**D-0 Tev Beam Tubes Through End Calorimeter
Design Description**

This Engineering Note studies the design of the Tev Beam Tubes, and their related components, that run through the End Calorimeter of the D0-Detector. The Tev tubes through the EC can be thought of as a cluster of

**TEV BEAM TUBES
THROUGH D-0 END CALORIMETER**

D-Zero Engineering Note #3740.225-EN-305

Jerry R. Leibfritz

7/11/91

Approved by Keith Primdahl

Keith Primdahl

A) TEV BEAM TUBES THROUGH D-0 END CALORIMETER
SUMMARY OF RESULTS

CASE	ASME* REQUIREMENT	ACTUAL	F.S.*	PAGE #
Flathead Thickness (in)				
3.740" dia. head	0.134	0.188	1.40	3
5.295" dia. head	0.128	0.250	1.95	4
7.500" dia. head	0.282	0.313	1.11	5
7.760" dia. head	0.188	0.250	1.33	6
9.760" dia. head	0.272	0.375	1.38	7
12.50" dia. head	0.366	0.375	1.02	8
22.50" dia. head	0.445	0.500	1.12	9
Nozzle Wall Thickness (in)				
3.000" Nozzle	0.0340	0.0650	1.91	10
2.375" Nozzle	0.0019	0.0490	25.79	11
4.000" Nozzle	0.0140	0.1200	8.57	12
5.560" Nozzle	0.0090	0.1340	14.89	13
4.250" Nozzle	0.0072	0.1200	16.67	14
10.00" Nozzle	0.0380	0.1200	3.16	15
8.000" Nozzle	0.0063	0.1200	19.05	16
Nozzle Reinforcement (in ²)				
3.000" Nozzle	0.1434	0.2982	2.08	17
2.375" Nozzle	0.2163	0.4116	1.90	18
4.000" Nozzle	0.3741	0.5847	1.56	19
5.560" Nozzle	0.3680	0.7402	2.01	20
4.250" Nozzle	0.8100	0.8891	1.10	21
10.00" Nozzle	1.2590	1.3142	1.04	22
8.000" Nozzle	2.4366	2.6766	1.10	23
Bellows Design (psi)				
3.50" Bellows	See Details in Report		4.91	24
5.00" Bellows	See Details in Report		6417.23	26

* From ASME BOILER AND PRESSURE VESSEL CODE, section VIII, division I

* F.S. = Factor of Safety in addition to Factors imposed in ASME calculations

Flat Head Thickness Calculations for
The D0-Tev Beam Tubes through the EC

B1) 3.74 in. DIA HEAD

Plate Data:	Plate Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Plate O.D. (d)	3.74 in
	Plate Thickness (t)	0.1875 in

Minimum required thickness of plate

Calculations as per ASME Section VIII, Div. I, par. UG-34c

$$t_r = d(CP/(SE))^{0.5}$$

where: t_r = Minimum required thickness of flat head or cover (in)
 d = Diameter, or short span, measured as indicated in fig. UG-34 (ASME Section VIII, Div. I), in.
 P = Design pressure (psi)
 S = Max. allowable stress (psi)
 from: (ASME Section VIII, Div. I, subsection C) multiplied by (.8) as per Fermilab Code for room temp. pressure vessels
 E = Joint efficiency, specified in section UW-12(ASME Section VIII, Div. I)
 C = A factor depending upon the method of attachment of head.

$$d = 3.74 \text{ in}$$

$$C = 0.33 \quad \text{From fig. UG-34f of ASME Section VIII, Div. I.}$$

$$P = 32.2 \text{ psi}$$

$$S = 15040 \text{ psi}$$

$$E = 0.55$$

$$t_r = 3.74((0.33)(32.2)/(15040(0.55)))^{0.5}$$

$$t_r = 0.134 \text{ in}$$

$t_r < t$ Therefore the plate thickness of 0.1875 in. is sufficient

Flat Head Thickness Calculations for The D0-Tev Beam Tubes through the EC

B2) 5.295 in. DIA HEAD

Plate Data:	Plate Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Plate O.D. (d)	5.295 in
	Plate Thickness (t)	0.25 in

Minimum required thickness of plate

Calculations as per ASME Section VIII, Div. I, par. UG-34c

$$t_r = d(CP/(SE))^{0.5}$$

where: t_r = Minimum required thickness of flat head or cover (in)
 d = Diameter, or short span, measured as indicated in fig. UG-34 (ASME Section VIII, Div. I), in.
 P = Design pressure (psi)
 S = Max. allowable stress (psi)
 from: (ASME Section VIII, Div. I, subsection C) multiplied by (.8) as per Fermilab Code for room temp. pressure vessels
 E = Joint efficiency, specified in section UW-12(ASME Section VIII, Div. I)
 C = A factor depending upon the method of attachment of head.

$$d = 5.295 \text{ in}$$

$$C = 0.33 \quad \text{From fig. UG-34f of ASME Section VIII, Div. I.}$$

$$P = 14.7 \text{ psi}$$

$$S = 15040 \text{ psi}$$

$$E = 0.55$$

$$t_r = 5.295((0.33)(14.7)/(15040(0.55)))^{0.5}$$

$$t_r = 0.128 \text{ in}$$

$t_r < t$ Therefore the plate thickness of 0.25 in. is sufficient

Flat Head Thickness Calculations for
The D0-Tev Beam Tubes through the EC

B3) 7.50 in. DIA HEAD

Plate Data:	Plate Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Plate O.D. (d)	7.50 in
	Plate Thickness (t)	0.313 in

