EXHIBIT A-1

Vacuum Vessel Engineering Note
(per Fermilab ES&H Manual Chapter 5033)

Prepared by	R. J. Woods	Date	11/15/06	Div/Sec	PPD/MECH
Reviewed by	Bob Wands Ingrid Fang	Date	3/13/09	Div/Sec	PPD/MECH
Div/Sec Head		Date		Div/Sec	

1. Identification and Verification of Compliance

Fill in the Fermilab Engineering Conformance Label information below:

This vessel conforms to Fermilab ES&H Manual Chapter 5033

Vessel Title	MuCool Bayonet Box
Vessel Number	
Vessel Drawing Number	ME-435320 BAYONET BOX OVERALL ASSEMBLY !!
Internal MAWP	
External MAWP	14.7psi
Working Temperature Range	-20 °F +100 °F
Design/Manufacturer	Fermi Lab - Particle Physics Division
Date of Manufacture	
Acceptance Date	

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

Amendment No.	Reviewed by:	Date:

Laboratory location code	
Laboratory property number	
Purpose of vessel	

List all pertinent drawings

PART B
DESIGN OF THE BAYONET CAM

Drawing No. (SEE ATTACHED DRAWING LIST) Location of Original

2. Design Verification

Provide design calculations in the Note Appendix.

3. System Venting Verification

Can this vessel be pressurized either internally or externally? [ ] Yes [X] No
If "Yes", to what pressure? _____

List all reliefs and settings. Provide a schematic of the relief system components and appropriate calculations or test results to prove that the vessel will not be subjected to pressures greater than 110% beyond the maximum allowable internal or external pressure.

Manufacturer	Relief	Pressure Setting	Flow Rate	Size
CVI VACUUM SEAL-OFF VALVE # V-1046-31				1" w/ 1/8 FNPT for TC

4. Operating Procedure Section

Is an operating procedure necessary for the safe operation of this vessel?
[ ] Yes [X] No *(If "Yes", it must be appended)*

Is a testing procedure necessary for the safe acceptance testing (acceptance testing) of this vessel?
[ ] Yes [X] No
If "Yes", the written procedure must be approved by the division head prior to testing and supplied with this Engineering Note.

5. Welding Information

Has the vessel been fabricated in a Fermilab shop? [X] Yes [ ] No
If "Yes," append a copy of the welding shop statement of welder qualification.

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

Is this vessel or any part thereof in the above categories? [ ]Yes [X] No
If "Yes" follow the Engineering Note requirements for documentation and append to note.

MuCOOL CRYOGENIC SYSTEM - BAYONET BOX ASSEMBLY

(SIZE)	DWG. NO.	DWG.NAME	QTY.	FAB. IN	FAB. OUT	USED ON
MC-	120572	CHECK VALVE ASSEMBLY				
MD-	435186	bb cc dd 1.50 FEMALE BAY.ASSY - 1" TUBE""				
ME-	435320	**BAYONET BOX OVERALL ASSEMBLY !!**				
MD-	435321	!! OUTER BOX WELDMENT*				
MD-	435322	***OUTER BOX TOP PLATE				
MD-	435323	*OUTER BOX BOTTOM PLATE				
MD-	435324	!! INNER LINER WELDMENT**				
MD-	435325	**INNER LINER TOP PLATE				
MD-	435326	!!**INNER LINER SIDE & END PLATES				
MB-	435327	!! INNER LINER STANDOFF				
ME-	435328	!! OUTER BOX TOP PLATE PIPING				
ME-	435329	!! INTAKE PIPE SUB-ASSEMBLY aa				
MB-	435347	bb dd ADAPTER PLATE, 1.00 OD x .50 ID				
MC-	435349	bb dd DEFLECTOR ASSEMBLYzzz				
ME-	435362	bb dd CONTROL & SHUT-OFF VALVE ASSY.xxx				
MC-	435428	aa SPIDER #1				
MC-	435429	aa SPIDER #2				
ME-	435457	!! LN2 PIPING SUB-ASSEMBLY bb				
ME-	435458	!! 5K PIPING SUB-ASSEMBLY cc				
ME-	435459	!! 14K, 20K PIPING SUB-ASSEMBLY dd				
MC-	435460	dd SPIRAL TUBE FOR 14K PIPING				
MC-	435461	dd SPIRAL TUBE FOR 20K PIPING				
MC-	435462	bb SPIRAL TUBE FOR LN2 PIPING				
MB-	435463	bb cc dd ADAPTER PLATE, 2.88 OD x .75 ID				
MB-	435464	dd ADAPTER PLATE, 2.88 OD x 1.00 ID				
MB-	435520	aa LN2 SUPPLY PIPE, 4" x 16.50, SCH. 10S				
MB-	435498	aa END PLATE, 4.50 OD x 4.01 ID				

ASME SECTION VIII DIV. 1 APPENDIX 13
FIG. 13-2(a) SKETCH 1

$H = 27.0 - (2(0.625)) = 25.75''$
$L_V = 84''$

$L_V/H = 84/25.75 = 3.26 < 4.0$ 13-4(h) P. 416
> 2.0

∴ DESIGN BASED ON PROVISIONS OF U-2(g) USING ESTABLISHED TECHNIQUES OF STRUCTURAL ANALYSIS, ALSO SEE FESHM 5033 "PROCEDURE" SECTION

∴ USE RESULTS OF FINITE ELEMENT ANALYSIS, P8-10 THIS CALCULATION.

MAXIMUM ALLOWABLE STRESS FOR 304 STAINLESS STEEL AT OPERATING TEMPERATURE OF 0°F TO 100°F FROM TABLE ULT-23 FOR WELDED CONSTRUCTION = 20.0 KSI
= 20,000 PSI

MAXIMUM VON MISES STRESS FROM FEA < 18,000 PSI < 20,000 PSI

OK

VERIFY STRESS USING "ROARK'S FORMULAS FOR STRESS & STRAIN":

EXTERNAL PRESSURE = 14.7 psi
BAYONET = 15# EA
PIPING TO BAYONET = 50# EA.

USING 5/8" THICK STAINLESS PLATE:
DENSITY OF STAINLESS = 0.29 #/IN³ (FROM RYERSON CAT.)
FOR 5/8" PLATE, WT. = 0.29(5/8) = 0.18 #/IN²

WEIGHT OF BAYONET CAN:

LONG SIDES: 84 × 31 × 2 = 5208 IN²
TOP & BOTTOM: 84 × 27 × 2 = 4536 IN²
END PLATES = 31 × 27 × 2 = 1674 IN²
11,418 IN²

TOTAL WEIGHT = 0.18(11,418)
= 2055#

FROM PAGE 464 TABLE 26 CASE 8a:

$a/b = 84/27 = 3.11$

FROM CHART:
@ ∞, $\beta_1 = 0.500$ $\beta_2 = 0.2500$ $\alpha = 0.0284$

$q = 14.7 + 0.18 = 14.88$ psi

MAX σ @ CENTER OF LONG EDGE $= \dfrac{-\beta_1 q b^2}{t^2}$

$= \dfrac{0.500(14.88)(27)^2}{(0.625)^2}$

$= -13,885$ psi

MAX σ @ CENTER $= \dfrac{\beta_2 q b^2}{t^2}$

$= \dfrac{0.2500(14.88)(27)^2}{(0.625)^2}$

$= 6942$ psi

FROM PAGE 465 TABLE 26 CASE 8b

FROM CHART: @ ∞, $\beta_1 = 0.067$, $\beta_2 = 1.008$ $\alpha = 0.0791$

MAX σ @ CENTER OF LONG EDGE $= \dfrac{-\beta_2 W}{t^2}$

$W = 15^{\#} + 50^{\#} = 65^{\#}$

$= \dfrac{-1.008(65)}{(0.625)^2}$

$= 168$ psi EA. LOAD

168 × 7 BAYONETS = 1,176 psi

ν = POISSON'S RATIO (P. 398) $r_o' = r_o = 1.0$

MAX σ @ CENTER $= \dfrac{3W}{2\pi t^2}\left[(1+\nu)\ln\dfrac{2b}{\pi r_o'} + \beta_1\right]$

$= \dfrac{3(65)}{2(3.14)(0.625)^2}\left[(1+0.29)\ln\left(\dfrac{2(22)}{3.14(1.0)}\right) + 0.067\right]$

$= 297$ psi

297 × 7 BAYONETS = 2079 psi

TOTAL BENDING STRESS:

@ CENTER OF LONG EDGE:

$\sigma = 13885 + 1,176$

$= \underline{\underline{15,061 \text{ psi}}}$ < 20,000 psi <u>OK</u>

@ CENTER:

$\sigma = 6942 + 2079$

$= \underline{\underline{9021 \text{ psi}}}$ < 20,000 psi <u>OK</u>

WELDS:

ALL CORNER WELDS ARE FULL PENETRATION USING 308 STAINLESS ELECTRODES W/ FULL RADIOGRAPHIC EXAMINATION.

LONG WELD BETWEEN TOP & SIDES = CATEGORY A WELD
WELDS AROUND END PLATES = CATEGORY A WELD

SINGLE BUTT WELD = TYPE 2, JOINT EFFICIENCY = 0.90

STRESS IN WELD = 18,000 PSI MAX. FROM FEA ANALYSIS
ALLOWABLE STRESS FOR 308 STAINLESS = 20,000 PSI*

ALLOWABLE STRESS IN JOINT = σ_{ALLOW} (JOINT EFF.)
= 20 000 (0.9)
= 18,000 PSI ok

*ASME SECT. II PART D
TABLE 1A, PAGE 92
LINE 4 FOR −20°–100°F

OPENINGS IN TOP PLATE:

SINCE FIRST FEA ANALYSIS INDICATED LOCAL OVERSTRESS AROUND OPENINGS, SEE IF NOZZLES PROVIDE ENOUGH STIFFENING. IF SO, RERUN FEA ANALYSIS WITH NOZZLES INCLUDED TO VERIFY.

FROM UG39(b)(2): 2(2.75) = 5.5" MIN. SPACING
17.22 − 8.53 = 8.69" ok
(DRWG. 435322)

t_n = PIPE THICKNESS
$f_{r1} = 1.0$, t = SHELL THICKNESS, d = DIA. OF OPENING

$\therefore A_{REQ'D} = 0.5dt + t t_n(1 - f_{r1})$ UG 39(b)(1)

$A = 0.5(2.75)(0.625) + 0.625(0.120)(1-1)$
$= 0.859 \text{ IN}^2$

AREA OF 2½" Φ PIPE
O.D. = 2.500
WALL THICKNESS = 0.120"
I.D. = 2.500 − (0.120 × 2)
= 2.260

$$A_{PIPE} = \frac{\pi\left((2.500)^2 - (2.260)^2\right)}{4}$$

$= 0.8972 \text{ IN}^2$

REINFORCEMENT FOR 6.625" OPENING:
FROM APPENDIX 13-4(j)(1) & 13-4(j)(2) → COMPLY W/ UG 39

FROM UG 39(b)(1):
SHORTEST SPAN = 25.75
∴ THIS SECTION APPLIES SINCE $6.625 < 25.75/2$

$A_{REQ'D} = 0.5dt + tt_n(1-f_{r1})$ WHERE $d = 6.625$, $t = 0.625$, $t_n = 0.134$, $f_{r1} = 1.0$

$= 0.5(6.625)(0.625) + 0.625(0.134)(1-1)$
$= 2.070\ IN^2$

AREA OF 6"ϕ PIPE:
O.D. = 6.625"
WALL THICKNESS = 0.134
I.D. = 6.625 − (0.134 x 2)
= 6.357"

$A_{PIPE} = \frac{\pi((6.625)^2 - (6.357)^2)}{4} = 2.733\ IN^2$

$A_{PIPE} > A_{REQ'D}$ OK

CHECK 2½"ϕ PIPE FOR 14.7 PSI EXTERNAL PRESSURE AND REINFORCING LOAD:

REQ'D REINF. AREA = 0.859 IN²
A_{PIPE} = 0.897 IN²
0.038 IN² FOR EXTERNAL PRESSURE

WALL THICKNESS FOR A = 0.859 IN²:
$\pi((2.50)^2 - X^2)/4 = 0.859$
$X^2 = 5.156$
$X = 2.27$

$t = \frac{2.27 - 2.26}{2} = 0.01\ IN$

$L = 6"$ $D_o = 2.50 \pm 0.01$

$D_o/t = 2.50/0.01 = 250 > 10$

$L/D_o = 6.00/2.50 = 2.4$

FROM FIG. G P622 SECTION II PART D:
FACTOR A = 0.0001

FROM FIG. HA-1 p628 SECTION II PART D:

SINCE VALUE OF A FALLS TO LEFT OF MATERIAL/TEMPERATURE LINE, USE:

$$P_a = \frac{2AE}{3(D_o/t)} \qquad E = 28.0 \times 10^6$$

$$= \frac{2(0.0001)(28\,000\,000)}{3(250)}$$

$$= 74.7 \text{ psi}$$

$$74.7 > 14.7 \quad \underline{ok}$$

2½"ϕ PIPE OK FOR VACUUM & REINFORCING OPENING.

