BROOKHAVEN NATIONAL LABORATORY

LHC PROJECT
MEMORANDUM

Date: 10 April 2002
To: Richard Thomas, Chmn, CSC
From: Steve Plate
Subj: Review of LHC D1 Phase Separator

Attached is an engineering analysis of the phase separator unit of the LHC D1 cryogenic magnet. Please circulate it to the other committee members for review and approval.

DESCRIPTION:
The LHC D1 magnet is cooled via a bath of pool boiling liquid helium at 1.9K. The phase separator is part of the cooling circuit, operating at 4 bar (60 psia) and tested at 5 bar (75 psia), and is a reservoir in the vapor return line. Its function is to trap liquid that is entrained in the vapor that would otherwise collect elsewhere at low points in the piping; this would prohibit proper pumping. The phase separator is not subject to the higher pressure of the cold mass, which operates at 20 bar. The reservoir is located under the cold mass, one near each end of the magnet. Passive heaters are used to boil off liquid that might accumulate in the reservoir, and liquid presence temperature sensors are used as instrumentation to verify evaporation of any liquid collected.

As shown on the drawing and the accompanying parts list, the phase separator is made up of a number of components: the reservoir shell and closure heads, inlet and outlet tubes and tube fittings, and mounting features. The shell is fabricated from 5 inch 304 SST pipe, sch. 10, and is 38.8 inches long and 5.6 inches in diameter. The heads are made from 304 SST plate, 0.5 inches thick and are attached to the cylinder using full penetration welds. The stress analysis of the shell and heads is attached.

Tubing and welded tube fittings of 2.00 inch diameter x .065 inch wall form the inlet line that brings the mixed phase helium vapor into the phase separator. The line is inserted through one head. All tubing welds are butt type, full penetration, but are not x-rayed; the weld efficiency factors used in the calculations match this lower level of inspection. The analysis that follows contains an FEM stress plot for the off-center penetration of the inlet line through the head.

A vapor outlet tube (2.00 inch diameter) penetrates the shell of the phase separator as shown in the drawing. The stress analysis for this non-radial penetration is attached. This size and wall thickness tubing has been used before at higher pressures and meets Code requirements at those pressures. Therefore the following analysis does not show calculations for the tubing alone.

The four parts labeled as item 10, two mounted at 20° and two at 40°, are mounting lugs used only to locate the phase separator properly under the magnet cold mass. They are not part of the pressure vessel.

The temperature sensors are external to the phase separator and are fastened to a small copper bar attached mechanically to the U-shaped tube. They are not part of this analysis, nor should they be. Only the tube, which is the passive heater, is a part of the pressure vessel. This tube is fabricated from 316L SST, and is .375 inches diameter x .049 inches wall thickness. It has not been analyzed formally, but by inspection will meet ASME Code requirements.

The results of the analysis show that the phase separator is far below the allowable stress levels in all areas analyzed. The tubing is also used at low stress levels. The welded connections meet the ASME Code as well.

LHC MAGNET D1

PHASE SEPARATOR STRESS ANANYSIS

P/N 14010265

Steve Plate

PART NUMBER.......	DESCRIPTION...........	QPA.....	UM.	PN.REV	PL.REV	ITM NBR	REF. DESG	COMMENTS..........
14010265	PHASE SEPARATOR ASSEMBLY		EA	C	C			
14010282	SHELL, PHASE SEPARATOR	1.0000	EA	A		1		
14010283	FLANGE,PHASE SEPARATOR FRONT	1.0000	EA	A		2		
14010284	FLANGE, PHASE SEPARATOR REAR	1.0000	EA	A		3		
14010285	TUBE, LONG	1.0000	EA	A		4		
14010286	TUBE, SHORT	1.0000	EA	A		5		
14010289	ELBOW,90 DEGREE	3.0000	EA	0		6		
14010371	TUBE,HEAT TRANSFER,PHASE SEPARATOR ASSY	1.0000	EA	B		7		
14010288	TUBE, INCLINED, PHASE SEPARATOR ASSY	1.0000	EA	A		8		
12010441-02	FILLER WIRE, WELDING	0.0000	LB	B		9		
14010486	AXIAL RESTRAINT	4.0000	EA	0		10		