Minimum required thickness of plate

Calculations as per ASME Section VIII, Div. I, par. UG-34c

$$t_r = d(CP/(SE))^{0.5}$$

where: t_r = Minimum required thickness of flat head or cover (in)
 d = Diameter, or short span, measured as indicated in fig. UG-34 (ASME Section VIII, Div. I), in.
 P = Design pressure (psi)
 S = Max. allowable stress (psi)
 from: (ASME Section VIII, Div. I, subsection C) multiplied by (.8) as per Fermilab Code for room temp. pressure vessels
 E = Joint efficiency, specified in section UW-12(ASME Section VIII, Div. I)
 C = A factor depending upon the method of attachment of head.

$$d = 7.50 \text{ in}$$

$$C = 0.33 \quad \text{From fig. UG-34e of ASME Section VIII, Div. I.}$$

$$P = 32.2 \text{ psi}$$

$$S = 15040 \text{ psi}$$

$$E = 0.50$$

$$t_r = 7.50((0.33)(32.2)/(15040(0.50)))^{0.5}$$

$$t_r = 0.282 \text{ in}$$

$t_r < t$ Therefore the plate thickness of 0.313 in. is sufficient

Flat Head Thickness Calculations for
The D0-Tev Beam Tubes through the EC

B4) 7.76 in. DIA HEAD

Plate Data:	Plate Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Plate O.D. (d)	7.76 in
	Plate Thickness (t)	0.25 in

Minimum required thickness of plate

Calculations as per ASME Section VIII, Div. I, par. UG-34c

$$t_r = d(CP/(SE))^{0.5}$$

where: t_r = Minimum required thickness of flat head or cover (in)
 d = Diameter, or short span, measured as indicated in fig. UG-34 (ASME Section VIII, Div. I), in.
 P = Design pressure (psi)
 S = Max. allowable stress (psi)
 from: (ASME Section VIII, Div. I, subsection C) multiplied by (.8) as per Fermilab Code for room temp. pressure vessels
 E = Joint efficiency, specified in section UW-12(ASME Section VIII, Div. I)
 C = A factor depending upon the method of attachment of head.

$$d = 7.76 \text{ in}$$

$$C = 0.33 \quad \text{From fig. UG-34f of ASME Section VIII, Div. I.}$$

$$P = 14.7 \text{ psi}$$

$$S = 15040 \text{ psi}$$

$$E = 0.55$$

$$t_r = 7.76((0.33)(14.7)/(15040(0.55)))^{0.5}$$

$$t_r = 0.188 \text{ in}$$

$t_r < t$ Therefore the plate thickness of 0.25 in. is sufficient

Flat Head Thickness Calculations for
The D0-Tev Beam Tubes through the EC

B5) 9.76 in. DIA HEAD

Plate Data:	Plate Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Plate O.D. (d)	9.76 in
	Plate Thickness (t)	0.375 in

Minimum required thickness of plate

Calculations as per ASME Section VIII, Div. I, par. UG-34c

$$t_r = d(CP/(SE))^{0.5}$$

where: t_r = Minimum required thickness of flat head or cover (in)
 d = Diameter, or short span, measured as indicated in fig. UG-34 (ASME Section VIII, Div. I), in.
 P = Design pressure (psi)
 S = Max. allowable stress (psi)
 from: (ASME Section VIII, Div. I, subsection C) multiplied by (.8) as per Fermilab Code for room temp. pressure vessels
 E = Joint efficiency, specified in section UW-12(ASME Section VIII, Div. I)
 C = A factor depending upon the method of attachment of head.

$$d = 9.76 \text{ in}$$

$$C = 0.20 \quad \text{From fig. UG-34f of ASME Section VIII, Div. I.}$$

$$P = 32.2 \text{ psi}$$

$$S = 15040 \text{ psi}$$

$$E = 0.55$$

$$t_r = 9.76((0.20)(32.2)/(15040(0.55)))^{0.5}$$

$$t_r = 0.272 \text{ in}$$

$t_r < t$ Therefore the plate thickness of 0.375 in. is sufficient

Flat Head Thickness Calculations for
The D0-Tev Beam Tubes through the EC

B6) 12.5 in. DIA HEAD

Plate Data:	Plate Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Plate O.D. (d)	12.5 in
	Plate Thickness (t)	0.375 in

Minimum required thickness of plate

Calculations as per ASME Section VIII, Div. I, par. UG-34c

$$t_r = d(CP/(SE))^{0.5}$$

where: t_r = Minimum required thickness of flat head or cover (in)
 d = Diameter, or short span, measured as indicated in fig. UG-34 (ASME Section VIII, Div. I), in.
 P = Design pressure (psi)
 S = Max. allowable stress (psi)
 from: (ASME Section VIII, Div. I, subsection C) multiplied by (.8) as per Fermilab Code for room temp. pressure vessels
 E = Joint efficiency, specified in section UW-12(ASME Section VIII, Div. I)
 C = A factor depending upon the method of attachment of head.

$$d = 12.5 \text{ in}$$

$$C = 0.20 \quad \text{From fig. UG-34e of ASME Section VIII, Div. I.}$$

$$P = 32.2 \text{ psi}$$

$$S = 15040 \text{ psi}$$

$$E = 0.50$$

$$t_r = 12.5((0.20)(32.2)/(15040(0.50)))^{0.5}$$

$$t_r = 0.366 \text{ in}$$

$t_r < t$ Therefore the plate thickness of 0.375 in. is sufficient

Flat Head Thickness Calculations for
The D0-Tev Beam Tubes through the EC

B7) 22.5 in. DIA HEAD

Plate Data:	Plate Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Plate O.D. (d)	22.5 in
	Plate Thickness (t)	0.50 in

Minimum required thickness of plate

Calculations as per ASME Section VIII, Div. I, par. UG-34c

$$t_r = d(CP/(SE))^{0.5}$$

where: t_r = Minimum required thickness of flat head or cover (in)
 d = Diameter, or short span, measured as indicated in fig. UG-34 (ASME Section VIII, Div. I), in.
 P = Design pressure (psi)
 S = Max. allowable stress (psi)
 from: (ASME Section VIII, Div. I, subsection C) multiplied by (.8) as per Fermilab Code for room temp. pressure vessels
 E = Joint efficiency, specified in section UW-12(ASME Section VIII, Div. I)
 C = A factor depending upon the method of attachment of head.

