTIES TO ASTM A276-85a
QQ-S- 5C AMEND 6 COND A

Heat	Slip	Size	Pcs	Weight
15647	71108	.6250 x 96.0000 x 270.0000	1	4830
15640	71109	.6250 x 96.0000 x 259.0000	1	4633
15648	71110	.6250 x 96.0000 x 253.0000	1	4526

Heat	C ✓	MN ✓	P ✓	S ✓	SI ✓	NI ✓	CR ✓	MO	CO	CU	N
15647	.061	1.75	.027	.003	.57	8.30	18.40	.39	.13	.24	.079
15648	.060	1.75	.030	.011	.49	8.15	18.18	.44	.12	.25	.084

Heat		Gauge	Yield ✓ Strength	Tensile ✓ Strength	Elong ✓	Red. of Area	Hardness	Bend	Corrosion	Grai Si
15647		.6250	43.4 KSI	87.8 KSI	62.8	72.3	BHN170 ✓	OK	OK	
15648	1-3	.6250	43.0 KSI	87.4 KSI	62.1	71.6	BHN179 ✓	OK	OK	

MAGNE C PERMEABILITY-LESS THAN 1.02
MATER L WAS PRODUCED WITHOUT KNOWN CONTACT WITH MERCURY OR LOW MELTING POINT CONTAMINANTS

STACEY MFG. QUALITY CONTROL DEPARTMENT:

Material on this MTR was ordered from:
Williams & Co on
P.O. # Q16036-6309 Item # 1, 2.
This material applies to Stacey MFG.,
S.O. # 6309
MK. # 1-3

This MTR. has been checked against
ASME. spec. SA 240 T304
By: Date: 1/13/87

Q.A.
APPROVED
OCT 10 '86
JB

Abmessung (mm, Zoll) Size (mm, inch) Dimensions (mm)	Menge Quantity Quantite	Nettogewicht (kg) Net weight (kgs) poids net (kg)	Charge Nr. Heat No. Coulée no.	Serie Nr. Series No. Série No.	Kolli Nr. Parcel No. Colis No.
			99108, 99082 -87314		

Chemische Analyse - Chemical Analysis - Analyse chimique

Charge Heat Coulee	Serie Serie Série	C ✓ %	Si ✓ %	Mn ✓ %	P ✓ %	S ✓ %	Cr ✓ %	Mo ✓ %	Ni ✓ %	Cu ✓ %		Nb %
99108		0,016	0,65	0,78	0,024	0,014	20,06	0,33	10,20	0,090		
99082		0,018	0,69	0,79	0,024	0,011	20,28	0,04	9,91	0,060		
87314		0,028	0,73	0,74	0,027	0,011	19.91	0,26	10,22	0,18		

Mechanische Gütewerte - Mechanical Properties - Propriétées mécaniques

Charge. Heat Coulée No.	Serie Serie Série No.	Wärmebehandl. Heat Treatm. Traite ment thermique	Streckgrenze Yield point Limite élastique N/mm²	Zugfestigkeit Tensile strength Resistance à la traction N/mm²	Dehnung Elongation Allongement (L = 5.65 √A) %	Einschnürung Reduction Striction %	Härte Hardness Durete	Kerbschlagarbeit Impact strength Résilience Charpy-V Joule
99108)				✓	✓			
99082)		u		min.520	min.35			
~~87314~~)								

u = unbehandelt – as welded – non traité
a = angelassen – tempered – revenu
s = spannungsarmgeglüht – stress relieved – recuit de détente

VEREINIGTE EDELSTAHLWERKE
AKTIENGESELLSCHAFT (VEW)
Werksgruppe Kapfenberg
Schweißversuchsanstalt
Kontrolle und Abnahme

131.268 c VEW – DVR 0055107 – Schmetzeck, Bruck/

STACEY MFG. QUALITY CONTROL DEPARTMENT:

Material on this MTR was ordered from:
AGA on
P.O. # 16118-Blanket Item # 1 & 2
This material applies to Stacey MFG.
S.O. # 6308 - 6309
MK. # WELDING MATERIALS
This MTR has been checked against
ASME. spec. SFA 5.4 - 308L-16
By: D. Heins Date: 4/6/87

P.O. Bo
Baltimo ry. 21203

EASTERN STAI SS STEEL COMPANY

DIVISION OF Eastmet CORPORATION
THINK FIRST . . . THINK EASTERN

C IER COPY

CERTIFIED MATERIAL TEST REPORT

We certify that all of the test results and the statements of performed operations recorded here are in compliance with the ordered material specifications and the applicable material requirements

J E Bongardt

MANIFE:).
6871
DATE
01/1 87
CUST. N
9649
MILL OR
B63

SHIP TO:
STACEY MFG
259 TOWNSHIP AVE
CINCINNATI OH 45216

MAIL TO:
DIRECT
WILLIAMS AND COMPANY INC.
901 PENNSYLVANIA AVENUE
PITTSBURGH PA 15233

CUSTOMER ORDER NO.	LOC.	SHIPPED VIA	SHIP MODE	B/L NUMBER	CAR NUMBER		RLS-DT
M316810306	NP	UNIVERSAL AM-CAN	T	2698		COLLECT ☐	01/26/87

ITEM	AT NO.	COIL NO.	M.P.O. NO.	GAUGE	SIZE	FINISH CODE	DESCRIPTION	COUPON	W-LOC	BNDL CODE	PLATES COILS SHEETS	GROSS	TARE	NET	PK	GP	FA	WS
S 02	0653		92031	0.5000	85.5000 X 277.5000	17	304 HRAP				1	3569		3569	01	1	5	8
S 02	0653		92032	0.5000	85.5000 X 277.5000	17	304 HRAP				1	3569		3569	01	1	3	9
S 02	0653		92033	0.5000	85.5000 X 277.5000	17	304 HRAP				1	3569		3569	01	1	5	8
S 02	0653		92034	0.5000	85.5000 X 277.5000	17	304 HRAP				1	3569		3569	01	1	5	8
											4	14276	0	14276				

Q16035-6308
1/20/87 6303
OB 1-1

PECS ASTM A240-84A ASME SA240 SECT II S85 ADD

REE FI KNOWN CONTACT WITH MERCURY MINIMUM SOLUTION ANNEALING TEMPERATURE 1900 F

HEAT NO		C %	MN %	P %	S %	SI %	CR %	NI %	CU %	TI %	CB+TA %	MO %	CO %	N %		
60653	4	.048	1.78	.031	.006	.50	18.17	8.08	.19			.32	.14	.080		
60653	4	.048	1.78	.031	.006	.50	18.17	8.08	.19			.32	.14	.080		
60653	4	.048	1.78	.031	.006	.50	18.17	8.08	.19			.32	.14	.080		
60653	4	.048	1.78	.031	.006	.50	18.17	8.08	.19			.32	.14	.080		

CORROSION TEST CODES
- A. ASTM A262-'A'
- B. ASTM A262-'B'
- C. ASTM A262-'C'
- D. ASTM A262-'E'
- E. QQS-766(CUS04)

	TRANSVERSE OR FRONT							LONGITUDINAL OR BACK								CORROSION TEST		MAG PERM.	SOLUTION ANNEAL	
HEAT NO.	O.	TENSILE PSI	YIELD PSI	ELONG %	HARDNESS	BEND	R/A %	TENSILE PSI	YIELD PSI	ELONG %	HARDNESS	BEND	R/A %	GR	C	CODE	RESULT	TEST	TIME MINUTES	TEMP. °F
60653	031	93.8	46.3	56	HB170	G	64	93.6	47.0	56	HB170	G	64	5		AE	SAT			
60653	032	93.8	46.3	56	HB170	G	64	93.6	47.0	56	HB170	G	64	5		AE	SAT			
60653	033	93.8	46.3	56	HB170	G	64	93.6	47.0	56	HB170	G	64	5		AE	SAT			
60653	034	93.8	46.3	56	HB170	G	64	93.6	47.0	56	HB170	G	64	5		AE	SAT			

CAUTION: PROCESSING THAT MAKES FUMES, DUST OR SOLUTIONS MAY

~~M~~aterial d'apport:

Abmessung (mm, Zoll) Size (mm, inch) Dimensions (mm)	Menge Quantity Quantité	Nettogewicht (kg) Net weight (kgs) poids net (kg)	Charge Nr. Heat No. Coulée no.	Serie Nr. Series No. Série No.	Kolli Nr. Parcel No. Colis No.
			99108,99082 ~~87314~~		

Chemische Analyse - Chemical Analysis - Analyse chimique

Charge Heat Coulee	Serie Serie Série	C ✓ %	Si ✓ %	Mn ✓ %	P ✓ %	S ✓ %	Cr ✓ %	Mo ✓ %	Ni ✓ %	Cu ✓ %		Nb %
99108		0,016	0,65	0,78	0,024	0,014	20,06	0,33	10,20	0,090		
99082		0,018	0,69	0,79	0,024	0,011	20,28	0,04	9,91	0,060		
87314		0,028	0,73	0,74	0,027	0,011	19.91	0,26	10,22	0,18		

Mechanische Gütewerte - Mechanical Properties - Propriétées mécaniques

Charge Heat Coulée No.	Serie Serie Série No.	Wärmebehandl. Heat Treatm. Traite ment thermique	Streckgrenze Yield point Limite élastique N/mm²	Zugfestigkeit Tensile strength Resistance à la traction N/mm²	Dehnung Elongation Allongement (L=5.65 √A) %	Einschnürung Reduction Striction %	Härte Hardness Dureté	Kerbschlagarbeit Impact strength Résilience Charpy-V Joule
99108)				✓	✓			
99082)		u		min.520	min.35			
~~87314)~~								

u = unbehandelt – as welded – non traité
a = angelassen – tempered – revenu
s = spannungsarmgeglüht – stress relieved – recuit de détente

VEREINIGTE EDELSTAHLWERKE
AKTIENGESELLSCHAFT (VEW)
Werksgruppe Kapfenberg
Schweißversuchsanstalt
Kontrolle und Abnahme

131.268 c VEW – DVR 0055107 – Schmerzeck, Bruckl/

STACEY MFG. QUALITY CONTROL DEPARTMENT:

Material on this MTR was ordered from:
AGA on
P.O. # 16118-BLANKET Item # 1 & 2
This material applies to Stacey MFG.
S.O. # 6308 - 6309
MK. # WELDING
MATERIALS
[illegible]
ASME. spec. SFA 5.4 - 308L-16
By: D [illegible] Date: 4/6/87

THE STACEY MFG. CO.
RECEIVED
APR - 6 1987

NO.	INIT'L	DATE
	DH	4/6/87

MADE: JFV 7/9/90
CHKD: TJA 7/9/90

REPORT OF WELDED ☒ REPAIR OR ☐ ALTERATION

1. Work done by CBI Na-Con, Inc. Houston, Texas (Name and Address of repair or alteration organization) C70708 (Contract No.)

2. Owner Fermi National Accelerator Laboratory Batavia, IL (Name and Address of Owner)

3. Location of Installation Fermi National Accelerator Laboratory Batavia, IL (Name and Address)

4. Unit Identification Outer Jacket (Boiler, Pressure Vessel) Name of Manufacturer Richmond-Lox Equipment Company

CBI Contract No. of Existing Vessel NA

5. Identifying Nos.

(Mfr. Serial No.)	(National Board No.)	(Jurisdiction)	(Other)	(Year Built)
None	None			1987

6. Description of Work: (Use separate sheet or sketch if necessary)

See attached sheet(s)

Pressure Test, if Applied No test psi

7. Remarks: Attached are Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors for the following items of this report:

None
(Name of part, item number, Mfr's name and identifying stamp)

8. Work done in accordance with Fermi Lab Purchase Order 938570/Spec #3740.214-ES-224130 (Owner's Spec. No., Nat'l Bd. Rules, ASME Code & Addenda, etc.)

CERTIFICATE OF COMPLIANCE

We certify that the statements made in this report are correct and that all - (design) if applicable material, construction, and workmanship on this Repair (repair, alteration) conform to Item 8 above.

8-29-90 (Date Signed) CBI Na-Con, Inc. (Repair, Alteration Organization) By (Authorized Representative)

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of Illinois and employed by HSBI & I Co. of Hartford, CT have inspected the work described in this Data Report on ________, 19__ and state that to the best of my knowledge and belief, this work has been done in accordance with Item 8 above.

By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the work described in this Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection, except such liability as may be provided in a policy of insurance which the Inspector's insurance company may issue upon said object and then only in accordance with the terms of said policy.

DATE ________ ________ (Inspector) Commissions ________ Nat'l Board, State or Province and No.

Data Report Documenting the Reattachment of the CC Cryostat Heads

Engineering Note # 3740.214-EN-266

Issued: November 6, 1990

Originator: Rick Luther

Made: FV 7/9/90
Chkd: TJA 7/9/90

FORM R-1, REPORT OF WELDED ☒ REPAIR OR ☐ ALTERATION
as required by the provisions of the National Board Inspection Code

1. Work performed by CBI Na-Con, Inc. (name of repair or alteration organization) Contract C70708 (P.O. no., job no., etc.)
8900 Fairbanks N. Houston Road, Houston, Texas 77064 (address)

2. Owner (name) Fermi National Accelerator Laboratory
PO Box 500, Batavia, Illinois 60510 (address)

3. Location of Installation Fermi National Accelerator Laboratory (name)
PO Box 500, Batavia, Illinois 60510 (address)

4. Unit identification: Pressure Vessel (boiler, pressure vessel) Name of original manufacturer Richmond-Lox Equipment Company

5. Identifying nos.:

30093	3688			1987
(mfr's. serial no.)	(original National Board no.)	(jurisdiction no.)	(other)	(year built)

6. Description of work: (use back, separate sheet, or sketch if necessary)
See attached sheet(s)

Pressure test, if applied No test psi

7. Replacement Parts. Attached are Manufacturers' Partial Data Reports properly identified and signed by Authorized Inspectors for the following items of this report:
None
(name of part, item number, mfr's. name and identifying stamp)

8. Remarks: Only the inner pressure vessel was originally U stamped. Therefore, only the work items on this vessel are included under the R stamp and this data report.

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229 NB-66 Rev 5

Inger ll Steel

Divis of Avesta Inc.

Certificate of Analysis and Tests

ORDER NUMBER	23764
CUSTOMER CODE	9600003
DATE	12/10/86

SOLD TO

AVE A STAINLESS INC.
721 NION BLVD
P.   BOX 269
TOTO A NJ 07511

SHIP TO — SAME UNLESS NOTED OTHERWISE

WILLIAMS & COMPANY, INC.
7640 REINHOLD DRIVE
CINCINNATI OH 45237

USTOMER ORDER NO	ATE	ROUTING	WHEN WANTED	TERMS
72143-9 -0306	12/09/86			

TEM NO.	MFG. CLASS		FIN	DESCRIPTION
	304		1	.500 X 96.000 X 296.000 EXACT ASTM A-240-84A ASME SA-240-80 83ED,S84 ADD DOS-7660 ASTM A-312 83 CHEM ONLY

LATES & EST PCS SOLUTION ANNEALED @ 1950 DEGREES FARENHEIT MINIMUM.
HEN WAT COOLED OR RAPIDLY COOLED BY AIR
REE OF RCURY CONTAMINATION
OT RO , ANNEALED & PICKLED (HRAP)

QUANTITY ORDERED: WEIGHT — PIECES
SHIPMENTS: PIECES — WEIGHT

STACEY MFG. QUALITY CONTROL DEPARTMENT

Material on this MTR was ordered from: W CLLAMS & Co

P.O. # Q16035-6308 Item # 1, 2

This material applies to Stacey MFG.

MECHANI ND OTHER TESTS

HEAT NUMBER	ESS	PIECES	YIELD STRENGTH LBS PER SQ IN.	TENSILE STRENGTH LBS PER SQ. IN.	ELONG % IN 2"	BEND	RED AREA %	INTERGRANULAR CORROSION	GRAIN SIZE	
7571	✓	1	44074	82744	65.0	OK	66.3	OK		2B

MK. # — REMARKS: ~~6308~~ 6308
1-3

This MTR. has been checked against ASME. spec. SA 240 T304

By: D Ahern Date: 1/13/87

HEMICAL OSITION

EAT NO		Mn ✓	P ✓	S ✓	Si ✓	Cr ✓	Ni ✓	Co	Cu	Mo	N	Cb/Ta	Ti	AL	SN	Ce	FE
7571	045	1.860	.031	.014	.520	18.180	8.170	.090	.420	.240	.089						

Q A
APPROVED
DEC 11 '86
JB

gersoll
vision of A
) Box 370
w Castle
47362

STATE OF INDIANA
COUNTY OF HENRY

By Donald Elliott

Subscribed And Sworn To Before Me This

DESIGN CERTIFICATION

The undersigned certifies that the statements made in this report are correct and that the design changes described in this report conform to the requirements of the National Board Inspection Code.

