Muon Cryosystem Design Note #13

SUBSYSTEM: ☐ CCM ☐ CVM ☒ Cryoplant

TITLE: CDM Built 400 Liter Liquid Helium Dewar

AUTHOR: R.I. Dachniwskyj MD

DATE: March 3, 1986

Objective of Note

To catalog the engineering calculations done by CDM Machining and Fabrication Corporation for the inner and outer vessels of the 400 liter liquid helium dewar.

Discussion

The CDM engineering calculations can be found in Appendix A.

The following are comments on the appropriateness of the calculations done by CDM:

1) I feel that when a flange calculation is done the thickness (t) used in the stress calculations should be the flange thickness minus the depth of the o-ring groove. There is nothing in the Pressure Vessel Code, Section VIII, Division 1, that I could find that would corroborate my opinion. Flange calculations are shown on pages 7, 8, 9, 10 and 11 of Appendix A.

2) The stress calculation done for the junction between the inner vessel head and neck takes into account only the stress seen by the head not the neck. The equation

$$t = t_o \, e^{-nx^2/6}$$

is incorrectly applied to determine the t that should be used in the following stress equation $\sigma = 6m/t^2$. The equation for thickness should only be used to determine the coefficient n that would duplicate the thickness profile of an existing head. Then from tables and graphs the stress can be found. The secondary bending stress seen by the neck is $(60)(90.3) / (0.109)^2 = 45{,}602$ psi. The allowable secondary bending stress per Division II is $(3)(18.8 \times 10^3) = 56{,}400$ psi. The tensile load on the neck is $597/(\pi \times 8.625 \times 0.109) = 202$ psi. The longitudinal stress due to internal pressure $= (250)(4.31) / (0.109)(2) = 4{,}943$ psi. The total longitudinal stress experienced by the neck is $45{,}602 + 202 + 4{,}943 = 50{,}747$ psi which is lower then the allowable stress of 56,400 psi.

3) The welding detail given for the attachment of the flat head to the doubler ring using an unsupported fillet will in all probability adequately hold the vacuum vessel together, but a full penetration weld or a double fillet weld would definitely increase the durability of the dewar.

4) The typed information on the CDM design analysis sheets, Appendix A, are corrections that were needed to be done to bring CDM's analysis to complete agreement with the ASME Pressure Vessel Code, Section VIII, Division 1.

Conclusion

1) The design of the flange for the inner helium vessel abides by the rules given in the Pressure Vessel Code, Section VIII, Division 1.

2) The stress in the neck would be reduced if the neck were made thicker at it's base. Since the secondary moment dies off exponentially the height of thickened base therefore would only need to be a few inches. The current design by CDM is adequate.

3) All the welding details given for the inner vessel are per ASME Pressure Vessel Code, Section VIII, Division 1.

4) All the welds for the vacuum jacket including flat head to doubler ring are adequate.

5) Any future dewars that are procured should be specified to have full penetration welds for all the welds in the vacuum jacket.

Reviewed By

Robert 4/8/82

Name Date

# DESIGN ANALYSIS

Client Fermi Lab Job No. A762

Subject Muon Storage Dewar (Inner Shell) Date 1-11-86 By RW

Per ASME Sect. VIII, Div 1, 1983 Ed. Checked By

Location Summer Addendum Revised 1-29-86 By RW

Design Press. Inner Shell = 100 PSID × 2.5 = 250 PSID internal
= 15 PSID × 2.5 = 37.5 PSID external
(Per UHA-51 (b) No Charpy Impact Tests Req'd.

Design Temp. Inner Shell = -452 °F

Design Press Top Flange = 100 PSID
Design Temp. Top Flange = 70 °F

I) Shell : 3/8 Pl., A240, 304 S.S., 36 O.D.

A) Internal Press: UG-27(c)(1)(1)

$P = SEt/R + 0.6t$
$= (18800)(0.7)(.375)/17.625 + 0.6(.375)$
$= 276.47$ PSI Acceptable

B) External Press: UG-28(c)

L = 20.158 in. $L/D_o = .572$ $D_o/t = 96$
A = .0027 B = 12300

$P_a = 4B/3(D_o/t)$
$= 4(12300)/3(96)$
$= 170.83$ PSI Acceptable

II) Heads : 3/8 Pl., A240, 304 S.S., 36 O.D. Brighton 80:10
E = .80 (Per UW-12(c)

A) Internal Press: Appendix 1(d)(3)

$t = PLM/2SE - 0.2P$
$= (250)(28.8)(1.46)/2(18800)(.8) - 0.2(250)$
$= .350$ Acceptable

$L/r = 7.68$

# DESIGN ANALYSIS

Client: Fermi Lab — Job No. A762

Subject: Muon Storage Dewar (Inner Shell) — Date 1-11-86 By RJ

Checked — By

Location — Revised 2-10-86 By RJ

B) External Press: UG-33 (Use t = .350 to see if t for internal press. is acceptable here)