$$d = 22.50 \text{ in}$$

$$C = 0.20 \quad \text{From fig. UG-34e of ASME Section VIII, Div. I.}$$

$$P = 14.7 \text{ psi}$$

$$S = 15040 \text{ psi}$$

$$E = 0.50$$

$$t_r = 22.50((0.20)(14.7)/(15040(0.50)))^{0.5}$$

$$t_r = 0.445 \text{ in}$$

$t_r < t$ Therefore the plate thickness of 0.50 in. is sufficient

Nozzle Wall Thickness Calculations for The D0-Tev Beam Tubes through the EC

C1) 3.00 in. Nozzle (Cold Tube) see Dwg. 3740.220-ME-295181

Shell Data:	Nozzle Material	Stn. Std. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Nozzle O.D.	3.00 in
	Nozzle Thickness (t)	0.065 in
	Nozzle Length (L)	90 in
	External Pressure (P)	32.2 psi

Minimum required thickness of nozzle

Calculations as per ASME Section VIII, Div. I, par. UG-28c

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

where: D_o = Nozzle O.D. (in)
 t = Min. required thickness of the nozzle (in)
 A = Factor determined from fig. 5-UGO-28.0
in Appendix 5 (ASME Section VIII, Div. I) and used to enter the applicable material chart in Appendix 5 for the determination of the factor B.
 B = Factor determined from the applicable material chart in Appendix 5 (ASME Section VIII, Div. I) for maximum design metal temperature (psi)
 P_a = Allowable working pressure for given nozzle thickness (psi)
 P = External design pressure (psi)

$$L/D_o = 90/3 = 30$$

$$D_o/t = 3/.065 = 46.2$$

$$A = 0.0006$$

$$B = 7,200 \quad (\text{from ASME Section VIII, Div. I, fig. 5-UHA-28.1})$$

$$P_a = 4(7200)/(3(46.2)) = 208 \text{ psi}$$

$P_a > P$, Therefore .065 in thickness is sufficient

By trial and error $t_r = .034$ in

Nozzle Wall Thickness Calculations for
The D0-Tev Beam Tubes through the EC

C2) 2.375 in Nozzle (Warm Tube) see Dwg. 3740.220-ME-295181

Nozzle Data:	Material	Stn. Std. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Nozzle O.D.	2.375 in
	Nozzle Thickness (t)	0.049 in
	Internal Pressure (P)	14.7 psi

Minimum required thickness of shell

Calculations as per ASME Section VIII, Div. I, par. UG-27c

$$t = PR / (SE - 0.6P)$$

where: t = Min. required thickness of nozzle (in)
P = Design pressure (psi)
R = Inside radius of nozzle (in)
S = Max. allowable stress (psi)
from: (ASME Section VIII, Div. I, subsection C)
multiplied by (.8) as per Fermilab Code for
room temp. pressure vessels
E = Joint efficiency, specified in section
UW-12(ASME Section VIII, Div. I)

P= 14.7 psi
R= 1.1385 in
S= 15,040 psi
E= 0.60

$$t = 14.7(1.1385) / (15,040(0.60) - 0.60(14.7)) = 0.00186 \text{ in}$$

The actual wall thickness is greater than the minimum required thickness by a factor of 26, therefore 0.049 in thickness is sufficient

Nozzle Wall Thickness Calculations for The D0-Tev Beam Tubes through the EC

C3) 4.00 in. Nozzle (see Dwg. 3740.220-ME-295181)

Shell Data:	Nozzle Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Nozzle O.D.	4.00 in
	Nozzle Thickness (t)	0.120 in
	Nozzle Length (L)	1.563 in
	External Pressure (P)	32.2 psi

Minimum required thickness of nozzle

Calculations as per ASME Section VIII, Div. I, par. UG-28c

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

where: D_o = Nozzle O.D. (in)
 t = Min. required thickness of the nozzle (in)
 A = Factor determined from fig. 5-UGO-28.0
in Appendix 5 (ASME Section VIII, Div.
I) and used to enter the applicable
material chart in Appendix 5 for the
determination of the factor B.
 B = Factor determined from the applicable
material chart in Appendix 5 (ASME
Section VIII, Div. I) for maximum
design metal temperature (psi)
 P_a = Allowable working pressure for given
nozzle thickness (psi)
 P = External design pressure (psi)

$$L/D_o = 1.563/4.00 = 0.3908$$

$$D_o/t = 4.00/0.120 = 33.33$$

$$A = 0.022$$

$$B = 14600 \quad (\text{from ASME Section VIII, Div. I, fig. 5-UHA-28.1})$$

$$P_a = 4(14600)/(3(33.33)) = 584 \text{ psi}$$

$P_a > P$, Therefore 0.024 in thickness is sufficient

By trial and error $t_r = 0.014$ in

Nozzle Wall Thickness Calculations for The D0-Tev Beam Tubes through the EC

C4) 5.56 in. Nozzle (see Dwg. 3740.220-ME-295181)

Shell Data:	Nozzle Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Nozzle O.D.	5.56 in
	Nozzle Thickness (t)	0.134 in
	Nozzle Length (L)	1.25 in
	External Pressure (P)	14.7 psi

