Steel-Pro

771 Main Street

Rockland, ME 04841

Tele: 207-596-0061

FLUOR		
	FLUOR TO COMPLETE	
TO BE COMPLETED BY VENDOR	PDDM REC'D DATE:	FLUOR REV.
CONTRACT No: A5KM		
P.O. NUMBER: A5KM-4-0701-01/A4WK100004		A - PROCEED
FIRST ISSUE: YES NO X		B - PROCEED, CHANGE AS NOTED & RESUBMIT
EDR CODE(S): CDO		C - DO NOT PROCEED, CHANGE AS NOTED & RESUBMIT
ITEM/TAG NUMBERS: 12-F-13321 TO 12-F-14321		D - REVIEWED FOR INFORMATION ONLY
FLUOR CONTROL NUMBER BY FLUOR		Q - QUALITY IS BELOW STANDARDS. CORRECT & RESUBMIT
	AUTHORIZATION TO PROCEED DOES NOT RELIEVE CONTRACTOR/VENDOR OF ITS RESPONSIBILITY OR LIABILITY UNDER THE CONTRACT/PURCHASE ORDER.	

Pressure Vessel Design Calculations

(Document#) S.O. #: 20725

Vessel Name: 54" x 48" HyPulse GSV Filter Vessel

Customer: Mott Corp

Revision B

Date: 03/20/15

FLUOR®

A – PROCEED

Authorization to proceed does not relieve Contractor/Supplier of its responsibility or liability under the Contract and or Purchase Order.

By Jeremiah Telado on Apr 01, 2015

FLUOR 00A5KM23
DOC. NO. REC'D: 23-MAR-2015

A5KM-4-0701-01-00051-3

EQUIP/TAG NUMBER

12-F-13321 12-F-14321

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Nozzle Schedule

Specifications									
Nozzle mark	Identifier	Size	Materials		Impact Tested	Normalized	Fine Grain	Flange	Blind
A1	Process Gas Inlet	NPS 10 Sch 80S (XS)	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 10 Class 300 WN A182 F304	No
			Pad	SA-240 304	No	No	No		
A2	Backpulse Gas Inlet	NPS 4 Sch 80S (XS)	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 4 Class 300 WN A182 F304	No
			Pad	SA-240 304	No	No	No		
A3	Backpulse Gas Inlet	NPS 4 Sch 80S (XS)	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 4 Class 300 WN A182 F304	No
			Pad	SA-240 304	No	No	No		
A4	Backpulse Gas Inlet	NPS 4 Sch 80S (XS)	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 4 Class 300 WN A182 F304	No
			Pad	SA-240 304	No	No	No		
A5	Backpulse Gas Inlet	NPS 4 Sch 80S (XS)	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 4 Class 300 WN A182 F304	No
			Pad	SA-240 304	No	No	No		
B1	Process Gas Outlet	NPS 10 Sch 80S (XS)	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 10 Class 300 WN A182 F304	No
			Pad	SA-240 304	No	No	No		
H1	Cleanout Handhole	NPS 6 Sch 80S (XS)	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 6 Class 300 WN A182 F304	NPS 6 Class 300 A182 F304
			Pad	SA-240 304	No	No	No		
L	Level Indicator Conn	NPS 3 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 3 Class 300 WN A182 F304	NPS 3 Class 300 A182 F304
MW1	Manway	24 OD x 0.375	Nozzle	SA-240 304	No	No	No	NPS 24 Class 300 WN A182 F304	NPS 24 Class 300 A182 F304
			Pad	SA-240 304	No	No	No		
P1	High Diff Press Xmittr Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	No
P2	Low Diff Press Xmittr Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	No
			Pad	SA-240 304	No	No	No		
S1	Shipping Support Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	NPS 2 Class 300 A182 F304
			Pad	SA-240 304	No	No	No		
S2	Shipping Support Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	NPS 2 Class 300 A182 F304
			Pad	SA-240 304	No	No	No		
S3	Shipping Support Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	NPS 2 Class 300 A182 F304
			Pad	SA-240 304	No	No	No		
S4	Shipping Support Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	NPS 2 Class 300 A182 F304
S5	Shipping Support Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	NPS 2 Class 300 A182 F304
S6	Shipping Support Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	NPS 2 Class 300 A182 F304
T1	Spare Conn	NPS 2 Sch 160	Nozzle	SA-312 TP304 Wld pipe	No	No	No	NPS 2 Class 300 WN A182 F304	NPS 2 Class 300 A182 F304

Nozzle Summary

Dimensions												
Nozzle mark	OD (in)	t_n (in)	Req t_n (in)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (in)	A_a/A_r (%)
						Nom t (in)	Design t (in)	User t (in)	Width (in)	t_{pad} (in)		
A1	10.75	0.5	0.365	Yes	Yes	0.5	0.5		5.25	0.375	0.125	108.3
A2	4.5	0.337	0.3369	Yes	Yes	0.3125*	0.3125		2	0.25	0.125	136.6
A3	4.5	0.337	0.3369	Yes	Yes	0.3125*	0.3125		2	0.25	0.125	136.6
A4	4.5	0.337	0.3369	Yes	Yes	0.3125*	0.3125		2	0.25	0.125	136.6
A5	4.5	0.337	0.3369	Yes	Yes	0.3125*	0.3125		2	0.25	0.125	136.6
B1	10.75	0.5	0.365	Yes	Yes	0.5	0.4657		5.25	0.375	0.125	100.0
H1	6.625	0.432	0.1906	Yes	Yes	0.3125	0.2961		1	0.25	0.125	100.0
L	3.5	0.438	0.3589	Yes	Yes	0.5	0.4076		N/A	N/A	0.125	100.0
MW1	24	0.375	0.1925	Yes	Yes	0.5	0.2686		1	0.25	0.125	100.0
P1	2.375	0.344	0.2969	Yes	Yes	0.5	N/A		N/A	N/A	0.125	Exempt
P2	2.375	0.344	0.2969	Yes	Yes	0.3125	N/A		1	0.25	0.125	Exempt
S1	2.375	0.344	0.2969	Yes	Yes	0.3125	N/A		1	0.25	0.125	Exempt
S2	2.375	0.344	0.2969	Yes	Yes	0.3125	N/A		1	0.25	0.125	Exempt
S3	2.375	0.344	0.2969	Yes	Yes	0.3125	N/A		1	0.25	0.125	Exempt
S4	2.375	0.344	0.2969	Yes	Yes	0.5	N/A		N/A	N/A	0.125	Exempt
S5	2.375	0.344	0.2969	Yes	Yes	0.5	N/A		N/A	N/A	0.125	Exempt
S6	2.375	0.344	0.2969	Yes	Yes	0.5	N/A		N/A	N/A	0.125	Exempt
T1	2.375	0.344	0.2969	Yes	Yes	0.5	N/A		N/A	N/A	0.125	Exempt

*Head minimum thickness after forming

Definitions	
tn	Nozzle thickness
Req tn	Nozzle thickness required per UG-45/UG-16
Nom t	Vessel wall thickness
Design t	Required vessel wall thickness due to pressure + corrosion allowance per UG-37
User t	Local vessel wall thickness (near opening)
A_a	Area available per UG-37, governing condition
A_r	Area required per UG-37, governing condition
Corr	Corrosion allowance on nozzle wall