ASME Certificate of Authorization no. ________ to use the ________ symbol expires ________, 19____.

Date________, 19____ ________ (name of organization) Signed________ (authorized representative)

CERTIFICATE OF REVIEW OF DESIGN CHANGE

The undersigned, holding a valid Commission issued by The National Board of Boiler and Pressure Vessel Inspectors and certificate of competency issued by the state or province of ________ and employed by ________ of ________ has examined the design change as described in this report and verifies that to the best of his knowledge and belief such change complies with the applicable requirements of the National Board Inspection Code. By signing this certificate, neither the undersigned nor his employer makes any warranty, expressed or implied, concerning the work described in this report. Furthermore, neither the undersigned nor my employer shall be liable in any manner for any personal injury, property damage or loss of any kind arising from or connected with this inspection, except such liability as may be provided in a policy of insurance which the undersigned's insurance company may issue upon said object and then only in accordance with the terms of said policy.

Date________, 19____ Signed________ (Authorized Inspector) Commissions________ (National Board (incl. endorsements), state, prov., and no.)

CONSTRUCTION CERTIFICATION

The undersigned certifies that the statements made in this report are correct and that all construction and workmanship on this Repair (repair or alteration) conform to the National Board Inspection Code.

Certificate of Authorization no. R1330 to use the R symbol expires April 20, 1993.

Date 10 July, 1992 CBI Na-Con, Inc. (repair or alteration organization) Signed (authorized representative)

CERTIFICATE OF INSPECTION

The undersigned, holding a valid Commission issued by The National Board of Boiler and Pressure Vessel Inspectors and certificate of competency issued by the state or province of Illinois and employed by HSBI & I Co. of Hartford, Conn. has inspected the work described in this report on 10 JUL, 1990 and state that to the best of my knowledge and belief this work has been done in accordance with the National Board Inspection Code. By signing this certificate, neither the undersigned nor my employer makes any warranty, expressed or implied, concerning the work described in this report. Furthermore, neither the undersigned nor my employer shall be liable in any manner for any personal injury, property damage or loss of any kind arising from or connected with this inspection, except such liability as may be provided in a policy of insurance which the undersigned's insurance company may issue upon said object and then only in accordance with the terms of said policy.

Date 10 JUL. 1990 Signed (Authorized Inspector) Commissions N.B 10522 IL 1547 (National Board (incl. endorsements), state, prov., and no.)

Calorimeter Conduction, Radiation and Fire Loads

S. J. Wintercorn
5/23/85

D-Zero Engineering Note 3740.214,224-EN-6

Revised 7/21/87

2nd Revision
John Wu
10/11/91

Checked by Kurt J Krempetz

EN-6, 5/23/85, revised 10/11/91

S. J. Wintercorn
revised John Wu

Calorimeter Radiation Heat Load

The radiative and gaseous heat loads of the liquid argon end and central calorimeter vessels, drawings 3740.220-MD-222075, 3740.220-MD-222076, 3740.210-MD-222111 , 3740.210-MD-222075, and the vacuum break and fire safety relief valve capacities are calculated.

Heat Transfer with Hard Vacuum and Super Insulation

The heat transfer is;

$$\dot{q} = \frac{k \Delta T A}{L}$$

where k is the apparent mean thermal conductivity of the insulation, L is the thickness of the insulation (1"), A is the surface area of the inner vessel and ΔT is the difference between ambient and one atmosphere equilibrium liquid argon temperature (87.2 K). The apparent mean thermal conductivity value, k (2 micro-watts/cm-K), is a conservative value based on industrial practice.

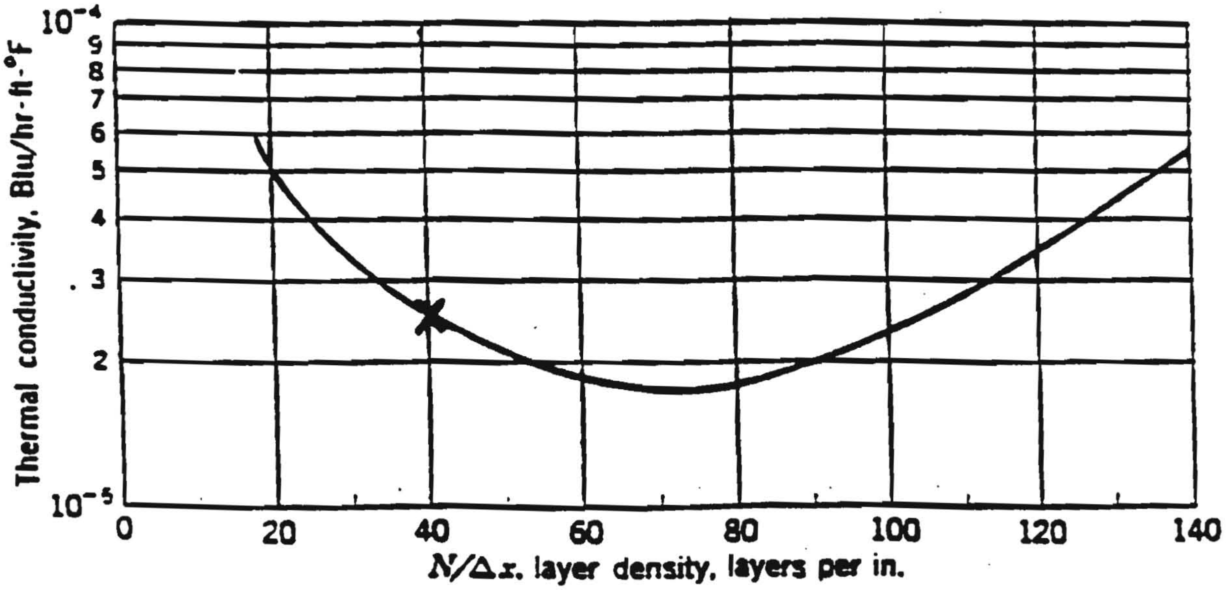


FIG. 1 Variation of thermal conductivity with layer density for a typical multilayer insulation [37]. The warm- and cold-side temperatures for the insulation are 530°R (70°F) and 140°R (−320°F).

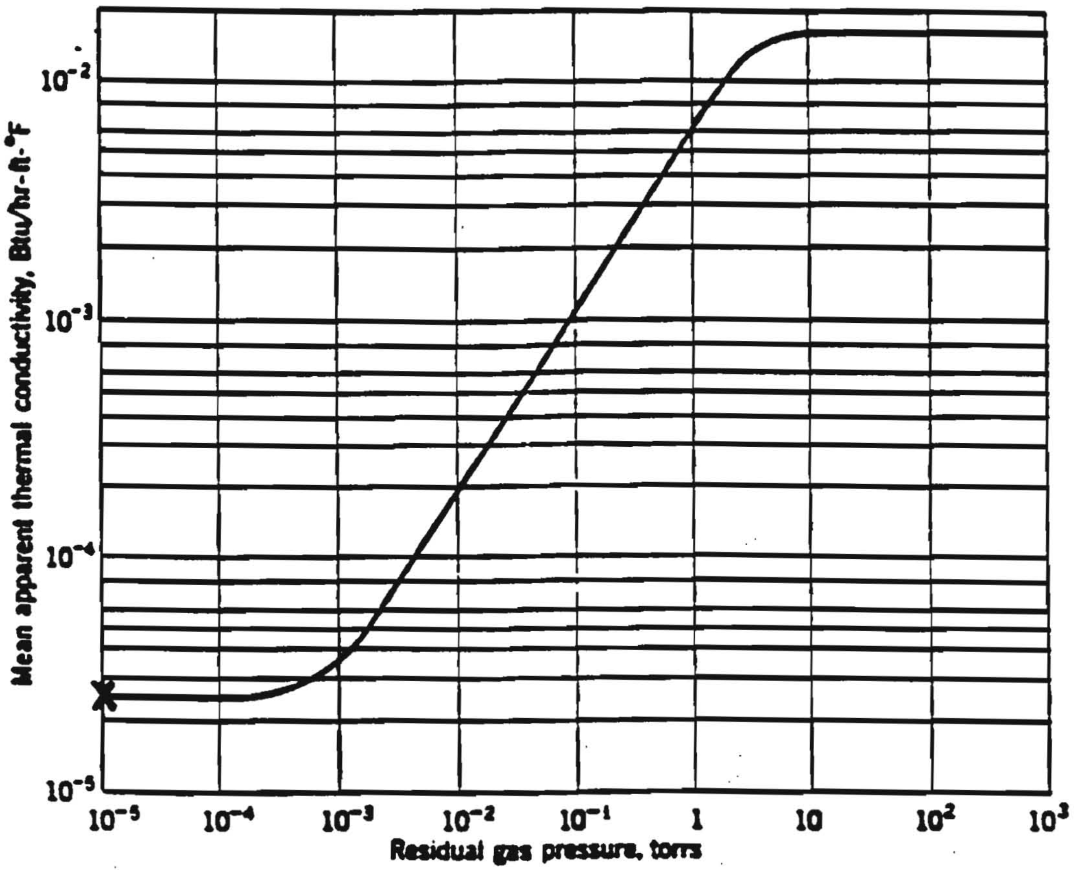


FIG. 2 Variation of thermal conductivity with residual gas pressure for a typical multilayer insulation. The insulation-layer density is 60 layers per inch, and the warm- and cold-side temperatures for the insulation are 540°R (80°F) and 163°R (−297°F).

The value 2.5 E-5 Btu/hr-ft-°F, indicated in figures 1 and 2, obtained from ref. 2, is a very optimistic value and is based on multilayer insulation manufacturers data. This report uses a more conservative value, 2 micro-watts/cm-K (0.000116 Btu/hr-ft-°F), as the thermal conductivity of the insulation (see fig. 3). This value is more realizable in an industrial environment because it is based on the actual use of multilayer insulations in large installations. The significant difference between the high and low vacuum ratios in figs. 2 and 3 is dependent on the geometry considered. The D-Zero geometry, an average annular spacing of no less than 2 in., is considered in fig. 3, but not in fig. 2.

Note: micro-watts/cm-K*57.793E-6 = Btu/hr-ft-°F

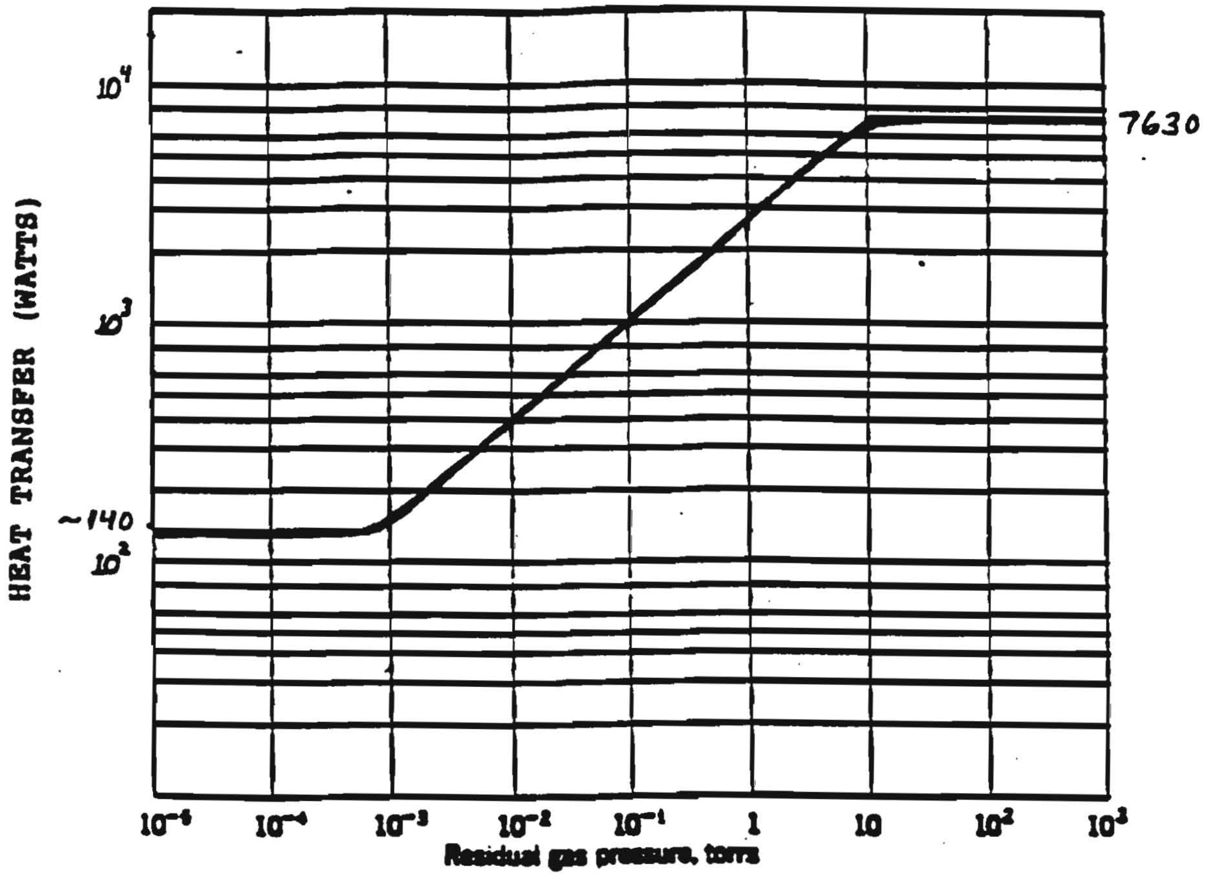


Fig. 3 Actual variation of heat transfer with residual gas pressure for a super insulated D0 cryostat.

Radiation Heat Transfer with Vacuum Only

Using Stephan's law, the heat transfer with good vacuum i.e. better than 10E-4 mm Hg is;

$$\dot{q} = \mu\left(5.7\times10^{-12}\right)\left(T_1^4 - T_2^4\right)$$

where T_1 is the ambient temperature and T_2 is the temperature of one atmosphere liquid argon. An emissivity (μ) of 0.3 is assumed.

Gaseous Conduction Heat Transfer without Vacuum

The heat transfer with the vacuum space at one atmosphere is;

$$\dot{q} = UA\Delta T_{oper}$$

where U is the thermal conductivity of one atmosphere, room temperature air divided by the radial thickness of the annulus (assume 2" average), A is the surface area of the inner vessel and ΔT_{oper} is the difference in temperature between ambient and one atmosphere equilibrium liquid argon. Note that air, rather than argon thermal conductivity is used because it is larger.

Gaseous Conduction Heat Transfer Under Fire Conditions

The conduction is;

$$\dot{q} = UA\Delta T_{fire}$$

where U is the thermal conductivity of one atmosphere, 1200 °F air divided by the average annular space (2"), A is the surface area of the inner vessel and ΔT_{fire} is the temperature difference between 1200 °F and one atmosphere equilibrium liquid argon temperature (87.2 K). For more accuracy, the area, A, in the formula was determined experimentally to be $A^{0.82}$, however, the table of results uses the theoretical formula above.

Flow Capacities

This section deals with the required flow capacity of the vessel relief valves under vacuum break and fire conditions (see ref. 1).

Required Flow Capacity without Vacuum , but with Insulation

The required flow capacity is;

$$Q_a = \frac{130-T}{4(1200-T)} G_i U A$$

where Q_a is the flow capacity in cubic feet per minute of free air (SCFM), G_i is the gas factor for the insulated vessel (=10.2, see ref. 1), U is the thermal conductivity (Btu/hr-ft-°F) of one atmosphere mean air at -100 °F (0.01045 Btu/hr-ft-°F) divided by the average annular space (2"), A is the surface area of the inner vessel, and T is the temperature of one atmosphere liquid argon.

Required Flow Capacity Under Fire Conditions

The required flow capacity is;

$$Q_a = G_i U A^{0.82}$$

where Q_a is the flow capacity in SCFM, G_i is the gas factor, U is the thermal conductivity of one atmosphere 1200 °F air (0.0363 Btu/hr-ft-°F) divided by the average annular space and A is the surface area of the inner vessel.

Results

Note: Revised numbers are scaled from the last revision using new surface areas and annular space thickness.