CHECK 6"ϕ PIPE FOR 14.7 PSI EXTERNAL PRESSURE AND REINFORCING LOAD:

REQ'D REINF AREA = 2.070 IN²

A_{PIPE} = 2.733 IN²

0.663 IN² FOR EXTERNAL PRESSURE

WALL THICKNESS FOR A = 2.070:

$$\pi((6.625)^2 - (x)^2)/4 = 2.070$$

$$x^2 = 41.255$$

$$x = 6.423$$

$$t = (6.423 - 6.357)/2$$

$$= 0.033 \text{ IN}$$

$L = 12''$, $D_o = 6.625$, $t = 0.033$

$D_o/t = 6.625/0.033 = 200.76$

$L/D_o = 12/6.625 = 1.811$

FROM FIG G P622 SECTION II PART D:

FACTOR A = 0.00025

FROM FIG. HA-1 p626 SECTION II PART D:

FACTOR B = 3500

$$P_a = 4B/3(D_o/t)$$

$$= 4(3500)/3(200.76)$$

$$= 23.2 \text{ PSI} > 14.7 \text{ PSI} \quad \underline{ok}$$

6"ϕ PIPE OK FOR VACUUM & REINFORCING OPENING

BASED ON REVISED ANSYS ANALYSIS WITH NOZZLES INCLUDED, MAXIMUM STRESS = 11,550 PSI < 20,000 PSI ok

USE 5/8" PLATE, NO ADD'L REINF @ OPENINGS REQUIRED.

WELDS @ OPENINGS:

FOR 1 5/8 & 2 1/4 OPENINGS:

FROM UW-15(b)(2) p. 129 STRENGTH CALCULATIONS FOR NOZZLE ATTACHEMENT WELDS FOR PRESSURE LOADING ARE NOT REQ'D FOR OPENINGS THAT ARE EXEMPT FROM THE REINFORCEMENT REQUIREMENTS BY UG-36(c)(3) SINCE VESSEL NOT SUBJECT TO RAPID FLUCTUATIONS IN PRESSURE AND ARE LESS THAN 2 3/8" DIAMETER.

FOR 2 3/4" ϕ OPENINGS:

SECTION II PART D TABLE 1A FOR TEMP -20 F TO 100F:

S = ALLOWABLE STRESS OF VESSEL MATERIAL = 18,800

S_n = ALLOWABLE STRESS OF NOZZLE MATERIAL = 18,800

DESIGN WELD TO CARRY FULL NOZZLE NECK SHEAR:

d_m = MEAN ϕ OF NOZZLE

t_n = NOZZEL WALL THICKNESS

STRENGTH OF NOZZLE NECK:

ⓐ NOZZLE WALL SHEAR $= \frac{\pi d_m}{2} \times t_n \times 18{,}800(0.70)$

$$d_m = (2.75 + (2.75 - 2(0.120)))/2$$

$$= 2.63''$$

$$\frac{\pi(2.63)}{2} \times 0.120 \times 18{,}800(0.7)$$

$$= 6524\#$$

d_o = OD OF NOZZLE

ⓑ FILLET WELD SHEAR $= \frac{\pi d_o}{2} \times$ WELD SIZE $\times 18{,}800(0.49)$

$$= \frac{\pi(2.75)}{2} \times 1/8 \times 18{,}800(0.49)$$

$$= 4974\# < 6524\# \quad \text{N.G.}$$

ⓒ ADD 1/8" PARTIAL PENETRATION GROVE WELD TO INTERIOR DIAMETER OF PIPE

$$= \frac{\pi(2.75 - 2(0.120))}{2} \times 1/8 \times 18{,}800(0.60)$$

$$= 5559\#$$

$$5559 + 4974 = 10\,553\# > 6524\# \text{ ok}$$

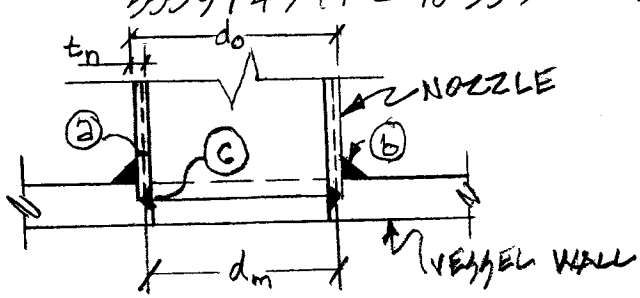


FIG. 1

FOR 6.625" OPENING:

NOZZLE WALL SHEAR $= \frac{\pi d_m}{2} \times t_n \times 18{,}800(0.70)$

$d_m = 6.625 + (6.625 - 2(0.134))/2$
$= 6.491$

$\frac{\pi(6.491)}{2} \times 0.134 \times 18{,}800(0.70)$
$= 17{,}980\#$

FILLET WELD SHEAR $= \frac{\pi d_o}{2} \times$ WELD SIZE $\times 18{,}800(0.49)$
$= \frac{\pi(6.625)}{2} \times 1/8 \times 18800(0.49)$
$= 11{,}983\# < 17{,}980$ N.G.

ADD 1/8" PARTIAL PENETRATION GROOVE WELD TO INTERIOR DIAMETER OF PIPE
$= \frac{\pi(6.625 - 2(0.134))}{2} \times 1/8 \times 18{,}800(0.60)$
$= 14080\#$

$11983 + 14080 = 26063\# > 17980\#$
OK

VACUUM RELIEF CALCULATIONS CONTINUED ON PAGES 11 & 12 THIS SECTION.

Fermi National Accelerator Laboratory
PPD / Mechanical Support / Engineering Analysis

Stress and Displacement of Bayonet Box Top Plate

Zhijing Tang
October 18, 2006

Bayonet outer box top plate is 84 inch long, 25.75 inch wide, and 0.62 inch thick. It is made of stainless steel 304. There are quite a few holes drilled on it. It is subjected to vacuum pressure load. Besides that, on seven top row 2.25 inch holes each has 50 lb weight. We calculate the load on each hole as follows:

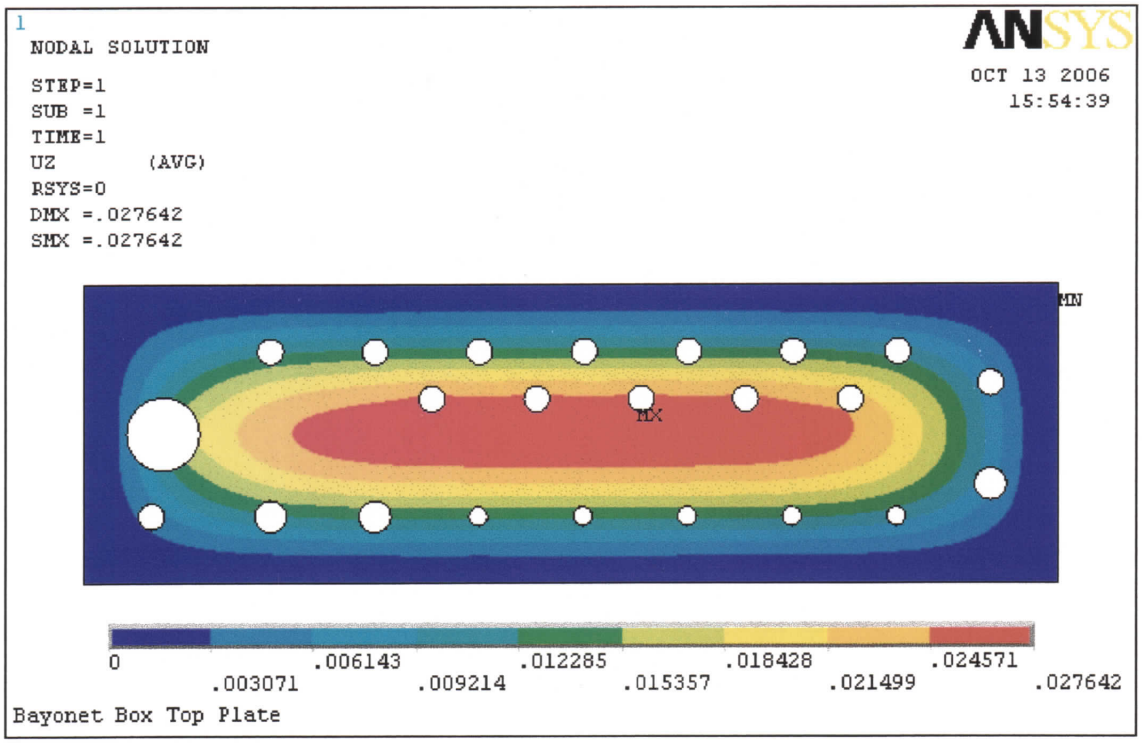
$$f = \frac{\pi}{4n} D^2 P_0$$

Where D is the diameter of the hole, P_0 = 14.5 psi is the atmosphere pressure, n is the number of nodes on the hole, f is force on each node. 1 hole of D = 6.5 in, n = 32, f = 15 lb; 5 holes of D = 1.625 in, n = 16, f = 1.88 lb; 3 holes of D = 2.75 in, n = 24, f = 3.6 lb; 7 holes of D = 2.25 in, n = 24, f = 2.4 lb; 7 holes of D = 2.25 in, n = 24, plus 50 lb weight, f = 4.5 lb.

Boundary conditions are simply supported but no rotations. Conditions on the holes are divided into two cases: One without constraint, and one rotation at hole is set to zero. Stress and displacement are calculated for each case. The real situation may lies between these two cases.

		Max Disp (in)	Max stress (psi)
1	No constraint	0.02764	11549
2	No rotation	0.01124	23748

The maximum stress of 23748 psi in the second case may seem a little too large. This is mainly due to the over constraint at the hole. The real boundary condition at hole may rest between these two extreme cases, and we expect the maximum stress below 18000 psi.