$R_o = K_o D_o$
$= (.97)(36)$
$= 34.92$

$K_o = .97$

$D_o = 36$

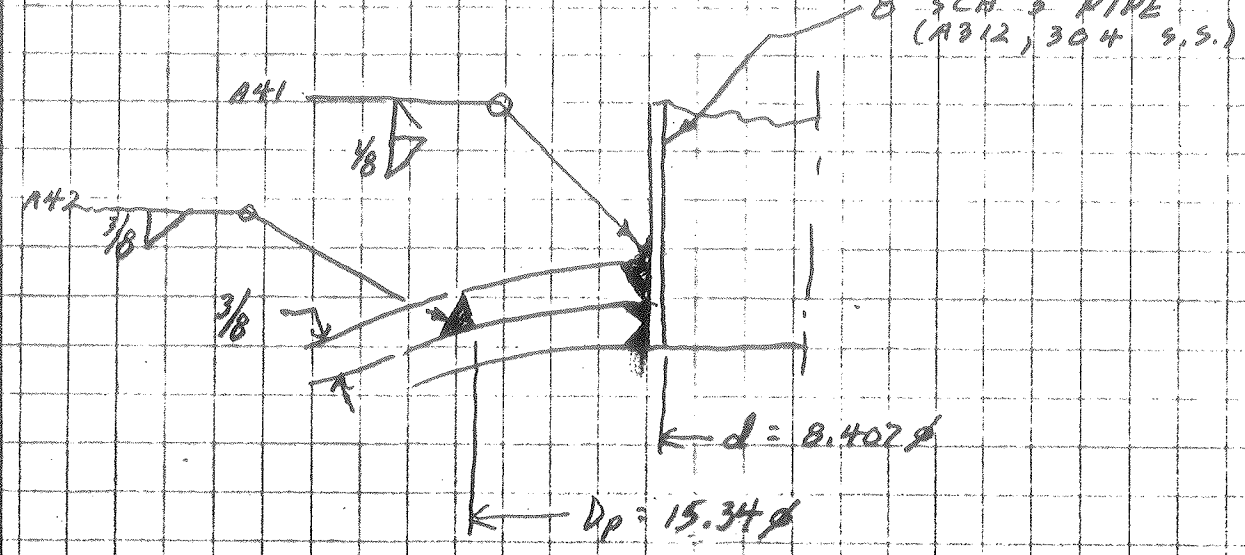
$D_o/2h_o = 36/2(8.3125)$
$= 2.165$

$A = 0.125/R_o/t$
$= 0.125/(34.92/.350)$
$= .0012$

$B = 9500$

$P_a = B/(R_o/t)$
$= 9500/(34.92/.350)$
$= 95.22$ PSI — Acceptable

C) Reinforcement Reqd. (UG-37)




$A = d t_r F$
$= (8.407)(.350)(1)$
$= 2.942$ in²

# DESIGN ANALYSIS

Client Fermi Lab Job No. A762

Subject Muon Storage Dewar (Inner Shell) Date 1-11-86 By RJ

Checked By

Location Revised 2-10-86 By RJ

$A_1 = (E_1 t - F t_r) d$
$= (.375 - .350)\, 8.407$
$= .210 \text{ in}^2$

$a = 2(E_1 t - F t_r)(t + t_n)$
$= 2(.375 - .350)(.375 + .066)$
$= .022 \text{ in}^2$

$A_2 = (t_n - t_{rn})\, 5t$
$= (.109 - .066)(5)(.375)$
$= .081 \text{ in}^2$

$a = (t_n - t_{rn})(5t_n + 2t_c)$
$= (.109 - .066)(5 \times .109 + 2 \times .375)$
$= .056 \text{ in}^2$

$A_{41} = .125^2 (1)$
$= .016 \text{ in}^2$

$A_{42} = .375^2 (1)$
$= .141 \text{ in}^2$

$f_{r1} = 16000 / (18800)(.8)$
$= 1.063 \rightarrow 1.0$

$A_1 + A_2 + A_{41} + A_{42} = .423 \text{ in}^2$

Req'd. Reinforcement $(A_r) = 2.942 - .423$
$= 2.519 \text{ in}^2$

$2.519 \overset{(A_r)}{=} (D_p - 8.625)(.375)$
$D_p = 2.519 / .375 + 8.625$
$= 15.34$ in. Dia

Use 3/8 Plate 15 3/8 O.D.

III) Neck : 8 SCH 5 Pipe, A312, 304 S.S., WLD. (W.T. = .109 in.)

A) Internal Press: UG-27(c)(1)(1)