		Heat Transfer (Watts)			
	Area (ft^2)	Vacuum w/super	Vacuum w/o super	No vacuum w/super	No vacuum w/fire
EC	650	101	8280	5510	61500
CC	900	140	11500	7630	85200

	Required Flow Capacities		
	Area (ft^2)	No vacuum (SCFM)	Fire condition (SCFM)
EC	650	29	450
CC	900	40	590

References

1. Pressure Relief Device Standards, "S-1.3-Compressed Gas Storage Containers," Compressed Gas Association, Inc., 1980.

2. Barron, R. F., "Cryogenic Systems," McGraw-Hill Book Co., New York, 1966.

3. "Insulated Tank Truck Specification CGA-341," Compressed Gas Association Inc., 1972.

3740.210-EN-25

Central Calorimeter Piping Flexibility

A. Pitas

The flexing of the piping between the vacuum shell and the cold shell of the Central Cryostat was examined. The method used was taken from Piping Engineering, Tube Turns Company, Louisville, Kentucky, 4th edition. Each pipe was checked twice, first by A. Parker and then by A. Pitas. All simplifying assumptions are conservative. The largest calculated stress is 75% of the maximum allowable stress.

The effect of the cold shell's movement during cooldown was also analyzed. The cold ends of the piping moves approximately 1/2 inch. The stresses generated are calculated to be less than 5000 p.s.i.

CC Pressure Test

3740.214-EN-259

July 12, 1990
K. Dixon

Checked by GTM.

Vessel Status Prior to Testing

The inner vessel heads including bypass and beam tubes had just been welded into place and dye penetrant checked. The vacuum heads were not on at this time but the vacuum shell was on covering the piping penetrating into the inner vessel. Signal boxes with all feed through boards, the instrumentation box, and high voltage boxes were all installed with their pump outs capped. All 1/4" instrumentation lines were terminated at their respective shutoff valves.

All vacuum piping used for pumping down the inner vessel was isolated using o-ring sealed blind flanges. PV215A (VAT Series 12), the 4" VRC gate valve isolating the cyropump, and the rupture disk had to be removed and replaced with blind flanges before pressurizing due to their pressure limitations. Stresses in plates used as blind flanges were checked using Code calcualtions. Before the CC test, vacuum style blanks and clamps were hydrostatically pressure tested to 150% of the maximum test pressure, 60 psig.

The Code inspector and Research Division Safety had all given their approval to the test pressure and procedure prior to filling the vessel with argon.

Test Results

The test was a major success. Based on the lack of any distinguishable pressure drop indicated on the pressure gages, the vessel appeared to be structurally sound throughout the duration of the test (approx. 3 hrs.). A major leak in the instrumentation tubing was discovered at half of the maximum test pressure and was quickly isolated by crimping and capping with a compression fitting.

There were some slight deviations in the actual procedure used (see attachments). The 44 psig relief valve located just outside the cleanroom had to be capped until the pressure in the vessel indicated 38 psi. This was to allow higher supply pressures and hence, higher flows through the pressurizing line. Also, in order to get pressure readings at the cryostat without exposing any personnel to the potentially dangerous stored energy near the maximum test pressure, a camera was installed at the top of the vessel to view the indicator mounted there. The monitor was viewed at the ante room adjacent to the cleanroom.

The holding pressure of 32 psig (4/5 of the maximum test pressure) was only maintained for about 20 minutes instead of the half hour recommendation in the procedure. We felt that this was sufficient time to Snoop test and perform the pressure drop test.

After the test was completed, the inspector for CBI Na-Con and the Research Divison Safety Officer signed all of required documentation.

From: FNAL::MULHOLLAND 6-JUL-1990 12:47:23.92
To: KDIXON
CC: MULHOLLAND
Subj: As you requested.

7/5/90 Final version

PTest is the CC Pressure Test

This note describes the rationale for the test pressure of the completed CC calorimeter Pressure Test, provides a detailed operating procedure, and a Safety documentation and interface outline.

TEST PRESSURE

The CC vessel was pneumatically pressure tested to 50 psig at the fabricator, LOX in Delphi, Indiana. The test pressure was determined as follows,

	MAWP	15.0	psig
	+ Vacuum	14.73	psig
	LAr head	10.0	psig
	Sum	39.73	psig
Test Pressure	1.25(Sum)	49.66	psig

Removal and replacement of the heads and the installation of the nozzle extensions (4 signal boxes, 2 high voltage boxes, 1 instrumentation box, cold valve, and other appurtenances) are considered justification to repeat the pressure test on the completed calorimeter.

The vessel's multiple extensions will never see an operational pressure more than 15 psig, i.e. they don't see the vacuum because they are outside the vacuum envelope and they don't see the head (or at least any significant portion thereof) pressure. To Pneumatically test the vessel to 125% of the sum of the MAWP and liquid head, tests the upper portions of the vessel to 166%, and the nozzle extensions and their parts to 333%, of the respective maximum allowable working pressures.

The solution to the upper and lower vessel disparity is to fill the vessel with liquid for the test, and the solution to the vacuum loading is to install the vacuum jacket before the pressure test. Unfortunately, the vessel can not be filled with liquid without compromising the integrity of the calorimeter modules. The vacuum vessel can not reasonably be put in place (welded) to provide the vacuum loading, if the final leak check is to follow the pressure test. The latter is the accepted practice for obvious reasons.

The usual accomodation is to relinquish the head pressure requirement. That works well on high pressure vesssels, those with small heights (horizontal vessels), and/or those with low density liquids (Helium) because the effect is a small fraction of the maximum load test pressure. The resolution for low pressure, tall, and high density liquid vessels (our situation) is more difficult, and not as obvious. The compromise proposed in this case, and by extension for the EC's, is,

Source			Remarks
MAWP	15	psig	Relief is 13 psig
+ Vacuum	14.36	psig	707' above sea level

	Head LAr	10.0	psig
	Sum	39.36	psig
Test Pressure	ca. Sum	40.0	psig

In that way the upper pressure is limited to 136% of its maximum allowable value, the lower portion is tested to 100% of its maximum allowable pressure plus head, and the nozzle extensions pressures are limited to 267% of their maximum allowable pressures. Note that there are extension items that will necessarily, be removed for the pressure test and later reinstalled (see the Procedures, below), and others that must remain (e.g. signal boxes). GAr will be used as the pressurizing gas because it is the operating fluid.

Conclusion

The pneumatic test pressure will be 40.0 psig, GAr, as the best compromise among competing requirements.

PROCEDURE

General

Provide a source (actual calculated requirement is 1840 scft, but provide 5000 scf minimum) of GAr through a LP regulator and a line fitted with a 110% test pressure relief valve of larger flow capacity than the LP regulator. Provide two test gauges, one on an independent cryostat port, the other on the pressurizing line. A shutoff and then a vent valve should be located just downstream of the LP regulator and relief. All of the equipment, except for the cryostat pressure gage, must be located out of the line of sight of the vessel and behind a barrier of sufficient strength to assure shrapnel, that might be created in a vessel failure, can not reasonably be expected to injure the test operators at the pressure test stand.

The test will be performed insitu, in the clean room of the D Zero Assembly building, and must be done with the building empty of all personnel not essential to the test as the vessel is pressurized. All entry doors should be equipped with a sign warning of the test and clearly stating "Keep Out". One member of the test team should make it his task to assure stray spectators do not find their way to the test area. See the last section on Safety participation and abide by those constraints as well. Complete any necessary or desireable communication with CBI NACON or their Code inspector before conducting the pressure test.

Actual Procedure

1. Assure that the two immediately preceeding paragraphs are read, understood, and all actions taken and completed.

2. The vessel should be inspected to assure it is properly closed and does not exhibit any irregularities that might preclude a successful test.

2a. The following extension items must be removed and their nozzles suitablly capped before the pressure test;

A. The pump and purge valve, it has a one atmosphere rating.
B. The 18 psig Rupture disk assembly.
C. The 13 psig Relief valve assembly.
D. Vulnerable (over ranged) Pressure Transmitters.

E. All vacuum pumping appendages not Test Pressure rated.

3. The pressure in the vessel (ca. 660 cft) shall be gradually increased with GAr to not more than one-half of the test pressure. The agreement of the test station and vessel presssure gages should be verified or corrected as required. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure is reached. The test pressure should be held for a minimum of ten minutes. The pressure shall be reduced to a value equal to four-fifths of the test pressure and held for a time sufficient to permit complete inspection of the vessel. The visual inspection will be augmented with a half-hour or more gas pressure drop test and Snoop checking as may be required. All observations will be carefully and chronologically recorded in a logbook expressly for that purpose.

4. Should any sign of vessel failure or distortion be observed the test is terminated immediately by reducing the pressure to one atmosphere. A final disposition for the vessel will be arranged with the appropriate authorities.

5. Upon successful completion of the test the pressure is slowly reduced to atmospheric pressure, the test stand and source secured, and the pressure test precautions relaxed and signs removed.

SAFETY

The "Technical Appendix to Pressure Vessel Testing", Fermilab safety manual, 5034TA, is the appropriate and governing document. The salient points will be repeated here for continuity of context, but no attempt is made to provide another authority. Read 5034TA, attached.

The test requires a Pressure Testing Permit, see the last page of the TA, 5034TA-6, it is the permit application. It must be signed by the Test Coordinator (Kelly Dixon), Safety Officer (Bill Freeman), and the Division Head (Peter Garbincius). The test must be witnessed by the Safety Officier or his designee; a duly authorized Safety representative must be present for the test. Rick Luther, who has been directing the closure of the vessel and dealing with the construction crew, will coordinate this note with the requirements of the CBI NACON ASME Pressure Vessel Code inspector. Any modifications arising from those discussions will be made a part of this Procedure and be subject to approval by the Fermilab Safety office.

This test and procedure will be communicated to the DO Cryogenic Safety committee, but pressure testing is a Safety Office function and need not be approved by the Cryogenic Safety committee.

July 9, 1990

CC Pressure Test Check List

✓ Check 0-ring groove requirement for signal box, relief port flanges

✓ Make sealing provisions for above flanges

✓ Hydrostatically test 4" Marmon and KF50 flange/cap ass'ys to 60 psi

✓ Install pressurization field piping at outside cryobridge

✓ Install female VCO fittings at pump #90 trap

✓ Install pressure indicator on top of vessel

✓ Install transducer, chart recorder and associated wiring if available

✓ Perform leak analyses using RGA and HMSLD

✓ Call TJ Sarlina to confirm testing time

✓ Break vacuum and perform ROR until 2PM, then bring vacuum up the rest of the way to 1 atm

✓ Regenerate cold traps if manpower is available

✓ Remove pirani gage on top of vessel and plug

✓ Remove rupture disc assembly and install blind flange

✓ Remove relief valve port vacuum hose and install blind flange

✓ Remove cryopump gate valve and the pump if necessary, install blind flange.

✓ Remove PV215A and install KF50 cap and clamp

✓ Remove Welch pump vacuum hose at Marmon flange and install cap and clamp

__ Using a second party, check all bolts on blind fanges for tightness

✓ Replace 10 psi relief with 44 psi one

✓ Place warning signs at building entryways, ensure non-essential personnel has been evacuated

Fermilab

EXHIBIT B

Pressure Testing Permit*

Date: 10 July 90

Type of Test: ☐ Hydrostatic ☒ Pneumatic

Test Pressure: 40 psig Maximum Allowable Working Pressure: 29.36** psig

Items to be Tested: CC CALORIMETER & ITS EXTENSIONS - AFTER HEAD REASSEMBLY AND EXTENSION INSTALLATION

Location of Test: DAB Clean Room Date and Time:

Hazards Involved: ONLY THOSE ASSOCIATED WITH A PNEUMATIC TEST

Safety Precautions Taken: ISOLATED TEST, TEST STAND, SOUND DESIGN, REMOVAL OF L.P. DEVICES & CONSISTENT WITH 5034TA.

Special Conditions or Requirements: TEST MUST BE MADE WITH VACUUM JACKET OFF (NOT YET ASSEMBLED)

Test Coordinator: Kelly Dixon Dept/Date: RD/DØ 6 July 90

Division/Section Safety Officer: Dept/Date: RD Safety 9 July 90

Division/Section Head: Dept/Date: R.D. Office 9 July 90

Results: Pressure test was completed successfully. Pressure was held at 40 PSIG, then reduced to 32 PSIG and the entire assembly was leak checked. One variation from the original procedure was the installation of a TV camera & monitor to remotely view the pressure gage on the vessel in the clean room.

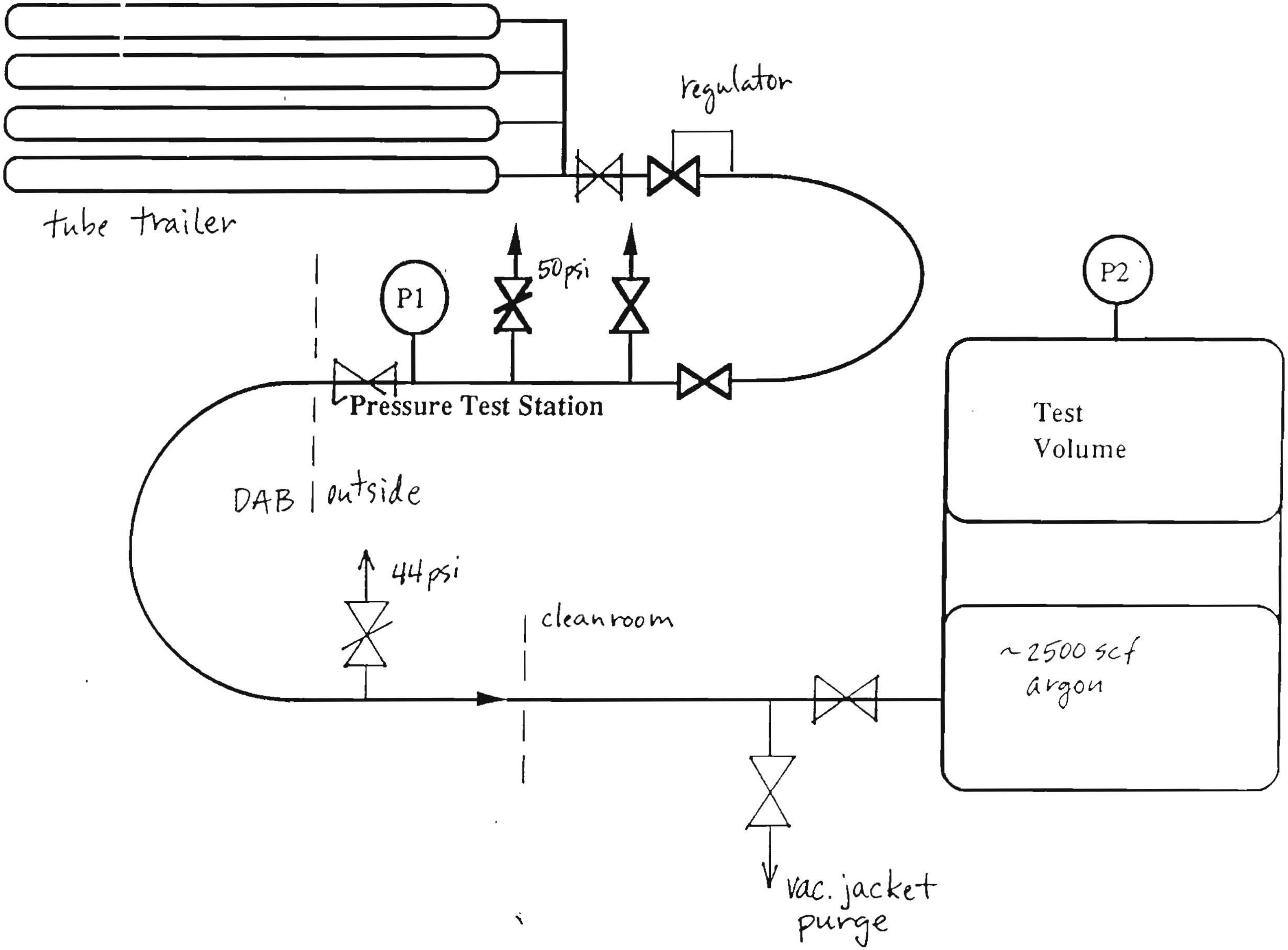
Witness: Dept/Date: 10 July 90
(Safety Officer or Designee)

*Must be signed by division/section safety officer and division head prior to conducting test. It is the responsibility of the test coordinator to obtain signature

** 15 psig + Full Vac on Jacket
15 + 14.36 = 29.36

5034TA-6
6/86

CC Pressure Test



Cryostat Filling Limitations for Proposed Ar Dewar Pressure Increase

3740.512-EN-321
July 23, 1991

J. Wu/K. Dixon

Revised October 17, 1991

Checked by Kurt J Krempetz

Cryostat Filling Limitations for Proposed Ar Dewar Pressure Increase

In order to significantly decrease the amount of time required to fill the cryostats, it is desired to raise the setpoint of the "operating" relief valve on the argon storage dewar to 20 psig from its existing 16 psig setting. This additional pressure increases the flow to the cryostats and will overwhelm the relief capacity if the temperature of the modules within these vessels is warm enough. Using some conservative assumptions and simple calculations within this note, the maximum average temperature that the modules within each cryostat can be at prior to filling from the storage dewar with liquid argon is at least 290 K.