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UZ (AVG)
RSYS=0
DMX =.027642
SMX =.027642
ANSYS
OCT 13 2006
15:54:39
MN
MX
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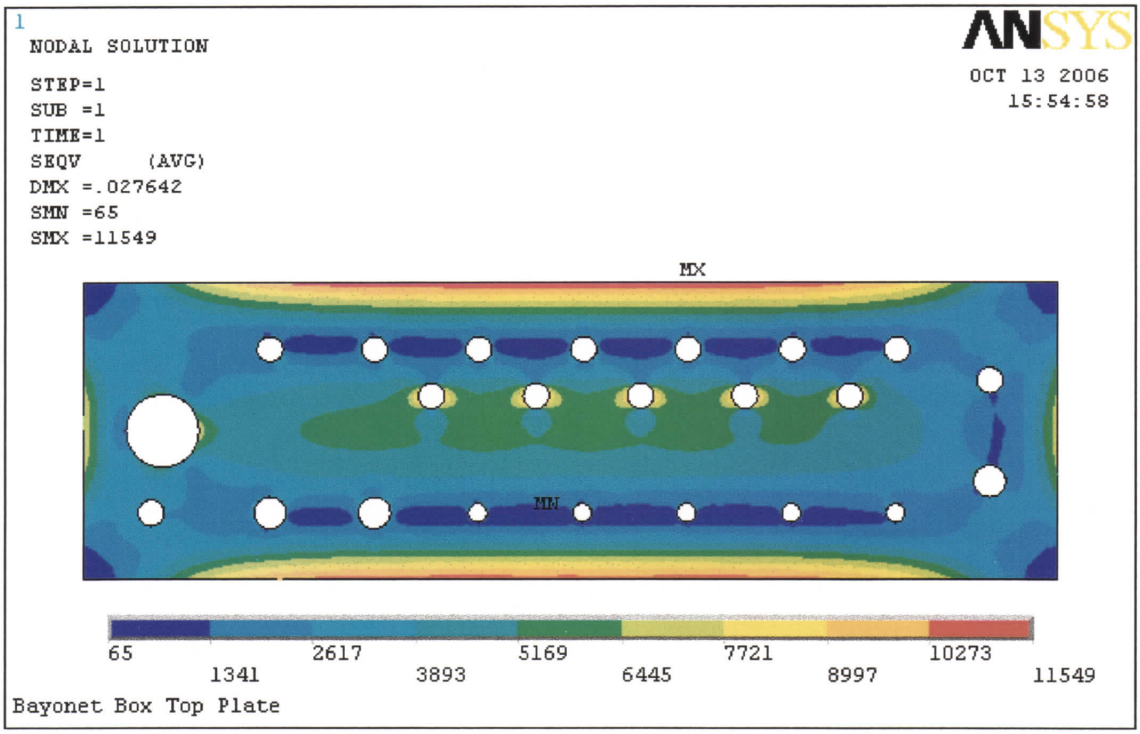
.006143
.009214
.012285
.015357
.018428
.021499
.024571
.027642
Bayonet Box Top Plate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NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.027642
SMN =65
SMX =11549
ANSYS
OCT 13 2006
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MN
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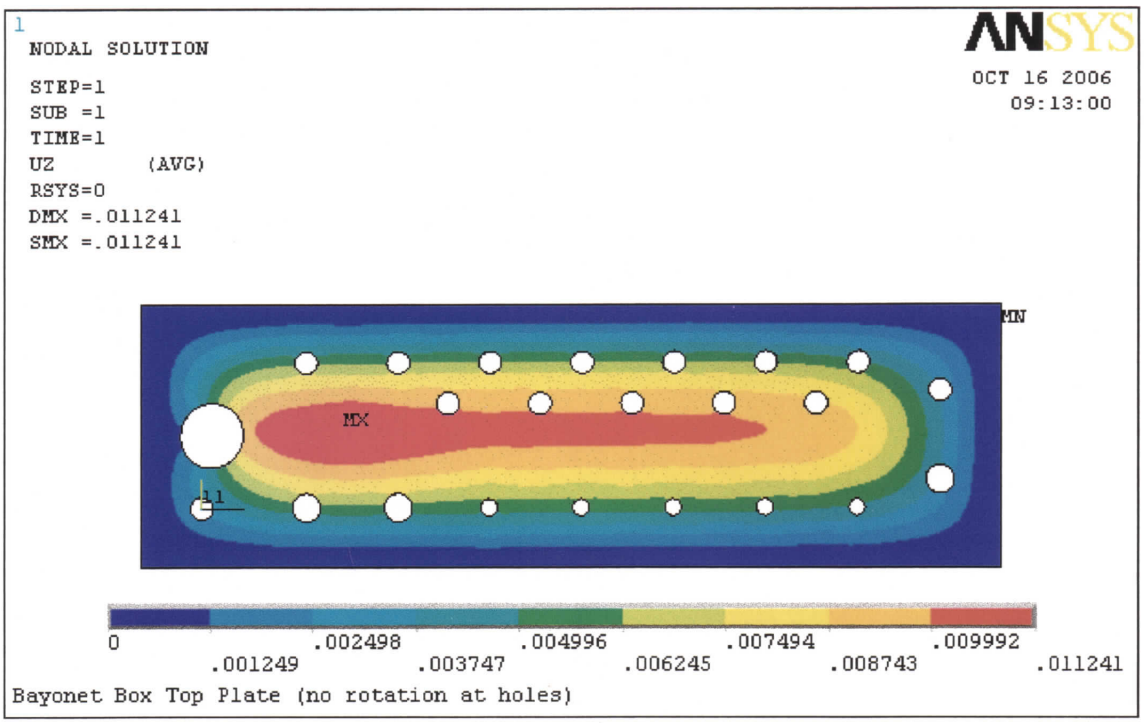
1341
2617
3893
5169
6445
7721
8997
10273
11549
Bayonet Box Top Plate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NODAL SOLUTION
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SUB =1
TIME=1
UZ (AVG)
RSYS=0
DMX =.011241
SMX =.011241
ANSYS
OCT 16 2006
09:13:00
MN
MX
0
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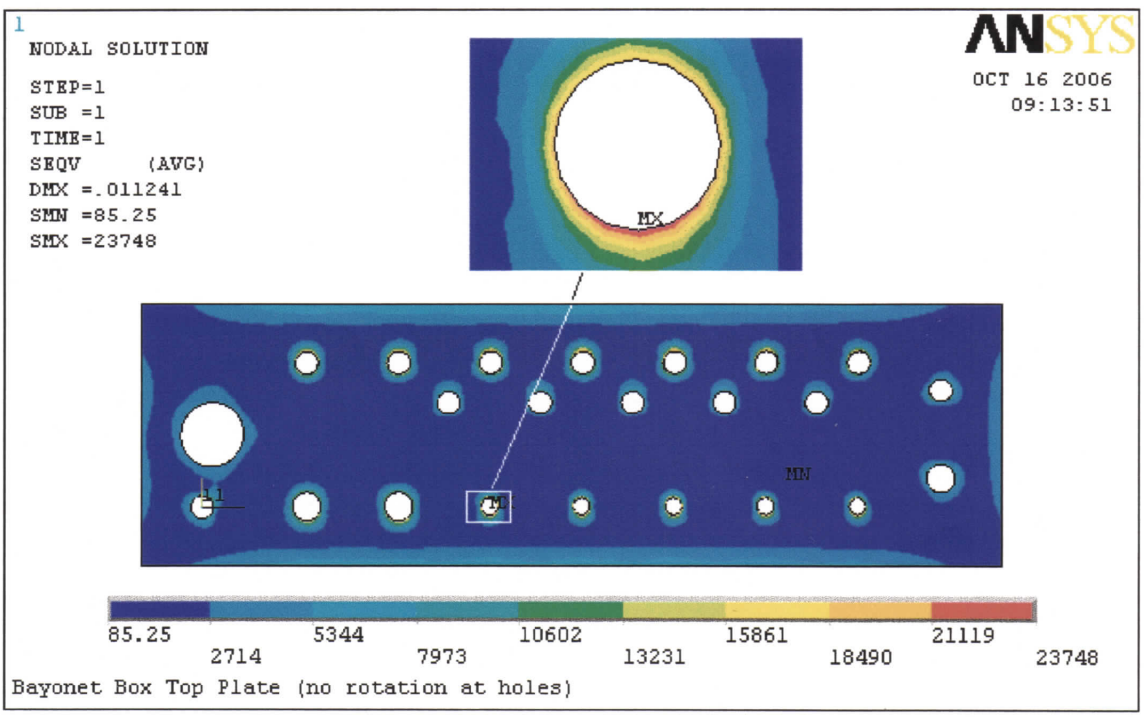
.003747
.004996
.006245
.007494
.008743
.009992
.011241
Bayonet Box Top Plate (no rotation at holes)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NODAL SOLUTION
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SUB =1
TIME=1
SEQV (AVG)
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SMN =85.25
SMX =23748
ANSYS
OCT 16 2006
09:13:51
MX
MN
85.25
2714
5344
7973
10602
13231
15861
18490
21119
23748
Bayonet Box Top Plate (no rotation at holes)

10 R1

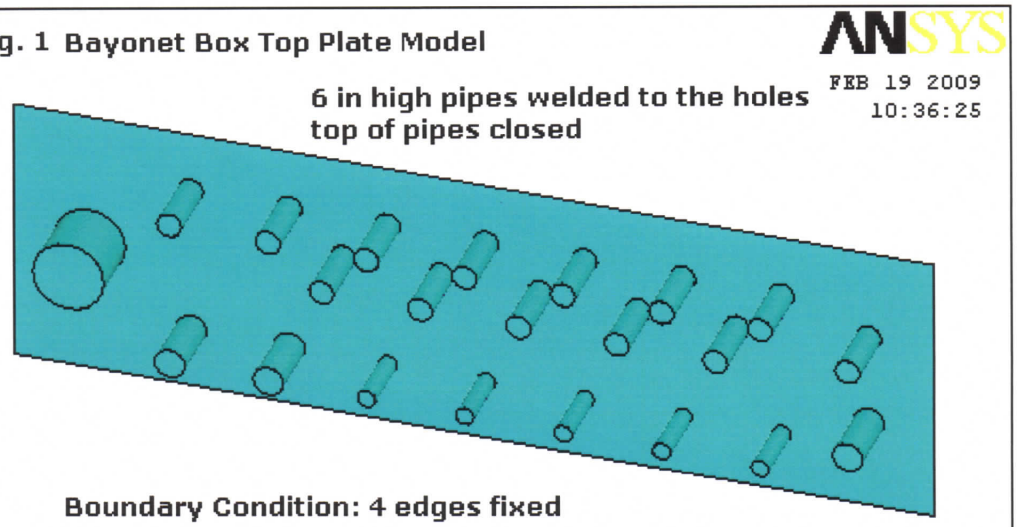
Fermi National Accelerator Laboratory
PPD / Mechanical Support / Engineering Analysis

Stress and Displacement of Bayonet Box Top Plate (Revised)

Zhijing Tang
February 19, 2009

Bayonet outer box top plate is 84 inch long, 25.75 inch wide, and 0.62 inch thick. It is made of stainless steel 304. There are quite a few holes drilled on it. It is subjected to vacuum pressure load. Besides that, on seven top row 2.25 inch holes each has 50 lb weight. In this revised model, we put 6 inch high schedule 10S pipes on the holes, so that the conditions on the holes will be more realistic. The model is shown in Fig.1. Figs. 2 and 3 show the stress and displacement distribution of the plate. The maximum equivalent stress is 11618 psi. The maximum displacement is 0.0276 in.