Pressure Summary

Component Summary										
Identifier	P Design (psi)	T Design (° F)	MAWP (psi)	MAP (psi)	MAEP (psi)	T_e external (° F)	MDMT (° F)	MDMT Exemption		Impact Tested
Top Head	60	980	66.66	117.84	32.75	0	-320	Note 1		No
Straight Flange on Top Head	60	980	139.36	237.43	72.04	0	-320	Note 2		No
Bonnet Shell	60	980	195.47	317.16	120.36	0	-320	Note 3		No
Bonnet Cone	60	980	75.92	120.96	43.26	0	-320	Note 4, 5, 6		No
Tube Sheet Thk Spacer (No Print)	60	980	125.37	222.51	98.58	0	-320	Note 7		No
Vessel Body Upper Shell	60	980	125.37	222.51	28.76	0	-320	Note 7		No
Vessel Body Mid Shell	60	980	219.97	357.14	97.82	0	-320	Note 8		No
Vessel Body Lower Shell	60	980	125.03	222.51	32.51	0	-320	Note 9		No
Vessel Body Cone	60	980	89.28	192.62	55.62	0	-320	Note 10, 5, 6		No
Cone Outlet Neck	60	980	431.41	759.38	354.74	0	-320	Note 11		No
Cone Outlet 12"x6" Sch 80s Reducer	60	980	506.93	893.39	354.74	0	-320	Note 12		No
Upper Body Flange	60	980	365	720	N/A	0	-320	Note 13		No
Bonnet Cone Lower Stiffening Ring	N/A	N/A	N/A	N/A	80.19	0	N/A	N/A		No
Lower Body Flange	60	980	365	720	N/A	0	-320	Note 13		No
Vessel Body Vacuum Ring	N/A	N/A	N/A	N/A	28.76	0	N/A	N/A		No
Support Lugs	60	980	61.16	N/A	N/A	N/A	N/A	N/A		N/A
Vessel Cone Upper Stiffening Ring	N/A	N/A	N/A	N/A	32.51	0	N/A	N/A		No
B2	60	980	364.04	720	N/A	0	-320	Note 13		No
Process Gas Inlet (A1)	60	980	63.58	420.16	97.82	0	-320	Nozzle	Note 4	No
								Pad	Note 14	No
Backpulse Gas Inlet (A2)	60	980	72.85	231.21	32.75	0	-320	Nozzle	Note 15	No
								Pad	Note 16	No
Backpulse Gas Inlet (A3)	60	980	72.85	231.21	32.75	0	-320	Nozzle	Note 15	No
								Pad	Note 16	No
Backpulse Gas Inlet (A4)	60	980	72.85	231.21	32.75	0	-320	Nozzle	Note 15	No
								Pad	Note 16	No
Backpulse Gas Inlet (A5)	60	980	72.85	231.21	32.75	0	-320	Nozzle	Note 15	No
								Pad	Note 16	No
Process Gas Outlet (B1)	60	980	61.16	347.36	120.36	0	-320	Nozzle	Note 4	No
								Pad	Note 17	No
Cleanout Handhole (H1)	60	980	103.29	185.81	27.09	0	-320	Nozzle	Note 18	No
								Pad	Note 18	No
Level Indicator Conn (L)	60	980	188.42	341.96	84.84	0	-320	Note 19		No
Manway (MW1)	60	980	73.93	130.4	20.06	0	-320	Nozzle	Note 20	No
								Pad	Note 21	No
High Diff Press Xmittr Conn (P1)	60	980	220.07	373.14	120.36	0	-320	Note 22		No
Low Diff Press Xmittr Conn (P2)	60	980	147.49	261.78	28.76	0	-320	Nozzle	Note 22	No
								Pad	Note 23	No
Shipping Support Conn (S1)	60	980	147.49	261.78	28.76	0	-320	Nozzle	Note 22	No
								Pad	Note 23	No
Shipping Support Conn (S2)	60	980	147.49	261.78	28.76	0	-320	Nozzle	Note 22	No

								Pad	Note 23	No
Shipping Support Conn (S3)	60	980	147.49	261.78	28.76	0	-320	Nozzle	Note 22	No
								Pad	Note 23	No
Shipping Support Conn (S4)	60	980	220.07	373.14	120.36	0	-320	Note 22		No
Shipping Support Conn (S5)	60	980	220.07	373.14	120.36	0	-320	Note 22		No
Shipping Support Conn (S6)	60	980	220.07	373.14	120.36	0	-320	Note 22		No
Spare Conn (T1)	60	980	220.07	373.14	120.36	0	-320	Note 22		No

Chamber Summary	
Design MDMT	-20 ° F
Rated MDMT	-320 ° F @ 61.16 psi
MAWP hot & corroded	61.16 psi @ 980 ° F
MAP cold & new	117.84 psi @ 70 ° F
MAEP	20.06 psi @ 0 ° F

Notes for MDMT Rating		
Note #	**Exemption**	**Details**
1.	Straight Flange governs MDMT	
2.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2638)	
3.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1884)	
4.	Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320° F	
5.	MAWP is governed by cone juncture.	
6.	MAP is governed by cone juncture.	
7.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2931)	
8.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1678)	
9.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2948)	
10.	Impact test exempt per UHA-51(g) (coincident ratio = 0.3403)	
11.	Impact test exempt per UHA-51(g) (coincident ratio = 0.0873)	
12.	Impact test exempt per UHA-51(g) (coincident ratio = 0.0744)	
13.	Flange rated MDMT per UHA-51(d)(1)(a) = -320° F	Bolts rated MDMT = -320° F
14.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1675)	
15.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2817)	
16.	Impact test exempt per UHA-51(g) (coincident ratio = 0.3318)	
17.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1885)	
18.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2942)	
19.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1668)	
20.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1441)	
21.	Impact test exempt per UHA-51(g) (coincident ratio = 0.1677)	
22.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
23.	Impact test exempt per UHA-51(g) (coincident ratio = 0.2932)	

Thickness Summary

Component Data								
Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
Top Head	SA-240 304	54 OD	9.756	0.3125*	0.2877	0.0625	0.85	Internal
Straight Flange on Top Head	SA-240 304	54 OD	1.5	0.375	0.1974	0.0625	0.85	Internal
Bonnet Shell	SA-240 304	54 OD	26.1275	0.5	0.1974	0.0625	0.85	Internal
Bonnet Cone	SA-240 304	48 / 54 OD	5.4375	0.3125	0.2166	0.0625	0.85	Internal
Tube Sheet Thk Spacer (No Print)	SA-240 304	48 OD	3.375	0.3125	0.1825	0.0625	0.85	Internal
Vessel Body Upper Shell	SA-240 304	48 OD	97.94	0.3125	0.2069	0.0625	0.85	External
Vessel Body Mid Shell	SA-240 304	48 OD	30	0.5	0.1998	0.0625	0.85	External
Vessel Body Lower Shell	SA-240 304	48 OD	16.75	0.3125	0.1998	0.0625	0.85	External
Vessel Body Cone	SA-240 304	12.75 / 48 OD	30.5625	0.3125	0.2335	0.0625	0.85	Seismic
Cone Outlet Neck	SA-312 TP304 Wld pipe	12.75 OD	2.0575	0.375	0.178	0.0625	0.85	Seismic
Cone Outlet 12"x6" Sch 80s Reducer	SA-403 304	12.75 OD	8	0.3281	0.1726	0.0625	0.85	Seismic
*Head minimum thickness after forming								

Definitions	
Nominal t	Vessel wall nominal thickness
Design t	Required vessel thickness due to governing loading + corrosion
Joint E	Longitudinal seam joint efficiency
Load	
Internal	Circumferential stress due to internal pressure governs
External	External pressure governs
Wind	Combined longitudinal stress of pressure + weight + wind governs
Seismic	Combined longitudinal stress of pressure + weight + seismic governs