Some Assumptions Used in the Analysis

1. Pressure in the argon storage dewar is at 20 psig.

2. The flow to the ECN cryostat is the most hazardous due to greater limitations on venting (see attached calculations).

3. The maximum flow of argon to the cryostat is 12.3 gpm (see attached calculations).

4. Gaseous nitrogen is concurrently flowing in the vent piping at a rate of 4861 lb/hr, this is derived from both ECS and CC cooling at their maximum rate and ECN condenser attempting to maintain pressure at its maximum.

5. Mixture mass flows are at the maximum at junction of relief devices on ECN(gN_2 mass flow actually increases gradually at junctions toward the ECS).

6. The temperature increase in the vent piping is negligible (large majority of piping is insulated).

7. All flows are treated as incompressible fluids (max. Mach No. = 0.2).

8. Temperature of the gaseous nitrogen prior to mixing in the vent manifold is 84 K, saturated property at 2 atm.

9. Flow equations apply to weight-averaged mixture densities and viscosities.

10. All liquid argon flashes to the bulk module temperature in the cryostat prior to entering the piping.

Explanation of Methodology

The basic purpose of the spreadsheet was to provide a complete model so that the maximum bulk temperature of the modules (line 2) could be determined. The maximum flow of argon to the ECN (line 3) was calculated separately and included after the spreadsheet. A number was picked as a guess for the bulk temperature (line 2). Then a number was picked as a guess for the percent of mass flow to the relief valve (line 18). The actual flow through the relief valve (line 98) was determined using the total flow and the percent of flow to the relief valve. The pressure drops across the inlet and outlets of the relief devices were then calculated. This allowed the calculation of the pressure drops across the relief valve and rupture disk. The various properties of argon were taken from tables at the bulk temperature of the modules.

The section "ΔP Across Relief Valve" calculated the maximum theoretical flow of argon through the relief valve (line 108). Then the theoretical percent of relief flow (line 109) was calculated based on the theoretical relief valve flow divided by the total flow through both the relief valve and rupture disk. The number guessed for the percent of flow to the relief valve (line 18) was then adjusted by iteration until it was close to, but not greater than, the theoretical value (line 109). At this point, the relief valve was operating near its full capacity, which could be checked by noting that the actual flow (line 98) was close to the maximum theoretical flow (line 108).

The next step was to examine the section "ΔP Across Rupture Disk". All of the total argon flow not going though the relief valve would be flowing through the rupture disk. In order to insure that the rupture disk could handle the flow, the maximum theoretical rupture disk flow (line 181) was calculated, and compared to the actual flow (line 182). The actual flow had to be under the maximum theoretical flow, but should be close to the maximum value to obtain the highest total flow. In the case that the actual flow was calculated to be higher than the maximum theoretical flow, the bulk temperature was lowered. Using the new temperature, the first set of iterations was repeated to determine the percent of flow to the relief valve, and the rupture disk flow was compared again. The temperature was lowered through iteration until an acceptable value was found.

Note that the sections on pressure drops were only needed to calculate inlet and outlet pressures for the relief valve and rupture disk. Other sections calculated the changes in various properties of the argon at certain points. Each time the temperature was changed, the values for density and viscosity were changed to reflect the new temperature. The maximum flow of nitrogen from the condensers was also accounted for, since it had an effect on the pressure drops of the outlets of the relief devices.

Notes on Maximum Module Temperature Calculation

*> means that this value is to be re-entered each time the bulk module temperature is changed.

> means that this value is a number, not a formula, but should only be entered once, i.e., it doesn't need to change with the temperature.

(conv.) means that this value is the same as a previous value, but converted to different units.

EN-263, Russ Rucinski, should be referred to for pressure drop calculations.

General Procedure:

In the first section, "Conversion of Liquid to Gas at Module Temp.," enter the bulk temperature of the modules. This is also the temperature that will be used for pressure drops in the relief and rupture disk inlets, and for the relief devices themselves. Enter the gas density at 2.2 bars and 2.4 bars, and at the bulk temperature, so that the density at the cryostat pressure can be calculated. Enter some percent of mass flow to the relief valve. This will be used to assume some mass flow to each relief device for pressure drop calculations. It will be adjusted by iteration later.

In the next section, "ΔP Across Relief Valve Inlet," enter the viscosity at 2.4 bars (or 2.375 bars for more accuracy) and the bulk temperature. The rest of the section is calculated.

The next section, "ΔP Across Rupture Disk Inlet," needs no entries, since it assumes the same gas properties as the previous section.

The section, "ΔP Across Relief Valve Outlet" requires the gas density, and the viscosity at an verge pressure of 2 bars and at the bulk temperature. This just accounts for the drop in pressure to about 1.5 bars. If more accuracy is required, the new pressure could be calculated by adding the common outlet pressure drops to atmospheric pressure.

The "ΔP Across Rupture Disk Outlet" section is completely calculated, based on the assumption that the gas properties remain the same as for the relief valve outlet.

The next section, "Change in Gas at Common Outlet to Outside" reflects the change in properties of the fluid at the junction of the relief device outlets due to the mixing of argon from the relief devices and nitrogen from the condensers.

The "ΔP Across Relief Valve" is completely calculated (ref.1, 3). The specific heat ratio, k, has been determined using the C_p and C_v at the correct temperature and pressure. Also, the flowing temperature is converted from the original bulk temperature, to the equivalent Rankine temperature. The basic purpose of this section is to compare the "Theoretical Percent of Relief Flow" to the actual percent that was entered in section 1. Since the theoretical percent of the relief flow is the maximum flow possible at the given inlet and outlet parameters, this number should be checked such that it does not fall below the "guessed" percentage in the first section of calculations.

The "ΔP Across Common Outlet to Platform" is calculated based on the properties from the "Change in Gas..." section. Also, all pressure drop calculations are based on a equation which relates the friction factor, f, to the Reynolds number and the relative roughness, e/D. The "Friction Factor Guess" is based on an equation in Introduction to Fluid Mechanics (ref.1) and that value is used in another equation in the same reference to find the actual friction factor. Calculations to determine equivalent lengths and relative roughness were based on dimensions from sketches and drawings of the ECN piping and platform manifold.

The section on the "ΔP from Platform Bayonet to Outside" is completely calculated like the previous section, but with a different diameter and equivalent length.

The "Summation of Equivalent ΔPs" is basically a summary of the pressure drops, where the "Rupture Disk Pressure Drop" is calculated based on the three relief valve values, and the rupture disk inlet and outlet values.

The "ΔP Across Rupture Disk Device" is calculated like the relief valve. The complete equation for the "Gas Flow Constant for Subsonic Flow (C1)" is found in reference 2. The specific heat ratio, k, was adjusted according to the actual pressure and temperature. In both the relief valve and the rupture disk, the outlet pressure should be compared to the critical pressure, which it must exceed for the flow to be subsonic. In all cases analyzed, the flow was subsonic.

Conclusions and Recommendations

The average temperature of the module mass for any of the three cryostats can be as high as 290 K prior to filling that particular cryostat. This should not be confused with the average temperature of a single type or location which is useful in protecting the modules-not necessarily the vessel itself. A few modules of each type and at different elevations should be used in an average which would account for the different weights of each module. Note that at 290 K, the actual flow of argon through the relief valve and the rupture disk was under the maximum theoretical flows for each relief device. This means that the bulk temperature could actually have been raised to flow argon through the reliefs at their maximum capacity. Therefore, the temperature of 290 K is a conservative value for the calculated flow rate of 12.3 gpm.

Safeguards in addition to and used in conjunction with operating procedures shall be implemented in such a way so that the above temperature limitation is not exceeded and such that it is exclusive of the programmable logic controller (PLC). One suggestion is using a toggle switch for each cryostat mounted in the PLC I/O box which would maintain control of the signals to open the cold fill valves of each cryostat.

With the safeguards in place while carefully monitoring the temperatures during a cooldown cycle in each cryostat, the set pressure in the argon storage dewar can safely be increased to 20 psig.

References

1. Introduction to Fluid Mechanics, 3rd Ed., Robert W. Fox, Alan T. McDonald, JohnWiley&Sons, 1985.

2. "Fike Technical Bulletin TB 8102, Rupture Disk Sizing", Fike Metal Products Corp.

3. "Catalog 1900-Series 90 Safety Relief Valves", Anderson, Greenwood & Co., 1980.

4. "DØ CC Pressure Vessel and Vacuum Vessel Safety Note", DØ Engineering Note #3740-EN-263, R. Rucinski/R. Luther, Nov., 1990.

Maximum Module Temperature Calculation 10/17/91

	A	B	C	D
1	Conversion of Liquid to Gas at Module Temp.			Units
2	*> Bulk Temp. of Modules	290	290	K
3	> Max. Flow of Liquid Argon to Cryostat	12.3	12.3	gpm
4	> Pressure in Cryostat	19.75	19.75	psig
5	Pressure in Cryostat (conv.)	=(B4/14.696+1)*1.01325	2.375	bars
6	> lAr Density @ 2.2 bars	1.342421	1.34	g/cc
7	> lAr Density @ 2.4 bars	1.335861	1.34	g/cc
8	lAr Density @ 2.375 bars	=(B5-2.2)/0.2*(B7-B6)+B6	1.337	g/cc
9	*> gAr Density @ 2.2 bars	3.655	3.655	mg/cc
10	*> gAr Density @ 2.4 bars	3.987	3.987	mg/cc
11	gAr Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	3.945	mg/cc
12	gAr Density @ 2.375 bars (conv.)	=B11/1000*62.428	0.246	lbm/ft^3
13	Maximum Flow of Argon Gas	=B3*B8/B11*1000	4167	gpm
14	Maximum Flow of Argon Gas (conv.)	=B13*0.13368	557	cfm
15	Air Equivalent Flow @STP	=6.32*B17*356/B16*SQRT(B99/(520*B177*28.97))	1443	scfm air
16	Specific Heat Constant, C, for Ar	=520*SQRT(B168*(2/(B168+1))^((B168+1)/(B168-1)))	378	
17	Max. Mass Flow of Argon Gas	=B14*B12*60	8232	lbm/hr
18	*> Percent of Mass Flow to Relief Valve	0.48	0.48	
19				
20	ΔP Across Relief Valve Inlet			Units
21	> Inner Pipe Diameter	0.206	0.206	ft
22	Inner Pipe Diameter (conv.)	=B21*12	2.472	in
23	> Equivalent Length	38	38	ft
24	Ar Gas Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	3.945	mg/cc
25	Ar Gas Density @ 2.375 bars (conv.)	=B24/1000*62.428	0.246	lbm/ft^3
26	*> gAr Viscosity @ 2.4 bars & Temp.	0.0002228	0.0002228	g/cm-s
27	gAr Viscosity @ 2.4 bars (conv.)	=B26*100	0.02228	centipoise
28	Max. Mass Flow to Relief Valve	=B17*B18	3952	lbm/hr
29	Reynolds Number	=6.31*B28/(B22*B27)	453000	
30	> Relative Roughness (e/D)	0.0007	0.0007	
31	Friction Factor Guess	=0.25*(LOG(B30/3.7+5.74/(B29^0.9)))^-2	0.019	
32	Friction Factor	=0.25*(LOG(B30/3.7+2.51/(B29*B31^0.5)))^-2	0.0189	
33	Pressure Drop	=0.00000336*B32*B23*(B28^2)/B25/(B22^5)	1.655	psi
34				

Maximum Module Temperature Calculation 10/17/91

	A	B	C	D
35	ΔP Across Rupture Disk Inlet			Units
36	Inner Pipe Diameter (conv.)	=B37/12	0.172	ft
37	> Inner Pipe Diameter	2.067	2.067	in
38	> Equivalent Length	49	49	ft
39	gAr Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	3.945	mg/cc
40	gAr Density @ 2.375 bars (conv.)	=B39/1000*62.428	0.246	lbm/ft^3
41	gAr Viscosity @ 2.4 bars	=B26	0.0002228	g/cm-s
42	gAr Viscosity @ 2.4 bars (conv.)	=B41*100	0.02228	centipoise
43	Max. Mass Flow to Rupture Disk	=B17*(1-B18)	4281	lbm/hr
44	Reynolds Number	=6.31*B43/(B37*B42)	587000	
45	> Relative Roughness (e/D)	0.0009	0.0009	
46	Friction Factor Guess	=0.25*(LOG(B45/3.7+5.74/(B44^0.9)))^-2	0.0198	
47	Friction Factor	=0.25*(LOG(B45/3.7+2.51/(B44*B46^0.5)))^-2	0.0197	
48	Pressure Drop	=0.00000336*B47*B38*(B43^2)/B40/(B37^5)	6.394	psi
51				
52	ΔP Across Relief Valve Outlet			Units
53	Inner Pipe Diameter (conv.)	=B54/12	0.272	ft
54	> Inner Pipe Diameter	3.26	3.26	in
55	> Equivalent Length	51	51	ft
56	*> gAr Density @ 2.0 bar & Temp.	3.324	3.324	mg/cc
57	gAr Density @ 2.0 bar (conv.)	=B56/1000*62.428	0.208	lbm/ft^3
58	*> gAr Viscosity @ 2.0 bar & Temp.	0.0002227	0.0002227	g/cm-s
59	gAr Viscosity @ 2.0 bar (conv.)	=B58*100	0.02227	centipoise
60	Max. Mass Flow to Relief Valve	=B28	3952	lbm/hr
61	Reynolds Number	=6.31*B60/(B54*B59)	343000	
62	> Relative Roughness (e/D)	0.00055	0.00055	
63	Friction Factor Guess	=0.25*(LOG(B62/3.7+5.74/(B61^0.9)))^-2	0.0185	
64	Friction Factor	=0.25*(LOG(B62/3.7+2.51/(B61*B63^0.5)))^-2	0.0183	
65	Pressure Drop	=0.00000336*B64*B55*(B60^2)/B57/(B54^5)	0.642	psi
66				

Maximum Module Temperature Calculation 10/17/91

	A	B	C	D
67	ΔP Across Rupture Disk Outlet			Units
68	Inner Pipe Diameter (conv.)	=B69/12	0.18	f t
69	> Inner Pipe Diameter	2.157	2.157	in
70	> Equivalent Length	1.75	1.75	f t
71	gAr Density @ 2.0 bar & Temp.	=B56	3.324	mg/cc
72	gAr Density @ 2.0 bar (conv.)	=B71/1000*62.428	0.208	lbm/ft^3
73	gAr Viscosity @ 2.0 bar & Temp.	=B58	0.0002227	g/cm-s
74	gAr Viscosity @ 2.0 bar (conv.)	=B73*100	0.02227	centipoise
75	Max. Mass Flow to Rupture Disk	=B43	4281	lbm/hr
76	Reynolds Number	=6.31*B75/(B69*B74)	562000	
77	> Relative Roughness (e/D)	0.0009	0.0009	
78	Friction Factor Guess	=0.25*(LOG(B77/3.7+5.74/(B76^0.9)))^-2	0.0198	
79	Friction Factor	=0.25*(LOG(B77/3.7+2.51/(B76*B78^0.5)))^-2	0.0197	
80	Pressure Drop	=0.00000336*B79*B70*(B75^2)/B72/(B69^5)	0.219	psi
81				
82	Change in Gas at Common Outlet to Outside			Units
83	Pressure in Cryostat	=B4	19.75	psig
84	Pressure in Cryostat (conv.)	=(B83/14.696+1)*1.01325	2.375	bars
85	gAr Density @ 2.2 bars	=B9	3.655	mg/cc
86	gAr Density @ 2.4 bars	=B10	3.987	mg/cc
87	gAr Density @ 2.375 & Temp.	=(B84-2.2)/0.2*(B86-B85)+B85	3.945	mg/cc
88	Temp. at Common Outlet	=(B2*B17+84*B189)/(B17+B189)	214	K
89	> Pressure to Calculate Density	1.5	1.5	bars
90	*> gAr Density @ 1.5 bars & New Temp.	3.396	3.396	mg/cc
91	*> gAr Viscosity @ 1.5 bars & New Temp.	0.0001696	0.0001696	g/cm-s
92	gAr Viscosity @ 1.5 bar (conv.)	=B91*100	0.01696	centipoise
93				