Minimum required thickness of nozzle

Calculations as per ASME Section VIII, Div. I, par. UG-28c

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

where: D_o = Nozzle O.D. (in)
 t = Min. required thickness of the nozzle (in)
 A = Factor determined from fig. 5-UGO-28.0
in Appendix 5 (ASME Section VIII, Div.
I) and used to enter the applicable
material chart in Appendix 5 for the
determination of the factor B.
 B = Factor determined from the applicable
material chart in Appendix 5 (ASME
Section VIII, Div. I) for maximum
design metal temperature (psi)
 P_a = Allowable working pressure for given
nozzle thickness (psi)
 P = External design pressure (psi)

$$L/D_o = 1.25/5.56 = 0.225$$

$$D_o/t = 5.56/0.134 = 41.49$$

$$A = 0.038$$

$$B = 15,700 \quad (\text{from ASME Section VIII, Div. I, fig. 5-UHA-28.1})$$

$$P_a = 4(14800)/(3(41.49)) = 504 \text{ psi}$$

$P_a > P$, Therefore 0.134 in thickness is sufficient

By trial and error $t_r = 0.009$ in

Nozzle Wall Thickness Calculations for
The D0-Tev Beam Tubes through the EC

C5) 4.25 in Nozzle (see Dwg. 3740.220-ME-295181)

Nozzle Data:	Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Nozzle O.D.	4.25 in
	Nozzle Thickness (t)	0.120 in
	Internal Pressure (P)	32.2 psi

Minimum required thickness of shell

Calculations as per ASME Section VIII, Div. I, par. UG-27c

$$t = PR / (SE - 0.6P)$$

where: t = Min. required thickness of nozzle (in)
P = Design pressure (psi)
R = Inside radius of nozzle (in)
S = Max. allowable stress (psi)
from: (ASME Section VIII, Div. I, subsection C)
multiplied by (.8) as per Fermilab Code for
room temp. pressure vessels
E = Joint efficiency, specified in section
UW-12(ASME Section VIII, Div. I)

P= 32.2 psi
R= 2.005 in
S= 15,040 psi
E= 0.60

$$t = 32.2(2.005) / (15,040(0.60) - 0.60(32.2)) = 0.0072 \text{ in}$$

The actual wall thickness is greater than the minimum required thickness by a factor of 17, therefore 0.120 in thickness is sufficient

Nozzle Wall Thickness Calculations for The D0-Tev Beam Tubes through the EC

C6) 10.00 in. Nozzle (see Dwg. 3740.220-ME-295181)

Shell Data:	Nozzle Material	Stn. Std. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Nozzle O.D.	10.00 in
	Nozzle Thickness (t)	0.120 in
	Nozzle Length (L)	6.724 in
	External Pressure (P)	32.2 psi

Minimum required thickness of nozzle

Calculations as per ASME Section VIII, Div. I, par. UG-28c

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

where: D_o = Nozzle O.D. (in)

t = Min. required thickness of the nozzle (in)

A = Factor determined from fig. 5-UGO-28.0

in Appendix 5 (ASME Section VIII, Div.

I) and used to enter the applicable material chart in Appendix 5 for the determination of the factor B.

B = Factor determined from the applicable material chart in Appendix 5 (ASME

Section VIII, Div. I) for maximum design metal temperature (psi)

P_a = Allowable working pressure for given nozzle thickness (psi)

P = External design pressure (psi)

$$L/D_o = 6.724/10.00 = 0.6724$$

$$D_o/t = 10.00/0.120 = 83.33$$

$$A = 0.0029$$

$$B = 12300 \quad (\text{from ASME Section VIII, Div. I, fig. 5-UHA-28.1})$$

$$P_a = 4(12300)/(3(83.33)) = 197 \text{ psi}$$

$P_a > P$, Therefore 0.120 in thickness is sufficient

By trial and error $t_r = 0.038$ in

Nozzle Wall Thickness Calculations for
The D0-Tev Beam Tubes through the EC

C7) 8.00 in Nozzle (see Dwg. 3740.220-ME-295181)

Nozzle Data:	Material	Stn. Stl. 304
	Temperature Range	-316 to 100 F
	Max. Allowable Stress (S)	15040 psi
	Nozzle O.D.	8.00 in
	Nozzle Thickness (t)	0.120 in
	Internal Pressure (P)	14.7 psi

Minimum required thickness of shell

Calculations as per ASME Section VIII, Div. I, par. UG-27c

$$t = PR / (SE - 0.6P)$$

where: t = Min. required thickness of nozzle (in)
P = Design pressure (psi)
R = Inside radius of nozzle (in)
S = Max. allowable stress (psi)
from: (ASME Section VIII, Div. I, subsection C)
multiplied by (.8) as per Fermilab Code for
room temp. pressure vessels
E = Joint efficiency, specified in section
UW-12(ASME Section VIII, Div. I)

P= 14.7 psi
R= 3.88 in
S= 15,040 psi
E= 0.60

$$t = 14.7(3.88) / (15,040(0.60) - 0.60(14.7)) = 0.0063 \text{ in}$$

The actual wall thickness is greater than the minimum required thickness by a factor of 19, therefore 0.120 in thickness is sufficient

Pressure Vessel Nozzle Reinforcement Calculations

D1) CASE: 3.00 in. nozzle, through 3.74 in. flat head, ext. pres. of 32.2 psi.