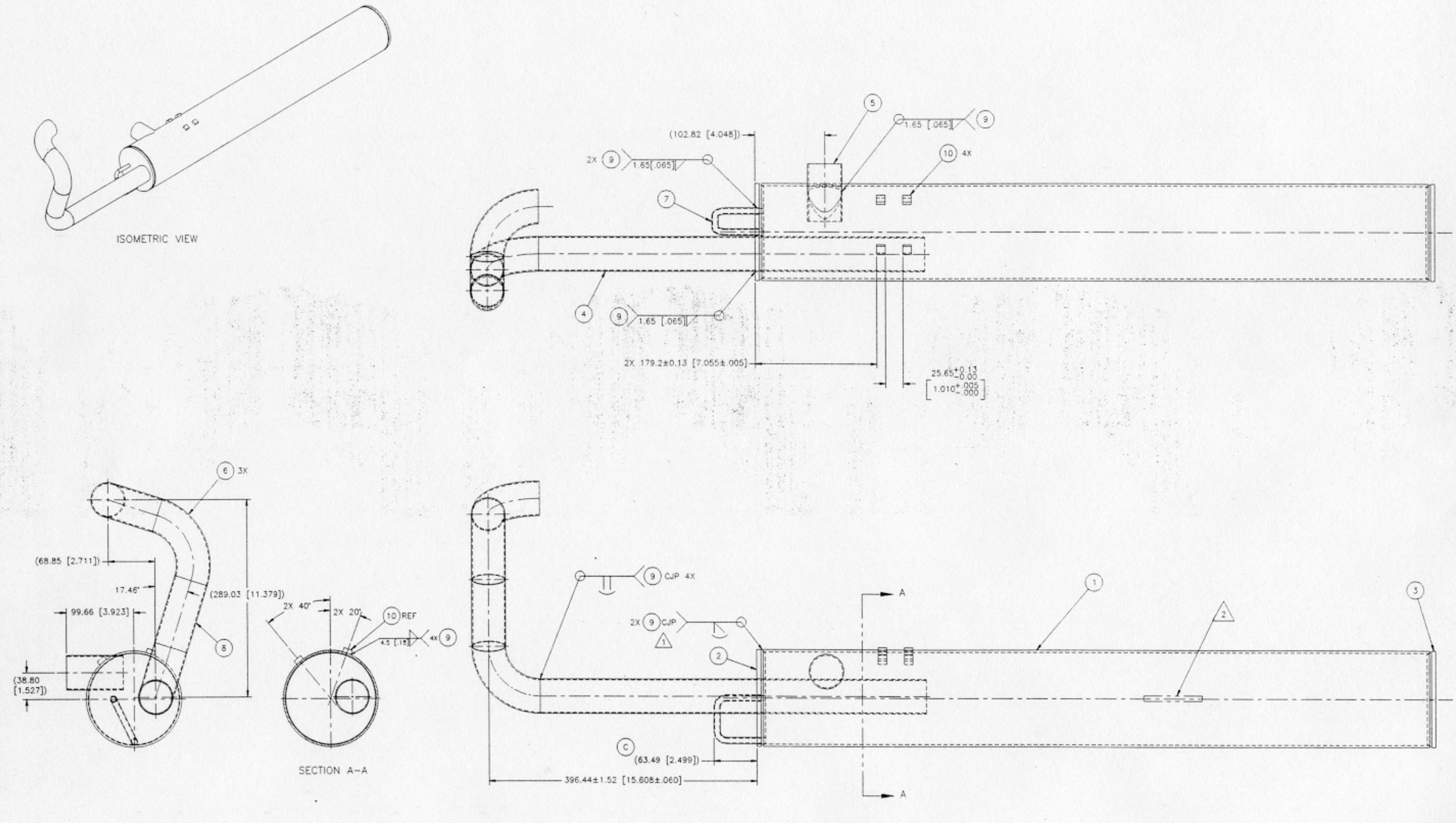
***

[redacted].