$t = PR / SE - 0.6P$
$= 250(4.204) / (16000) - 0.6(250)$
$= .066$ in Acceptable

SE = 16000 per UG-31

# DESIGN ANALYSIS

Client Fermi Lab Job No. A762

Subject Muon Storage Dewar (Inner Shell) Date 1-11-86 By RW

Checked By

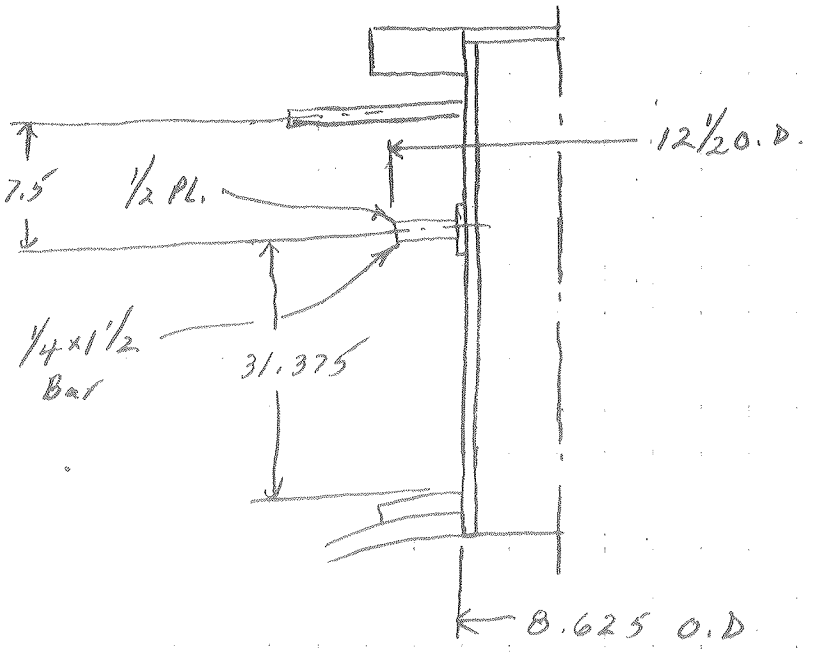
Location Revised 1-29-86 By RW

B) External Press: UG-28(c)

$t = .066$ in

$L = 31.375$ $L/D_o = 3.638$ $D_o/t = 130.682$

$A = .00029$ $B = 4050$




1) $P_a = \frac{4B}{3(D_o/t)}$

$= \frac{4(4050)}{3(130.682)}$

$= 41.322$ PSI Acceptable

2) Check if stiffener is adequate

Contribution of shell to stiffener

$= 1.10\sqrt{D_o t}$

$= 1.10\sqrt{8.625(.066)}$

$= .830$ in.

# DESIGN ANALYSIS

Client Fermi Lab Job No. A762

Subject Muon Storage Dewar (Inner Shell) Date 1-11-86 By R.W

Checked By

Location Revised 1-29-86 By R.W

$$B = 3/4\left(PD_o/t + A_s/L_s\right)$$

$$= 3/4\left((37.5)(8.625)/.066 + (1.219/19.438)\right)$$

$$= 1884.66$$ falls below left end of mat'l/temp line

$$A = 2B/E$$

$$= 2(1894.66)/28\times10^6$$

$$= .00013$$

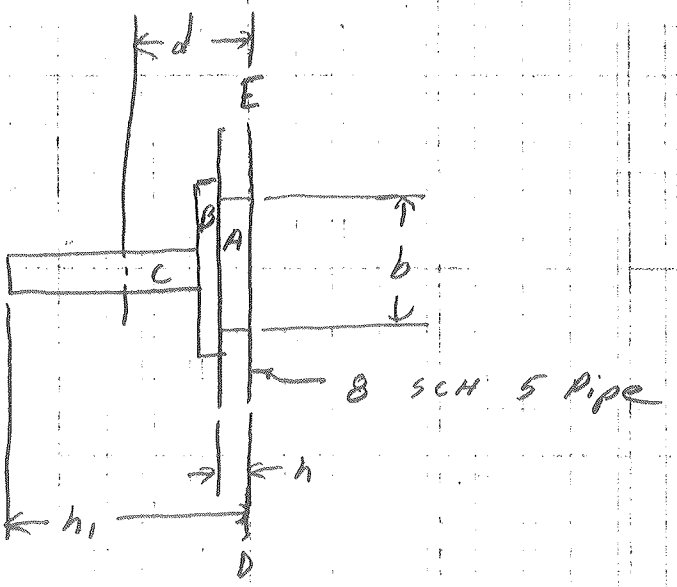
$$I_s' = D_o^2 L_s (t + A_s/L_s) A / 10.9$$

$$= (8.625^2)(19.438)[.066 + (1.219/19.438)](.00013)/10.9$$

$$= .0022 \text{ in}^4$$

Combined I of shell and stiffening ring In from sheet 6 = .507 in$^4$

Acceptable




| Sect. | b | $h_1$ | h | $b(h_1-h)$ | $h_1^2$ | $h^2$ | $\frac{b(h_1^2-h^2)}{2}$ | $h_1^3$ | $h^3$ | $\frac{b(h_1^3-h^3)}{3}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| A | .830 | .109 | 0 | .090 | .012 | 0 | .005 | .001 | 0 | .0003 |
| B | 1.5 | .359 | .109 | .375 | .129 | .012 | .088 | .046 | .001 | .023 |
| C | .5 | 2.047 | .359 | .844 | 4.188 | .129 | 1.015 | 8.571 | .046 | 1.421 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | Area = | 1.309 | | M = | 1.108 | | $I_{DE}$ = | 1.444 |