Settings Summary

COMPRESS 2015 Build 7500	
ASME Section VIII Division 1, 2013 Edition	
Units	U.S. Customary
Datum Line Location	40.38" from top seam
Vessel Design Mode	Get Thickness from Pressure
Minimum thickness	0.0625" per UG-16(b)
Design for cold shut down only	No
Design for lethal service (full radiography required)	No
Design nozzles for	Design P, find nozzle MAWP and MAP
Corrosion weight loss	100% of theoretical loss
UG-23 Stress Increase	1.20
Skirt/legs stress increase	1.0
Minimum nozzle projection	0.125"
Juncture calculations for α > 30 only	No
Preheat P-No 1 Materials > 1.25" and <= 1.50" thick	No
UG-37(a) shell tr calculation considers longitudinal stress	No
Cylindrical shells made from pipe are entered as minimum thickness	No
Nozzles made from pipe are entered as minimum thickness	No
Pipe caps are entered as minimum thickness	No
Butt welds	Tapered per Figure UCS-66.3(a)
Disallow Appendix 1-5, 1-8 calculations under 15 psi	No
Hydro/Pneumatic Test	
Shop Hydrotest Pressure	1.3 times vessel MAWP
Test liquid specific gravity	1.00
Maximum stress during test	90% of yield
Required Marking - UG-116	
UG-116(e) Radiography	RT4
UG-116(f) Postweld heat treatment	None
Code Cases\Interpretations	
Use Code Case 2547	No
Use Code Case 2695	No
Apply interpretation VIII-1-83-66	Yes
Apply interpretation VIII-1-86-175	No

Apply interpretation VIII-1-01-37	Yes
Apply interpretation VIII-1-01-150	No
Apply interpretation VIII-1-07-50	Yes
No UCS-66.1 MDMT reduction	No
No UCS-68(c) MDMT reduction	No
Disallow UG-20(f) exemptions	No
UG-22 Loadings	
UG-22(a) Internal or External Design Pressure	Yes
UG-22(b) Weight of the vessel and normal contents under operating or test conditions	Yes
UG-22(c) Superimposed static reactions from weight of attached equipment (external loads)	Yes
UG-22(d)(2) Vessel supports such as lugs, rings, skirts, saddles and legs	Yes
UG-22(f) Wind reactions	Yes
UG-22(f) Seismic reactions	Yes
UG-22(j) Test pressure and coincident static head acting during the test:	Yes
Note: UG-22(b),(c) and (f) loads only considered when supports are present.	

Hydrostatic Test

Horizontal shop hydrostatic test based on MAWP per UG-99(b)

Gauge pressure at 70° F = 1.3*MAWP*LSR
=
1.3*61.16*1.4167
= 112.63 psi

Horizontal shop hydrostatic test							
Identifier	Local test pressure (psi)	Test liquid static head (psi)	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test (psi)	Allowable test stress (psi)	Stress excessive?
Top Head	114.853	2.221	1.4184	1.30	9,923	27,000	No
Straight Flange on Top Head	114.851	2.218	1.4184	1.30	8,212	27,000	No
Bonnet Shell	114.846	2.214	1.4184	1.30	6,144	27,000	No
Bonnet Cone	114.851	2.219	1.4184	1.30	11,183	27,000	No
Upper Body Flange	114.749	2.116	N/A	1.30	NI	NI	NI
Tube Sheet Thk Spacer (No Print)	114.745	2.112	1.4184	1.30	8,755	27,000	No
Lower Body Flange	114.745	2.112	N/A	1.30	NI	NI	NI
Vessel Body Upper Shell	114.745	2.112	1.4184	1.30	8,755	27,000	No
Vessel Body Mid Shell	114.738	2.106	1.4184	1.30	5,450	27,000	No
Vessel Body Lower Shell	114.745	2.112	1.4184	1.30	8,755	27,000	No
Vessel Body Cone	114.743	2.111	1.4184	1.30	10,020	27,000	No
Cone Outlet Neck (2)	114.106	1.474	1.4167	1.30	2,143	27,000	No
Cone Outlet 12"x6" Sch 80s Reducer	114.108	1.475	1.4184	1.30	2,159	27,000	No
B2	113.999	1.367	N/A	1.30	NI	NI	NI
Backpulse Gas Inlet (A2)	114.32	1.687	1.4167	1.30	9,383	40,500	No
Backpulse Gas Inlet (A3)	113.598	0.965	1.4167	1.30	9,324	40,500	No
Backpulse Gas Inlet (A4)	113.598	0.965	1.4167	1.30	9,324	40,500	No
Backpulse Gas Inlet (A5)	114.32	1.687	1.4167	1.30	9,383	40,500	No
Cleanout Handhole (H1)	113.023	0.391	1.4167	1.30	15,623	40,500	No
High Diff Press Xmittr Conn (P1)	114.937	2.304	1.4167	1.30	8,566	40,500	No
Level Indicator Conn (L)	114.973	2.34	1.4167	1.30	7,683	40,500	No
Low Diff Press Xmittr Conn (P2)	114.887	2.255	1.4167	1.30	11,141	40,500	No
Manway (MW1)	114.309	1.677	1.4184	1.30	26,510	40,500	No
Process Gas Inlet (A1)	114.066	1.433	1.4167	1.30	6,727	40,500	No
Process Gas Outlet (B1)	114.066	1.433	1.4167	1.30	8,757	40,500	No
Shipping Support Conn (S1)	113.92	1.288	1.4167	1.30	7,950	40,500	No
Shipping Support Conn (S2)	114.843	2.21	1.4167	1.30	8,015	40,500	No
Shipping Support Conn (S3)	113.155	0.522	1.4167	1.30	7,897	40,500	No
Shipping Support Conn (S4)	114.476	1.843	1.4167	1.30	8,531	40,500	No
Shipping Support Conn (S5)	114.476	1.843	1.4167	1.30	8,531	40,500	No

Shipping Support Conn (S6)	112.915	0.283	1.4167	1.30	8,415	40,500	No
Spare Conn (T1)	113.92	1.288	1.4167	1.30	8,490	40,500	No

(1) NI indicates that test stress was not investigated.
(2) Cone Outlet Neck limits the UG-99(b) stress ratio.
(3) P_L stresses at nozzle openings have been estimated using the method described in Division 2 Part 4.5.
(4) $1.5*0.9*S_y$ used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.
(5) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

The field test condition has not been investigated.

Corroded Hydrostatic Test

The shop test condition has not been investigated.

Vertical field hydrostatic test based on design P per UG-99(b)

Gauge pressure at 70° F = 1.3*Design
P*LSR
= 1.3*60*1.4167
= 110.5 psi

Vertical field hydrostatic test							
Identifier	**Local test pressure (psi)**	**Test liquid static head (psi)**	**UG-99(b) stress ratio**	**UG-99(b) pressure factor**	**Stress during test (psi)**	**Allowable test stress (psi)**	**Stress excessive?**
Top Head	111.211	0.708	1.4184	1.30	12,025	27,000	No
Straight Flange on Top Head	111.211	0.708	1.4184	1.30	9,553	27,000	No
Bonnet Shell	112.154	1.652	1.4184	1.30	6,865	27,000	No
Bonnet Cone	112.35	1.848	1.4184	1.30	13,712	27,000	No
Upper Body Flange	112.668	2.166	N/A	1.30	NI	NI	NI
Tube Sheet Thk Spacer (No Print)	112.79	2.288	1.4184	1.30	10,771	27,000	No
Lower Body Flange	113.108	2.606	N/A	1.30	NI	NI	NI
Vessel Body Upper Shell	116.644	6.141	1.4184	1.30	11,139	27,000	No
Vessel Body Mid Shell	117.727	7.224	1.4184	1.30	6,399	27,000	No
Vessel Body Lower Shell	118.331	7.829	1.4184	1.30	11,301	27,000	No
Vessel Body Cone	119.434	8.932	1.4184	1.30	13,077	27,000	No
Cone Outlet Neck (2)	119.509	9.006	1.4167	1.30	2,808	27,000	No
Cone Outlet 12"x6" Sch 80s Reducer	119.797	9.295	1.4184	1.30	2,815	27,000	No
B2	119.797	9.295	N/A	1.30	NI	NI	NI
Backpulse Gas Inlet (A2)	110.872	0.37	1.4167	1.30	13,073	40,500	No
Backpulse Gas Inlet (A3)	110.872	0.37	1.4167	1.30	13,073	40,500	No
Backpulse Gas Inlet (A4)	110.872	0.37	1.4167	1.30	13,073	40,500	No
Backpulse Gas Inlet (A5)	110.872	0.37	1.4167	1.30	13,073	40,500	No
Cleanout Handhole (H1)	118.015	7.513	1.4167	1.30	22,035	40,500	No
High Diff Press Xmittr Conn (P1)	112.067	1.565	1.4167	1.30	10,626	40,500	No
Level Indicator Conn (L)	117.499	6.996	1.4167	1.30	9,795	40,500	No
Low Diff Press Xmittr Conn (P2)	113.62	3.118	1.4167	1.30	14,239	40,500	No
Manway (MW1)	117.609	7.107	1.4184	1.30	35,656	40,500	No
Process Gas Inlet (A1)	117.366	6.863	1.4167	1.30	8,826	40,500	No
Process Gas Outlet (B1)	111.924	1.421	1.4167	1.30	10,122	40,500	No
Shipping Support Conn (S1)	116.559	6.056	1.4167	1.30	11,017	40,500	No
Shipping Support Conn (S2)	116.559	6.056	1.4167	1.30	11,017	40,500	No
Shipping Support Conn (S3)	116.559	6.056	1.4167	1.30	11,017	40,500	No