Fig. 1 Bayonet Box Top Plate Model



Boundary Condition: 4 edges fixed

Load: Pressure = 14.5 psi
50 lb weight on each of top row pipes

10 R2

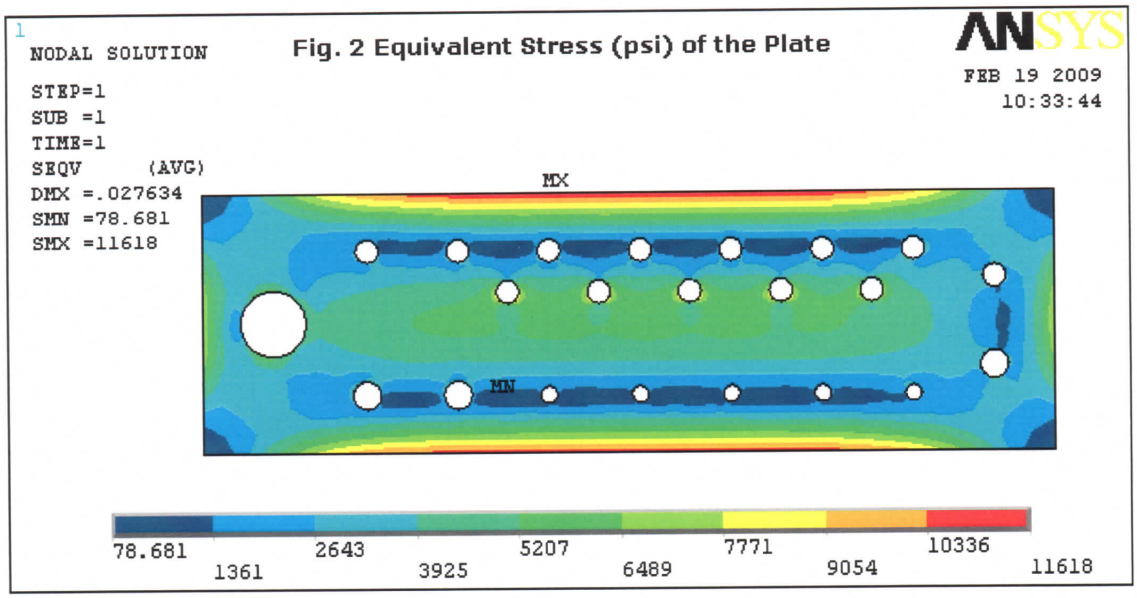


Fig. 2 Equivalent Stress (psi) of the Plate

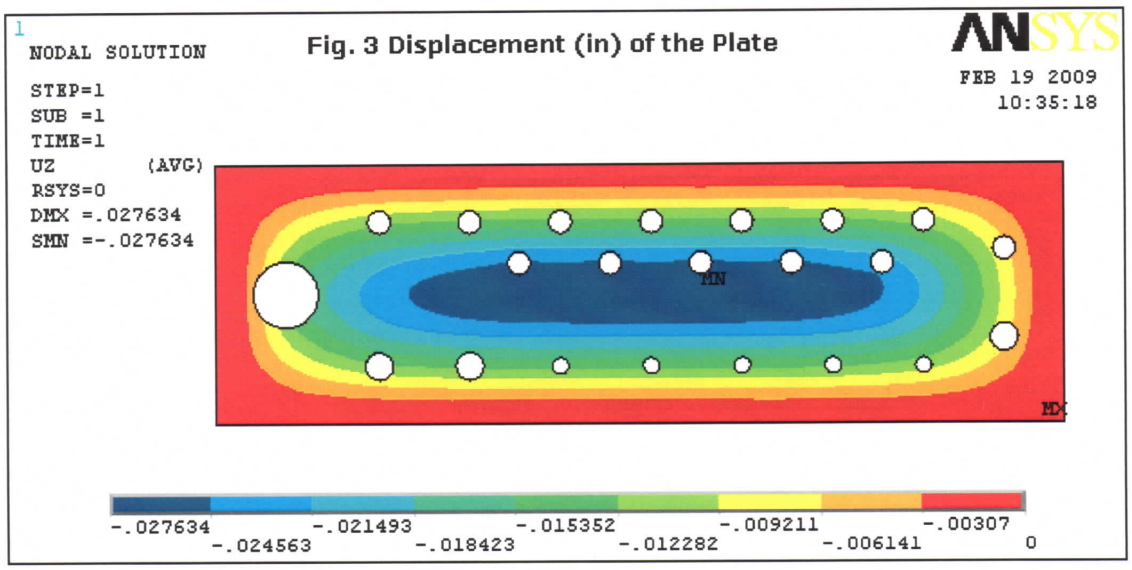


Fig. 3 Displacement (in) of the Plate

$$A = \frac{F \cdot \sqrt{T \cdot Z}}{C \cdot K \cdot P_1 \cdot K_b \cdot \sqrt{M}} = \frac{1100 \cdot \sqrt{(-288+460) \cdot 1}}{356 \cdot 0.795 \cdot [(65+14.7) \cdot 1.1] \cdot 1 \cdot \sqrt{29}} = 0.108\_in^2$$

7.A.2.e. No additional (except tanker fill) external sources exist to pressurize the dewars. Plant production will not bring the dewar's pressure over 65 psig since the Nitrogen Plant is limited at 65 psig with 20k dewars pressure reliefs.

7.A.3. As it is shown above in §7.A.2.a through §7.A.2.d the flow capacity of each of the relief is sufficient to ensure that the vessel pressure will not exceed 110% of MAWP for fire, loss of vacuum, and pumping overfill combined. Then the stamped rupture disk pressure at 70 deg.F must be less than 150%(MAWP+15)-15 = 120 psig. The installed rupture disks are 2" BS&B type RB-90 set at 95 psig.

7.A.4. Dewar has nine (9) 4" parallel plate reliefs for vacuum jacket. The discharge area for each relief is 7.069 in^2, and total available area is 63.62 in^2, which is more than the area required. The minimum required discharge area for vacuum reliefs installed on the dewar should be (according to CGA-341 6.2.4.):

$$A_{min} = 0.00024 \cdot capacity_{water} = 0.00024 \cdot \overbrace{11{,}000}^{\text{gallons}} \cdot 8.345 \frac{lb}{gal} = 22.03\_in^2$$

7.A.5. There is no rupture disk installed for the vacuum vessel.

7.A.6. The inlet and vent piping of relief devices provide for proper performance. 11k dewars have two sets of identical relief devices with 2" Worcester diverter valve incorporated into the flow path. The losses in the inlet piping are shown in §7.A.2.b. The vent losses are 0.725 psi for 4399 lb/hr of saturated gas flow @ 15 psia, plus 0.08 psi for 18,752 lb/hr of saturated liquid @ 15 psia.

LIQUID PIPELINE SIZING SUMMARY

VALUES OF PIPELINE SEGMENT		FITTINGS	NO.	EQ FT
GALLONS/MIN	46	90 DEG SHORT RAD	1	4.1
POUNDS/HR	18752	90 DEG LONG RAD	0	0.0
DENSITY, LB/CU.FT	50.43	45 DEG ELBOW	0	0.0
VISCOSITY, CP	0.15	180 DEG ELBOW	0	0.0
TEMP, DEG.F.	-320.0	TEE THRU	0	0.0
HEAD LOSS, FT	0.2	TEE BRANCH	0	0.0
INTERNAL DIA., IN.	2.469	PIPE ENTRANCE	0	0.0
VELOCITY, FT/SEC	3.1	PIPE EXIT	1	10.6
PIPE EPSILON, IN	0.0018	GATE/BALL VALVES	0	0.0
REYNOLDS NUMBER	320255	BUTTERFLY VALVES	0	0.0
FRICTION FACTOR	0.019349	GLOBE VALVES	0	0.0
PIPE LENGTH, FT	1.0	CHECK VALVES	0	0.0
EQUIVALENT FT	15.7	REDUCTN DIA, IN.	0.0	0.0
PSI DROP/100 FT	0.4963	ENLARGE DIA, IN.	0.0	0.0
TOTAL PSI DROP	0.08	MISC EQUIV.FT.		0.0

Box

$27.00 \cdot 29.38 \cdot 84.00 = 66633.84\ IN^3$

$66633.84 \div 1728 = 38.56\ FT^3$

$38.56 \cdot 7.481 = 288.47\ GAL$

$.00024 \cdot 288.47 \cdot 8.345 = .578\ IN^2$ RELIEF AREA

CAN

$\phi\ 24.0 \times 34.00$ LG.

$\pi r^2 h$

$\pi \cdot 144 \cdot 34 = 4896$

$4896 \div 1728 = 2.833$

1.167 DISHED HEADS

$4.00\ FT^3$

$4.0 \cdot 7.481 = 29.924\ GAL$

$.00024 \cdot 29.924 \cdot 8.345 = .060\ IN^2$ RELIEF AREA

XFER LINE

$\phi\ 6.63 \times 1200$ LG.

$\pi r^2 h$

$\pi \cdot 10.99 \cdot 1200 = 13187.07$

$13187.07 \div 1728 = 7.63$

$7.63 \cdot 7.481 = 57.08\ GAL$

$.00024 \cdot 57.08 \cdot 8.345 = .114\ IN^2$ RELIEF AREA

$.578 + .060 + .114 = .752\ IN^2$ TOTAL RELIEF AREA

CRYOLAB V-1046 $= .7854\ IN^2 \cdot 2 = 1.5708\ IN^2$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

LOADS:

VACUUM PRESSURE = 15 PSI
BAYONET = 15# EA.
LINE TO BAYONET = 50# @ EA. BAYONET

ASSUME 5/8" THICK STAINLESS PLATE

DENSITY OF STAINLESS = 0.29 #/IN³ (FROM RYERSON CAT.)

0.29 (5/8) = 0.18 #/IN²

WEIGHT OF BAYONET CAN ASSUMING 5/8" STAINLESS STEEL:

LONG SIDES: 84" × 31" × 2 = 5208#
TOP & BOTTOM: 84" × 27" × 2 = 4536#
END PLATES: 31" × 27" × 2 = 1674 IN²
11,418 IN²

0.18 (11,418) = 2055#

TOP PLATE:

VACUUM LOAD = 15.0 PSI PLATE WT. = 0.18 PSI
BAYONET LOAD + STINGER & PIPE = 15# + 50# = 65#

FROM ROARK & YOUNG:

TABLE 26 PAGE 464, CASE 8a

MAX σ = $-\beta q b^2/t^2$ a/b = 72/27 = 2.7

= 0.5000 (15.18)(27)²/0.625² β @ 2.0 = 0.4974

= -14,165 PSI β @ ∞ = 0.5000

ALONG EDGE USE β₁ = 0.5000

TABLE 26 PAGE 464 CASE 8b r'₀ = r₀ = 2"/2 = 1.0"

MAX σ = $-\beta_2 W/t^2$ β₂ = 1.008

= -1.008 (65)/0.625²

= -168 PSI FOR EA. LOAD

FOR 7 LOADS:

7(168) = 1,176 PSI

TOTAL NEG. STRESS @ CENTER OF LONG EDGE =

14,165 + 1,176 = **15,341 PSI**

ALLOWABLE LOAD FROM ASME BOILER & PRESSURE VESSEL CODE PART D, TABLE 1-A PAGE 108 = 18.8 KSI FOR SA 304 SS = 18,800 PSI > 15,341 PSI ok

USE 5/8" PLATE

VERIFY RESULTS FINITE ELEMENT ANALYSIS
MODELED BY Z. TANG. SEE FOLLOWING PAGES
FOR REPORT. MAXIMUM STRESS < 16,549 PSI
(IGNORE LOCAL STRESS AROUND OPENINGS)

MAX. ALLOW. STRESS = 18,800 PSI OK

Fermi National Accelerator Laboratory
PPD / Mechanical Support / Engineering Analysis

Valve Box under Vacuum Pressure

Zhijing Tang

February 11, 2005

The valve box under vacuum pressure is analyzed using finite element method. The box is 72 inch long, 27 inch wide and 31 inch high. The material is 5/8 inch stainless steel 304. There are seven tubes with diameter 2 inch on the top, each weighs 15 lbs. In addition to that there is 50 lbs load on each tube plus vacuum suction. So the total load on each hole is about 111 lbs.

Fig.1 is the stress plot, Fig. 2 is the total displacement and Fig.3 is the z-direction displacement.