$d = M/A$
$= .846$

$I_N = I_{DE} - Ad^2$
$= .507 \text{ in}^4$

$Z = I_N / y$
$= .422$

$y$ = distance from neutral axis to extreme fiber
$= 1.201$

# DESIGN ANALYSIS

Client Fermi Lab — Job No. A762

Subject Muon Storage Dewar (Inner Shell) — Date 1-11-86 — By RM

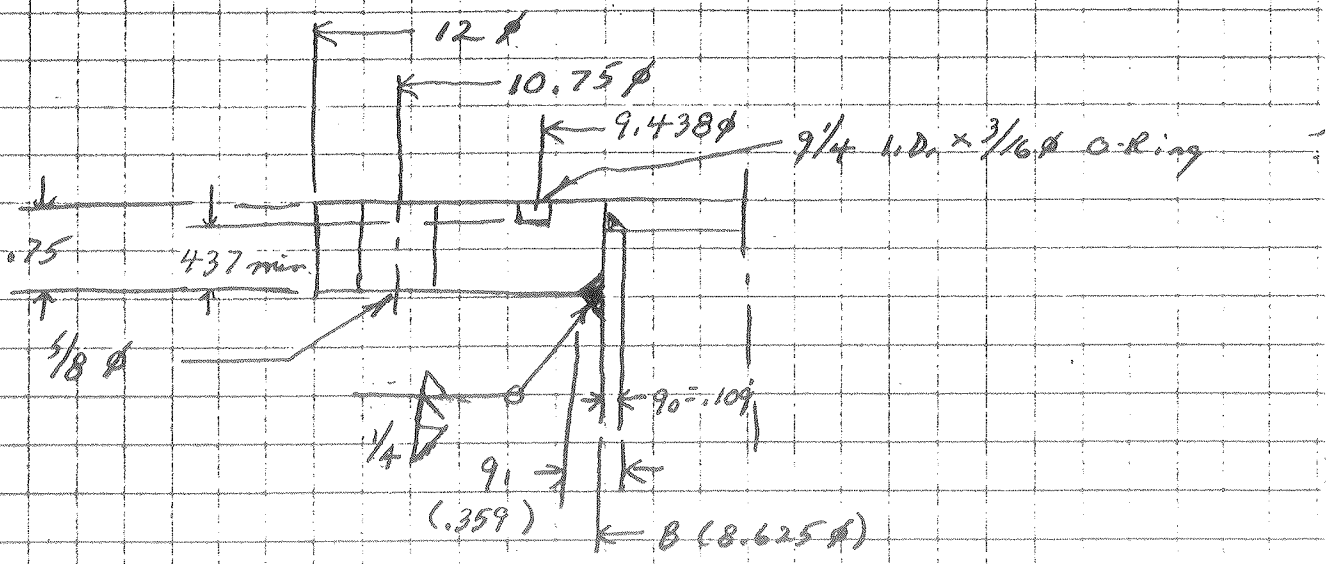
Checked — By

Location — Revised 2-12-86 — By RM

IV) Top flange

Design Press: 100 PSID

Design Temp: 70° F




A) Thickness UG-34 (c)(2)

1) Operating Conditions

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3}$$

$$= 9.438\sqrt{(.3)(100)/(18800)(1) + [1.9(6992.45)(.656)/(18800)(1)(9.438^3)]}$$

$$= .437$$

2) Gasket Seating (P = 0)

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3}$$

$$= 9.438\sqrt{(.3)(0)/(18800)(1) + [1.9(11968)(.656)/(18800)(1)(9.438^3)]}$$

$$= .290$$

# DESIGN ANALYSIS

Client Fermi Lab Job No. A762

Subject Muon Storage Dewar (Inner Shell) Date 1-11-86 By R.M

Checked By

Location Revised 2-12-86 By R.M

$W_{m_1} = 0.785\,G^2\,P + (2b \times 3.14\,G\,m\,P)$

$= (0.785)(9.438^2)(100) + 0$ since $m = 0$

$= 6992.45$ lb

$W = (A_m + A_b)\,S_a / 2$

$= (.318 + .770)(22000)/2$

$= 11968$ lb.

$A_m = A_{m_1} = W_{m_1} / S_b$

$= 6992.45 / 22000$

$= .318$ in

Bolts = 6 ea. 1/2-13NC, Root $\phi$ = .4041 in

$A_b = .770$ in$^2$

$R = \frac{C-B}{2} - q_1 = \frac{10.75 - 8.625}{2} - 0.359 = 0.704$

B) Moment (Operating Conditions)

$M_o = M_D + M_T + M_G$

$= 6892.22 + 1062.87 + 0$ — 5159 + 929.15

$= 6955.09$ = 6,088 in-lbs

$M_D = H_D\,h_D$

$= (5839.66)(1.409)$ (5839.66)(0.884)

$= 5822.22$ = 5,159

$H_D = .785\,B^2\,P$

$= (.785)(8.625^2)(100)$

$= 5839.66$

Incorrect R used

$h_D = R + .5g_1$

$= .829 + .5(.359) = 1.009$

$= 0.704 + 0.5(0.351) = 0.884$

# DESIGN ANALYSIS

Client Fermi Lab Job No. A762

Subject Muon Storage Dewar (Inner Shell) Date 1-11-86 By RW

Checked By

Location Revised 2-12-86 By RW

$R = \left(\frac{C-B}{2}\right) - g.1$

$= \left(\frac{10.75 - 8.625}{2}\right) - .234$

$= .829$

Incorrect

R = 0.704

$M_T = H_T h_T$

$= (1152.79)(.822)$

$= 1062.87$

$(1152.79)(0.860)$

$= 929.15$

$H_T = H - H_D$

$= 6992.45 - 5839.66$

$= 1152.79$

$H = .785 G^2 P$

$= .785 (9.438^2)(100)$

$= 6992.45$

$h_T = (R + g. + h_G)/2$

$= (.829 + .359 + .656)/2$

$= .822$

$= (0.704 + .359 + .656)/2$

$= 0.860$

$h_G = (C - G)/2$

$= (10.75 - 9.438)/2$

$= .656$

$M_G = H_G h_G$

$= (0)(.656)$

$= 0$

$H_G = W - H$

$= 6992.45 - 6992.45$

$= 0$

# DESIGN ANALYSIS

Client Fermi Lab  Job No. A762

Subject Muon Storage Dewar (Inner Shell)  Date 1-11-86  By RW

Checked  By

Location  Revised 2-12-86  By RW

c) Moment (Gasket Seating)