Shipping Support Conn (S4)	111.566	1.064	1.4167	1.30	10,579	40,500	No
Shipping Support Conn (S5)	111.566	1.064	1.4167	1.30	10,579	40,500	No
Shipping Support Conn (S6)	111.566	1.064	1.4167	1.30	10,579	40,500	No
Spare Conn (T1)	112.067	1.565	1.4167	1.30	10,626	40,500	No

(1) NI indicates that test stress was not investigated.
(2) Cone Outlet Neck limits the UG-99(b) stress ratio.
(3) P_L stresses at nozzle openings have been estimated using the method described in Division 2 Part 4.5.
(4) $1.5*0.9*S_y$ used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	28.14"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	4,212 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

Accumulator

Commentary for Accumulator

Notes On Calculation Set Coordinate System:
1.) System elevation datum (zero) is the face of the upper body flange.
2.) System elevation values are positive (+), in the downward direction from the datum.
3.) System elevation values are negative (-), in the upward direction from the datum.

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ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	-101"
Direction Angle	0.00°
Distance from Center of Vessel	17.63"
Magnitude of Force	1,865 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

See Component Commentary

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	-31.81"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	2,398 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

A1 Internal Pipe

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	78.13"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	326 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	-84.15"
Direction Angle	180.00°
Distance from Center of Vessel	11.45"
Magnitude of Force	88 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	-74.45"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	224 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	-62.56"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	381 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	-67.57"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	787 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

Model Discrepancy Make-up Weight

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	-70"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	417 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	Yes
Present When Vessel is Empty	Yes
Present During Hydrotest	Yes

Solids Full Level

ASME Section VIII Division 1, 2013 Edition	
Location from Datum (in)	132.375
Operating Liquid Specific Gravity	0.385

Top Head

ASME Section VIII Division 1, 2013 Edition				
Component		F&D Head		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Attached To		Bonnet Shell		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		2.22	61.5151	1
Dimensions				
Outer Diameter		54"		
Crown Radius L		54"		
Knuckle Radius r		4"		
Minimum Thickness		0.3125"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Length L_{sf}		1.5"		
Nominal Thickness t_{sf}		0.375"		
Weight and Capacity				
		Weight (lb)[1]	**Capacity (US gal)[1]**	
New		271.36	71.87	
Corroded		218.66	72.68	
Radiography				
Category A joints		Seamless No RT		
Head to shell seam		Spot UW-11(b) Type 1		

[1] includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.2877"
Design thickness due to external pressure (t_e)	0.1741"
Maximum allowable working pressure (MAWP)	66.66 psi
Maximum allowable pressure (MAP)	117.84 psi
Maximum allowable external pressure (MAEP)	32.75 psi
Straight Flange governs MDMT	-320° F

Note: Endnote 90 used to determine allowable stress.

Factor M		
$M = 1/4*[3 + (L / r)^{1/2}]$		
Corroded	$M = 1/4*[3 + (54.0625 / 4.0625)^{1/2}]$	1.662
New	$M = 1/4*[3 + (54 / 4)^{1/2}]$	1.6686

Design thickness for internal pressure, (Corroded at 980 ° F) Appendix 1-4(d)

t = $P*L_o*M / (2*S*E + P*(M - 0.2)) + Corrosion$
= $60*54.3125*1.662 / (2*14,100*0.85 + 60*(1.662 - 0.2)) + 0.0625$
= 0.2876"

Maximum allowable working pressure, (Corroded at 980 ° F) Appendix 1-4(d)

P = $2*S*E*t / (M*L_o - t*(M - 0.2)) - P_s$
= $2*14,100*0.85*0.25 / (1.662*54.3125 - 0.25*(1.662 - 0.2)) - 0$
= 66.66 psi

Maximum allowable pressure, (New at 70 ° F) Appendix 1-4(d)

P = $2*S*E*t / (M*L_o - t*(M - 0.2)) - P_s$
= $2*20,000*0.85*0.3125 / (1.6686*54.3125 - 0.3125*(1.6686 - 0.2)) - 0$
= 117.84 psi

Design thickness for external pressure, (Corroded at 0 ° F) UG-33(e)

Equivalent outside spherical radius (R_o)
= Outside crown radius
= 54.3125 in

A = $0.125 / (R_o / t)$
= $0.125 / (54.3125 / 0.1115)$
= 0.000257

From Table HA-1: B = 3,604.5965 psi

P_a = $B / (R_o / t)$
= $3,604.5965 / (54.3125 / 0.1115)$

= 7.4 psi

t = 0.1115" + Corrosion = 0.1115" + 0.0625" = 0.174"
Check the external pressure per UG-33(a)(1) Appendix 1-4(d)

t = $1.67*P_e*L_o*M / (2*S*E + 1.67*P_e*(M - 0.2)) + Corrosion$
= $1.67*7.4*54.3125*1.662 / (2*20{,}000*1 + 1.67*7.4*(1.662 - 0.2)) + 0.0625$
= 0.0904"

The head external pressure design thickness (t_e) is 0.174".

Maximum Allowable External Pressure, (Corroded at 0 ° F) UG-33(e)

Equivalent outside spherical radius (R_o)
= Outside crown radius
= 54.3125 in

A = $0.125 / (R_o / t)$
= $0.125 / (54.3125 / 0.25)$
= 0.000575

From Table HA-1: B = 7,114.9966 psi

P_a = $B / (R_o / t)$
= $7{,}114.9966 / (54.3125 / 0.25)$
= 32.7503 psi

Check the Maximum External Pressure, UG-33(a)(1) Appendix 1-4(d)

P = $2*S*E*t / ((M*L_o - t*(M - 0.2))*1.67)$
= $2*20{,}000*1*0.25 / ((1.662*54.3125 - 0.25*(1.662 - 0.2))*1.67)$
= 66.61 psi

The maximum allowable external pressure (MAEP) is 32.75 psi.