Shell or Head Data		Nozzle Data	
t=Actual Thickness (in)	0.1875	tn= Actual Thickness (in)	0.065
tr=Calculated Thickness (in)	0.0999	trn= Calc. Thickness (in)	0.034
F=Correction Factor	1	c= Corrosion Allow. (in)	0
E=Joint Efficiency	1	di=Effective I.D. (in)	2.87
		d=Limit of Reinfor. (in)	2.87
		fr= Strength Factor	1
		h= Available Nozzle Inward Length	0.1625
Weld Data		Element Data	
W1= Length of Top Leg (in)	0	Dp= O.D. of Element (in)	0
W2= Length of Bot. Leg (in)	0.125	te= Element Thick. (in)	0
W3= Length of Element Weld Leg (in)	0	fr= Strength Factor	1
fr= Strength Factor	1		
Reinforcement Areas		Formula	Area (in^2)
Area of reinforcement required		$A = d_i \cdot t_r \cdot F + 2t_n \cdot t_r \cdot F(1 - fr)$	0.286713
(for vessel under external pressure multiply by 0.5)			0.143357
Area of excess thickness in shell or head		$A_1 = d(E \cdot t - F \cdot t_r) - 2t_n(E \cdot t - F \cdot t_r)(1 - fr)$	0.251412
(use greater value)		or $A_1 = 2(t + t_n)(E \cdot t - F \cdot t_r) - 2t_n(E \cdot t - F \cdot t_r)(1 - fr)$	0.044238
		Greater Value=	0.251412
Area of excess thickness in nozzle wall projecting outward		$A_2 = 5t(t_n - tr_n)fr$	0.029063
(use smaller value)		$A_2 = 2(t_n - tr_n)(2.5t_n + te)fr$	0.010075
		Smaller Value=	0.010075
Area of excess thickness in nozzle wall projecting inward		$A_3 = 2h(t_n - c)fr$	0.021125
Area of outward nozzle welds		$A_{41} = fr(W_1)^2$	0
Area of inward nozzle welds		$A_{43} = fr(W_2)^2$	0.015625
Area of element welds		$A_{42} = fr(W_3)^2$	0
Area in element		$A_5 = te(D_p - d_i - 2t_n)fr$	0
Total area available		$A_t = A_1 + A_2 + A_3 + A_4 + A_5$	0.298237

Note: All calculations as per ASME Section VIII, Div. I, par. UG-37.

Pressure Vessel Nozzle Reinforcement Calculations

D2) CASE: 2.375 in. Nozzle through 5.295 in. flat head, inter. pres. of 14.7 psi.
 Shell or Head Data Nozzle Data

t=Actual Thickness (in)	0.25	tn= Actual Thickness (in)	0.049
tr=Calculated Thickness (in)	0.095	trn= Calc. Thickness (in)	0.0019
F=Correction Factor	1	c= Corrosion Allow. (in)	0
E=Joint Efficiency	1	di=Effective I.D. (in)	2.277
		d=Limit of Reinfor. (in)	2.277
		fr= Strength Factor	1
		h= Available Nozzle Inward Length	0.1225
Weld Data		Element Data	
W1= Length of Top Leg (in)	0	Dp= O.D. of Element (in)	0
W2= Length of Bot. Leg (in)	0.1875	te= Element Thick. (in)	0
W3= Length of Element Weld Leg (in)	0	fr= Strength Factor	1
fr= Strength Factor	1		
Reinforcement Areas		Formula	Area (in ²)

Area of reinforcement required $A = di \cdot tr \cdot F + 2tn \cdot tr \cdot F(1 - fr)$ 0.216315
 (for vessel under external pressure multiply by 0.5)

Area of excess thickness in shell or head $A1 = d(E \cdot t - F \cdot tr) - 2tn(E \cdot t - F \cdot tr)(1 - fr)$ 0.352935
 (use greater value) or $A1 = 2(t + tn)(E \cdot t - F \cdot tr) - 2tn(E \cdot t - F \cdot tr)(1 - fr)$ 0.09269
 Greater Value= 0.352935

Area of excess thickness in nozzle wall projecting outward $A2 = 5t(tn - trn)fr$ 0.058875
 $A2 = 2(tn - trn)(2.5tn + te)fr$ 0.01154
 (use smaller value) Smaller Value= 0.01154

Area of excess thickness in nozzle wall projecting inward $A3 = 2h(tn - c)fr$ 0.012005

Area of outward nozzle welds $A41 = fr(W1)^2$ 0
 Area of inward nozzle welds $A43 = fr(W2)^2$ 0.035156
 Area of element welds $A42 = fr(W3)^2$ 0

Area in element $A5 = te(Dp - di - 2tn)fr$ 0

Total area available $At = A1 + A2 + A3 + A4 + A5$ 0.411636

Note: All calculations as per ASME Section VIII, Div. I, par. UG-37.

Pressure Vessel Nozzle Reinforcement Calculations

D3) CASE: 4.00 in. nozzle through 7.50 in. flat head, ext. pres. of 32.2 psi.

Shell or Head Data		Nozzle Data	
t=Actual Thickness (in)	0.313	tn= Actual Thickness (in)	0.12
tr=Calculated Thickness (in)	0.199	trn= Calc. Thickness (in)	0.014
F=Correction Factor	1	c= Corrosion Allow. (in)	0
E=Joint Efficiency	1	di=Effective I.D. (in)	3.76
		d=Limit of Reinfor. (in)	3.76
		fr= Strength Factor	1
		h= Available Nozzle Inward Length	0.125
Weld Data		Element Data	
W1= Length of Top Leg (in)	0	Dp= O.D. of Element (in)	0
W2= Length of Bot. Leg (in)	0.25	te= Element Thick. (in)	0
W3= Length of Element Weld Leg (in)	0	fr= Strength Factor	1
fr= Strength Factor	1		
Reinforcement Areas		Formula	Area (in ²)
Area of reinforcement required (for vessel under external pressure multiply by 0.5)		$A = d_i \cdot t_r \cdot F + 2t_n \cdot t_r \cdot F(1 - fr)$	0.74824
			0.37412
Area of excess thickness in shell or head (use greater value)		$A1 = d(E \cdot t - F \cdot tr) - 2t_n(E \cdot t - F \cdot tr)(1 - fr)$ or $A1 = 2(t + t_n)(E \cdot t - F \cdot tr) - 2t_n(E \cdot t - F \cdot tr)(1 - fr)$ Greater Value=	0.42864
			0.098724
			0.42864
Area of excess thickness in nozzle wall projecting outward (use smaller value)		$A2 = 5t(t_n - trn)fr$ $A2 = 2(t_n - trn)(2.5t_n + te)fr$ Smaller Value=	0.16589
			0.0636
			0.0636
Area of excess thickness in nozzle wall projecting inward		$A3 = 2h(t_n - c)fr$	0.03
Area of outward nozzle welds		$A41 = fr(W1)^2$	0
Area of inward nozzle welds		$A43 = fr(W2)^2$	0.0625
Area of element welds		$A42 = fr(W3)^2$	0
Area in element		$A5 = te(Dp - d_i - 2t_n)fr$	0
Total area available		$At = A1 + A2 + A3 + A4 + A5$	0.58474

Note: All calculations as per ASME Section VIII, Div. I, par. UG-37.