NOTES:

1. VACUUM LEAK TEST: LEAK RATE NOT TO EXCEED 2 X 10^{-10} STD CC HELIUM/SEC PER RHIC-CR-E-4703-0041.
2. RUBBER STAMP ASSY14010265- APPLICABLE REV LTR, LOCATED APPROX. AS SHOWN PER MIL-STD-130, USING 3 [.12] HIGH CHARACTERS.

REVISIONS							
REV	ZONE	ECN NO.	DESCRIPTION	BY	DATE	CKR	APP
A			INITIAL RELEASE	BW	[illegible]		
B		MG2052	AS PER ECN	NW	[illegible]		
C		MG2072	AS PER ECN	BW	[illegible]		



SEE SEPARATE PARTS LIST PL14010265

OUTSTANDING ECN NUMBERS

INTERPRET IN ACCORDANCE WITH ASME Y14.24M-1989

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN MILLIMETERS, DIMENSIONS IN [ ] ARE INCHES

CERN LHC PROGRAM

BROOKHAVEN NATIONAL LABORATORY
UPTON, N.Y. 11973

DRAWN BY	B. WONG
DESIGN APPROVAL	J. COZZOLINO
CHECKED BY	C. AMAPITO
ENGINEER APPROVAL	J. COZZOLINO
	S. PLATE
	M. ANERELLA
SAFETY APPROVAL	M. GAFFNEY
Q.A. APPROVAL	C. PORRETTO

TITLE: DIPOLE MAGNET
COLD MASS ASSY, D1
PHASE SEPARATOR ASSY

SIZE E | DRAWING NUMBER 14010265 | REV C

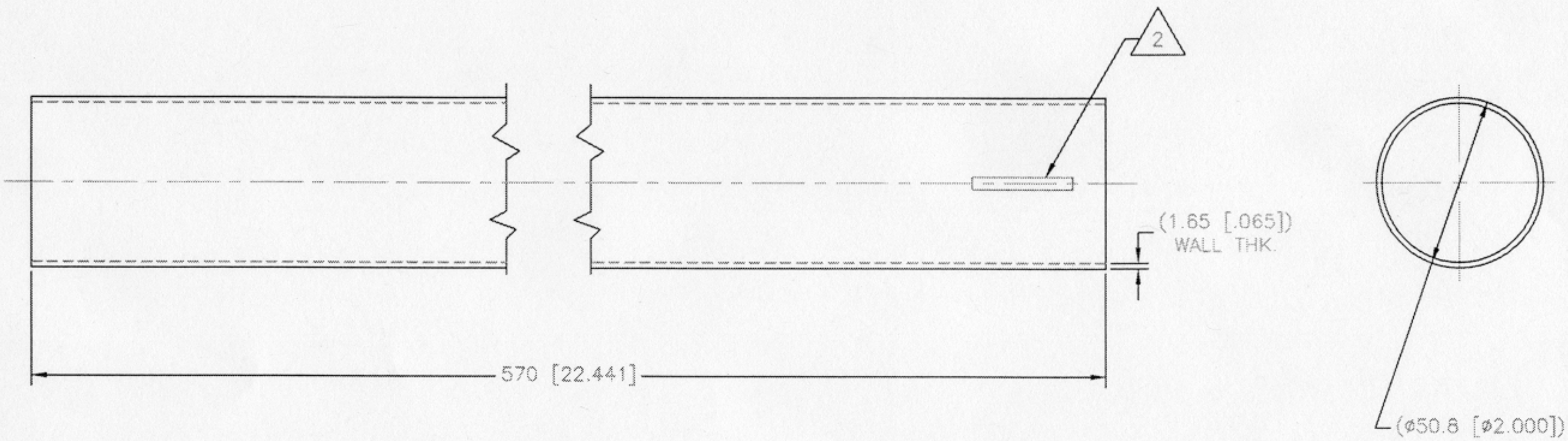
SCALE 1/2 | SHEET 1 OF 1

DWG NO 14010265

NOTES:

1. MATERIAL: SEAMLESS STAINLESS STEEL TUBING, TYPE 304 PER ASTM A269, ø50.8 [ø2.000] X 1.65 [.065] WALL.
2. (2) RUBBER STAMP 14010285-APPLICABLE REV LTR USING 3 [.12] HIGH CHARACTERS PER MIL-STD-130. LOCATE APPROXIMATELY AS SHOWN.