Maximum Module Temperature Calculation 10/17/91

	A	B	C	D
94	ΔP Across Relief Valve			Units
95	> Critical Ratio (Pcr/P1) for Argon	0.487	0.487	
96	> Specific Heat Ratio (k) for Argon	=B168	1.67	
97	> Area of 2" x 3" Relief Valve	2.29	2.29	in^2
98	Flow Through Relief Valve	=B28	3952	lbm/hr
99	Flowing Temperature	=1.8*B2	522	deg R
100	> Compressibility Factor	1	1	
101	> Nozzle Coefficient for type 93T	0.939	0.939	
102	Flowing Inlet Pressure (P1)	=B4+14.696-B33	32.79	psia
103	> Molecular Weight of Argon	39.948	39.95	g/mol
104	Critical Pressure (Pcr)	=B95*B102	15.97	psia
105	Outlet Pressure (P2) (using delta p's)	=14.696+B154+B133+B65	27.39	psia
106	Pressure Ratio (P2*/P1)	=(B102-0.55*((B102-B105)^0.98))/B102	0.912	
107	Theoretical Factor (F*) (using P2)	=SQRT((B96/(B96-1))*(B106^(2/B96)-B106^((B96+1)/B96)))	0.284	
108	Max. Theoretical Relief Flow (using F*)	=735*B97*B101*B102*B107*SQRT(B103/B99/B100)	4072	lbm/hr
109	Theoretical Percent of Relief Flow	=B108/B17	0.4947	
110	Pressure Drop Across Relief Valve	=B102-B105	5.403	psi
111				

Maximum Module Temperature Calculation 10/17/91

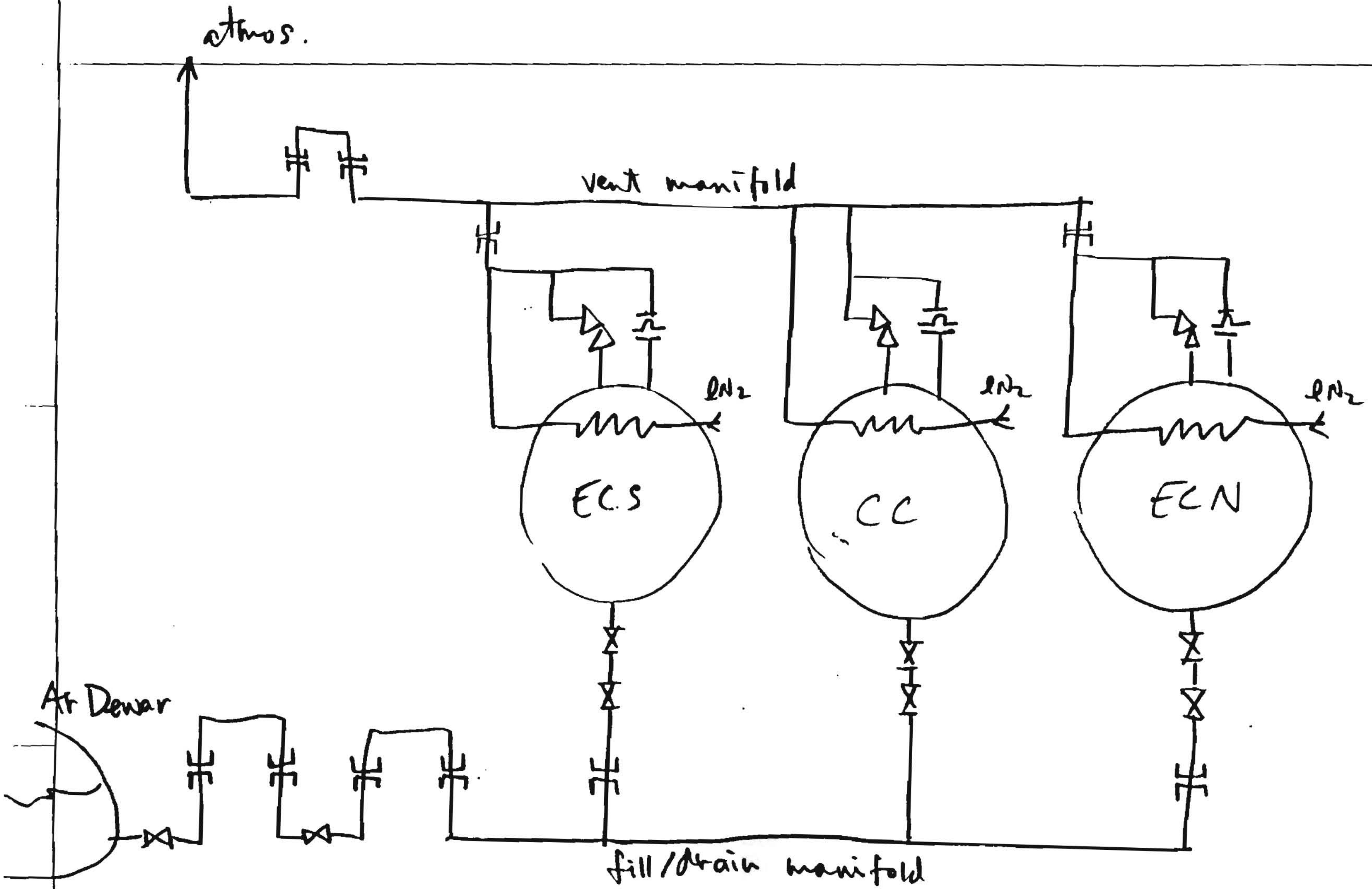
	A	B	C	D
112	ΔP Across Common Outlet to Platform Bayonet			Units
113	> Inner Pipe Diameter	0.355	0.355	ft
114	Inner Pipe Diameter (conv.)	=B113*12	4.26	in
115	> Equivalent Length	273	273	ft
116	gAr Density @ 1.5 bar & New Temp.	=B90	3.396	mg/cc
117	gAr Density @ 1.5 bar (conv.)	=B116/1000*62.428	0.212	lbm/ft^3
118	*> gN2 Gas Density @ 1.5 bar & New Temp.	2.411028	2.411	mg/cc
119	gN2 Gas Density @ 1.5 bar (conv.)	=B118/1000*62.428	0.151	lbm/ft^3
120	Gas Mixture Density @1.5 bar	=(B17*B117+B127*B119)/B128	0.189	lbm/ft^3
121	gAr Viscosity @ 1.5 bar & New Temp.	=B91	0.0001696	g/cm-s
122	gAr Viscosity @ 1.5 bar (conv.)	=B121*100	0.01696	centipoise
123	*> gN2 Viscosity @ 1.5 bar & New Temp.	0.000136454	0.0001365	g/cm-s
124	gN2 Viscosity @ 1.5 bar (conv.)	=B123*100	0.01365	centipoise
125	Mixture Viscosity @1.5 bar	=(B17*B122+B127*B124)/B128	0.01573	centipoise
126	Max. Mass Flow of Argon Gas	=B17	8232	lbm/hr
127	Max. Flow of Nitrogen Gas	=B189	4861	lbm/hr
128	Mass Flow of Mixture	=B126+B127	13093	lbm/hr
129	Reynolds Number	=6.31*B128/(B114*B125)	1230000	
130	> Relative Roughness (e/D)	0.0004	0.0004	
131	Friction Factor Guess	=0.25*(LOG(B130/3.7+5.74/(B129^0.9)))^-2	0.0165	
132	Friction Factor	=0.25*(LOG(B130/3.7+2.51/(B129*B131^0.5)))^-2	0.0164	
133	Pressure Drop	=0.00000336*B132*B115*(B128^2)/B120/(B114^5)	9.705	psi
134				

Maximum Module Temperature Calculation 10/17/91

	A	B	C	D
135	ΔP from Platform Bayonet to Outside			Units
136	> Inner Pipe Diameter	0.53	0.53	f t
137	Inner Pipe Diameter (conv.)	=B136*12	6.36	in
138	> Equivalent Length	516	516	f t
139	gAr Gas Density @ 1.5 bar & New Temp.	=B90	3.396	mg/cc
140	gAr Gas Density @ 1.5 bar (conv.)	=B139/1000*62.428	0.212	lbm/ft^3
141	gN2 Gas Density @ 1.5 bar & New Temp.	=B118	2.411	mg/cc
142	gN2 Gas Density @ 1.5 bar (conv.)	=B141/1000*62.428	0.151	lbm/ft^3
143	Gas Mixture Density @1.5 bar	=(B17*B140+B189*B142)/B149	0.189	lbm/ft^3
144	gAr Viscosity @ 1.5 bar & New Temp.	=B121	0.0001696	g/cm-s
145	gAr Viscosity @ 1.5 bar (conv.)	=B144*100	0.01696	centipoise
146	gN2 Viscosity @ 1.5 bar & New Temp.	=B123	0.0001365	g/cm-s
147	gN2 Viscosity @ 1.5 bar (conv.)	=B146*100	0.01365	centipoise
148	Gas Mixture Viscosity @1.5 bar	=(B17*B145+B189*B147)/B149	0.01573	centipoise
149	Max. Mass Flow of Gas Mixture	=B128	13093	lbm/hr
150	Reynolds Number	=6.31*B149/(B137*B148)	826000	
151	> Relative Roughness (e/D)	0.00027	0.00027	
152	Friction Factor Guess	=0.25*(LOG(B151/3.7+5.74/(B150^0.9)))^-2	0.0156	
153	Friction Factor	=0.25*(LOG(B151/3.7+2.51/(B150*B152^0.5)))^-2	0.0155	
154	Pressure Drop	=0.00000336*B153*B138*(B149^2)/B143/(B137^5)	2.345	psi
155				
156	Summation of Equivalent ΔPs			Units
157	Relief Valve Inlet Pressure Drop	=B33	1.655	psi
158	Relief Valve Outlet Pressure Drop	=B65	0.642	psi
159	Relief Valve Pressure Drop	=B110	5.403	psi
160	Relief Valve/Disk Branch	=B33+B65+B110	7.7	psi
161	Rupture Disk Inlet Pressure Drop	=B48	6.394	psi
162	Rupture Disk Outlet Pressure Drop	=B80	0.219	psi
163	Rupture Disk Pressure Drop	=B157+B158+B159-B161-B162	1.087	psi
164	Common Outlet Pressure Drop	=B133	9.705	psi
165	Platform to Outside Pressure Drop	=B154	2.345	psi
166				

Maximum Module Temperature Calculation 10/17/91

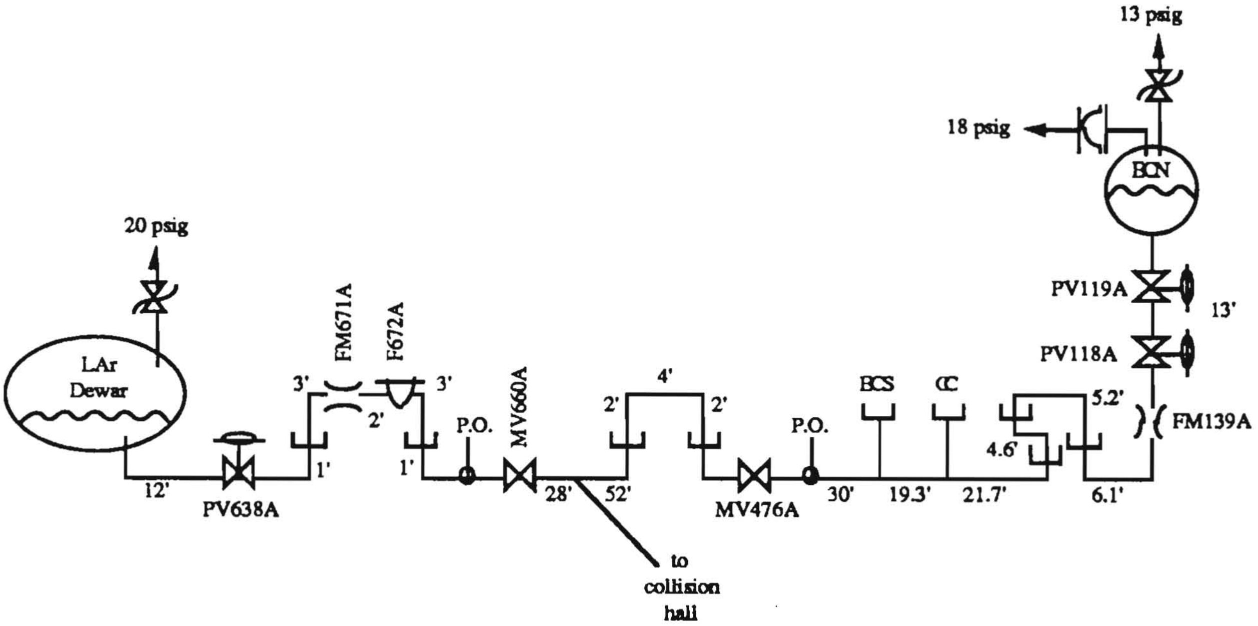
	A	B	C	D
167	ΔP Across Rupture Disk			Units
168	'>Argon Specific Heat Ratio (k)	1.673	1.673	
169	Critical Ratio	=(2/(B168+1))^(B168/(B168-1))	0.486	
170	> Area of 3" Rupture Disk	=3.14159*(3^2)/4	7.069	in^2
171	Flow Through Rupture Disk	=B43	4281	lbm/hr
172	Flowing Temperature	=1.8*B2	522	deg R
173	> ASME Coefficient (K)	0.62	0.62	
174	Pressure Ratio (Pe/Po)	=B179/B176	0.961	
175	gAr Flow Constant for Subsonic Flow(C1)	=SQRT(2*32.2/1545*(B168/(B168-1))*(B174^(2/B168)-B17	0.039	
176	Flowing Inlet Pressure (Po)	=B4+14.696-B48	28.05	psia
177	> Molecular Weight of Argon	39.948	39.948	g/mol
178	Critical Pressure (Pcr)	=B169*B176	13.64	psia
179	Outlet Pressure (Pe) (using delta p's)	=14.696+B154+B133+B80	26.97	psia
180	Pressure Drop Across Rupture Disk	=B176-B179	1.087	psi
181	Maximum Theoretical Rupture Disk Flow	=B170*B173*B175*B176*SQRT(B177/B172)*60*60	4833	lbm/hr
182	Actual Rupture Disk Flow	=B43	4281	lbm/hr
183				
184	Maximum Flow from Condensers			units
185	> Max. Flow of Liquid Nitrogen	13	13	gpm
186	Max. Flow of Liquid Nitrogen (conv.)	=B185/7.48	1.74	ft^3/min
187	Density of LN2 @ 3.5 atm	0.747	0.747	g/cc
188	Density of LN2 (conv.)	=B187*62.4	46.6128	lbm/ft^3
189	Mass Flow of LN2	=B186*B188*60	4861	lbm/hr



Simplified Cryostat Fill/Vent Arrangement

Max. Flow to ECN, 5/23/91, revised 10/17/91 John Wu

Calculation of Max. Flowrate from LAr Dewar to ECN



$d = 1.682 \text{ in} = 0.1402 \text{ ft}$ [1 1/2" SCH. 10 inner pipe dia.]

$A = 0.01543 \text{ ft}^2$ [cross-sectional area]

Reference: drawings from Tony Parker	up to cryocorner	cryocorner to CC	CC to ECN	TOTAL
# of elbows, 90°	17	4	19	40
# of elbows, 45°	1	3	1	5
# of tees, branch	3	0	0	3
# of tees, thru	0	2	0	2

Calculation of Equivalent Length

Calculate the equivalent length of the piping from the LAr dewar to the inner vessel of the ECN.

$L_{piping} = L_{1.7\text{" dia.}} + L_{1.0\text{" dia.}}$

Adjust 169 ft length to CC (ref. Kelly Dixon) to include ECN.

$L_{1.7\text{" dia.}}$ = 169 ft (length to CC) - 8.3 ft (CC drain line) + 21.7 ft (CC to rotary bayonet assembly) + 4.6 ft + 5.2 ft (rotary U-tube dimensions) + 6.1 ft + 13 ft (ECN drain line) = 211.3 ft total.

Equivalent lengths of the flowmeters are accounted for by including a 4 foot length of 1.0" diameter piping. Convert 1.0" diameter equivalent length to 1.7" dia. equivalent length:

Reference: Crane Technical Paper No. 410

(1" SCH. 40 to 1 1/2" SCH. 10)

$$L_{1.0\text{" dia.}} = \left(\frac{1.682}{1.049}\right)^5 \times 4' = 42.4'$$

L_{piping} = 211.3 ft + 42.4 ft = 253.7 ft total

Convert elbows and tees into equivalent lengths of pipe.