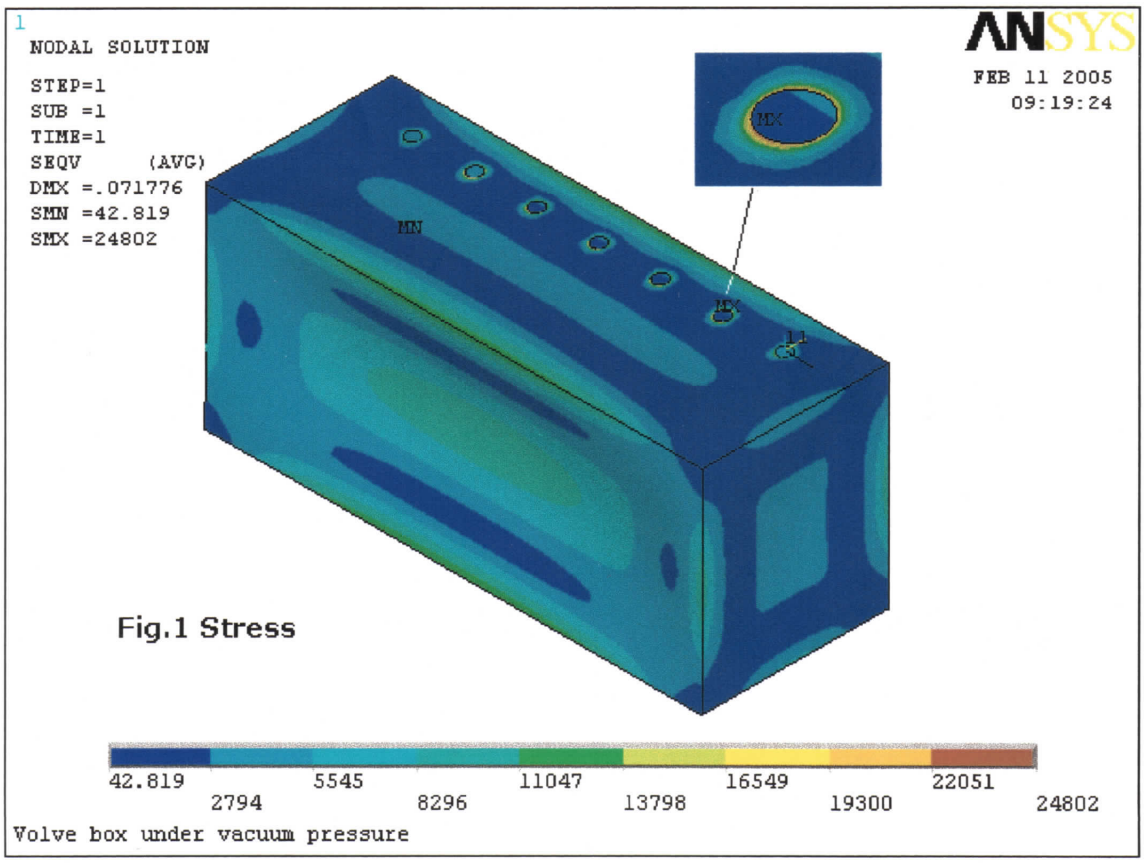


Fig.1 Stress

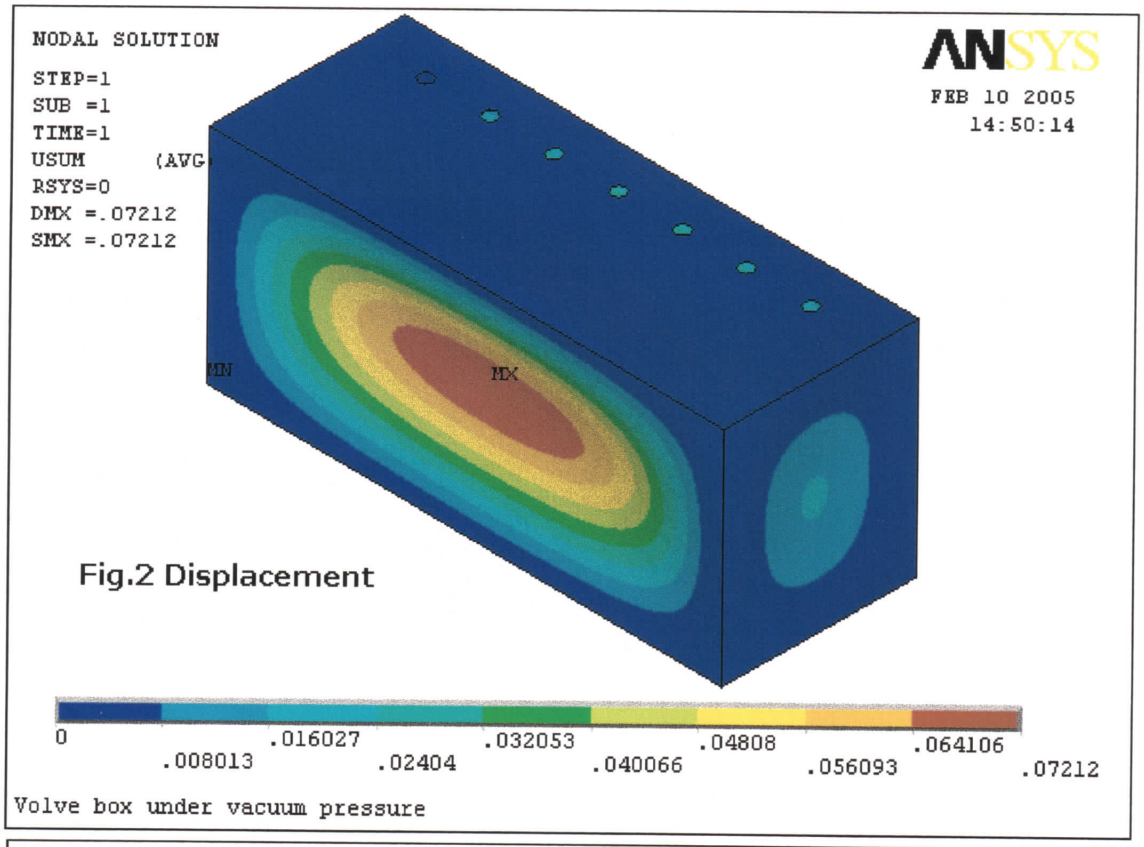


Fig.2 Displacement

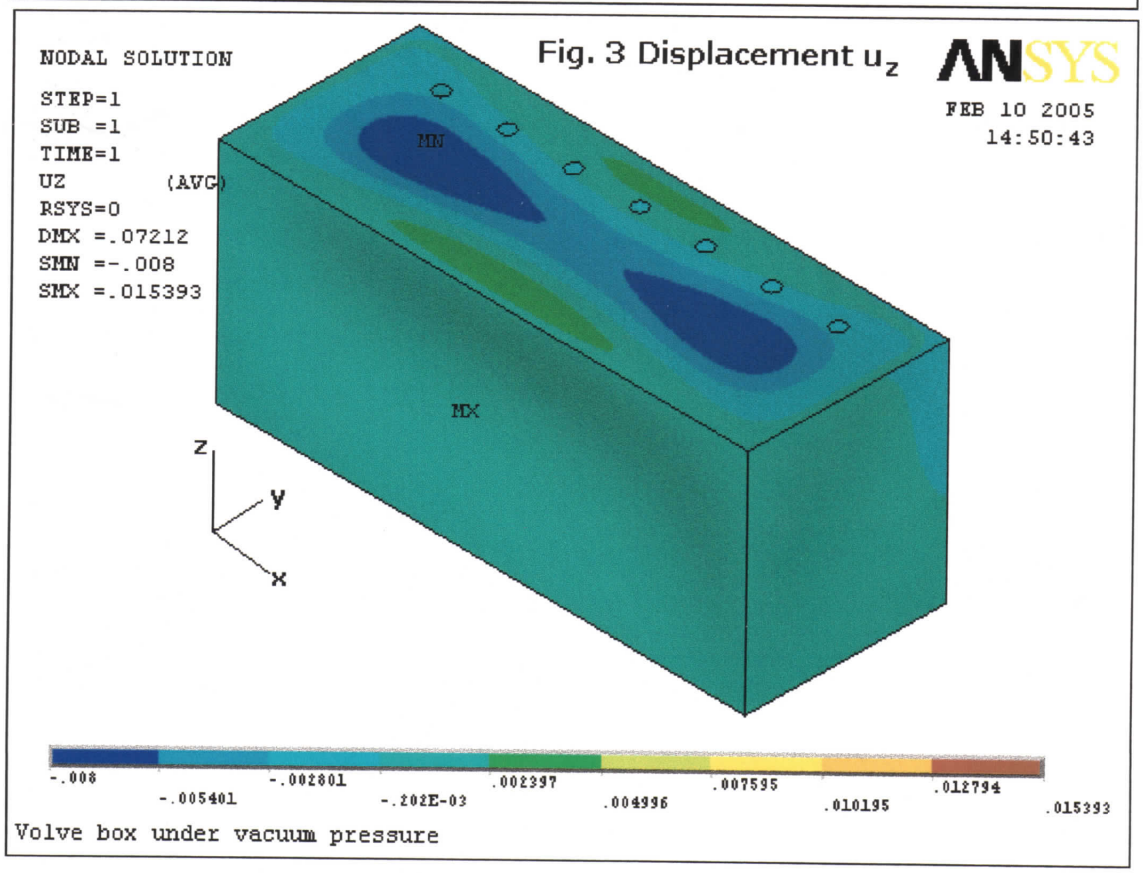


Fig. 3 Displacement u_z

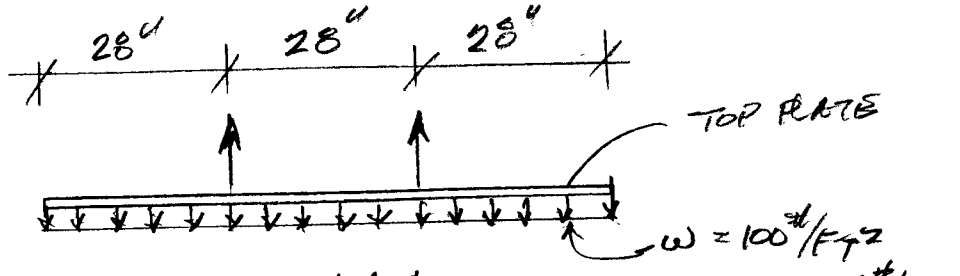
TABLE ULT-23
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR 5%, 8%, AND 9% NICKEL STEELS, TYPE 304 STAINLESS STEEL, AND 5083-0 ALUMINUM ALLOY AT CRYOGENIC TEMPERATURES FOR WELDED AND NONWELDED CONSTRUCTION

5% Nickel Steels Plates: SA-645[2]				8% and 9% Nickel Steels Plates:[2] SA-353, SA-553 Type I, and SA-553 Type II Pipes and Tubes: SA-333 Grade 8 and SA-334 Grade 8 Forgings: SA-522			
		Welded Construction[3]				Welded Construction	
Temperature,[1] °F	Nonwelded Construction, ksi	UTS 100 ksi	UTS 95 ksi	Temperature,[1] °F	Nonwelded Construction, ksi	UTS 100 ksi	UTS 95 ksi
-320	37.7	34.0	32.3	-320	38.4	34.0	32.3
-300	34.5	33.2	31.6	-300	37.2	33.2	31.6
-250	32.4	31.8	30.3	-250	34.8	31.8	30.3
-200	31.5	30.6	29.1	-200	32.6	30.6	29.1
-150	30.2	29.3	27.8	-150	30.6	29.3	27.8
-100	28.8	28.1	26.7	-100	29.0	28.1	26.7
- 50	27.4	27.1	25.8	- 50	27.7	27.1	25.8
0	23.7	23.7	23.7	0	25.0	25.0	23.7
100	23.7	23.7	23.7	100	25.0	25.0	23.7

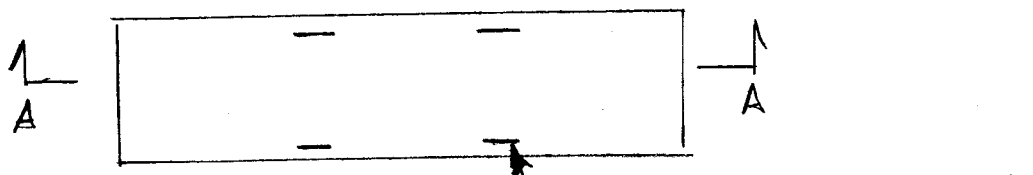
TYPE 304 STAINLESS STEEL

		Specified Minimum Strengths at Room Temperature		Maximum Allowable Stress, ksi, for Temperatures,[1] °F, Not Exceeding								
Spec. No.	Grade	Tensile, ksi	Yield, ksi	-320	-300	-250	-200	-150	-100	-50	0	100
SA-240	304	75.0	30.0	20.7	20.6	20.3	20.0	19.7	19.4	19.1	18.8	18.8