$M_o = W \frac{(C-G)}{2}$

$= 11968 \left[\frac{10.75 - 9.438}{2}\right]$

$= 7851.91$

D.) Flange Stresses

1) Longitudinal Hub stress (24000 PSI allowable) $1.5 S_m$

$S_H = f M_o / L g_1^2 B$ (2.56)

$= (8.4)(7851.01) / (3.082)(.359^2)(8.625)$ (6.5)

$= 19249.11$ PSI  Acceptable

= 17,933 psi

$f = 8.4$

$g_1/g_o = .359/.109 = 3.294$

$h/h_o = .125/.970 = .129$ (0.258)

h = 0.250" not 0.125 in

$L = \frac{te + 1}{T} + \frac{t^3}{d}$

$= (.75)(.923) + 1 / 1.80 + .75^3/.197$

= 2.56

$= 3.082$ (0.26)

$e = F/h_o = .895/.970 = .923$

$K = A/B = 12/8.625 = 1.391$

$d = U/V h_o g_o^2$

$= (7/.41)(.970)(.109^2)$

$= .197$

$(7/0.26)(0.970)(0.109)^2$

= 0.310

# DESIGN ANALYSIS

Client Fermi Lab Job No. A762

Subject Muon Storage Dewar (Inner Shell) Date 1-11-86 By RW

Checked By

Location Revised 1-29-86 By RW

2) Radial Flange Stress (18800 PSI allowable)

$S_R = (1.33te + 1) M_o / L t^2 B$

$= [(1.33)(.75)(.923) + 1](7851.01) / (3.082)(.75^2)(8.625)$ (2.56)

= 1,214 psi $= 1008.48$ PSI Acceptable

3) Tangential Flange Stress (18800 PSI allowable)

$S_T = (Y M_o / t^2 B) - Z S_R$

$= [(6.1)(7851.01) / (.75^2)(8.625)] - (3.3)(1008.48)$ (0.3)

= 9,709 psi $= 6543.30$ PSI Acceptable

For simplicity ignore the Z $S_R$ partion of the tangential flange stress equation let it be zero. "Conservative to do it this way".

# DESIGN ANALYSIS

Client Fermi Lab Job No. 8762

Subject Muon Storage Dewar (Outer Shell) Date 1-11-86 By RW

Per Compressed Gas Assoc. Std. Checked By

Location CGA-341, Para 1 (f) Revised 1-29-86 By RW

Design Press: 7.5 PSI External

Design Temp: 70° F

I) Shell: 42 O.D., 3/16 THK, A240 304 S.S. (UG-28)

$L = 37.417$ $L/D_o = .891$ $D_o/t = 223.40$

$A = .00046$ $B = 6300$

$$P_a = \frac{4B}{3(D_o/t)}$$

$$= \frac{4(6300)}{3(223.40)}$$

$$= 37.60 \text{ PSI}$$ Acceptable

II) Heads: ASME Flanged & Dished, 3/16 THK

A240, 304 S.S. (UG-33)

A) Thickness Req'd.

$t = .090$ $R_o = 42.188$

$A = .00027$

$R_o/t = 468.76$

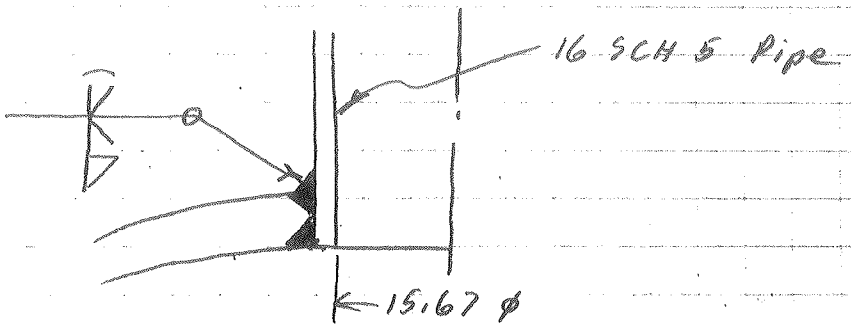
$B = 3700$

$$P_a = \frac{B}{R_o/t}$$

$$= 3700/468.76$$

$$= 7.893$$ Acceptable

B) Reinforcement Req'd. (UG-37)(c)