REVISIONS							
REV	ZONE	ECN NO.	DESCRIPTION	BY	DATE	CKR	APP
A			INITIAL RELEASE	BW	01/09/01		



OUTSTANDING ECN NUMBERS	INTERPRET IN ACCORDANCE WITH ASME Y14.24M-1989
	UNLESS OTHERWISE SPECIFIED
	DIMENSIONS ARE IN MILLIMETERS DIMENSIONS IN [ ] ARE INCHES — ANGULAR TOLERANCE ± 1°

GENERAL TOLERANCES							
DIMENSION	<=6 [.24]	> 6 [.24]	> 30 [1.18]	> 120 [4.72]	> 315 [12.4]	>1000 [39.4]	>2000 [78.7]
MEDIUM MACHINING	± 0.1 [.004]	± 0.2 [.008]	± 0.3 [.012]	± 0.5 [.020]	± 0.8 [.031]	± 1.2 [.047]	± 2 [.079]
WELDED STRUCTURE	± 0.5 [.020]	± 1 [.039]	± 2 [.079]	± 3 [.118]	± 5 [.20]	± 7 [.28]	± 10 [.39]

THIRD ANGLE PROJECTION

FINISH 3.2 [125]

BREAK SHARP EDGES MAX. 0.7 [.03] MIN. 0.2 [.01]

CERN LHC PROGRAM

DRAWN BY	B. WONG	10/26/00
DESIGN APPROVAL	J.COZZOLINO	11/29/00
CHECKED BY	C. AMARITO	11/20/00
ENGINEER APPROVAL	J.COZZOLINO	11/29/00
MC MAGNET APPROVAL	S. PLATE	12/4/00
SUPERVISOR APPROVAL	M. ANERELLA	12/06/00
SAFETY APPROVAL	M. GAFFNEY	12/11/00
Q.A. APPROVAL	C. PORRETTO	12/11/00