LIFTING LUGS:



SECTION A-A



TOP VIEW

$M_R = -0.694(28)/2 = -9.72$ #-IN

$M_C = w/8\,(L-4a)$

$= 0.694(84)/8\,(84-4(28))$

$= -204$ #-IN

MAX BENDING STRESS $= 204/0.065$

$= 3139$ psi $< 18{,}800$ psi

OK

LOAD PER LUG:

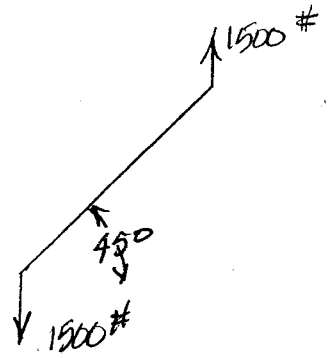
$(84(25.75)(0.694))/4 = 375$ #/LUG

DESIGN LUG FOR 1500# LOAD

SAFETY FACTOR $= 1500/375$

$= 4.00$

MIN. SLING ANGLE $= 45°$



HORIZ LOAD = 1500 (1/TAN 45)
= 1500(1)
= 1500 #

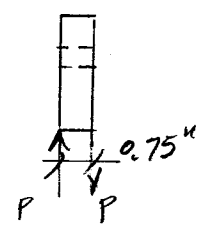
FOR WEAK DIRECTION LOAD:
CENTER OF LUG OPENING = 1.25 ABOVE BASE
MOMENT = 1.25(1500)
= 1875 #-IN

FOR 3/4" THICK PL, 3" LONG:

$S_y = 3(0.75)^2/6$
$= 0.281 \text{ IN}^3$

$f_b = 1875/0.281$
$= 6,673 \text{ psi} < 18,800 \text{ PSI}$ ok

REQUIRED WELD:



$P = 1875/0.75 = \pm 2500\#$

FOR 1/4" WELD 3" LONG,

TENSION:
$0.60 F_y = 0.60(35,000)$
$= 21,000 \text{ psi}$

$0.707(21,000)(1/4) = 3,712 \#/\text{IN}$

OMITTING 1ST 1/2" & LAST 1/2" WELD:
ALLOW. $P = (3" - 2(0.5")(3712)$
$= 7,424\# > 1875\#$ ok

SHEAR:
$0.3(.707)(35,000)(1/4) = 1856 \#/\text{IN}$

OMITTING 1ST 1/2" & LAST 1/2" WELD:

ALLOW. $P = (3" - 2(0.5"))(1856)$
$= 3712\# > 1875\#$ ok

COMBINED LOADING:

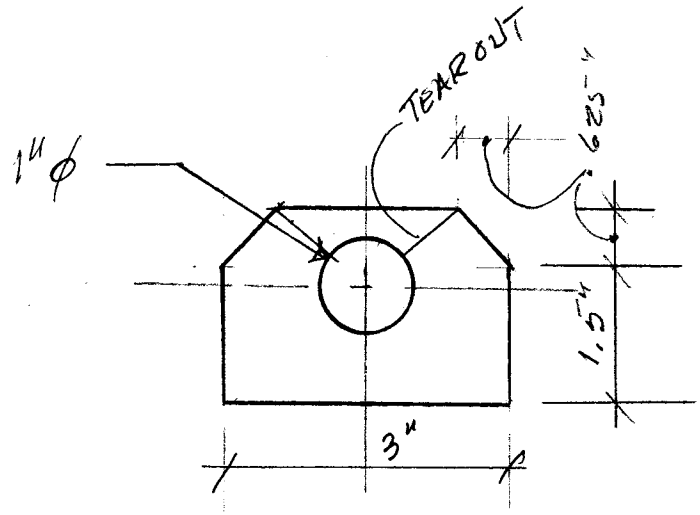
SHEAR + TENSION $1875/3712 + 1875/7424 \overset{?}{\leq} 1.0$

$0.505 + 0.253 \overset{?}{\leq} 1.0$

$0.758 < 1.0$ ok

USE 1/4" FILLET WELD
FULL LENGTH BOTH SIDES.

TEAR OUT SHEAR @ HOLE



SHEAR AREA = 3/4 (3/4) = 0.5625"

ALLOW. SHEAR = 0.40 F_y = 0.4 (35000)
= 14000 PSI

14,000 (0.5625) × 2 SIDES = 15750#
> 1500# ok

CHECK LUG FOR CAPACITY TO CARRY COMPLETE BOX LOAD

OUTSIDE BOX:

2 SIDES @ 84(29.38)(2) = 4936
BOTTOM @ 84(27.25) = 2289
2 ENDS @ 29.38(27.25)(2) = 1601
8826 IN²

FOR 5/8" THICK PLATE:

5/8(8826) = 5516 IN³

FOR 304 STAINLESS:

5516(0.694) = 3828#

TOP PLATE & PIPING = 1500#
5328#
+ MISC. 500#
5828# SAY 6000#

LOAD/LUG = 6000/4
= 1500#

FOR 2-1 SAFETY FACTOR, USE 3000# LOAD

WEAK AXIS BENDING:

M_y = 1.25(3000) = 3750#-IN

f_b = 3750/0.281 = 13345 psi < 18,800 psi ok

TEAR OUT SHEAR = 15700# ALLOW. > 3000# ok

WELD SIZE MUST BE INCREASED, TRY 5/16"

ALLOW. SHEAR = 0.3(0.707)(35000)(5/16) = 2320#/IN
ALLOW. P = 2320(3 - 2(0.5")) = 4640#

ALLOW TENSION = 0.707(21,000)(5/16) = 4640#/IN
ALLOW P = 4640(3 - 2(0.5")) = 9280#

3000/4640 + 3000/9280 = 0.970 < 1.0 ok

USE 5/16" FILLET WELD

PART C

COOL DOWN CALCULATIONS FOR CONTRACTION OF THE ONE INCH TUBING WITHIN THE BAYONET BOX

5K SUPPLY (FIGURE I)

$\Delta L = (304 \times 10^{-5}) L$

$= (304 \times 10^{-5})(9.4)''$

$= 0.029''$

.049" WALL TUBING

$I_{TUBE} = 0.049087 (d^4 - d_i^4)$

$= 0.049087 (1^4 - 0.9^4)$

$= 0.0166 \text{ IN}^4$

$y = Pl^3 / 3EI$

$y(3EI)/l^3 = P$

FIX @ PT "A"

$\frac{0.029(3)(28 \times 10^6)(0.0166)}{(19+29)^3} = 0.37\#$

$M = 0.37(19+29) = 17.6 \#\text{-IN}$

$f_b = Mc/I = 17.6(0.5)/0.0166$

$= 528 \text{ psi}$ ok

FIX @ PT. "A"

$\Delta L = (304 \times 10^{-5})(19+29)$

$= 0.15''$

$y(3EI)/l^3 = P$

$\frac{0.15(3)(28 \times 10^6)(0.0166)}{(9.4)^3} = P$

$252\# = P$

$M = 252(9.4) = 2369 \#\text{-IN}$

$f_b = Mc/I = 2369(0.5)/0.0166$

$= 71{,}400$ PSI N.G TOO LARGE

(SEE REVISION ON PAGE 5)

5K RETURN (FIGURE I)

$\Delta L = 304 \times 10^{-5}(7.7+3.0+7.7)$

$= 0.056''$

FIX @ PT "A"

$\frac{0.056(3)(28 \times 10^6)(0.0166)}{(19+29)^3} = 0.71\#$

$M = 0.71(19+29) = 34 \#\text{-IN}$

$f_b = 34(0.5)/0.0166 = 1024 \text{ psi}$ ok

CHECK BOTTOM ELBOW @ PT. "B"

$$\frac{(0.056/2)(3)(28\times10^6)(0.0166)}{(7.7^3+3.0^3+7.7^3)} = 42\#$$

$$M = 8.458(42) = 355\#\text{-IN}$$

$$f_b = 355(0.5)/0.0166 = 10{,}700\ \text{psi}\ \underline{\underline{ok}}$$

CHECK VERT. CONTRACTION

$$\Delta L = (19+29)(304\times10^{-5}) = 0.15''$$

$$\frac{0.15(3)(28\times10^6)(0.0166)}{(7.7+3.0+7.7)^3} = P$$

$$= 33.6\#$$

$$M = 33.6(7.7+3.0+7.7) = 618\#\text{-IN}$$

$$f_b = 618(0.5)/0.0166 = 18{,}622\ \text{psi} < 18{,}800\ \text{psi}$$

$\underline{\underline{ok}}$

14K SUPPLY (FIGURE IV)

$\Delta L = 26(304 \times 10^{-5}) = 0.08''$

$y(3)EI/\ell^3 = P$

$\frac{0.0166(.08)(3)(28\times10^6)}{(19)^3} = 16\#$

@ PT. C:

$M = 16(19) = 304$ #-IN

$f_b = Mc/I = 304(0.5)/0.0166$

$= 9{,}157$ PSI ok

$y(3)EI/\ell^3 = P$

$0.0166(0.08)(3)(28\times10^6)/(9^3+21^3+12^3+19^3)$

$= 6.00\#$

@ PT. C:

$M = 6.00(19) = 114$ #-IN

$f_b = 114(0.5)/0.0166 = 3{,}434$ PSI ok

BETWEEN VALVES:

$\Delta L = 9(304\times10^{-5}) = 0.0274$

$P = y(3)(EI)/\ell^3 = \frac{\left(\frac{0.0274}{2}\right)(3)(28\times10^6)(0.0166)}{(20)^3}$

$= 2.38\#$

$M = 2.38(20) = 47.6$ #-IN

$f_b = 47.6(0.5)/0.0166 = 1434$ PSI ok

14K SUPPLY (CON'T) (FIGURE III)

$\Delta L = 44.4\,(304 \times 10^{-5}) = 0.135''$

$y(3)(EI)/(\ell)^3 = P$

$3(0.0166)(0.135)(28 \times 10^6)/(29^3 + 18^3) = 5.77\#$

$M = 5.77\,(18+29) = 271\ \#\text{-IN}$

$f_b = 271(0.5)/0.0166 = 8168$ psi ok

$y(3)(EI)/\ell^3 = P$

$3(0.0166)(0.135)(28 \times 10^6)/(9^3 + 18^3 + 9^3) = 25.8\#$

$M = 25.8(24) = 620\ \#\text{-IN}$

$f_b = 620(0.5)/0.0166 = 18{,}675$ PSI ok

WITHIN 10% ok

20K RETURN (FIGURE II)

$\Delta L = 37.4\,(304 \times 10^{-5}) = 0.114''$

$y(3)(EI)/(\ell)^3 = P$

$3(0.0166)(0.114)\,(28 \times 10^6)/(29^3 + 22^3) = 4.54\#$

$M = 4.54\,(22+29) = 232\ \#\text{-IN}$

$f_b = 232(0.5)/0.0166 = 6974$ psi ok

$y(3)(EI)/\ell^3 = P$

$3(0.0166)(0.114)(28 \times 10^6)/(9^3 + 18^3 + 9^3) = 21.8\#$

$M = 21.8(28) = 610\ \#\text{-IN}$

$f_b = 610(0.5)/0.0166 = 18{,}390$ psi

WITHIN 10% ok

REVISED DESIGN FOR 5K SUPPLY (FIGURE I)

$$\Delta_L = (304 \times 10^{-5})(19+29)$$
$$= 0.15''$$

$$y(3EI)/\ell^3 = P$$

$$\frac{0.15(3)(28\times10^6)(0.0166)}{(4.88+4.5+6.0+6.0)^3} = P$$

$$21.4^{\#} = P$$

$$M = 21.4(9.4) = 201^{\#-IN}$$

$$f_b = Mc/I = 201(0.5)/0.0166$$
$$= 6060 \text{ psi } \underline{\underline{ok}} \quad < 18{,}800 \text{ psi}$$

SEE FIGURE V

Mucooler LN2 Box Tubing Contraction Analysis

Section Length between ends	X (width)	Y (height)	Z (length)
	-9.75	-11.25	-71.5
	19.5	-10.75	76.5
	-10	13.218	-76.5
	7	13.032	76.5
			-66.75
Effective length between fixed ends	6.75	4.25	-61.75

Stainless steel tubing properties

cte =	1.10E-05	per K
E =	2.80E+07	psi
OD =	1	inch
ID =	0.902	inch
wall t =	0.049	inch
I =	0.0165939	inch^4
L =	26.25	inch

ΔT = 216 K

ΔX, inch	Δy, inch	ΔZ, inch
0.016038	0.010098	-0.146718

Resultant, ΔL, due to ΔX and ΔZ
0.147592 inches

WORST CASE ANALYSIS

Assuming all ΔL occurs at the outlet tubing that has the longest L of 26.25".
This displacement will create a cantilever-mode bending stress on the tubing at top wall connection.