# DESIGN ANALYSIS

Client: Fermi Lab — Job No. A262

Subject: Muon Storage Dewar (Outer Shell) — Date: 1-11-06 — By: RM

Checked — By

Location — Revised: 2-12-06 — By: RM

$A = d\,t_r\,F / 2$

$= (15.67)(.090)(1)/2$

$= .705\ in^2$

$A_1 = (E_1 t - F t_r) d$

$= (.188 - .090)(15.67)$

$= 1.536\ in^2$

$a = 2(E_1 t - F t_r)(t + t_n)$

$= 2(.188 - .090)(.188 + .165)$

$= .069\ in^2$

No additional Reinforcement Req'd

III) Neck: 16 SCH 5 Pipe, A312, 304 S.S. (UG-28)

$t = .165$ $\quad L = 32$ $\quad L/D_o = 2$

$D_o/t = 96.97$ $\quad A = .0007$ $\quad B = 7700$

$P_a = \dfrac{4B}{3(D_o/t)}$

$= \dfrac{4(7700)}{3(96.97)}$

$= 105.87\ PSI$ Acceptable

# DESIGN ANALYSIS

Client: Fermi Lab — Job No. A762

Subject: Muon Storage Dewar — Date: 1-31-86 — By: RW

Instrumentation & Radiation Shield — Checked — By

Location — Revised — By

Design Press: 100 PSI (Instrumentation)
Design Press Radiation Tubing: 100 PSI + 15 PSI = 115 PSI
Design Temp Radiation Tubing: -320°F

I) Radiation Tubing: 1/2 O.D., 6061-T6 Alum.

$t = PR_o / SE + 0.4P$

$= 115(.50) / 10500 + 0.4(115)$

$= .005$ in. min. Reqd.

II) Instrumentation

A) ΔP Gauge = Dwyer Capsuhelic

B) Tubing = 1/4 O.D., 304 S.S.

$t = PR_o / SE + 0.4P$

$= 115(.25) / 17000 + 0.4(115)$

$= .002$ in min. Reqd.

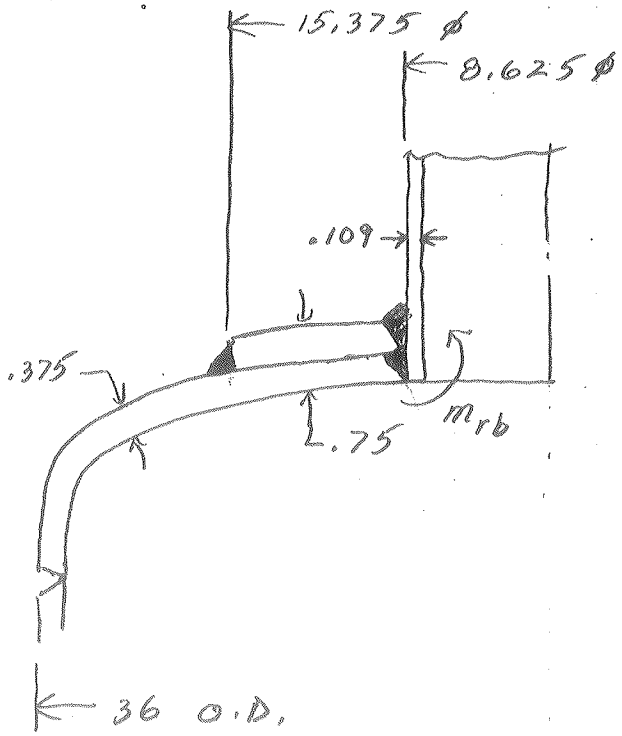
# DESIGN ANALYSIS

Client Fermi Lab — Job No. 4762

Subject Muon Storage Dewar — Date 2-16-86 — By R.A.L

Top Head Loading — Checked — By

Location — Revised — By




Weight

1) 2a. 304 80:10 Hdz = 325.14 #
2) Cylinder, 3/8 Pl. = 153.91 #
3) Insulation = 6.03 #
4) LHe, 407 LTRS = 112.05 #
597.13 #

I) Roark 5th Ed., Table 24 Case 1f, outer edge fixed, inner edge guided.