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES
UPTON, N.Y. 11973

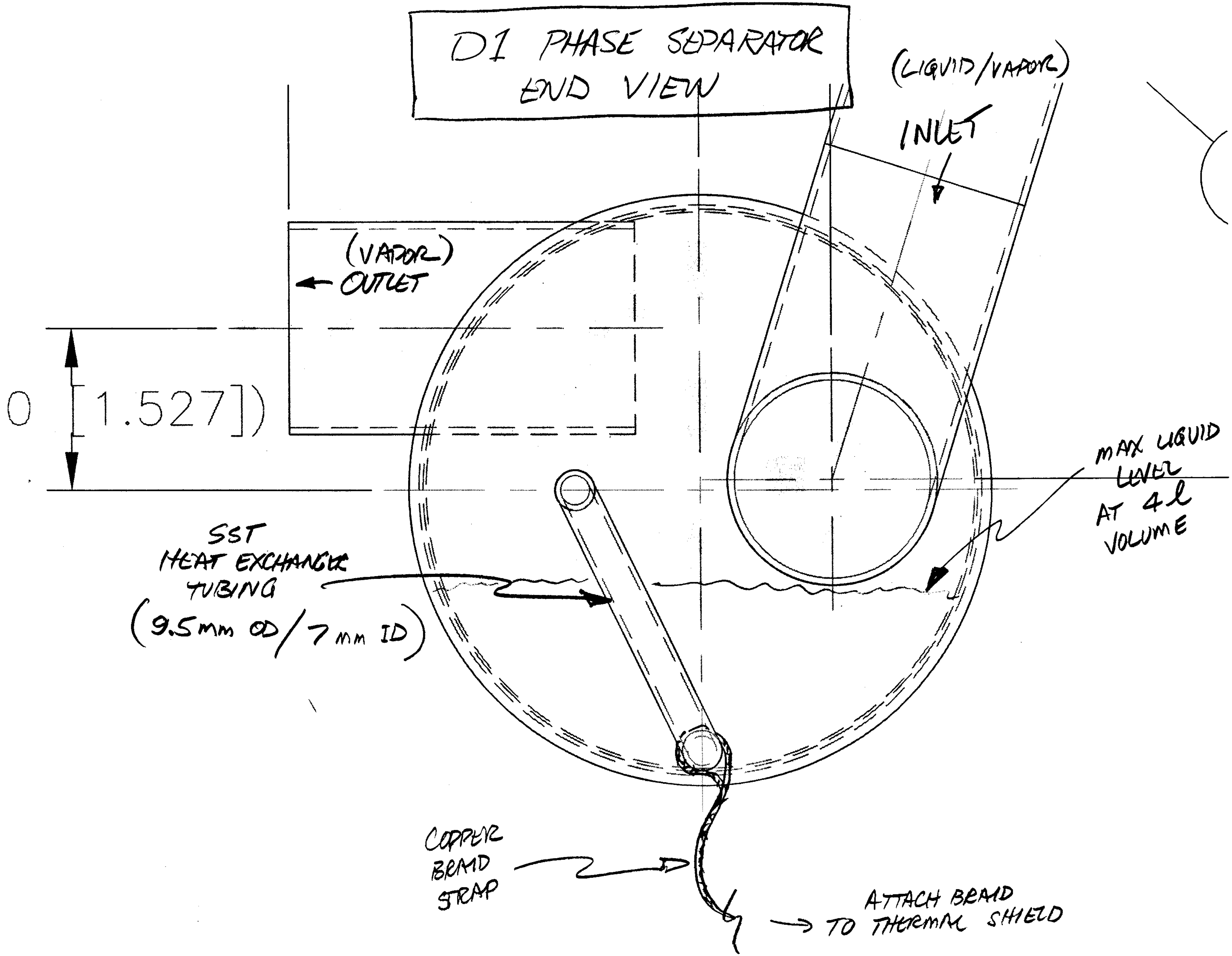
TITLE: DIPOLE MAGNET PHASE SEPARATOR ASSEMBLY, D1 TUBE, LONG

SIZE: C — DRAWING NUMBER: 14010285 — REV: A

Q.A. CATEGORY: — SCALE: 1/1 — WEIGHT: — SHEET 1 OF 1

DWG NO 14010285 SHT 1 OF 1 REV A

1401/0285a
plot: 1/1


D1 PHASE SEPARATOR
END VIEW
(LIQUID/VAPOR)
INLET
(VAPOR)
OUTLET
0 [1.527])
MAX LIQUID LEVEL AT 4 l VOLUME
SST HEAT EXCHANGER TUBING (9.5 mm OD / 7 mm ID)
COPPER BRAID STRAP
ATTACH BRAID TO THERMAL SHIELD

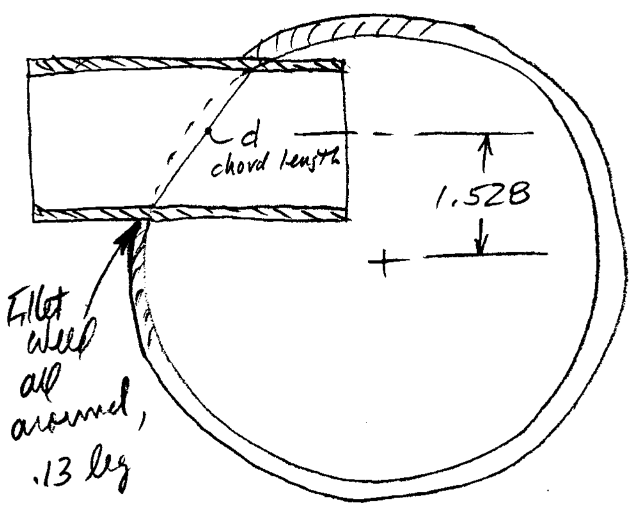
Analyze penetration per ASME Code, determining additional reinforcement if required.