Force P created due to displacement ΔL, (P = 3*E*I*ΔL/L^3), =	11	lb
Bending moment, M, created (M = P*L) =	299	inch-lb
Bending stress, S (S = M*(OD/2)/I), =	8,996	psi
Allowable stress, Fb, for 304 stainless steel tubing =	18,800	psi

AS BENDING STRESS IS < THE ALLOWABLE STRESS, TUBING WILL BE OK.

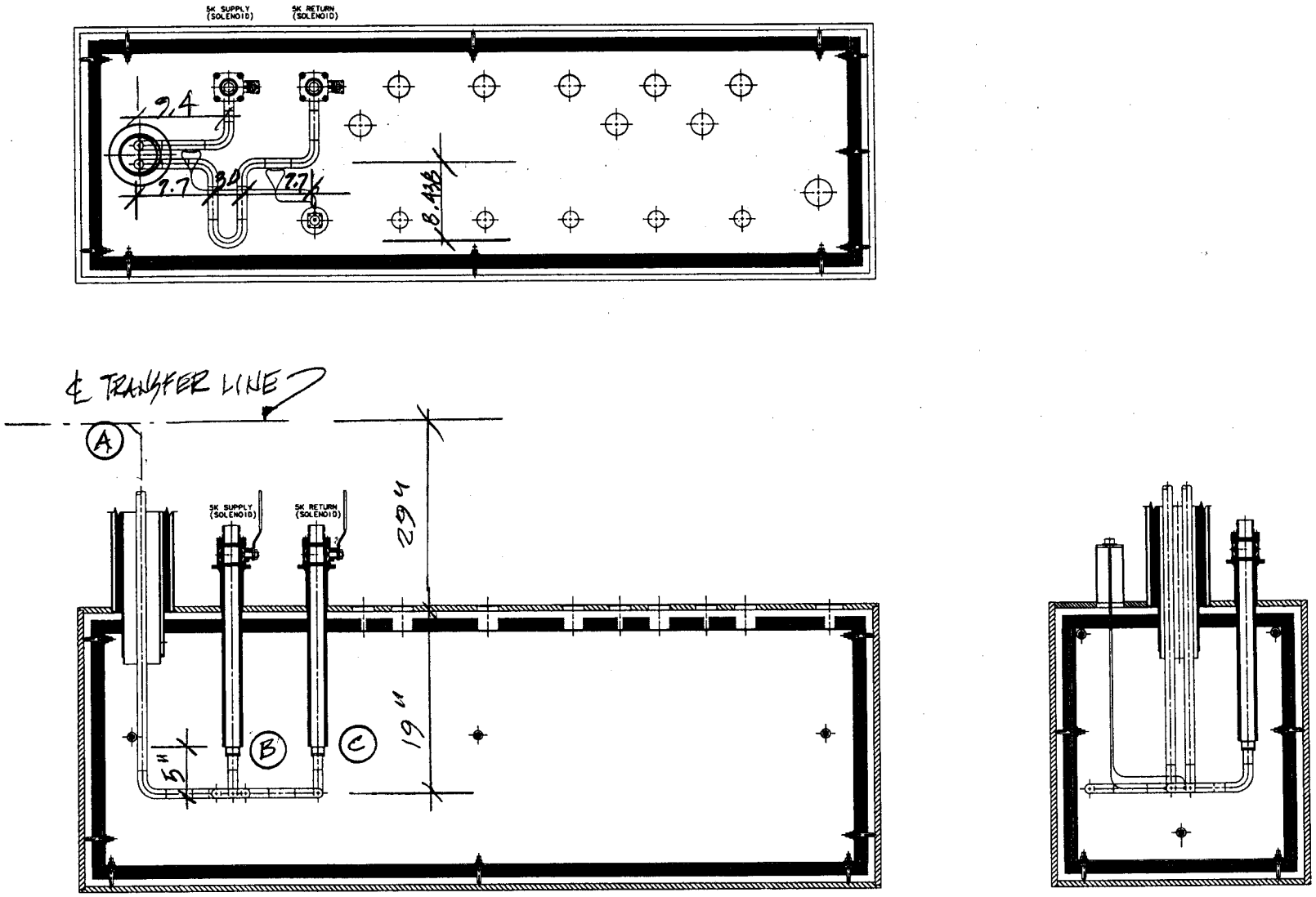


FIGURE I

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE

UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON
4. MAX. ALL MACH. SURFACES
5. DRAWING UNITS:

ORIGINATOR
DRAWN
CHECKED
APPROVED
USED ON
MATERIAL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SCALE | DRAWING NUMBER | SHEET 1 OF 1 | REV

CREATED WITH: | GROUP:

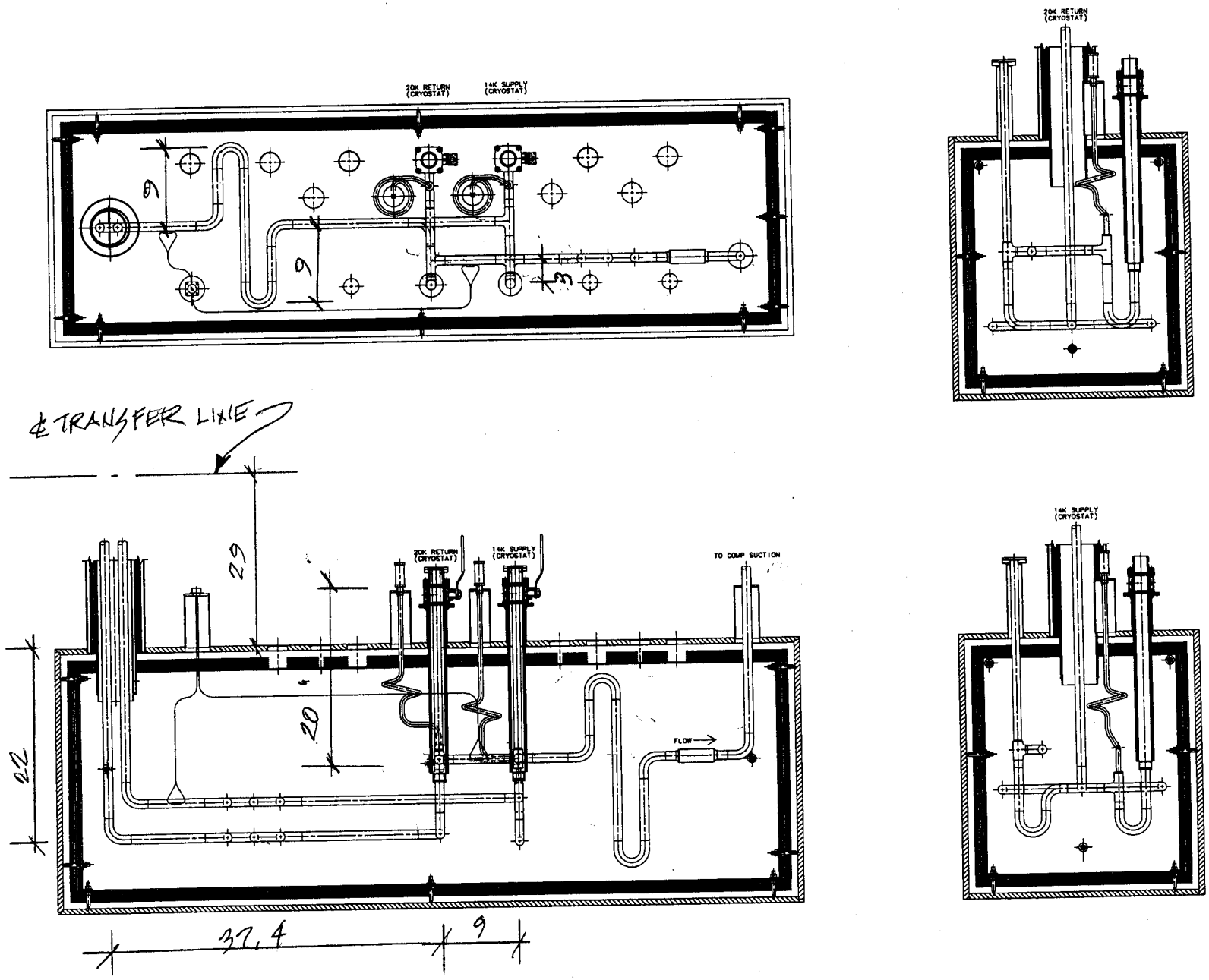


FIGURE II

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE

UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS MADE UPON
4. MAX. ALL MACH. SURFACES
5. DRAWING UNITS:

ORIGINATOR
DRAWN
CHECKED
APPROVED
USED ON
MATERIAL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SCALE | DRAWING NUMBER | SHEET 1 OF 1 | REV

CREATED WITH : | GROUP:

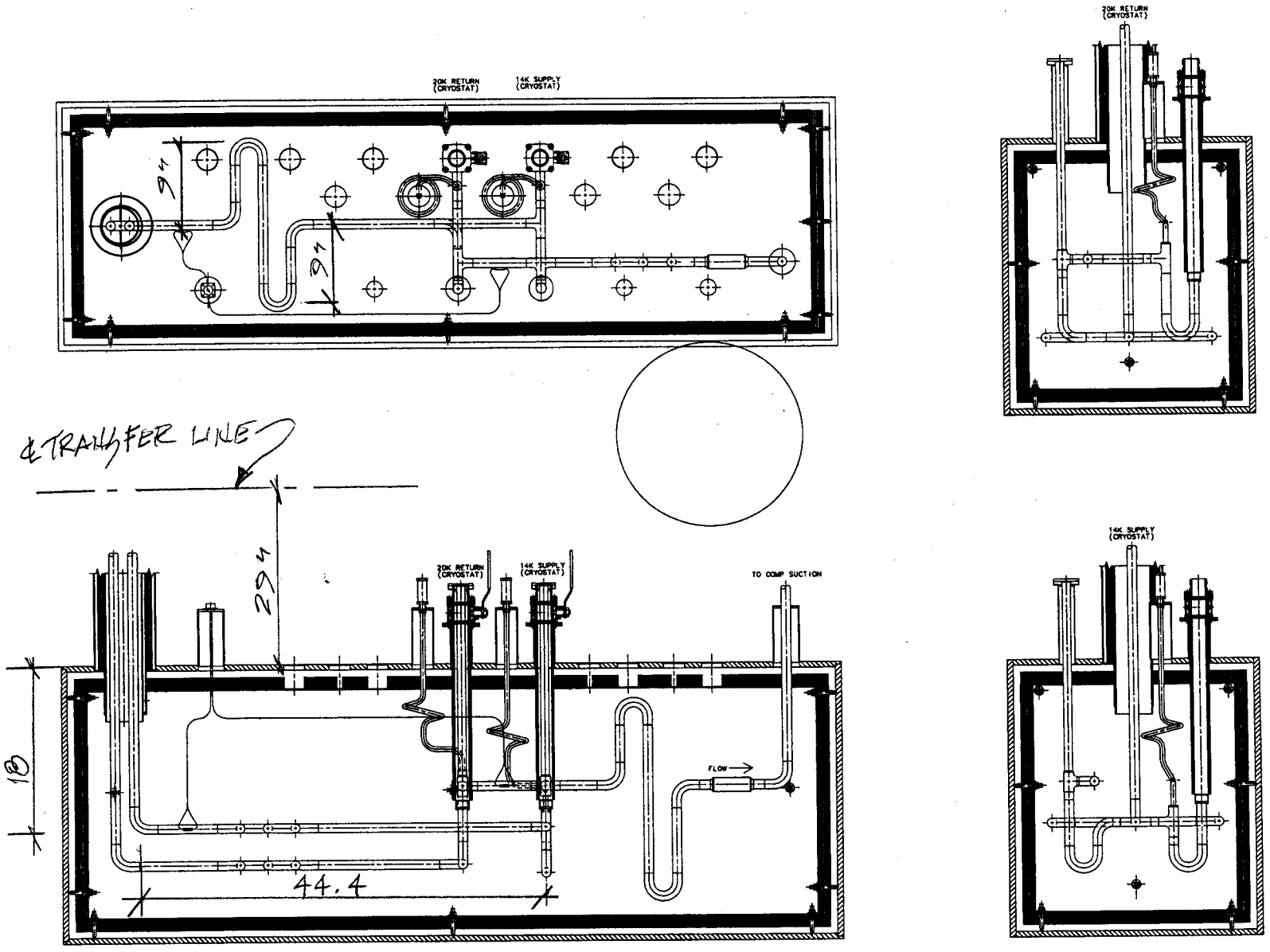


FIGURE III

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE

UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES
2. DO NOT SCALE DRAWING
3. DIMENSIONS SHOWN
4. MAX. ALL MACH. SURFACES
5. DRAWING UNITS:

ORIGINATOR
DRAWN
CHECKED
APPROVED
USED ON
MATERIAL

FERMI NATIONAL ACCELERATOR LABORATORY
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SCALE | DRAWING NUMBER | SHEET 1 OF 1 | REV

CREATED WITH : | GROUP:

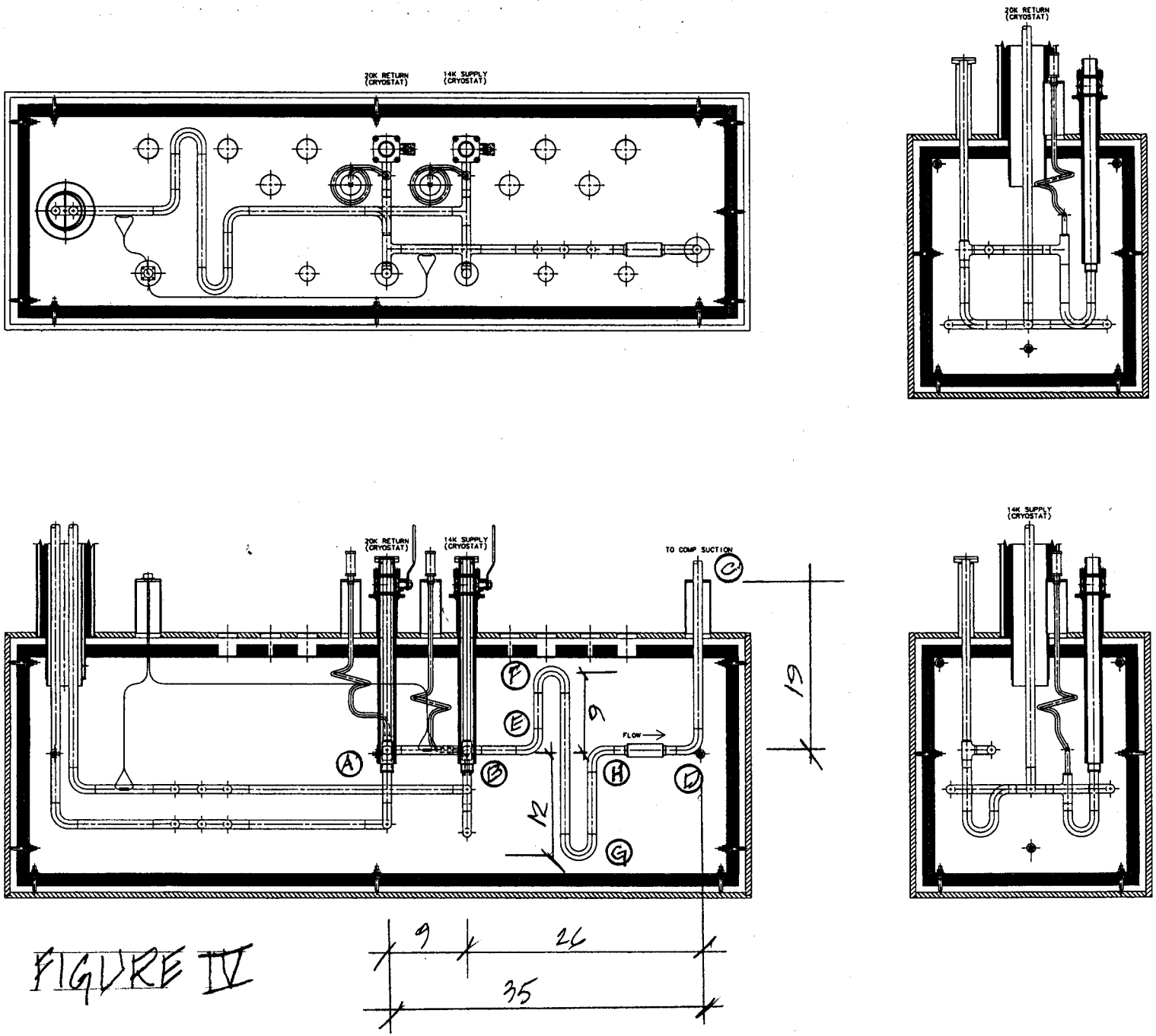

FIGURE IV

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE

UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS MADE OVER
4. MAX. ALL MACH. SURFACES
5. DRAWING UNITS:

ORIGINATOR
DRAWN
CHECKED
APPROVED
USED ON
MATERIAL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SCALE | DRAWING NUMBER | SHEET 1 OF 1 | REV

CREATED WITH : | GROUP:

1" 304 [illegible]

[illegible]

ELB[illegible]

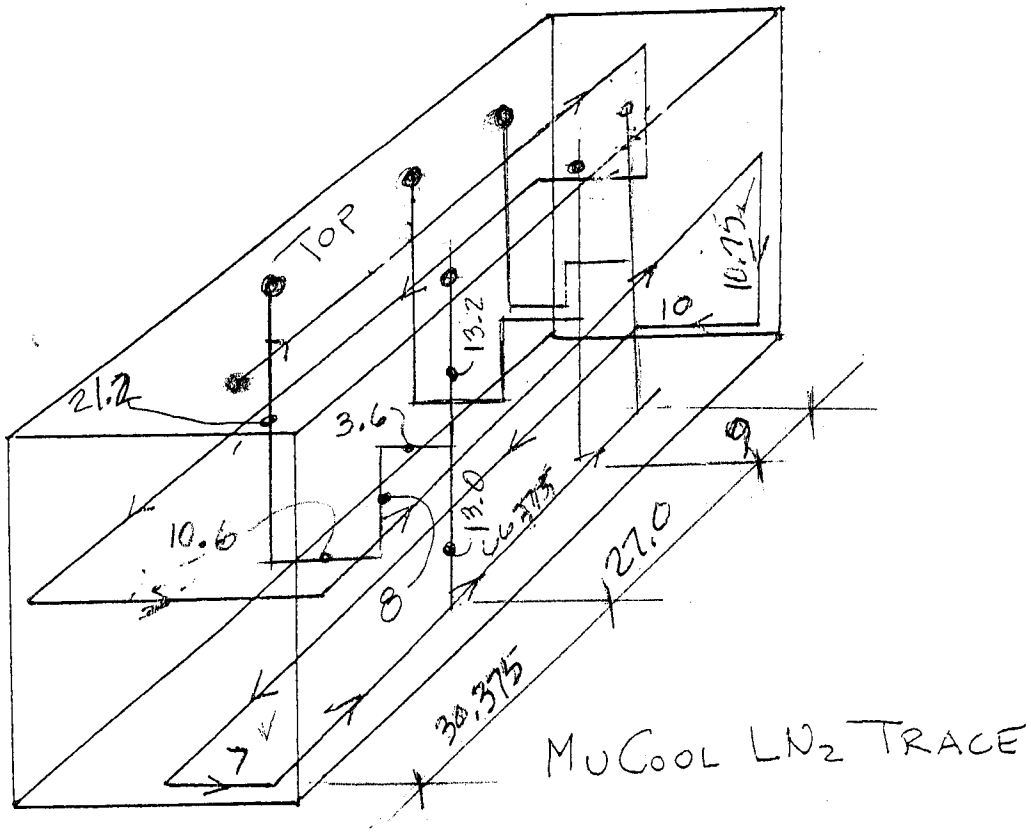

FIGURE V

1" 304 [illegible]

.049 [illegible]

ELBOW [illegible]

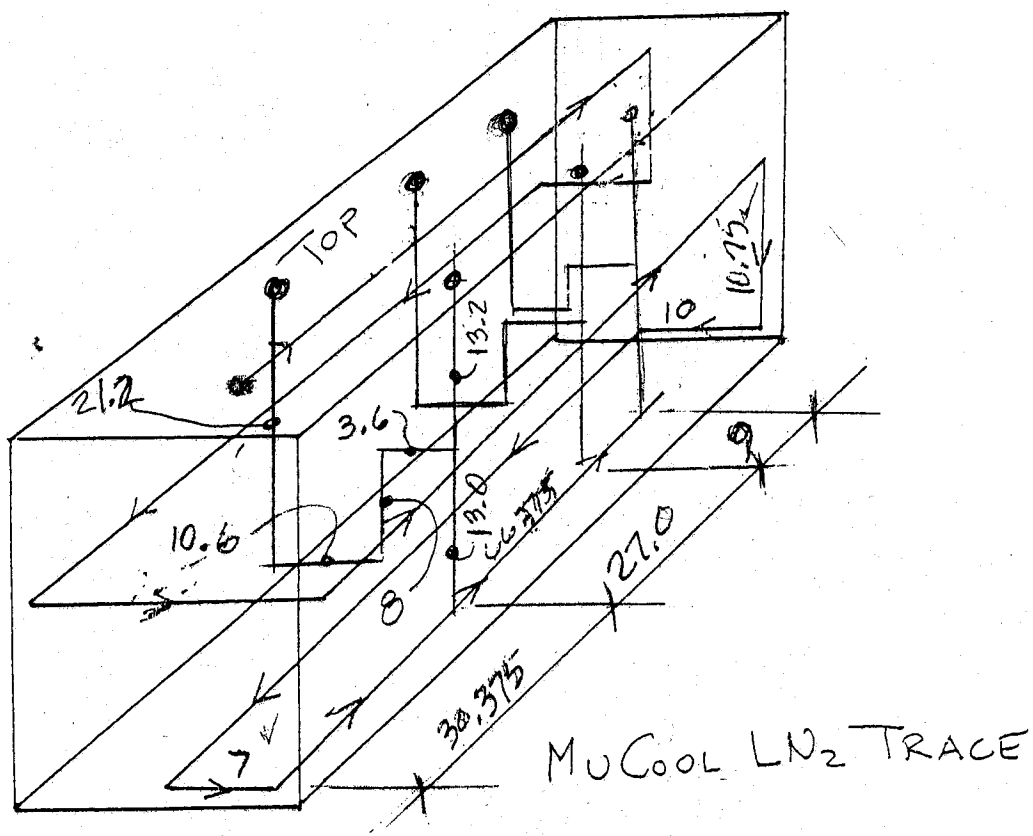

FIGURE V