$L_{fittings}$ = [40(20) + 5(14) + 3(60) + 2(20)] x 0.1402 ft = 152.8 ft

L_{eq} = 253.7 ft + 152.8 ft = **406.5 ft**

Calculation of Resistance Coefficient

Reference: Crane Technical Paper No. 410

Calculate the resistance coefficient for the piping and fittings.

$$K_{\text{piping, fittings}} = f\left(\frac{L_{eq}}{d}\right)$$

let f = 0.022 [friction factor guess]

$$K_{\text{piping, fittings}} = 0.022\left(\frac{406.5\text{ ft}}{0.1402\text{ ft}}\right) = 63.79$$

Include inlet and outlet losses (ref. Kelly Dixon).

$K_{\text{inlet}} = 0.5$

$K_{\text{outlet}} = 1.0$

Calculate resistance coefficient for the valves.

$$K_{\text{valves}} = \left(\frac{29.9\,d^2}{C_v}\right)^2 \text{ x (\# of valves)} = \left(\frac{29.9\,(1.682)^2}{34}\right)^2 \text{ x } 4 = 24.76$$

where the diameter, d, is in inches, not feet.

$\Sigma K = 63.79 + 1.5 + 24.76 =$ **90.05**

Driving Pressure

Calculate the differential pressure available under relieving conditions.

max. head available = 720.3 ft (dewar @ 16,000 gallons)

- 715.2 ft (bottom of ECN)

5.1 ft (total elevation difference)

Calculate the pressure due to elevation difference.

Density of liquid argon @ 19.75 psig = 1.337 g/cc, which corresponds to a specific weight of 0.580 psi/ft.

Δp due to head = 5.1 ft x 0.580 psi/ft = 2.96 psi

$$\Delta p_{relieving} = \text{(LAr dewar pressure)} - \text{(ECN pressure)} + \text{(head pressure)}$$

$$= 34.7 \text{ psia} - 34.45 \text{ psia} + 2.96 \text{ psi} = 3.21 \text{ psid}$$

Determine the pressure drop across the cryofilter.

Actual experience shows that with a 30 gpm flow, the pressure drop across the cryofilter is 4 psid.

$$\Delta p_{filter} = \left(\frac{q}{30}\right)^2 \times 4 \text{ psid} = 0.00444\, q^2$$

where Δp_{filter} is in psid if q is in gpm.

$$\Delta p_{available} = \Delta p_{relieving} - \Delta p_{filter}$$

Calculation of Flowrate

Calculate the flowrate, q, by rearranging Darcy's formula (ref. Crane 410).

modified Darcy's formula:

$$\Delta p = \frac{\rho\,\Sigma K}{144}\,\frac{v^2}{2\,g_c}$$

where: Δp is in psid,

ρ is in lb_m/ft^3,

and v is in ft/s.

(144 is a conversion factor of in^2/ft^2.)

Rearrange to solve for the velocity, v.

$$v = \sqrt{\frac{2\,g_c(144\,\Delta p)}{\rho\,\Sigma K}} = \sqrt{\frac{2\left(32.174\,\frac{lb_m\text{-}ft}{lb_f\text{-}s^2}\right)\left(144\,\frac{in^2}{ft^2}\right)\Delta p_{available}}{\left(83.47\,\frac{lb_m}{ft^3}\right)(90.05)}}$$

$$v = 1.110\sqrt{\Delta p_{available}}$$

where v is in ft/s if $\Delta p_{available}$ is in psid.

Substitute formulas with q into both sides of the equation for v and Δp.

Substitute for v: (Let Q be the flow rate in cfs.)

$$v = \frac{Q}{A} = \frac{4Q}{\pi d^2} = \frac{4Q}{\pi(0.1402\ \text{ft})^2} = 64.78Q$$

where v is in ft/s if Q is in cfs.

Convert the equation so that v will be in ft/s if q is in gpm.

$$v = 64.78\left(q\ \frac{\text{gal}}{\text{min}} \times \frac{\text{min}}{60\ \text{sec}} \times 0.13368\ \frac{\text{ft}^3}{\text{gal}}\right) = 0.1443q$$

where v is in ft/s if q is in gpm.

Substitute for Δp:

From before, $\Delta p_{\text{available}} = \Delta p_{\text{relieving}} - \Delta p_{\text{filter}}$.

$$\Delta p_{\text{available}} = 3.21\ \text{psid} - 0.00444q^2$$

where $\Delta p_{\text{available}}$ is in psid if q is in gpm.

From before,

$$v = 1.110\sqrt{\Delta p_{\text{available}}}$$

where v is in ft/s if $\Delta p_{\text{available}}$ is in psid.

Substitute formula for $\Delta p_{\text{available}}$ to get v in terms of q.

$$v = 1.110\sqrt{3.21 - 0.00444q^2}$$

where v is in ft/s if q is in gpm.

Set the two equations for v in terms of q equal, and solve for q.

$$v = 0.1443q = 1.110\sqrt{3.21 - 0.00444q^2}$$

$$q = \sqrt{\frac{3.21}{\left(\frac{0.1443}{1.110}\right)^2 + 0.00444}}$$

$$q = \mathbf{12.26} \quad \mathbf{gpm}$$

Check Friction Factor

$$Re_{d_{relieving}} = \frac{\rho V_{rel.} d}{\mu}$$

$$\mu = 2.4185 \times 10^{-3} \frac{g}{cm\text{-}s} \text{ @sat. 1.3 bars} = 1.6252 \times 10^{-4} \frac{lb_m}{ft\text{-}s}$$

$$q_{relieving} = 12.26 \text{ gpm}$$

$$v_{rel.} = \frac{q_{relieving}}{A} = \frac{4\, q_{relieving}}{\pi\, d^2} = \frac{4\left(12.26 \text{ gpm} \times \frac{1 \text{ cfs}}{448.83 \text{ gpm}}\right)}{\pi\,(0.1402 \text{ ft})^2} = 1.769 \frac{ft}{s}$$

$$Re_{d_{relieving}} = \frac{\left(83.47 \frac{lb_m}{ft^3}\right)\left(1.769 \frac{ft}{s}\right)(0.1402 \text{ ft})}{1.6252 \times 10^{-4} \frac{lb_m}{ft\text{-}s}} = 1.274 \times 10^5$$

Assuming a value of 0.00015 roughness for commercial steel pipe, the relative roughness is 0.001, and the friction factor is 0.022, which checks.

TK Solver Plus Analysis

The following two pages are printouts of the variable and rule sheet from a TK Solver model set up to verify the hand calculations for the maximum flow rate to the ECN from the Argon dewar. The first page is the variable sheet, which shows the typed inputs and calculated outputs for various parameters. The complete solution requires guessing a number for the friction factor. The program then iterates to find the exact solution. Also note that the columns have a set width, so that not all of the entries are shown completely, specifically, g has units of lbm-ft/lbf-s^2. The second sheet is the rule sheet, which shows the various formulas used. The complete model has been saved in the Co-op Mac, under the name "TK LAD Flow to ECN".

```
St Input     Name    Output    Unit      Comment
   1.682     D                 in        inner pipe dia.
             d       .14016667 ft        inner pipe dia. (converted)
             A       .01543046 ft^2      cross-sectional area
   40        Els90                       number of 90° elbows
   5         Els45                       number of 45° elbows
   3         TeesBr                      number of tees, branch
   2         TeesTh                      number of tees, thru
   253.7     Lpiping           ft        equivalent length of 1.7" piping
             Lfittin 152.78167 ft        equivalent length of fittings
             Leq     406.48167 ft        equivalent length
             f       .02195416           friction factor (guess)
   .5        Kinlet                      inlet resistance
   1         Koutlet                     outlet resistance
             Kpiping 63.66681            resistance of piping
   34        Cv                          coeff. of valves
   4         valves                      number of valves counted
             Kvalves 24.759878           resistance of valves
             SumK    89.926688           summation of resistances
   5.1       elev              ft        max. head available
   83.47     rho               lbm/ft^3  density of argon
             SpWt    .57965278 psi/ft    specific weight of argon
             DPhead  2.9562292 psi       delta p from head
             DPrel   3.2062292 psi       delta p relieving
             DPfilte .66797323 psi       delta p from filter
             DPavail 2.5382559 psi       delta p available
             Vrel    1.7701374 ft/s      relieving velocity
             Re      127431.07           Reynold's number
   .00016252 visc              lbm/ft-s  viscosity
   .00015    e                           roughness coefficient
             rough   .00107015           relative roughness (e/d)
             pi      3.14159             pi constant
             g       32.174    lbm-ft/lb gc conversion constant
             q       12.259444 gpm       flow rate
```

```
S Rule
* pi = 3.14159     "constant for pi
* g = 32.174      "constant for gc, in units of (lbm-ft)/(lbf-s^2)
* d = D/12      "conversion of inner pipe dia. from inches to feet
* A = pi*(d^2)/4      "cross-sectional area of pipe
* Lfittings = d*(Els90*20+Els45*14+TeesBr*60+TeesTh*20)       "equivalent length
* Leq = Lpiping + Lfittings      "total equivalent length of 1.7" dia piping
* Kpiping = f*Leq/d      "resistance coeff. for piping and fittings
* Kvalves = valves*((29.9*(D^2)/Cv)^2)      "resistance of valves
* SumK = Kpiping+Kvalves+Kinlet +Koutlet      "summation of K coeff.
* SpWt = rho/144      "specific weight at correct density
* DPhead = elev * SpWt      "delta p due to max. head pressure
* DPrel = 34.7 - 34.45 + DPhead      "delta p due to elevation difference
* DPfilter = 4*((q/30)^2)      "pressure drop across cryofilter
* DPavail = DPrel - DPfilter      "available differential driving pressure
* DPavail = (rho*SumK*(Vrel^2))/(144*2*g)      "modified Darcy's formula
* Vrel = (q*.13368/60)/A      "velocity in ft/s from flow rate in gpm
* Re = rho*Vrel*d/visc      "Reynold's number for pipe flow
* rough = e/d      "relative roughness for commercial steel of 1 1/2" dia.
* 1/(f^.5) = -2.0*log((rough/3.7) + (2.51/(Re*(f^.5))))      "Moody chart
```

KD
22Jul91

ECN Equivalent Lengths of Relief / Exhaust Piping

① Relief Valve Inlet

$l_e = 38'$, $d = 0.206'$ ref: EN-263

② Rupture Disk Inlet

\# els: 8

$l_{pipe} = 51'' + 23 + 5 + 15 = 94'' = 7.8'$

$d = 0.172'$ (2" sch 40)

$l_e = 7.8' + 30(0.172) = 49'$

③ Relief Valve Outlet

\# tees (branch) : 1
\# els, 90° : 1 (mitered)
\# els, 45° : 2 (mitered)

~~lee~~ $d = 0.27'$

$l_e = 1.9' + (60 + 60 + 2(30))(0.27) = 51'$

④ Rupture Disk Outlet

$d = 0.180'$
$l_e = 1.75'$

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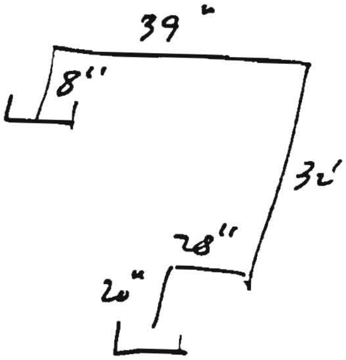
⑧ Relief Common Outlet to Platform Bayonet

d = 0.355'

length rot. bayonet spool assy

8" + 39 + 32 + 28 + 20 = 127"



l_{piping} = 24" + 127" + 62" + 2(157.5") + 38 + 10 + 40 + 67 + 210.5 + 457.5 + 74 + 16
= 1441" = 120 ft

els, 90° : 11
els, 45° : 1 (approx)
tees (thru): 2
tees (brch) : 1

l_e = 120 + 0.355(11(30) + 2(20) + 1(60))
= 120 + 153
= 273'

⑥ Platform Bayonet to Outside

d = 0.530'
l_e = 516'

Ref. EN263

Determine Worst Case Cryostat to Fill Due to Pressure

Fill capacity

Reference: ECN numbers taken from previous “Calculation of Max. Flowrate from LAr Dewar to ECN”.

$$\left(q_{\text{fill}}^{\text{ECN}}\right)_{\max} = 12.3 \text{ gpm}$$

$$\Sigma K^{\text{ECN}} = 90.05$$

$$\Sigma K^{\text{CC}} = \Sigma K^{\text{ECN}} - \frac{f(L_{eq})}{d} \cong 90.05 - \frac{(0.022)(30 \text{ ft})}{0.1402 \text{ ft}} = 85.34$$

$$\Sigma K^{\text{ECS}} = \Sigma K^{\text{CC}} - \frac{f(L_{eq})}{d} \cong 85.34 - \frac{(0.022)(27 \text{ ft})}{0.1402 \text{ ft}} = 81.10$$

The ECS has the smallest resistance coefficient because it has the shortest equivalent length of piping from the argon dewar. Therefore, the same driving pressure from the dewar will produce the largest inlet flow to the ECS. The flowrate is inversely proportional to the square root of the resistance coefficient:

$$q^{\text{cryostat}} \propto \frac{1}{\sqrt{\Sigma K^{\text{cryostat}}}}$$

Therefore, the flowrates of the ECS and ECN can be compared as follows:

$$\frac{q_{\text{fill}}^{\text{ECS}}}{q_{\text{fill}}^{\text{ECN}}} = \frac{\sqrt{\Sigma K^{\text{ECN}}}}{\sqrt{\Sigma K^{\text{ECS}}}} = \frac{\sqrt{90.05}}{\sqrt{81.10}} = 1.054$$

The maximum inlet flow to the ECS is greater than the maximum inlet flow to the ECN by about 5%. However, the ECS is not the worst case cryostat to fill because it also has a shorter equivalent length of relief piping.

Venting capacity

Reference: DØ Engineering Note 3740.224-EN-323, ECN Pressure and Vacuum Vessel Engineering Notes.

The first spreadsheet in EN-323 calculates the ECN relief flow capacity. In the section, "ΔP Across Relief Valve", line 108 shows the maximum theoretical flow through the relief valve. In the section, "ΔP Across Rupture Disk", line 181 shows the maximum theoretical flow through the rupture disk. Therefore, the total mass flow can be calculated as:

$$\rho\left(q_{rel}^{ECN}\right)_{max} = 7740\,\frac{lb_m}{hr}\,(\text{relief valve}) + 7458\,\frac{lb_m}{hr}\,(\text{rupture disk}) = 15{,}198\,\frac{lb_m}{hr}$$

Note that q here represents the flow through the relief piping, out of the ECN, whereas the q on the previous page represented the inlet fill piping, into the ECN.

The calculation of the venting capacity of the ECS is more complicated, because the numbers can not be referenced from EN-323. To calculate the ECS capacity, the ECN spreadsheet was modified for the ECS, changing the section, "ΔP Across Common Outlet to Cryocorner". Line 115 is the equivalent length of this section of piping. ECN had an equivalent length of 273 ft, which was calculated in this note (see previous K. Dixon's hand calculations, "ECN Equivalent Lengths of Relief/Exhaust Piping"). The only difference in the relief piping of the ECS is that the equivalent length of the common outlet changes to 238 ft. Using this new equivalent length, the spreadsheet was re-calculated to find the maximum theoretical flows through the relief valve and rupture disk. The following pages show the actual spreadsheet, modified for the ECS.