Pressure Vessel Nozzle Reinforcement Calculations

D4) CASE: 5.56 in. nozzle, through 7.76 in. flat head, ext. pres. of 14.7 psi.
 Shell or Head Data Nozzle Data

t=Actual Thickness (in)	0.25	tn= Actual Thickness (in)	0.134
tr=Calculated Thickness (in)	0.139	trn= Calc. Thickness (in)	0.009
F=Correction Factor	1	c= Corrosion Allow. (in)	0
E=Joint Efficiency	1	di=Effective I.D. (in)	5.295
		d=Limit of Reinfor. (in)	5.295
		fr= Strength Factor	1
		h= Available Nozzle Inward Length	0.125
Weld Data		Element Data	
W1= Length of Top Leg (in)	0	Dp= O.D. of Element (in)	0
W2= Length of Bot. Leg (in)	0.1875	te= Element Thick. (in)	0
W3= Length of Element Weld Leg (in)	0	fr= Strength Factor	1
fr= Strength Factor	1		
Reinforcement Areas		Formula	Area (in ²)

Area of reinforcement required (for vessel under external pressure multiply by 0.5)	$A = d_i \cdot t_r \cdot F + 2t_n \cdot t_r \cdot F(1 - fr)$	0.736005 0.368003
Area of excess thickness in shell or head (use greater value)	$A1 = d(E \cdot t - F \cdot tr) - 2t_n(E \cdot t - F \cdot tr)(1 - fr)$ or $A1 = 2(t + t_n)(E \cdot t - F \cdot tr) - 2t_n(E \cdot t - F \cdot tr)(1 - fr)$ Greater Value=	0.587745 0.085248 0.587745
Area of excess thickness in nozzle wall projecting outward (use smaller value)	$A2 = 5t(t_n - trn)fr$ $A2 = 2(t_n - trn)(2.5t_n + te)fr$ Smaller Value=	0.15625 0.08375 0.08375
Area of excess thickness in nozzle wall projecting inward	$A3 = 2h(t_n - c)fr$	0.0335
Area of outward nozzle welds	$A41 = fr(W1)^2$	0
Area of inward nozzle welds	$A43 = fr(W2)^2$	0.035156
Area of element welds	$A42 = fr(W3)^2$	0
Area in element	$A5 = te(Dp - d_i - 2t_n)fr$	0
Total area available	$At = A1 + A2 + A3 + A4 + A5$	0.740151

Note: All calculations as per ASME Section VIII, Div. I, par. UG-37.

Pressure Vessel Nozzle Reinforcement Calculations

D5) CASE: 4.25 in. nozzle, through 9.76 in. flat head, int. pres. of 32.2 psi.
 Shell or Head Data Nozzle Data

t=Actual Thickness (in)	0.375	tn= Actual Thickness (in)	0.12
tr=Calculated Thickness (in)	0.202	trn= Calc. Thickness (in)	0.0072
F=Correction Factor	1	c= Corrosion Allow. (in)	0
E=Joint Efficiency	1	di=Effective I.D. (in)	4.01
		d=Limit of Reinfor. (in)	4.01
		fr= Strength Factor	1
		h= Available Nozzle Inward Length	0.125
Weld Data		Element Data	
W1= Length of Top Leg (in)	0	Dp= O.D. of Element (in)	0
W2= Length of Bot. Leg (in)	0.3125	te= Element Thick. (in)	0
W3= Length of Element Weld Leg (in)	0	fr= Strength Factor	1
fr= Strength Factor	1		
Reinforcement Areas	Formula	Area (in ²)	

Area of reinforcement required $A = di \cdot tr \cdot F + 2tn \cdot tr \cdot F(1 - fr)$ 0.81002
 (for vessel under external pressure multiply by 0.5)

Area of excess thickness in shell or head $A1 = d(E \cdot t - F \cdot tr) - 2tn(E \cdot t - F \cdot tr)(1 - fr)$ 0.69373
 (use greater value) or $A1 = 2(t + tn)(E \cdot t - F \cdot tr) - 2tn(E \cdot t - F \cdot tr)(1 - fr)$ 0.17127
 Greater Value= 0.69373

Area of excess thickness in nozzle wall projecting outward $A2 = 5t(tn - trn)fr$ 0.2115
 (use smaller value) $A2 = 2(tn - trn)(2.5tn + te)fr$ 0.06768
 Smaller Value= 0.06768

Area of excess thickness in nozzle wall projecting inward $A3 = 2h(tn - c)fr$ 0.03

Area of outward nozzle welds $A41 = fr(W1)^2$ 0
 Area of inward nozzle welds $A43 = fr(W2)^2$ 0.097656
 Area of element welds $A42 = fr(W3)^2$ 0

Area in element $A5 = te(Dp - di - 2tn)fr$ 0

Total area available $At = A1 + A2 + A3 + A4 + A5$ 0.889066

Note: All calculations as per ASME Section VIII, Div. I, par. UG-37.