% Forming strain - UHA-44(a)(2)

EFE = $(75*t / R_f)*(1 - R_f / R_o)$
= $(75*0.375 / 4.1875)*(1 - 4.1875 / \infty)$
= 6.7164%

Straight Flange on Top Head

ASME Section VIII Division 1, 2013 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		2.22	61.4526	1
Dimensions				
Outer Diameter		54"		
Length		1.5"		
Nominal Thickness		0.375"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		27.48		14.46
Corroded		22.93		14.53
Radiography				
Longitudinal seam		Seamless No RT		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.1974"
Design thickness due to external pressure (t_e)	0.1676"
Design thickness due to combined loadings + corrosion	0.1185"
Maximum allowable working pressure (MAWP)	139.36 psi
Maximum allowable pressure (MAP)	237.43 psi
Maximum allowable external pressure (MAEP)	72.04 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 61.16*27 / (20,000*0.85 + 0.4*61.16) =	0.097"
Stress ratio = t_r*E^* / (t_n - c) = 0.097*0.85 / (0.375 - 0.0625) =	0.2638
Impact test exempt per UHA-51(g) (coincident ratio = 0.2638)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 60*27 / (14,100*0.85 + 0.40*60) + 0.0625
= 0.1974"

Maximum allowable working pressure, (at 980 ° F) Appendix 1-1

P = $S*E*t / (R_o - 0.40*t) - P_s$
= 14,100*0.85*0.3125 / (27 - 0.40*0.3125) - 0
= 139.36 psi

Maximum allowable pressure, (at 70 ° F) Appendix 1-1

P = $S*E*t / (R_o - 0.40*t)$
= 20,000*0.85*0.375 / (27 - 0.40*0.375)
= 237.43 psi

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 30.7962 / 54 = 0.5703
D_o / t = 54 / 0.1051 = 513.7661
From table G: A = 0.000203
From table HA-1: B = 2,851.4259 psi

P_a = $4*B / (3*(D_o / t))$
= 4*2,851.43 / (3*(54 / 0.1051))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t + Corrosion = 0.1051 + 0.0625 = 0.1676"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 30.7962 / 54 = 0.5703
D_o / t = 54 / 0.3125 = 172.8000
From table G: A = 0.001105
From table HA-1: B = 9,335.8174 psi

P_a = 4*B / (3*(D_o / t))
= 4*9,335.82 / (3*(54 / 0.3125))
= 72.04 psi

% Forming strain - UHA-44(a)(2)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.375 / 26.8125)*(1 - 26.8125 / ∞)
= 0.6993%

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	60	14,100	5,166	980	0.0625	Wind	0.056	0.0525
						Seismic	0.0559	0.0526
Operating, Hot & New	60	14,100	5,346	980	0	Wind	0.0559	0.0523
						Seismic	0.0557	0.0525
Hot Shut Down, Corroded	0	14,100	5,166	980	0.0625	Wind	0.0004	0.0073
						Seismic	0.0003	0.0069
Hot Shut Down, New	0	14,100	5,346	980	0	Wind	0.0004	0.0072
						Seismic	0.0002	0.0068
Empty, Corroded	0	20,000	10,442	70	0.0625	Wind	0	0.0031
						Seismic	0.0002	0.0035
Empty, New	0	20,000	11,048	70	0	Wind	0.0001	0.003
						Seismic	0.0002	0.0034
Vacuum	-7.4	20,000	10,442	0	0.0625	Wind	0.0074	0.0115
						Seismic	0.0076	0.0113
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,100	5,166	980	0.0625	Weight	0.002	0.0075

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (27 / 0.3125)
= 0.001447

B = 5,166 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHC} = min(B, S) = 5,166 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (27 / 0.375)
= 0.001736

B = 5,346 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHN} = min(B, S) = 5,346 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (27 / 0.375)
= 0.001736

B = 11,048 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCN} = min(B, S) = 11,048 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (27 / 0.3125)
= 0.001447

B = 10,442 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCC} = min(B, S) = 10,442 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (27 / 0.3125)
= 0.001447

B = 10,442 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cVC} = min(B, S) = 10,442 psi

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*26.6875 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0556"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 47,088 / (π*26.8438^2*14,100*1.20*0.85)
= 0.0014"

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.60*4,137.3 / (2*π*26.8438*14,100*1.20*0.85)
= 0.001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0556 + 0.0014 - (0.001)
= 0.056"

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 4,137.3 / (2*π*26.8438*14,100*1.20*0.85)
= 0.0017"

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |0.0014 + (0.0017) - (0.0556)|
= 0.0525"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*0.85*(0.3125 - 0.0014 + (0.001)) / (26.6875 - 0.40*(0.3125 - 0.0014 + (0.001)))
= 337.94 psi

Operating, Hot & New, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)

= 60*26.625 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0555"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 47,088 / (π*26.8125^2*14,100*1.20*0.85)
= 0.0014"

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.60*4,227.4 / (2*π*26.8125*14,100*1.20*0.85)
= 0.001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0555 + 0.0014 - (0.001)
= 0.0559"

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 4,227.4 / (2*π*26.8125*14,100*1.20*0.85)
= 0.0017"

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |0.0014 + (0.0017) - (0.0555)|
= 0.0523"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*0.85*(0.375 - 0.0014 + (0.001)) / (26.625 - 0.40*(0.375 - 0.0014 + (0.001)))
= 406.98 psi

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 47,088 / (π*26.8438^2*14,100*1.20*0.85)
= 0.0014"

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.60*4,137.3 / (2*π*26.8438*14,100*1.20*0.85)
= 0.001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0014 - (0.001)
= 0.0004"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 47,088 / (π*26.8438^2*5,166.44*1.20)
= 0.0034"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 4,137.3 / (2*π*26.8438*5,166.44*1.20)
= 0.004"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0034 + (0.004) - (0)
= 0.0073"

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 47,088 / (π*26.8125^2*14,100*1.20*0.85)
= 0.0014"

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.60*4,227.4 / (2*π*26.8125*14,100*1.20*0.85)
= 0.001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0014 - (0.001)
= 0.0004"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 47,088 / (π*26.8125^2*5,346.22*1.20)
= 0.0032"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 4,227.4 / (2*π*26.8125*5,346.22*1.20)
= 0.0039"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0032 + (0.0039) - (0)
= 0.0072"

Empty, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 32,183 / (π*26.8438^2*10,441.82*1.20)
= 0.0011"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*4,137.3 / (2*π*26.8438*10,441.82*1.20)
= 0.0012"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0011 - (0.0012)|
= 0"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 4,137.3 / (2*π*26.8438*10,441.82*1.20)
= 0.002"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0011 + (0.002) - (0)
= 0.0031"

Empty, New, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 32,183 / (π*26.8125^2*11,048.16*1.20)
= 0.0011"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*4,227.4 / (2*π*26.8125*11,048.16*1.20)
= 0.0011"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0011 - (0.0011)|
= 0.0001"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 4,227.4 / (2*π*26.8125*11,048.16*1.20)
= 0.0019"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0011 + (0.0019) - (0)
= 0.003"

Vacuum, Wind, Bottom Seam

t_p = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*26.6875 / (2*10,441.82*1.20 + 0.40*|7.4|)
= -0.0079"

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 47,088 / (π*26.8438^2*10,441.82*1.20)
= 0.0017"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*4,137.3 / (2*π*26.8438*10,441.82*1.20)
= 0.0012"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |-0.0079 + 0.0017 - (0.0012)|
= 0.0074"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 4,137.3 / (2*π*26.8438*10,441.82*1.20)
= 0.002"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0017 + (0.002) - (-0.0079)
= 0.0115"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*10,441.82*1.20*(0.3125 - 0.0017 - 0.002) / (26.6875 - 0.40*(0.3125 - 0.0017 - 0.002))
= 291.4 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 31,872 / (π*26.8438^2*5,166.44*1.00)
= 0.0027"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)

= 4,137.3 / (2*π*26.8438*5,166.44*1.00)
= 0.0047"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0027 - (0.0047)|
= 0.002"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0027 + (0.0047) - (0)
= 0.0075"

Operating, Hot & Corroded, Seismic, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*26.6875 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0556"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 39,201 / (π*26.8438²*14,100*1.20*0.85)
= 0.0012"

t_w = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*4,137.3 / (2*π*26.8438*14,100*1.20*0.85)
= 0.0009"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0556 + 0.0012 - (0.0009)
= 0.0559"

t_{wc} = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 1.04*4,137.3 / (2*π*26.8438*14,100*1.20*0.85)
= 0.0018"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0012 + (0.0018) - (0.0556)|
= 0.0526"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= 2*14,100*1.20*0.85*(0.3125 - 0.0012 + (0.0009)) / (26.6875 - 0.40*(0.3125 - 0.0012 + (0.0009)))
= 338.12 psi