X6 dimensions: (2" tubing) 304 seamless
$OD = 2.00$
$ID = 1.87 = 2R_n$
wall $= .065 = t_n$

shell dimensions: (5" NPS pipe) 304, welded
$OD = 5.563$
$ID = 5.295 = D$
wall $= .134 = t$

$P = 5$ bar $= 75$ psia
$E = 1$
$F = .5;\ 1.0$
$h = 2.5t_n = .163$
$S_n = 18,800$ psi
$S_v = 16,000$ psi

opening in shell: $\phi 2.012$ (non-radial)



$$A_{min} = d t_r F + 2 t_n t_r F (1 - f_{r_1})$$

1. CHECK WELD SIZE

$t_{min} = .065$
t_c = smaller of 1/4" or $0.7 t_{min} = .046$ (minimum throat allowed)

Actual throat $= (.707)(.13) = .092 \Rightarrow$ WELD IS OK

2. CHECK REINFORCEMENT REQUIREMENTS

$f_{r_1} = S_n/S_v = 18.8/16$ (but not greater than 1.0) $= 1.0$

$f_{r_2} = S_n/S_v$ ($\not>$ 1.0 allowed) $= 1.0$

Calculate chord length in shell opening in transverse plane (major diameter of ellipse) at the midsurface of the required shell thickness R_m.

$$R_m = R + t_r/2 \; ; \quad t_r = \frac{PR}{SE - .6P} = \frac{(75)(5.295/2)}{(16\times10^3)(1) - (.6)(75)} = .012$$

$$= 5.295/2 + .012/2$$
$$= 2.654$$

$$L = 1.528$$

$$\alpha_1 = \cos^{-1}\left(\frac{L + R_n}{R_m}\right) = \cos^{-1}\left(\frac{1.528 + 1.87/2}{2.654}\right) = 21.9^\circ$$

$$\alpha_2 = \cos^{-1}\left(\frac{L - R_n}{R_m}\right) = 77.1^\circ$$

$$\alpha = \alpha_2 - \alpha_1 = 55.2^\circ$$

$$d = 2R_m\sqrt{1 - \cos^2(\alpha/2)} = 2.459$$ (checks with scaled measurement)