Pressure Vessel Nozzle Reinforcement Calculations

D6) CASE: 10.00 in. nozzle, through 12.5 in. flat head, ext. pres. of 32.2 psi.
 Shell or Head Data Nozzle Data

t=Actual Thickness (in)	0.375	tn= Actual Thickness (in)	0.12
tr=Calculated Thickness (in)	0.258	trn= Calc. Thickness (in)	0.038
F=Correction Factor	1	c= Corrosion Allow. (in)	0
E=Joint Efficiency	1	di=Effective I.D. (in)	9.76
		d=Limit of Reinfor. (in)	9.76
		fr= Strength Factor	1
		h= Available Nozzle Inward Length	0.1875
Weld Data		Element Data	
W1= Length of Top Leg (in)	0.125	Dp= O.D. of Element (in)	0
W2= Length of Bot. Leg (in)	0.25	te= Element Thick. (in)	0
W3= Length of Element Weld Leg (in)	0	fr= Strength Factor	1
fr= Strength Factor	1		
Reinforcement Areas		Formula	Area (in ²)

Area of reinforcement required $A = d_i \cdot t_r \cdot F + 2t_n \cdot t_r \cdot F(1 - fr)$ 2.51808
 (for vessel under external pressure multiply by 0.5) 1.25904

Area of excess thickness in shell or head $A_1 = d(E \cdot t - F \cdot tr) - 2t_n(E \cdot t - F \cdot tr)(1 - fr)$ 1.14192
 (use greater value) or $A_1 = 2(t + t_n)(E \cdot t - F \cdot tr) - 2t_n(E \cdot t - F \cdot tr)(1 - fr)$ 0.11583
 Greater Value= 1.14192

Area of excess thickness in nozzle wall projecting outward $A_2 = 5t(t_n - trn)fr$ 0.15375
 (use smaller value) $A_2 = 2(t_n - trn)(2.5t_n + te)fr$ 0.0492
 Smaller Value= 0.0492

Area of excess thickness in nozzle wall projecting inward $A_3 = 2h(t_n - c)fr$ 0.045

Area of outward nozzle welds $A_{41} = fr(W_1)^2$ 0.015625
 Area of inward nozzle welds $A_{43} = fr(W_2)^2$ 0.0625
 Area of element welds $A_{42} = fr(W_3)^2$ 0

Area in element $A_5 = te(D_p - d_i - 2t_n)fr$ 0

Total area available $A_t = A_1 + A_2 + A_3 + A_4 + A_5$ 1.314245

Note: All calculations as per ASME Section VIII, Div. I, par. UG-37.

D7) CASE: 8.00 in. nozzle, through 22.5 in. flat head, int. pres. of 14.7 psi.
 Shell or Head Data Nozzle Data

t=Actual Thickness (in)	0.5	tn= Actual Thickness (in)	0.12
tr=Calculated Thickness (in)	0.314	trn= Calc. Thickness (in)	0.0063
F=Correction Factor	1	c= Corrosion Allow. (in)	0
E=Joint Efficiency	1	di=Effective I.D. (in)	7.76
		d=Limit of Reinfor. (in)	7.76
		fr= Strength Factor	1
		h= Available Nozzle Inward Length	0.125
Weld Data		Element Data	
W1= Length of Top Leg (in)	0.125	Dp= O.D. of Element (in)	12
W2= Length of Bot. Leg (in)	0.25	te= Element Thick. (in)	0.25
W3= Length of Element Weld Leg (in)	0	fr= Strength Factor	1
fr= Strength Factor	1		
Reinforcement Areas		Formula	Area (in^2)

Area of reinforcement required $A = di \cdot tr \cdot F + 2tn \cdot tr \cdot F(1 - fr)$ 2.43664
 (for vessel under external pressure multiply by 0.5)

Area of excess thickness in shell or head $A1 = d(E \cdot t - F \cdot tr) - 2tn(E \cdot t - F \cdot tr)(1 - fr)$ 1.44336
 (use greater value) or $A1 = 2(t + tn)(E \cdot t - F \cdot tr) - 2tn(E \cdot t - F \cdot tr)(1 - fr)$ 0.23064
 Greater Value= 1.44336

Area of excess thickness in nozzle wall projecting outward $A2 = 5t(tn - trn)fr$ 0.28425
 $A2 = 2(tn - trn)(2.5tn + te)fr$ 0.12507
 (use smaller value) Smaller Value= 0.12507

Area of excess thickness in nozzle wall projecting inward $A3 = 2h(tn - c)fr$ 0.03

Area of outward nozzle welds $A41 = fr(W1)^2$ 0.015625
 Area of inward nozzle welds $A43 = fr(W2)^2$ 0.0625
 Area of element welds $A42 = fr(W3)^2$ 0

Area in element $A5 = te(Dp - di - 2tn)fr$ 0

Total area available $At = A1 + A2 + A3 + A4 + A5$ 2.676555

Note: All calculations as per ASME Section VIII, Div. I, par. UG-37.

3.50" EC BELLOWS

E 1)

**BELLOWS DESIGN
WORKSHEET****Patrick J.
Bolan****Revision 9/27/90****Date:****Run Date: 6/25/91****Filename: BELLOWS**

**References: "ASME Boiler and Pressure Vessel Code," Section VIII,
division 1, appendix BB
"Standards of the Expansion Joint Manufacturers Association."
"Roark's Formulas for Stress and Strain," 6th edition, Table 35
"Hyspan Design Calculations"**

**NOTE: You must open the File "BELLOWS_MACRO" for
this worksheet to work properly.**

INPUT

Inside Diameter, d =	3.500 in
Thickness/ply before forming, tm	0.0120 in
=	
Number of plies, np =	2
Bellows Modulus, Eb =	2.94E+07 psi
Poisson's Ratio, v =	0.300
Number of Convolutions, N =	9
Convolution Depth, w =	0.4375 in
Convolution Pitch, q =	0.3333 in/conv.
Temp correction factor, Tf	1.0000
Design Pressure, P =	35.00 psig
Internal or external Pressure?	INT ("INT" or "EXT")
Deflection, axial, ex =	0.0556 in/conv.
Deflection, lateral, ey =	0.0211 in/conv.
Deflection, angular, eo =	0.0000 rad/conv.
Fatigue strength red. fac., Kg =	1.0000 (default = 1)
Material constant, C =	1860000 (From EJMA code. Default
Material constant, B =	54000 values are for austenitic
Material constant, a =	3.4 stainless steel.)