Operating, Hot & New, Seismic, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*26.625 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0555"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 39,340 / (π*26.8125²*14,100*1.20*0.85)
= 0.0012"

t_w = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*4,227.4 / (2*π*26.8125*14,100*1.20*0.85)
= 0.001"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0555 + 0.0012 - (0.001)
= 0.0557"

t_{wc} = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 1.04*4,227.4 / (2*π*26.8125*14,100*1.20*0.85)
= 0.0018"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0012 + (0.0018) - (0.0555)|
= 0.0525"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= 2*14,100*1.20*0.85*(0.375 - 0.0012 + (0.001)) / (26.625 - 0.40*(0.375 - 0.0012 + (0.001)))
= 407.16 psi

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 39,201 / (π*26.8438²*14,100*1.20*0.85)
= 0.0012"

t_w = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*4,137.3 / (2*π*26.8438*14,100*1.20*0.85)
= 0.0009"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0012 - (0.0009)
= 0.0003"

t_{mc} = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= 39,201 / (π*26.8438²*5,166.44*1.20)
= 0.0028"

t_{wc} = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= 1.04*4,137.3 / (2*π*26.8438*5,166.44*1.20)
= 0.0041"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0028 + (0.0041) - (0)
= 0.0069"

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 39,340 / (π*26.8125²*14,100*1.20*0.85)
= 0.0012"

t_w = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*4,227.4 / (2*π*26.8125*14,100*1.20*0.85)
= 0.001"

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0012 - (0.001)$
$= 0.0002"$

$t_{mc} = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 39,340 / (\pi * 26.8125^2 * 5,346.22 * 1.20)$
$= 0.0027"$

$t_{wc} = (1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 1.04 * 4,227.4 / (2 * \pi * 26.8125 * 5,346.22 * 1.20)$
$= 0.0041"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0027 + (0.0041) - (0)$
$= 0.0068"$

Empty, Corroded, Seismic, Bottom Seam

$t_p = 0"$ (Pressure)

$t_m = M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
$= 41,167 / (\pi * 26.8438^2 * 20,000 * 1.20 * 0.85)$
$= 0.0009"$

$t_w = (0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
$= 0.56 * 4,137.3 / (2 * \pi * 26.8438 * 20,000 * 1.20 * 0.85)$
$= 0.0007"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0009 - (0.0007)$
$= 0.0002"$

$t_{mc} = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 41,167 / (\pi * 26.8438^2 * 10,441.82 * 1.20)$
$= 0.0015"$

$t_{wc} = (1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 1.04 * 4,137.3 / (2 * \pi * 26.8438 * 10,441.82 * 1.20)$
$= 0.002"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0015 + (0.002) - (0)$
$= 0.0035"$

Empty, New, Seismic, Bottom Seam

$t_p = 0"$ (Pressure)

$t_m = M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
$= 41,277 / (\pi * 26.8125^2 * 20,000 * 1.20 * 0.85)$
$= 0.0009"$

$t_w = (0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
$= 0.56 * 4,227.4 / (2 * \pi * 26.8125 * 20,000 * 1.20 * 0.85)$
$= 0.0007"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0009 - (0.0007)$

= 0.0002"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 41,277 / (π*26.8125^2*11,048.16*1.20)
= 0.0014"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 1.04*4,227.4 / (2*π*26.8125*11,048.16*1.20)
= 0.002"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0014 + (0.002) - (0)
= 0.0034"

Vacuum, Seismic, Bottom Seam

t_p = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*26.6875 / (2*10,441.82*1.20 + 0.40*|7.4|)
= -0.0079"

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 39,201 / (π*26.8438^2*10,441.82*1.20)
= 0.0014"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*4,137.3 / (2*π*26.8438*10,441.82*1.20)
= 0.0011"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |-0.0079 + 0.0014 - (0.0011)|
= 0.0076"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 1.04*4,137.3 / (2*π*26.8438*10,441.82*1.20)
= 0.002"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0014 + (0.002) - (-0.0079)
= 0.0113"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*10,441.82*1.20*(0.3125 - 0.0014 - 0.002) / (26.6875 - 0.40*(0.3125 - 0.0014 - 0.002))
= 291.58 psi

Bonnet Shell

ASME Section VIII Division 1, 2013 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		2.21	61.3276	1
Dimensions				
Outer Diameter		54"		
Length		26.1275"		
Nominal Thickness		0.5"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		620.38		249.53
Corroded		543.48		250.71
Radiography				
Longitudinal seam		Spot UW-11(b) Type 1		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.1974"
Design thickness due to external pressure (t_e)	0.1676"
Design thickness due to combined loadings + corrosion	0.1181"
Maximum allowable working pressure (MAWP)	195.47 psi
Maximum allowable pressure (MAP)	317.16 psi
Maximum allowable external pressure (MAEP)	120.36 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 61.16*27 / (20,000*0.85 + 0.4*61.16) =	0.097"
Stress ratio = t_r*E^* / (t_n - c) = 0.097*0.85 / (0.5 - 0.0625) =	0.1884
Impact test exempt per UHA-51(g) (coincident ratio = 0.1884)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 60*27 / (14,100*0.85 + 0.40*60) + 0.0625
= 0.1974"

Maximum allowable working pressure, (at 980 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 14,100*0.85*0.4375 / (27 - 0.40*0.4375) - 0
= 195.47 psi

Maximum allowable pressure, (at 70 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t)
= 20,000*0.85*0.5 / (27 - 0.40*0.5)
= 317.16 psi

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 30.7962 / 54 = 0.5703
D_o / t = 54 / 0.1051 = 513.7661
From table G: A = 0.000203
From table HA-1: B = 2,851.4259 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,851.43 / (3*(54 / 0.1051))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t + Corrosion = 0.1051 + 0.0625 = 0.1676"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 30.7962 / 54 = 0.5703
D_o / t = 54 / 0.4375 = 123.4286
From table G: A = 0.001789
From table HA-1: B = 11,142.0212 psi

P_a = 4*B / (3*(D_o / t))
= 4*11,142.02 / (3*(54 / 0.4375))
= 120.36 psi

% Forming strain - UHA-44(a)(2)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.5 / 26.75)*(1 - 26.75 / ∞)
= 0.9346%

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = W / (2*π*R_m) + M / (π*R_m^2)
= 7,396.2 / (2*π*26.7813) + 59,153 / (π*26.7813^2)
= 70.2057 lb/in
α = P_v / (P_e*D_o)
= 70.2057 / (7.4*54)
= 0.1757
n = 7
m = 1.23 / (L / D_o)^2
= 1.23 / (30.7962 / 54)^2
= 3.7818
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (7^2 - 1 + 3.7818 + 3.7818*0.1757) / (7^2 - 1 + 3.7818)
= 1.0128

Ratio P_e * P_e ≤ MAEP
(1.0128 * 7.4 = 7.49) ≤ 120.36
Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = (1 + 0.14*S_{DS})*W / (2*π*R_m) + M / (π*R_m^2)
= 1.04*7,396.2 / (2*π*26.7813) + 63,743 / (π*26.7813^2)
= 74.2121 lb/in
α = P_v / (P_e*D_o)
= 74.2121 / (7.4*54)
= 0.1857
n = 7
m = 1.23 / (L / D_o)^2
= 1.23 / (30.7962 / 54)^2
= 3.7818

Ratio P_e = $(n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
= $(7^2 - 1 + 3.7818 + 3.7818*0.1857) / (7^2 - 1 + 3.7818)$
= 1.0136

Ratio P_e * P_e ≤ MAEP

(1.0136 * 7.4 = 7.5) ≤ 120.36

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	60	14,100	5,491	980	0.0625	Wind	0.0554	0.0505
						Seismic	0.0556	0.0502
Operating, Hot & New	60	14,100	5,607	980	0	Wind	0.0552	0.0503
						Seismic	0.0555	0.05
Hot Shut Down, Corroded	0	14,100	5,491	980	0.0625	Wind	0	0.0107
						Seismic	0.0003	0.0113
Hot Shut Down, New	0	14,100	5,607	980	0	Wind	0.0001	0.0106
						Seismic	0.0003	0.0113
Empty, Corroded	0	20,000	11,530	70	0.0625	Wind	0.0007	0.0043
						Seismic	0.0004	0.0056
Empty, New	0	20,000	11,851	70	0	Wind	0.0008	0.0043
						Seismic	0.0004	0.0056
Vacuum	-7.4	20,000	11,530	0	0.0625	Wind	0.0071	0.0122
						Seismic	0.0068	0.0125
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,100	5,491	980	0.0625	Weight	0.0054	0.0106