Load applied @ inner edge $r_o = b$

$a = 18$ $b = 4.3125$ $b/a = .24$

$K_{mrb} = .2276$

A) From Pg. 334

$M = K_m w a$

1) $M_{rb} = K_{mrb} w a$
$= (.2276)(22.037)(18)$
$= 90.28$

# DESIGN ANALYSIS

Client Fermi Lab — Job No. A762

Subject Muon storage Dewar — Date 2-16-86 — By RW

Top Head Loading — Checked — By

Location — Revised — By

$w = 597.13 / 8.625\pi$

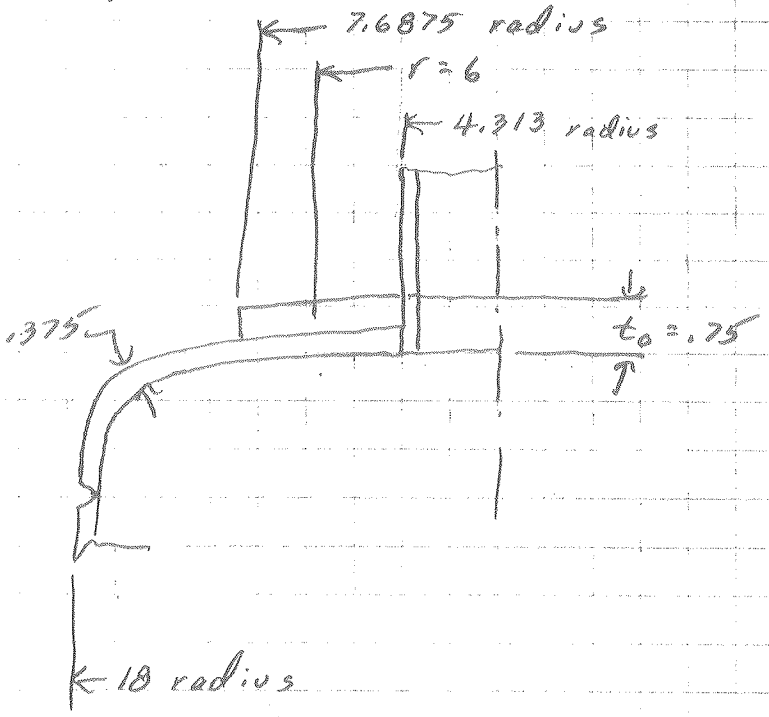
$= 22.037$

B) $\sigma_b = 6\, M/t^2$

$= 6(90.28)/.694^2$

$= 1124.67$ PSI

1) from page 382 average thickness of head.




$t = t_0 e^{-n x^2/6}$

$= (.75)(2.718^{-4.16(6/18)^2/6})$

$= .694$ in.

$n = 4.16$ from pg. 382

$x = r/a$

# DESIGN ANALYSIS

Client Fermi Lab  Job No. A762

Subject Muon Storage Dewar  Date 2-16-86  By RW

Top Head Loading  Checked  By

Location  Revised  By

II) Stress in head from internal Press.
Appendix 1(d)(3) Sect VIII

$$P = 2SEt/LM + 0.2t$$

$$2SEt = P(LM + 0.2t)$$

$$S = \frac{P(LM + 0.2t)}{2Et}$$

$$= \frac{(250)[(28.8)(1.46) + 0.2(.375)]}{2(.8)(.375)}$$

$$= 17551.25 \text{ PSI}$$

See Inner Shell Calc's for values of P, L, M, t, E

III Total stress on head

$$S_T = S(\text{from above}) + \sigma_b$$

$$= 17551.25 + 1124.67$$

$$= 18675.92 \text{ PSI}$$

Max allowable from Sect. VIII
18800 PSI Acceptable

# DESIGN ANALYSIS

| | | |
|---|---|---|
| Client | Job No. | |
| Subject | Date | By |
| | Checked | By |
| Location | Revised | By |

2) $M_{ra} = K_{mra}\, w_a$
$= (-.09432)(5.280)(18)$
$= -8.964$

$w = 597.13 / 36\pi$
$= 5.280$ lb. in

C) $\sigma_a = 6 M_{ra} / t^2$
$= 6(-8.964) / .694^2$
$= -111.67$ PSI

15054

# DESIGN ANALYSIS

Client: Fermi Lab — Job No. A762

Subject: Muon Storage Dewar Rupture Disc Sizing — Date 2-12-86 By RJV — Checked — By

Location: Per CGA-341, 6 (a) (13) — Revised — By

A) Capacity of Inner shell = 407 Liters
   1) Weight = 859.99 lbs / water

B) Discharge area of Rupture Disc Req'd.
   1) 859.99 × .00024 = .206 $in^2$

C) Discharge Area of Continental 2 IPS 2U Rupture Disc
   1) 2 SCH 40 Nipple
      a) $2.067^2$ × .785 = 3.356 $in^2$
      Acceptable

# DESIGN ANALYSIS

| | | | |
|---|---|---|---|
| Client Fermi Lab | | Job No. A762 | |
| Subject Moon Storage Dewar | | Date 1-31-86 | By RW |
| | | Checked | By |
| Location | | Revised | By |

I) Weights

A) Inner Shell

1) 36ø 80.10 Heads 2 in = 325.14 lb
2) Cylinder 3/8 Pl, 12 lg = 153.91 lb.
3) Inner Neck, 8 SCH5 Pipe = 37.38 lb
4) Insulation = 6.03 lb.

} 522.46

B) Shield

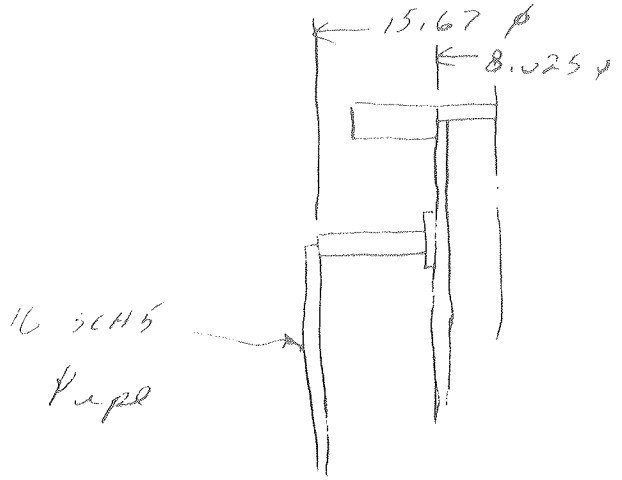
1) 1/8 Alum = 91.24 lb.
2) 1/2 O.D. × .049 Alum tube = 8.77 lb.
3) 1/2 THK × 12 1/2ø S.S. Adapter = 18.45 lb.
4) 1/4 × 1 1/2 S.S. Doubler = 2.96 lb
5) Insulation = 7.1 lb.