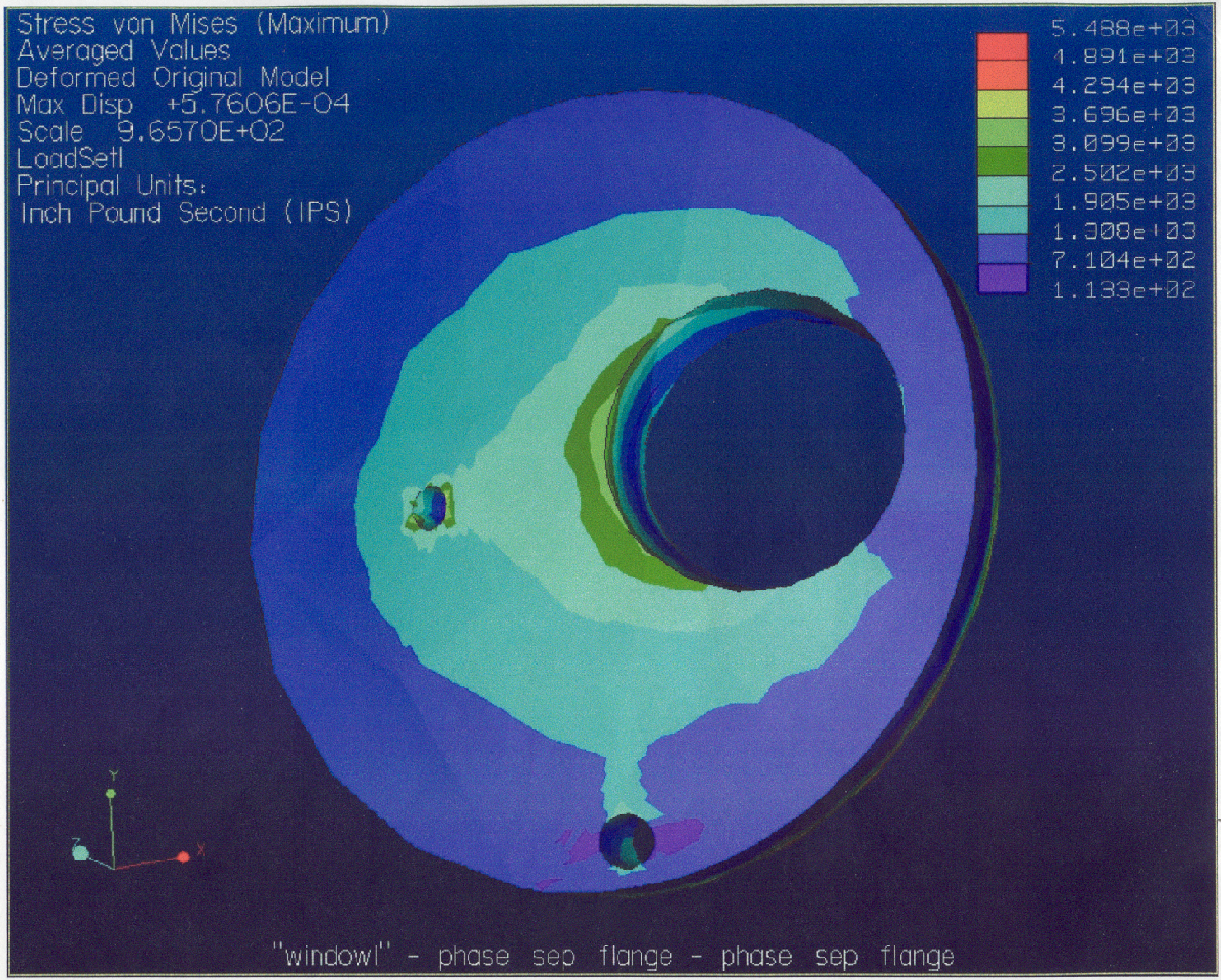
For plane yielding ellipse, $F = .5$

Calculate reinforcement area required:

$$A_{min} = (2.441)(.049)(.5) + (2)(.065)(.049)(.5)(0)$$
$$= .060$$

Calculate area available: can choose larger value.

$$A_1 = \text{larger of } d(E_1 t - F t_r) \text{ or } 2(t + t_n)(E_1 t - F t_r)$$
$$2.459((1)(.134) - (.5)(.012)) \text{ or } 2(.134 + .065)(.134 - (.5)(.049))$$
$$= .315 \text{ or } .044 = .315$$


Stress von Mises (Maximum)
Averaged Values
Deformed Original Model
Max Disp +5.7606E-04
Scale 9.6570E+02
LoadSet1
Principal Units:
Inch Pound Second (IPS)
5.488e+03
4.891e+03
4.294e+03
3.696e+03
3.099e+03
2.502e+03
1.905e+03
1.308e+03
7.104e+02
1.133e+02
Y
Z
X
"window1" - phase sep flange - phase sep flange

PHASE SEPARATOR STRESS ANALYSIS

FLAT HEAD
FIG. UG-34, (h)

$$t = d\sqrt{CP/SE}$$

P = design pressure = 5 bar = 75 psia
C = .33 (from Figure)
S = 18.8 ksi
E = .65 (single butt weld, no radiography, backed)
d = 5.26

$$\therefore\ t = 5.26\sqrt{\frac{(.33)(75)}{(18{,}800)(.65)}}$$

$$= .237$$

actual t = .50 inches $\Rightarrow$ OK and allows margin for penetrations (calculate)

CYLINDER
SEC UG-27

$$t_r = \frac{PR}{SE - 0.6P}$$

R = 5.26/2 = 2.63 inches
S = 18.8 ksi
E = 1.0

$$\therefore\ t_r = \frac{(75)(2.63)}{(18.8\times10^3)(1.0) - (0.6)(75)} = .011$$

actual t = .134 OK $\quad 1.25\,t_r = .013 \ll .134$ so flat head above, and cylinder, are OK.