Maximum ECS Relief Flow Calculation 10/18/91

	A	B	C	D
1	Conversion of Liquid to Gas at Module Temp.			Units
2	> Bulk Temp. of Modules	96	96	K
3	>* Max. Liquid Equivalent Flow of Argon to Reliefs	24.9	24.9	gpm
4	> Pressure in Cryostat	19.75	19.75	psig
5	Pressure in Cryostat (conv.)	=(B4/14.696+1)*1.01325	2.375	bars
6	> lAr Density @ 2.2 bars	1.342421	1.342	g/cc
7	> lAr Density @ 2.4 bars	1.335861	1.336	g/cc
8	lAr Density @ 2.375 bars	=(B5-2.2)/0.2*(B7-B6)+B6	1.337	g/cc
9	> gAr Density @ 2.2 bars	11.77	11.77	mg/cc
10	> gAr Density @ 2.4 bars	12.75	12.75	mg/cc
11	gAr Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	12.627	mg/cc
12	gAr Density @ 2.375 bars (conv.)	=B11/1000*62.428	0.788	lbm/ft^3
13	Maximum Flow of Argon Gas	=B3*B8/B11*1000	2636	gpm
14	Maximum Flow of Argon Gas (conv.)	=B13*0.13368	352	cfm
15	Air Equivalent Flow @STP	=6.32*B17*356/B16*SQRT(B99/(520*B177*28.97))	1658	scfm air
16	Specific Heat Constant, C, for Ar	=520*SQRT(B168*(2/(B168+1))^((B168+1)/(B168-1)))	383	
17	Max. Mass Flow of Argon Gas	=B14*B12*60	16666	lbm/hr
18	*> Percent of Mass Flow to Relief Valve	0.474	0.474	
19				
20	ΔP Across Relief Valve Inlet			Units
21	> Inner Pipe Diameter	0.206	0.206	ft
22	Inner Pipe Diameter (conv.)	=B21*12	2.472	in
23	> Equivalent Length	38	38	ft
24	Ar Gas Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	12.627	mg/cc
25	Ar Gas Density @ 2.375 bars (conv.)	=B24/1000*62.428	0.788	lbm/ft^3
26	> gAr Viscosity @ 2.4 bars & Temp.	0.0000803	0.0000803	g/cm-s
27	gAr Viscosity @ 2.4 bars (conv.)	=B26*100	0.00803	centipoise
28	Max. Mass Flow to Relief Valve	=B17*B18	7900	lbm/hr
29	Reynolds Number	=6.31*B28/(B22*B27)	2510000	
30	> Relative Roughness (e/D)	0.0007	0.0007	
31	Friction Factor Guess	=0.25*(LOG(B30/3.7+5.74/(B29^0.9)))^-2	0.0183	
32	Friction Factor	=0.25*(LOG(B30/3.7+2.51/(B29*B31^0.5)))^-2	0.0182	
33	Pressure Drop	=0.00000336*B32*B23*(B28^2)/B25/(B22^5)	1.993	psi
34				

Maximum ECS Relief Flow Calculation 10/18/91

	A	B	C	D
35	ΔP Across Rupture Disk Inlet			Units
36	Inner Pipe Diameter (conv.)	=B37/12	0.172	ft
37	> Inner Pipe Diameter	2.067	2.067	in
38	> Equivalent Length	49	49	ft
39	gAr Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	12.627	mg/cc
40	gAr Density @ 2.375 bars (conv.)	=B39/1000*62.428	0.788	lbm/ft^3
41	gAr Viscosity @ 2.4 bars	=B26	0.0000803	g/cm-s
42	gAr Viscosity @ 2.4 bars (conv.)	=B41*100	0.00803	centipoise
43	Max. Mass Flow to Rupture Disk	=B17*(1-B18)	8766	lbm/hr
44	Reynolds Number	=6.31*B43/(B37*B42)	3330000	
45	> Relative Roughness (e/D)	0.0009	0.0009	
46	Friction Factor Guess	=0.25*(LOG(B45/3.7+5.74/(B44^0.9)))^-2	0.0193	
47	Friction Factor	=0.25*(LOG(B45/3.7+2.51/(B44*B46^0.5)))^-2	0.0192	
48	Pressure Drop	=0.00000336*B47*B38*(B43^2)/B40/(B37^5)	8.185	psi
51				
52	ΔP Across Relief Valve Outlet			Units
53	Inner Pipe Diameter (conv.)	=B54/12	0.272	ft
54	> Inner Pipe Diameter	3.26	3.26	in
55	> Equivalent Length	51	51	ft
56	> gAr Density @ 2.0 bar & Temp.	10.55	10.55	mg/cc
57	gAr Density @ 2.0 bar (conv.)	=B56/1000*62.428	0.659	lbm/ft^3
58	> gAr Viscosity @ 2.0 bar & Temp.	0.0000798	0.0000798	g/cm-s
59	gAr Viscosity @ 2.0 bar (conv.)	=B58*100	0.00798	centipoise
60	Max. Mass Flow to Relief Valve	=B28	7900	lbm/hr
61	Reynolds Number	=6.31*B60/(B54*B59)	1920000	
62	> Relative Roughness (e/D)	0.00055	0.00055	
63	Friction Factor Guess	=0.25*(LOG(B62/3.7+5.74/(B61^0.9)))^-2	0.0174	
64	Friction Factor	=0.25*(LOG(B62/3.7+2.51/(B61*B63^0.5)))^-2	0.0173	
65	Pressure Drop	=0.00000336*B64*B55*(B60^2)/B57/(B54^5)	0.764	psi
66				

Maximum ECS Relief Flow Calculation 10/18/91

	A	B	C	D
67	ΔP Across Rupture Disk Outlet			Units
68	Inner Pipe Diameter (conv.)	=B69/12	0.18	ft
69	> Inner Pipe Diameter	2.157	2.157	in
70	> Equivalent Length	1.75	1.75	ft
71	gAr Density @ 2.0 bar & Temp.	=B56	10.55	mg/cc
72	gAr Density @ 2.0 bar (conv.)	=B71/1000*62.428	0.659	lbm/ft^3
73	gAr Viscosity @ 2.0 bar & Temp.	=B58	0.0000798	g/cm-s
74	gAr Viscosity @ 2.0 bar (conv.)	=B73*100	0.00798	centipoise
75	Max. Mass Flow to Rupture Disk	=B43	8766	lbm/hr
76	Reynolds Number	=6.31*B75/(B69*B74)	3210000	
77	> Relative Roughness (e/D)	0.0009	0.0009	
78	Friction Factor Guess	=0.25*(LOG(B77/3.7+5.74/(B76^0.9)))^-2	0.0193	
79	Friction Factor	=0.25*(LOG(B77/3.7+2.51/(B76*B78^0.5)))^-2	0.0192	
80	Pressure Drop	=0.00000336*B79*B70*(B75^2)/B72/(B69^5)	0.283	psi
81				
82	Change in Gas at Common Outlet to Outside			Units
83	Pressure in Cryostat	=B4	19.75	psig
84	Pressure in Cryostat (conv.)	=(B83/14.696+1)*1.01325	2.375	bars
85	gAr Density @ 2.2 bars	=B9	11.77	mg/cc
86	gAr Density @ 2.4 bars	=B10	12.75	mg/cc
87	gAr Density @ 2.375 & Temp.	=(B84-2.2)/0.2*(B86-B85)+B85	12.627	mg/cc
88	Temp. at Common Outlet	=(B2*B17+84*B189)/(B17+B189)	94	K
89	> Pressure to Calculate Density	1.5	1.5	bars
90	*> gAr Density @ 1.5 bars & New Temp.	7.99	7.99	mg/cc
91	*> gAr Viscosity @ 1.5 bars & New Temp.	0.000078	0.000078	g/cm-s
92	gAr Viscosity @ 1.5 bar (conv.)	=B91*100	0.0078	centipoise
93				

Maximum ECS Relief Flow Calculation 10/18/91

	A	B	C	D
94	ΔP Across Relief Valve			Units
95	> Critical Ratio (Pcr/P1) for Argon	0.487	0.487	
96	> Specific Heat Ratio (k) for Argon	=B168	1.75	
97	> Area of 2" x 3" Relief Valve	2.29	2.29	in^2
98	Flow Through Relief Valve	=B28	7900	lbm/hr
99	Flowing Temperature	=1.8*B2	173	deg R
100	> Compressibility Factor	1	1	
101	> Nozzle Coefficient for type 93T	0.939	0.939	
102	Flowing Inlet Pressure (P1)	=B4+14.696-B33	32.45	psia
103	> Molecular Weight of Argon	39.948	39.95	g/mol
104	Critical Pressure (Pcr)	=B95*B102	15.8	psia
105	Outlet Pressure (P2) (using delta p's)	=14.696+B154+B133+B65	25.43	psia
106	Pressure Ratio (P2*/P1)	=(B102-0.55*((B102-B105)^0.98))/B102	0.885	
107	Theoretical Factor (F*) (using P2)	=SQRT((B96/(B96-1))*(B106^(2/B96)-B106^((B96+1)/B96)))	0.321	
108	Max. Theoretical Relief Flow (using F*)	=735*B97*B101*B102*B107*SQRT(B103/B99/B100)	7918	lbm/hr
109	Theoretical Percent of Relief Flow	=B108/B17	0.4751	
110	Pressure Drop Across Relief Valve	=B102-B105	7.026	psi
111				

Maximum ECS Relief Flow Calculation 10/18/91

	A	B	C	D
112	ΔP Across Common Outlet to Cryocorner			Units
113	> Inner Pipe Diameter	0.355	0.355	ft
114	Inner Pipe Diameter (conv.)	=B113*12	4.26	in
115	> Equivalent Length	238	238	ft
116	gAr Density @ 1.5 bar & New Temp.	=B90	7.99	mg/cc
117	gAr Density @ 1.5 bar (conv.)	=B116/1000*62.428	0.499	lbm/ft^3
118	*> gN2 Gas Density @ 1.5 bar & New Temp.	5.653	5.653	mg/cc
119	gN2 Gas Density @ 1.5 bar (conv.)	=B118/1000*62.428	0.353	lbm/ft^3
120	Gas Mixture Density @1.5 bar	=(B17*B117+B127*B119)/B128	0.474	lbm/ft^3
121	gAr Viscosity @ 1.5 bar & New Temp.	=B91	0.000078	g/cm-s
122	gAr Viscosity @ 1.5 bar (conv.)	=B121*100	0.0078	centipoise
123	*> gN2 Viscosity @ 1.5 bar & New Temp.	0.0000643	0.0000643	g/cm-s
124	gN2 Viscosity @ 1.5 bar (conv.)	=B123*100	0.00643	centipoise
125	Mixture Viscosity @1.5 bar	=(B17*B122+B127*B124)/B128	0.007563	centipoise
126	Max. Mass Flow of Argon Gas	=B17	16666	lbm/hr
127	Max. Flow of Nitrogen Gas	=B189	3477	lbm/hr
128	Mass Flow of Mixture	=B126+B127	20143	lbm/hr
129	Reynolds Number	=6.31*B128/(B114*B125)	3940000	
130	> Relative Roughness (e/D)	0.0004	0.0004	
131	Friction Factor Guess	=0.25*(LOG(B130/3.7+5.74/(B129^0.9)))^-2	0.0161	
132	Friction Factor	=0.25*(LOG(B130/3.7+2.51/(B129*B131^0.5)))^-2	0.0161	
133	Pressure Drop	=0.00000336*B132*B115*(B128^2)/B120/(B114^5)	7.838	psi
134				

Maximum ECS Relief Flow Calculation 10/18/91

	A	B	C	D
135	ΔP from Cryocorner to Outside			Units
136	> Inner Pipe Diameter	0.53	0.53	ft
137	Inner Pipe Diameter (conv.)	=B136*12	6.36	in
138	> Equivalent Length	516	516	ft
139	gAr Gas Density @ 1.5 bar & New Temp.	=B90	7.99	mg/cc
140	gAr Gas Density @ 1.5 bar (conv.)	=B139/1000*62.428	0.499	lbm/ft^3
141	gN2 Gas Density @ 1.5 bar & New Temp.	=B118	5.653	mg/cc
142	gN2 Gas Density @ 1.5 bar (conv.)	=B141/1000*62.428	0.353	lbm/ft^3
143	Gas Mixture Density @1.5 bar	=(B17*B140+B189*B142)/B149	0.474	lbm/ft^3
144	gAr Viscosity @ 1.5 bar & New Temp.	=B121	0.000078	g/cm-s
145	gAr Viscosity @ 1.5 bar (conv.)	=B144*100	0.0078	centipoise
146	gN2 Viscosity @ 1.5 bar & New Temp.	=B123	0.0000643	g/cm-s
147	gN2 Viscosity @ 1.5 bar (conv.)	=B146*100	0.00643	centipoise
148	Gas Mixture Viscosity @1.5 bar	=(B17*B145+B189*B147)/B149	0.007563	centipoise
149	Max. Mass Flow of Gas Mixture	=B128	20143	lbm/hr
150	Reynolds Number	=6.31*B149/(B137*B148)	2640000	
151	> Relative Roughness (e/D)	0.00027	0.00027	
152	Friction Factor Guess	=0.25*(LOG(B151/3.7+5.74/(B150^0.9)))^-2	0.015	
153	Friction Factor	=0.25*(LOG(B151/3.7+2.51/(B150*B152^0.5)))^-2	0.0149	
154	Pressure Drop	=0.00000336*B153*B138*(B149^2)/B143/(B137^5)	2.13	psi
155				
156	Summation of Equivalent ΔPs			Units
157	Relief Valve Inlet Pressure Drop	=B33	1.993	psi
158	Relief Valve Outlet Pressure Drop	=B65	0.764	psi
159	Relief Valve Pressure Drop	=B110	7.026	psi
160	Relief Valve/Disk Branch	=B33+B65+B110	9.782	psi
161	Rupture Disk Inlet Pressure Drop	=B48	8.185	psi
162	Rupture Disk Outlet Pressure Drop	=B80	0.283	psi
163	Rupture Disk Pressure Drop	=B157+B158+B159-B161-B162	1.313	psi
164	Common Outlet Pressure Drop	=B133	7.838	psi
165	Cryocorner to Outside Pressure Drop	=B154	2.13	psi
166				

Maximum ECS Relief Flow Calculation 10/18/91

	A	B	C	D
167	ΔP Across Rupture Disk			Units
168	>Argon Specific Heat Ratio (k)	1.745	1.745	
169	Critical Ratio	=(2/(B168+1))^(B168/(B168-1))	0.476	
170	> Area of 3" Rupture Disk	=3.14159*(3^2)/4	7.069	in^2
171	Flow Through Rupture Disk	=B43	8766	lbm/hr
172	Flowing Temperature	=1.8*B2	173	deg R
173	> ASME Coefficient (K)	0.62	0.62	
174	Pressure Ratio (Pe/Po)	=B179/B176	0.95	
175	gAr Flow Constant for Subsonic Flow(C1)	=SQRT(2*32.2/1545*(B168/(B168-1))*(B174^(2/B168)-B17	0.045	
176	Flowing Inlet Pressure (Po)	=B4+14.696-B48	26.26	psia
177	> Molecular Weight of Argon	39.948	39.948	g/mol
178	Critical Pressure (Pcr)	=B169*B176	12.51	psia
179	Outlet Pressure (Pe) (using delta p's)	=14.696+B154+B133+B80	24.95	psia
180	Pressure Drop Across Rupture Disk	=B176-B179	1.313	psi
181	Maximum Theoretical Rupture Disk Flow	=B170*B173*B175*B176*SQRT(B177/B172)*60*60	8897	lbm/hr
182	Actual Rupture Disk Flow	=B43	8766	lbm/hr
183				
184	Maximum Flow from Condensers			units
185	> Max. Flow of Liquid Nitrogen	9.3	9.3	gpm
186	Max. Flow of Liquid Nitrogen (conv.)	=B185/7.48	1.24	ft^3/min
187	Density of LN2 @ 3.5 atm	0.747	0.747	g/cc
188	Density of LN2 (conv.)	=B187*62.4	46.6128	lbm/ft^3
189	Mass Flow of LN2	=B186*B188*60	3477	lbm/hr
190				
191	**Notes:**			
192	*> indicates that this value must be changed for a			
193	new flowrate			
194				
195	> indicates variable not requiring change for new			
196	flowrates			
197				
198	(conv.) indicates the previous value converted to new			
199	units			

As with the ECN, the total mass flow for the ECS can be calculated from line 108 for the maximum relief valve flow, and line 181 for the maximum rupture disk flow:

$$\rho\left(q_{rel}^{ECS}\right)_{max} = 7918\,\frac{lb_m}{hr}\text{(relief valve)} + 8897\,\frac{lb_m}{hr}\text{(rupture disk)} = 16{,}815\,\frac{lb_m}{hr}$$

Now the ECN and ECS relief piping flowrates can be compared:

$$\frac{q_{rel}^{ECS}}{q_{rel}^{ECN}} = \frac{\rho q_{rel}^{ECS}}{\rho q_{rel}^{ECN}} = \frac{16{,}815\,\frac{lb_m}{hr}}{15{,}198\,\frac{lb_m}{hr}} = 1.106$$

The maximum relief outlet flow from the ECS is greater than the maximum relief outlet flow from the ECN by about 10%.

Conclusion

Since the flowrate <u>out</u> of the ECS relative to the flowrate <u>out</u> of the ECN (1.106 times ECN) is greater than the flowrate <u>into</u> the ECS relative to the flowrate <u>into</u> the ECN (1.054 times ECN), the ECN is the flowrate limiting vessel.

Relief Valve Capacity for Filling ECN at Maximum Operating Temperature

Although the maximum temperature calculated by this engineering note is 290 K, the spreadsheet requires flow through both the relief valve and the rupture disk. Although this situation satifies safety conditions regarding the overpressurization of the vessel, in reality, the operating procedures should limit the temperature to a much lower value, to prevent the rupture disk from bursting. This section calculates the temperature at which the maximum flow from the argon dewar requires only the relief valve, and not the rupture disk.