} 128.52 lb.

C) LHe

1) 407 liters = 112.05 lb.

II) Load on top Weld Adapter



# DESIGN ANALYSIS

Client Fermilab Job No. A262

Subject Meson Storage Dewar Date 1-31-86 By RLL

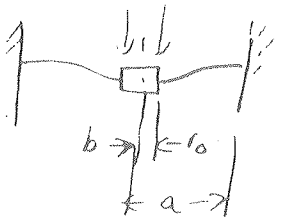
Checked By

Location Revised By

Roark & Young 5th Ed. Table 24, Case 1f

A) Shipping Load

$(522.46 + 120.32)\, 3_y = 1952.94$ lb.




$b = r_a = 4.313$

$a = 7.835$

$b/a = 4.313/7.835$

$= .550$

$K_{yb} = -.0056$

$K_{mrb} = .1940$

$K_{mra} = -.1284$

$w_b = 1952.94/8.625\pi = 72.07$ #

$w_a = 1952.94/15.67\pi = 39.67$ #

$D = Et^3/12(1-\nu^2)$

$= (28\times10^6)(.5^3)/12(1-.29^2)$

$= 318448.16$

$m_{rb} = K_{mrb}\, w_b\, a$

$(.1940)(72.07)(7.835)$

$= 109.55$

$m_{ra} = K_{mra}\, w_a\, a$

$= (-.1284)(39.67)(7.835)$

$= -39.91$

# DESIGN ANALYSIS

Client Fermi Lab  Job No. A762

Subject Muon Storage Dewar  Date 1-31-86  By RJL

Checked  By

Location  Revised  By

1) $\sigma_b = 6 M_{rb} / t^2$

$= 6(109.55) / .5^2$

$= 2629.2$ PSI

2) $\sigma_a = 6 M_{ra} / t^2$

$= 6(-39.91) / .5^2$

$= -957.84$ PSI

3) $y = K_{yb} \frac{w_b a^3}{D}$

$= -.0056 \left( \frac{12.07 (7.835^3)}{318448.16} \right)$

$= -.0006$ in.

In sufficient gas cooling it will be necessary to arrange the gas to escape through a narrow annular space between the plug and the neck tube. To [illegible] heat leak through the plug is adequately interrupted it may be necessary to modify the plug [illegible] thin sheets of metal sandwiched between [illegible] at 2 to 4 inch intervals.

as continued

Cp of He = 5 BTU/lb mole °R

= 1.25 BTU/lb °R

Q refrig available to $LN_2$ temp =

= $mC_p \Delta T$

= .139 × 1.25 × 132° = 22.9

Q mech tube ~~1.307~~ 2.76 2.85

Q plug 1.49 ~~2.797~~ = ~~2.8 BTU/hr~~ 4.25 BTU/HR

The 22.9 BTU of refrigeration should easily intercept 80% of these heat leaks.

∴ Net Q mech tube + plug = ~~.56~~ .85 BTU .85 .868

Q insulation = .23

Q gage tube = .113

Total heat leak = ~~.903~~ 1.193 BTU/hr

1.211

Q allowable = 1.23 BTU

We assume that inner shell is a cylinder having dimensions of $h = 31.75$ in $d = 36$"

then d of shield $= 35.00$ $d = 38$"

$$A_{cyl} = \pi D h = \pi \times 38 \times 35 = 4178 \text{ in}^2$$
$$= 29 \text{ ft}^2$$

$$Q_{min} = \frac{a}{x} \times k \Delta T$$

$$= \frac{29}{1/2} \times 5 \times 10^{-6} \times 139$$

$$= 29 \times 12 \times 5 \times 139 \times 10^{-6}$$

$$= 2296 \times 10^{-2} = 23 \text{ BTU/hr.}$$

Heat leak in a plug 8" ϕ

Area 1 plug $\pi r^2 = \pi \times 4^2 = 50.2 \text{ in}^2$

$= .35 \text{ ft}^2$

k for polystyrene use .019 BTU/hr ft °R.

$$Q = \frac{A}{X} k \Delta T$$

$X = 28"$
$= 2.33 \text{ ft}$

$$= \frac{.35}{2.33} \times .019 \times 522$$

$= 1.49$ BTU/hr.

Heat leak thru SS neck

Area $= \pi D t = \pi \times 8 \times .035$

$= .879$

$$Q = \frac{A}{X} \int k \Delta T = \frac{\cancel{.879}}{\cancel{19.5}} \times 29 \qquad \frac{2.916}{30.625}(29)$$

$29\frac{5}{8}$

$= \cancel{1.307}$ BTU/hr. 2.76 BTU/HR
2.85

Heat leak through gage tube Assume 1/4" OD × .010 wall × 2 in long to L

$$Q = \frac{.0078}{2} \times 29$$

$= .113$ BTU/hr.

$A = \pi \times D t$
$= \pi \times .25 \times .01$
$= .0078$

Q and heat off allowed.

Volume of tank = 107.5 gallons

3% loss/day = 3.225 gallons/day

= .134 gallons/hour

= .134 × 1.0407 lbs/hour

= .139 lbs of H₂O/hour

Allowable Q = = .139 × 8.82

= 1.23 BTU/hr