(added thickness will allow for penetrations, to be calculated later)

FLAT HEAD ANALYSIS, INCL. PENETRATIONS

BOUNDARY CONDITIONS & LOADS:

- SIMPLY SUPPORTED EDGE (MAXIMIZES STRESS AT HOLES)
- NO CREDIT FOR INLET PIPE MATERIAL THICKNESS
- INTERNAL PRESSURE (FAR SIDE) OF 5 BAR (75 PSIA)
- OTHER PROPERTIES, MAT'LS, ETC AS GIVEN ON SHT 1.

THE ASME DOES NOT COVER OFF-CENTER PENETRATIONS, EXCEPT IN A GENERAL SENSE. THEREFORE A FEM ANALYSIS WAS DONE USING PRO-ENGINEER MECHANICA. RESULTS FOLLOW ON NEXT PAGE.

smaller than t_n

A_2 = smaller of $5(t_n - t_{rn}) f_{r_2} t$ or $5(t_n - t_{rn}) f_{r_2} t_n$

$= 5(.065 - t_{r_n})(1.0)(.065)$; $t_{r_n} = \dfrac{PR_n}{SE - .6P} = .015$

$= .016$

$A_3 = 2(t_n - c) f_{r_2} h = 2(.063 - 0)(1.0)(.163) = .020$

$A_{41} = leg^2 = .13^2 = .017$

$A_{43} = 0$

$\Sigma = .315 + .016 + .020 + .017 = .368$ GOOD FOR THIS PLANE ONLY

3. CHECK PLANE OF MINOR AXIS OF ELLIPSE

$d = 1.87$

$A_{req} = (1.87)(.012)(1.0) + 0 = .022$

$A_1 = (1.87)(.134 - .012)$ or $(2)(.134 + .065)(.134 - .049)$
$.228$ or $.034 = .228$

A_1 is sufficient in itself $\Rightarrow$ no reinforcement is required in either plane.

ASME PRESSURE VESSEL CODE SECTION VIII, 1992

ASME_Allowables.xls 15-May-00

Division 1					Division 2				
alloy	form	max stress intensity (kpsi)	ultimate (kpsi)	yield (kpsi)	alloy	form	max stress intensity (kpsi)	ultimate (kpsi)	yield (kpsi)
304	smls tube	18.8	75	30	304	smls tube	20.0	75	30
	wld tube	16.0	"	"		wld tube	17.0	"	"
	smls pipe	18.8	"	"		smls pipe	20.0	"	"
	wld pipe	16.0	"	"		wld pipe	17.0	"	"
	plate	18.8	"	"		plate	20.0	"	"
	forgings	18.8	"	"		forgings	20.0	"	"
304L*	smls tube	16.3	70	25	304L	smls tube	16.7	70	25
	wld tube	14.2	"	"		wld tube	14.2	"	"
	smls pipe	16.3	"	"		smls pipe	16.7	"	"
	wld pipe	14.2	"	"		wld pipe	14.2	"	"
	plate	16.3	"	"		plate	16.7	"	"
	forgings	16.3	65	25		forgings	16.7	65	25
304LN	all not permitted				304LN	all not permitted			
316	smls tube	18.8	75	30	316	smls tube	?	?	?
	wld tube	16.0	"	"		wld tube	?	?	?
	smls pipe	18.8	"	"		smls pipe	?	?	?
	wld pipe	16.0	"	"		wld pipe	?	?	?
	plate	18.8	"	"		plate	?	?	?
316L	smls tube	16.7	70	25	316L	smls tube	16.7	70	25
	wld tube	14.2	"	"		wld tube	14.2	"	"
	smls pipe	16.7	"	"		smls pipe	16.7	"	"
	wld pipe	14.2	"	"		wld pipe	14.2	"	"
	plate	16.7	"	"		plate	16.7	"	"
316LN	all not permitted				316LN	all not permitted			

NOTE: all stress intensities are at or below room temperature
* These values are from 1989 version of Code.