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t)$
= $0.125 / (27 / 0.4375)$
= 0.002025

B = 5,491 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHC} = min(B, S) = 5,491 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = $0.125 / (R_o / t)$
= $0.125 / (27 / 0.5)$
= 0.002315

B = 5,607 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHN} = min(B, S) = 5,607 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (27 / 0.5)
= 0.002315

B = 11,851 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCN} = min(B, S) = 11,851 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (27 / 0.4375)
= 0.002025

B = 11,530 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCC} = min(B, S) = 11,530 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (27 / 0.4375)
= 0.002025

B = 11,530 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cVC} = min(B, S) = 11,530 psi

Operating, Hot & Corroded, Wind, Bottom Seam

$t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*26.5625 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0554"

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 59,153 / (π*26.7813^2*14,100*1.20*0.85)
= 0.0018"

$t_w = 0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.60*7,396.2 / (2*π*26.7813*14,100*1.20*0.85)
= 0.0018"

$t_t = t_p + t_m - t_w$ (total required, tensile)
= 0.0554 + 0.0018 - (0.0018)
= 0.0554"

$t_{wc} = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 7,396.2 / (2*π*26.7813*14,100*1.20*0.85)
= 0.0031"

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0018 + (0.0031) - (0.0554)|
= 0.0505"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}100*1.20*0.85*(0.4375 - 0.0018 + (0.0018)) / (26.5625 - 0.40*(0.4375 - 0.0018 + (0.0018)))$
$= 476.91$ psi

Operating, Hot & New, Wind, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\|P\|)$	(Pressure)
	=	$60*26.5 / (2*14{,}100*1.20*0.85 + 0.40*\|60\|)$	
	=	0.0552"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$59{,}149 / (\pi*26.75^2*14{,}100*1.20*0.85)$	
	=	0.0018"	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$0.60*7{,}572.4 / (2*\pi*26.75*14{,}100*1.20*0.85)$	
	=	0.0019"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	$0.0552 + 0.0018 - (0.0019)$	
	=	0.0552"	
t_{wc}	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$7{,}572.4 / (2*\pi*26.75*14{,}100*1.20*0.85)$	
	=	0.0031"	
t_c	=	$\|t_{mc} + t_{wc} - t_{pc}\|$	(total, net tensile)
	=	$\|0.0018 + (0.0031) - (0.0552)\|$	
	=	0.0503"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}100*1.20*0.85*(0.5 - 0.0018 + (0.0019)) / (26.5 - 0.40*(0.5 - 0.0018 + (0.0019)))$
$= 546.9$ psi

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p	=	0"	(Pressure)
t_m	=	$M / (\pi*R_m^2*S_c*K_s)$	(bending)
	=	$59{,}153 / (\pi*26.7813^2*5{,}490.6*1.20)$	
	=	0.004"	
t_w	=	$0.6*W / (2*\pi*R_m*S_c*K_s)$	(Weight)
	=	$0.60*7{,}396.2 / (2*\pi*26.7813*5{,}490.6*1.20)$	
	=	0.004"	
t_t	=	$\|t_p + t_m - t_w\|$	(total, net compressive)
	=	$\|0 + 0.004 - (0.004)\|$	
	=	0"	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$	(Weight)

= 7,396.2 / (2*π*26.7813*5,490.6*1.20)
= 0.0067"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.004 + (0.0067) - (0)
= 0.0107"

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 59,149 / (π*26.75^2*5,606.76*1.20)
= 0.0039"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*7,572.4 / (2*π*26.75*5,606.76*1.20)
= 0.004"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0039 - (0.004)|
= 0.0001"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 7,572.4 / (2*π*26.75*5,606.76*1.20)
= 0.0067"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0039 + (0.0067) - (0)
= 0.0106"

Empty, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 36,240 / (π*26.7813^2*11,529.96*1.20)
= 0.0012"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*7,396.2 / (2*π*26.7813*11,529.96*1.20)
= 0.0019"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0012 - (0.0019)|
= 0.0007"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 7,396.2 / (2*π*26.7813*11,529.96*1.20)
= 0.0032"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0012 + (0.0032) - (0)
= 0.0043"

Empty, New, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 36,236 / (π*26.75^2*11,850.96*1.20)
= 0.0011"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*7,572.4 / (2*π*26.75*11,850.96*1.20)
= 0.0019"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0011 - (0.0019)|
= 0.0008"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 7,572.4 / (2*π*26.75*11,850.96*1.20)
= 0.0032"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0011 + (0.0032) - (0)
= 0.0043"

Vacuum, Wind, Bottom Seam

t_p = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*26.5625 / (2*11,529.96*1.20 + 0.40*|7.4|)
= -0.0071"

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 59,153 / (π*26.7813^2*11,529.96*1.20)
= 0.0019"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*7,396.2 / (2*π*26.7813*11,529.96*1.20)
= 0.0019"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |-0.0071 + 0.0019 - (0.0019)|
= 0.0071"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= 7,396.2 / (2*π*26.7813*11,529.96*1.20)
= 0.0032"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0019 + (0.0032) - (-0.0071)
= 0.0122"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*11,529.96*1.20*(0.4375 - 0.0019 - 0.0032) / (26.5625 - 0.40*(0.4375 - 0.0019 - 0.0032))
= 453.44 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 31,848 / (π*26.7813^2*5,490.6*1.00)
= 0.0026"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 7,396.2 / (2*π*26.7813*5,490.6*1.00)
= 0.008"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0026 - (0.008)|
= 0.0054"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0026 + (0.008) - (0)
= 0.0106"

Operating, Hot & Corroded, Seismic, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*26.5625 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0554"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 63,743 / (π*26.7813^2*14,100*1.20*0.85)
= 0.002"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.56*7,396.2 / (2*π*26.7813*14,100*1.20*0.85)
= 0.0017"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0554 + 0.002 - (0.0017)
= 0.0556"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*7,396.2 / (2*π*26.7813*14,100*1.20*0.85)
= 0.0032"

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |0.002 + (0.0032) - (0.0554)|
= 0.0502"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*0.85*(0.4375 - 0.002 + (0.0017)) / (26.5625 - 0.40*(0.4375 - 0.002 + (0.0017)))
= 476.61 psi

Operating, Hot & New, Seismic, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*26.5 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0552"

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $64,514 / (\pi * 26.75^2 * 14,100 * 1.20 * 0.85)$
= 0.002"

t_w = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $0.56 * 7,572.4 / (2 * \pi * 26.75 * 14,100 * 1.20 * 0.85)$
= 0.0017"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0552 + 0.002 - (0.0017)
= 0.0555"

t_{wc} = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $1.04 * 7,572.4 / (2 * \pi * 26.75 * 14,100 * 1.20 * 0.85)$
= 0.0033"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.002 + (0.0033) - (0.0552)|
= 0.05"

Maximum allowable working pressure, Longitudinal Stress

$P = 2 * S_t * K_s * E_c * (t - t_m + t_w) / (R - 0.40 * (t - t_m + t_w))$
= $2 * 14,100 * 1.20 * 0.85 * (0.5 - 0.002 + (0.0017)) / (26.5 - 0.40 * (0.5 - 0.002 + (0.0017)))$
= 546.56 psi

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $63,743 / (\pi * 26.7813^2 * 14,100 * 1.20 * 0.85)$
= 0.002"

t_w = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $0.56 * 7,396.2 / (2 * \pi * 26.7813 * 14,100 * 1.20 * 0.85)$
= 0.0017"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.002 - (0.0017)
= 0.0003"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $63,743 / (\pi * 26.7813^2 * 5,490.6 * 1.20)$
= 0.0043"

t_{wc} = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $1.04 * 7,396.2 / (2 * \pi * 26.7813 * 5,490.6 * 1.20)$
= 0.007"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0043 + (0.007) - (0)
= 0.0113"