CALCULATED VARIABLES

Thickness/ply after forming, t =	0.011 in
Equivalent axial deflection, e =	0.077 in/conv.
Pressure constant, k =	0.249
$q/(2.2 \cdot (t(d+w))^{.5}) =$	0.718
$q/2w =$	0.381

TABULAR VALUES

Cp =	0.666
Cf =	1.383
Cd =	1.647

E 1) DESIGN OUTPUT

S _{cmp} =	953 psi*
S _{mmp} =	338 psi*
S _{m_{bp}} =	8713 psi
S _{m_{md}} =	1245 psi
S _{m_{bd}} =	134,793 psi
S _n =	145,090 psi
(S _{mmp} +S _{m_{bp}})/1.5 =	6034 psi*
.35*S _{m_{bp}} =	3050 psi*

*Note: These values must be less than
ASME code allowable stress, S_a.

Fatigue Life, as specified by:

ASME code, N _c =	4845 cycles
EJMA code, N _c =	31538 cycles
	(Both equations good for 300-level stainless steel)

Knuckle Radius Requirement met? Yes (Y or N)

Bellows Theoretical Axial Elastic

Spring Rate, per conv., fl_u = 4921 lbs/(in/conv
.)

Axial spring rate = 547 lbs/in

Lateral Spring rate = 1413 lbs/in

Angular Spring Rate = 17 lbs/deg

Limiting Internal design pressure 172 psi

=
Factor of safety = 4.91

5.00" EC BELLOWS

E 2)	BELLOWS DESIGN WORKSHEET	Patrick J. Bolan	
		Revision	9/27/90
		Date:	
		Run Date:	6/25/91
Filename: BELLOWS			
References: "ASME Boiler and Pressure Vessel Code," Section VIII, division 1, appendix BB			
"Standards of the Expansion Joint Manufacturers Association."			
"Roark's Formulas for Stress and Strain," 6th edition, Table 35			
"Hyspan Design Calculations"			

NOTE: You must open the File "BELLOWS_MACRO" for
this worksheet to work properly.

INPUT	
Inside Diameter, d =	5.000 in
Thickness/ply before forming, tm	0.0120 in
=	
Number of plies, np =	2
Bellows Modulus, Eb =	2.94E+07 psi
Poisson's Ratio, v =	0.300
Number of Convolutions, N =	9
Convolution Depth, w =	0.5000 in
Convolution Pitch, q =	0.3330 in/conv.
Temp correction factor, Tf	1.0000
Design Pressure, P =	14.70 psig
Internal or external Pressure?	EXT ("INT" or "EXT")
Deflection, axial, ex =	0.0556 in/conv.
Deflection, lateral, ey =	0.0211 in/conv.
Deflection, angular, eo =	0.0000 rad/conv.
Fatigue strength red. fac., Kg =	1.0000 (default = 1)
Material constant, C =	1860000 (From EJMA code. Default values are for austenitic stainless steel.)
Material constant, B =	54000
Material constant, a =	3.4

CALCULATED VARIABLES	
Thickness/ply after forming, t =	0.011 in
Equivalent axial deflection, e =	0.077 in/conv.
Pressure constant, k =	0.220
$q/(2.2 \cdot (t(d+w))^{.5}) =$	0.603
$q/2w =$	0.333

TABULAR VALUES	
Cp =	0.735
Cf =	1.391
Cd =	1.532

E 2) DESIGN OUTPUT

Scmp =	494 psi*
Smmp =	161 psi*
Smbp =	5161 psi
Smmd =	849 psi
Smbd =	112,302 psi
Sn =	118,472 psi
(Smmp+Smbp)/1.5 =	3548 psi*
.35*Smbp =	1806 psi*

*Note: These values must be less than
ASME code allowable stress, Sa.

Fatigue Life, as specified by:

ASME code, Nc =	9224 cycles
EJMA code, Nc =	100345 cycles
	(Both equations good for 300-level stainless steel)

Knuckle Radius Requirement met?	Yes (Y or N)
---------------------------------	--------------

Bellows Theoretical Axial Elastic

Spring Rate, per conv., fu =	4735 lbs/(in/conv .)
------------------------------	-------------------------

Axial spring rate =	526 lbs/in
---------------------	------------

Lateral Spring rate =	2658 lbs/in
-----------------------	-------------

Angular Spring Rate =	32 lbs/deg
-----------------------	------------

Limiting External design Pressure	94333 psi
-----------------------------------	-----------

=

Factor of safety =	6417.23
--------------------	---------

APPENDIX - A
(Drawings)

NOTE.

- 1.) ALL WELDS TO BE VACUUM LEAK TIGHT
- 2.) LEAK TEST: NO LEAK SHALL BE DETECTABLE ON THE MOST SENSITIVE SCALE OF A HELIUM LEAK DETECTOR WITH A MINIMUM SENSITIVITY OF 10⁻⁴ ATM.CC/SEC.
- 3.) ITEMS AS & S TO BE LOCATED AND TACK WELDED AT TIME OF INSTALLATION SO AS NOT TO INTERFERE WITH THE ELECTROMAGNET.

[illegible][illegible]

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DO DETECTOR - END CALORIMETER
BELLows ASSEMBLY

DATE	FILED	SEARCH NUMBER
1/2		3740.220-ME-295181
CREATED WITH: -DEAS.V		USER NAME: MATTHEW