The procedure is the same as before, so the same spreadsheet is used. The only difference is that in the section, "Conversion of Liquid to Gas at Module Temp.", line 18 is not guessed through iteration, but is set initially to 100%. This forces all of the flow through the relief valve, and all of the sections related to the rupture disk, including the pressure drops before and after the rupture disk, are essentially excluded from the calculation. Rather than physically remove these sections, they remain in the spreadsheet, but have no effect on the temperature. The bulk temperature is guessed as before, and iterations proceed, changing the various gas properties of argon and nitrogen each time, until a suitable temperature is found. The conclusion was that with a maximum flow of 12.3 gpm, as calculated previously, the maximum module temperature at which only the relief valve is required is at least 110 K. Note that the theoretical percent of relief flow (line 109) is greater than 100%, indicating that the relief capacity is above the inlet flow. This can be verified by comparing line 98 (actual flow) and line 108 (maximum theoretical flow).

Maximum Module Temperature - Lar Dewar to ECN - Relief Valve Only 10/18/91

	A	B	C	D
1	Conversion of Liquid to Gas at Module Temp.			Units
2	*> Bulk Temp. of Modules	110	110	K
3	> Max. Flow of Liquid Argon to Cryostat	12.3	12.3	gpm
4	> Pressure in Cryostat	19.75	19.75	psig
5	Pressure in Cryostat (conv.)	=(B4/14.696+1)*1.01325	2.375	bars
6	> lAr Density @ 2.2 bars	1.342421	1.34	g/cc
7	> lAr Density @ 2.4 bars	1.335861	1.34	g/cc
8	lAr Density @ 2.375 bars	=(B5-2.2)/0.2*(B7-B6)+B6	1.337	g/cc
9	*> gAr Density @ 2.2 bars	9.979	9.979	mg/cc
10	*> gAr Density @ 2.4 bars	10.922	10.922	mg/cc
11	gAr Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	10.804	mg/cc
12	gAr Density @ 2.375 bars (conv.)	=B11/1000*62.428	0.674	lbm/ft^3
13	Maximum Flow of Argon Gas	=B3*B8/B11*1000	1522	gpm
14	Maximum Flow of Argon Gas (conv.)	=B13*0.13368	203	cfm
15	Air Equivalent Flow @STP	=6.32*B17*356/B16*SQRT(B99/(520*B177*28.97))	881	scfm air
16	Specific Heat Constant, C, for Ar	=520*SQRT(B168*(2/(B168+1))^((B168+1)/(B168-1)))	381	
17	Max. Mass Flow of Argon Gas	=B14*B12*60	8232	lbm/hr
18	*> Percent of Mass Flow to Relief Valve	1	1	
19				
20	ΔP Across Relief Valve Inlet			Units
21	> Inner Pipe Diameter	0.206	0.206	ft
22	Inner Pipe Diameter (conv.)	=B21*12	2.472	in
23	> Equivalent Length	38	38	ft
24	Ar Gas Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	10.804	mg/cc
25	Ar Gas Density @ 2.375 bars (conv.)	=B24/1000*62.428	0.674	lbm/ft^3
26	*> gAr Viscosity @ 2.4 bars & Temp.	0.0000909	0.0000909	g/cm-s
27	gAr Viscosity @ 2.4 bars (conv.)	=B26*100	0.00909	centipoise
28	Max. Mass Flow to Relief Valve	=B17*B18	8232	lbm/hr
29	Reynolds Number	=6.31*B28/(B22*B27)	2310000	
30	> Relative Roughness (e/D)	0.0007	0.0007	
31	Friction Factor Guess	=0.25*(LOG(B30/3.7+5.74/(B29^0.9)))^-2	0.0183	
32	Friction Factor	=0.25*(LOG(B30/3.7+2.51/(B29*B31^0.5)))^-2	0.0182	
33	Pressure Drop	=0.00000336*B32*B23*(B28^2)/B25/(B22^5)	2.531	psi
34				

Maximum Module Temperature - Lar Dewar to ECN - Relief Valve Only 10/18/91

	A	B	C	D
35	ΔP Across Rupture Disk Inlet			Units
36	Inner Pipe Diameter (conv.)	=B37/12	0.172	ft
37	> Inner Pipe Diameter	2.067	2.067	in
38	> Equivalent Length	49	49	ft
39	gAr Density @ 2.375 & Temp.	=(B5-2.2)/0.2*(B10-B9)+B9	10.804	mg/cc
40	gAr Density @ 2.375 bars (conv.)	=B39/1000*62.428	0.674	lbm/ft^3
41	gAr Viscosity @ 2.4 bars	=B26	0.0000909	g/cm-s
42	gAr Viscosity @ 2.4 bars (conv.)	=B41*100	0.00909	centipoise
43	Max. Mass Flow to Rupture Disk	=B17*(1-B18)	0	lbm/hr
44	Reynolds Number	=6.31*B43/(B37*B42)	0	
45	> Relative Roughness (e/D)	0.0009	0.0009	
46	Friction Factor Guess	0	0	
47	Friction Factor	0	0	
48	Pressure Drop	0	0	psi
51				
52	ΔP Across Relief Valve Outlet			Units
53	Inner Pipe Diameter (conv.)	=B54/12	0.272	ft
54	> Inner Pipe Diameter	3.26	3.26	in
55	> Equivalent Length	51	51	ft
56	*> gAr Density @ 2.0 bar & Temp.	9.04	9.04	mg/cc
57	gAr Density @ 2.0 bar (conv.)	=B56/1000*62.428	0.564	lbm/ft^3
58	*> gAr Viscosity @ 2.0 bar & Temp.	0.0000907	0.0000907	g/cm-s
59	gAr Viscosity @ 2.0 bar (conv.)	=B58*100	0.00907	centipoise
60	Max. Mass Flow to Relief Valve	=B28	8232	lbm/hr
61	Reynolds Number	=6.31*B60/(B54*B59)	1760000	
62	> Relative Roughness (e/D)	0.00055	0.00055	
63	Friction Factor Guess	=0.25*(LOG(B62/3.7+5.74/(B61^0.9)))^-2	0.0174	
64	Friction Factor	=0.25*(LOG(B62/3.7+2.51/(B61*B63^0.5)))^-2	0.0173	
65	Pressure Drop	=0.00000336*B64*B55*(B60^2)/B57/(B54^5)	0.969	psi
66				

Maximum Module Temperature - Lar Dewar to ECN - Relief Valve Only 10/18/91

	A	B	C	D
67	ΔP Across Rupture Disk Outlet			Units
68	Inner Pipe Diameter (conv.)	=B69/12	0.18	ft
69	> Inner Pipe Diameter	2.157	2.157	in
70	> Equivalent Length	1.75	1.75	ft
71	gAr Density @ 2.0 bar & Temp.	=B56	9.04	mg/cc
72	gAr Density @ 2.0 bar (conv.)	=B71/1000*62.428	0.564	lbm/ft^3
73	gAr Viscosity @ 2.0 bar & Temp.	=B58	0.0000907	g/cm-s
74	gAr Viscosity @ 2.0 bar (conv.)	=B73*100	0.00907	centipoise
75	Max. Mass Flow to Rupture Disk	=B43	0	lbm/hr
76	Reynolds Number	=6.31*B75/(B69*B74)	0	
77	> Relative Roughness (e/D)	0.0009	0.0009	
78	Friction Factor Guess	0	0	
79	Friction Factor	0	0	
80	Pressure Drop	0	0	psi
81				
82	Change in Gas at Common Outlet to Outside			Units
83	Pressure in Cryostat	=B4	19.75	psig
84	Pressure in Cryostat (conv.)	=(B83/14.696+1)*1.01325	2.375	bars
85	gAr Density @ 2.2 bars	=B9	9.979	mg/cc
86	gAr Density @ 2.4 bars	=B10	10.922	mg/cc
87	gAr Density @ 2.375 & Temp.	=(B84-2.2)/0.2*(B86-B85)+B85	10.804	mg/cc
88	Temp. at Common Outlet	=(B2*B17+84*B189)/(B17+B189)	100	K
89	> Pressure to Calculate Density	1.5	1.5	bars
90	*> gAr Density @ 1.5 bars & New Temp.	7.458	7.458	mg/cc
91	*> gAr Viscosity @ 1.5 bars & New Temp.	0.0000826	0.0000826	g/cm-s
92	gAr Viscosity @ 1.5 bar (conv.)	=B91*100	0.00826	centipoise
93				

	A	B	C	D
94	ΔP Across Relief Valve			Units
95	> Critical Ratio (Pcr/P1) for Argon	0.487	0.487	
96	> Specific Heat Ratio (k) for Argon	=B168	1.72	
97	> Area of 2" x 3" Relief Valve	2.29	2.29	in^2
98	Flow Through Relief Valve	=B28	8232	lbm/hr
99	Flowing Temperature	=1.8*B2	198	deg R
100	> Compressibility Factor	1	1	
101	> Nozzle Coefficient for type 93T	0.939	0.939	
102	Flowing Inlet Pressure (P1)	=B4+14.696-B33	31.91	psia
103	> Molecular Weight of Argon	39.948	39.95	g/mol
104	Critical Pressure (Pcr)	=B95*B102	15.54	psia
105	Outlet Pressure (P2) (using delta p's)	=14.696+B154+B133+B65	21.22	psia
106	Pressure Ratio (P2*/P1)	=(B102-0.55*((B102-B105)^0.98))/B102	0.824	
107	Theoretical Factor (F*) (using P2)	=SQRT((B96/(B96-1))*(B106^(2/B96)-B106^((B96+1)/B96)))	0.385	
108	Max. Theoretical Relief Flow (using F*)	=735*B97*B101*B102*B107*SQRT(B103/B99/B100)	8723	lbm/hr
109	Theoretical Percent of Relief Flow	=B108/B17	1.0596	
110	Pressure Drop Across Relief Valve	=B102-B105	10.69	psi
111				

Maximum Module Temperature - Lar Dewar to ECN - Relief Valve Only 10/18/91

	A	B	C	D
112	ΔP Across Common Outlet to Platform Bayonet			Units
113	> Inner Pipe Diameter	0.355	0.355	ft
114	Inner Pipe Diameter (conv.)	=B113*12	4.26	in
115	> Equivalent Length	273	273	ft
116	gAr Density @ 1.5 bar & New Temp.	=B90	7.458	mg/cc
117	gAr Density @ 1.5 bar (conv.)	=B116/1000*62.428	0.466	lbm/ft^3
118	*> gN2 Gas Density @ 1.5 bar & New Temp.	4.76381	4.764	mg/cc
119	gN2 Gas Density @ 1.5 bar (conv.)	=B118/1000*62.428	0.297	lbm/ft^3
120	Gas Mixture Density @1.5 bar	=(B17*B117+B127*B119)/B128	0.403	lbm/ft^3
121	gAr Viscosity @ 1.5 bar & New Temp.	=B91	0.0000826	g/cm-s
122	gAr Viscosity @ 1.5 bar (conv.)	=B121*100	0.00826	centipoise
123	*> gN2 Viscosity @ 1.5 bar & New Temp.	0.00007488	0.00007488	g/cm-s
124	gN2 Viscosity @ 1.5 bar (conv.)	=B123*100	0.007488	centipoise
125	Mixture Viscosity @1.5 bar	=(B17*B122+B127*B124)/B128	0.007973	centipoise
126	Max. Mass Flow of Argon Gas	=B17	8232	lbm/hr
127	Max. Flow of Nitrogen Gas	=B189	4861	lbm/hr
128	Mass Flow of Mixture	=B126+B127	13093	lbm/hr
129	Reynolds Number	=6.31*B128/(B114*B125)	2430000	
130	> Relative Roughness (e/D)	0.0004	0.0004	
131	Friction Factor Guess	=0.25*(LOG(B130/3.7+5.74/(B129^0.9)))^-2	0.0162	
132	Friction Factor	=0.25*(LOG(B130/3.7+2.51/(B129*B131^0.5)))^-2	0.0161	
133	Pressure Drop	=0.00000336*B132*B115*(B128^2)/B120/(B114^5)	4.489	psi
134				

	A	B	C	D
135	ΔP from Platform Bayonet to Outside			Units
136	> Inner Pipe Diameter	0.53	0.53	ft
137	Inner Pipe Diameter (conv.)	=B136*12	6.36	in
138	> Equivalent Length	516	516	ft
139	gAr Gas Density @ 1.5 bar & New Temp.	=B90	7.458	mg/cc
140	gAr Gas Density @ 1.5 bar (conv.)	=B139/1000*62.428	0.466	lbm/ft^3
141	gN2 Gas Density @ 1.5 bar & New Temp.	=B118	4.764	mg/cc
142	gN2 Gas Density @ 1.5 bar (conv.)	=B141/1000*62.428	0.297	lbm/ft^3
143	Gas Mixture Density @1.5 bar	=(B17*B140+B189*B142)/B149	0.403	lbm/ft^3
144	gAr Viscosity @ 1.5 bar & New Temp.	=B121	0.0000826	g/cm-s
145	gAr Viscosity @ 1.5 bar (conv.)	=B144*100	0.00826	centipoise
146	gN2 Viscosity @ 1.5 bar & New Temp.	=B123	0.00007488	g/cm-s
147	gN2 Viscosity @ 1.5 bar (conv.)	=B146*100	0.007488	centipoise
148	Gas Mixture Viscosity @1.5 bar	=(B17*B145+B189*B147)/B149	0.007973	centipoise
149	Max. Mass Flow of Gas Mixture	=B128	13093	lbm/hr
150	Reynolds Number	=6.31*B149/(B137*B148)	1630000	
151	> Relative Roughness (e/D)	0.00027	0.00027	
152	Friction Factor Guess	=0.25*(LOG(B151/3.7+5.74/(B150^0.9)))^-2	0.0152	
153	Friction Factor	=0.25*(LOG(B151/3.7+2.51/(B150*B152^0.5)))^-2	0.0151	
154	Pressure Drop	=0.00000336*B153*B138*(B149^2)/B143/(B137^5)	1.07	psi
155				
156	Summation of Equivalent ΔPs			Units
157	Relief Valve Inlet Pressure Drop	=B33	2.531	psi
158	Relief Valve Outlet Pressure Drop	=B65	0.969	psi
159	Relief Valve Pressure Drop	=19.75-B157-(B165+B164+B158)	10.69	psi
160	Relief Valve/Disk Branch	=B33+B65+B110	14.19	psi
161	Rupture Disk Inlet Pressure Drop	=B48	0	psi
162	Rupture Disk Outlet Pressure Drop	=B80	0	psi
163	Rupture Disk Pressure Drop	0	0	psi
164	Common Outlet Pressure Drop	=B133	4.489	psi
165	Platform to Outside Pressure Drop	=B154	1.07	psi
166				

Maximum Module Temperature - Lar Dewar to ECN - Relief Valve Only 10/18/91

	A	B	C	D
167	ΔP Across Rupture Disk			Units
168	'>Argon Specific Heat Ratio (k)	1.7186	1.7186	
169	Critical Ratio	=(2/(B168+1))^(B168/(B168-1))	0.48	
170	> Area of 3" Rupture Disk	=3.14159*(3^2)/4	7.069	in^2
171	Flow Through Rupture Disk	=B43	0	lbm/hr
172	Flowing Temperature	=1.8*B2	198	deg R
173	> ASME Coefficient (K)	0.62	0.62	
174	Pressure Ratio (Pe/Po)	=B179/B176	0.588	
175	gAr Flow Constant for Subsonic Flow(C1)	=SQRT(2*32.2/1545*(B168/(B168-1))*(B174^(2/B168)-B174	0.103	
176	Flowing Inlet Pressure (Po)	=B4+14.696-B48	34.45	psia
177	> Molecular Weight of Argon	39.948	39.948	g/mol
178	Critical Pressure (Pcr)	=B169*B176	16.53	psia
179	Outlet Pressure (Pe) (using delta p's)	=14.696+B154+B133+B80	20.26	psia
180	Pressure Drop Across Rupture Disk	0	0	psi
181	Maximum Theoretical Rupture Disk Flow	=B170*B173*B175*B176*SQRT(B177/B172)*60*60	25250	lbm/hr
182	Actual Rupture Disk Flow	=B43	0	lbm/hr
183				
184	Maximum Flow from Condensers			units
185	> Max. Flow of Liquid Nitrogen	13	13	gpm
186	Max. Flow of Liquid Nitrogen (conv.)	=B185/7.48	1.74	ft^3/min
187	Density of LN2 @ 3.5 atm	0.747	0.747	g/cc
188	Density of LN2 (conv.)	=B187*62.4	46.6128	lbm/ft^3
189	Mass Flow of LN2	=B186*B188*60	4861	lbm/hr