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 64,514 / (π*26.75^2*14,100*1.20*0.85)
= 0.002"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.56*7,572.4 / (2*π*26.75*14,100*1.20*0.85)
= 0.0017"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.002 - (0.0017)
= 0.0003"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 64,514 / (π*26.75^2*5,606.76*1.20)
= 0.0043"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 1.04*7,572.4 / (2*π*26.75*5,606.76*1.20)
= 0.007"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0043 + (0.007) - (0)
= 0.0113"

Empty, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 72,296 / (π*26.7813^2*20,000*1.20*0.85)
= 0.0016"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.56*7,396.2 / (2*π*26.7813*20,000*1.20*0.85)
= 0.0012"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0016 - (0.0012)
= 0.0004"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 72,296 / (π*26.7813^2*11,529.96*1.20)
= 0.0023"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 1.04*7,396.2 / (2*π*26.7813*11,529.96*1.20)
= 0.0033"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0023 + (0.0033) - (0)
= 0.0056"

Empty, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 72,989 / (π*26.75^2*20,000*1.20*0.85)
= 0.0016"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.56*7,572.4 / (2*π*26.75*20,000*1.20*0.85)
= 0.0012"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0016 - (0.0012)
= 0.0004"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 72,989 / (π*26.75^2*11,850.96*1.20)
= 0.0023"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 1.04*7,572.4 / (2*π*26.75*11,850.96*1.20)
= 0.0033"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0023 + (0.0033) - (0)
= 0.0056"

Vacuum, Seismic, Bottom Seam

t_p = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*26.5625 / (2*11,529.96*1.20 + 0.40*|7.4|)
= -0.0071"

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 63,743 / (π*26.7813^2*11,529.96*1.20)
= 0.002"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*7,396.2 / (2*π*26.7813*11,529.96*1.20)
= 0.0018"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |-0.0071 + 0.002 - (0.0018)|
= 0.0068"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 1.04*7,396.2 / (2*π*26.7813*11,529.96*1.20)
= 0.0033"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.002 + (0.0033) - (-0.0071)
= 0.0125"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*11,529.96*1.20*(0.4375 - 0.002 - 0.0033) / (26.5625 - 0.40*(0.4375 - 0.002 - 0.0033))

= 453.13 psi

Bonnet Cone Lower Stiffening Ring

ASME Section VIII Division 1, 2013 Edition	
Attached to	Bonnet Cone
Ring type	Flat bar
Description	3/8x2 Flat Bar
Material	SA-479 304 Bar (II-D p. 94, ln. 39)
External design pressure	7.4 psi
External design temperature	0° F
Corrosion allowance	0"
Distance from ring neutral axis to datum	-9.375"
Distance to previous support	4.8725"
Distance to next support	0.565"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.25"
Vessel thickness at weld location, new	0.3125"
Vessel corrosion allowance at weld location	0.0625"
Stiffener thickness at weld location	0.375"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	1"
Ring area	0.75 in^2
Ring inertia	0.25 in^4

External Pressure, (Corroded & at 0° F) UG-29(a)

D_o / t > 1000 therefore use a U-2(g) analysis.

$P_a = (2.42*E_s / (1 - 0.3^2)^{0.75})*(t / OD)^{2.5} / (L / OD - 0.45 * Sqr(t / OD)) / 3$
$= (2.42*28{,}000{,}000 / (1 - 0.3^2)^{0.75})*(0.0442 / 48.6234)^{2.5} / (4.6299 / 48.6234 - 0.45 * Sqr(0.0442 / 48.6234)) / 3$
$= 7.4065$ psi

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*7.4*48.6234 / (0.0505 + 0.75 / 2.7188)$
$= 827$ psi

From Table HA-1: A = 0.000059 (ring, 0° F)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
$= [48.6234^2*2.7188*(0.0505 + 0.75 / 2.7188)*0.000059] / 10.9$

= 0.0113 in^4

I' for the composite corroded shell-ring cross section is 0.7048 in^4

As I' >= I_s' a 3/8x2 Flat Bar stiffener is adequate for an external pressure of 7.4 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.25 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 7.4*2.7188 = 20.12$ lb_f/in
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*7.4*2.7188*48.6234 = 9.78$ lb_f
First moment of area, $Q = 0.68*0.5902 = 0.4011$ in^3

Weld shear flow, $q = V*Q / I' = 5.5675$ lb_f/in
Combined weld load, $f_w = Sqr(20.1188^2 + 5.5675^2) = 20.87$ lb_f/in

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*20{,}000 = 11{,}000$ psi

Fillet weld size required to resist radial pressure and shear

$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$
= 20.87*(1 + 0) / (11,000*2) + 0
= 0.0009 in

The fillet weld size of 0.25 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 0° F) UG-29(a)

$L_e / D_o = 4.6299 / 48.6234 = 0.0952$
$D_o / t_e = 48.6234 / 0.2188944 = 222.132$
From Table G: A = 0.006084
From Table HA-1: B = 13,360 psi

$P_a = 4*B / (3*(D_o / t_e))$
= 4*13,360 / (3*(48.6234 / 0.2188944))
= 80.1938psi

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*80.19*48.6234 / (0.25 + 0.75 / 2.7188)
= 5,561 psi

From Table HA-1: A = 0.00040228 (ring, 0° F)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [48.6234^2*2.7188*(0.25 + 0.75 / 2.7188)*0.00040228] / 10.9
= 0.1248 in^4

I' for the composite corroded shell-ring cross section is 0.7048 in^4

As I' >= I_s' a 3/8x2 Flat Bar stiffener is adequate for an external pressure of 80.19 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.25 in is adequate per UG-30(f)(1).

Radial pressure load, $P^*L_s = 80.19^*2.7188 = 218.03$ lb_f/in
Radial shear load, $V = 0.01^*P^*L_s^*D_o = 0.01^*80.19^*2.7188^*48.6234 = 106.01$ lb_f
First moment of area, $Q = 0.68^*0.5902 = 0.4011$ in^3

Weld shear flow, $q = V^*Q / I' = 60.3346$ lb_f/in
Combined weld load, $f_w = Sqr(218.0266^2 + 60.3346^2) = 226.22$ lb_f/in

Allowable weld stress per UW-18(d) $S_w = 0.55^*S = 0.55^*20{,}000 = 11{,}000$ psi

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w^*(d_{\text{weld segment}} + d_{toe}) / (S_w^*d_{\text{weld total}}) + \text{corrosion}$$
$$= 226.22^*(1 + 0) / (11{,}000^*2) + 0$$
$$= 0.0103 \text{ in}$$

The fillet weld size of 0.25 in is adequate to resist radial pressure and shear.

Bonnet Cone

ASME Section VIII Division 1, 2013 Edition				
Component		Cone		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal	**Large**	2.22	61.4707	1
	Small	2.11	58.4707	
Dimensions				
Outer Diameter	**Large**	54"		
	Small	48"		
Length		5.4375"		
Nominal Thickness		0.3125"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		89.54	46.8	
Corroded		71.73	47.07	
Radiography				
Longitudinal seam		Spot UW-11(b) Type 1		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.2166"
Design thickness due to external pressure (t_e)	0.116"
Design thickness due to combined loadings + corrosion	0.1264"
Maximum allowable working pressure (MAWP)	75.92 psi
Maximum allowable pressure (MAP)	120.96 psi
Maximum allowable external pressure (MAEP)	43.26 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320° F
Material is exempt from impact testing at the Design MDMT of -20° F.

Design thickness, (at 980 ° F) App 1-4(e) (Large End)

t = $P*D_o / (2*\cos(\alpha)*(S*E + 0.40*P)) + Corrosion$
= $60*54 / (2*\cos(28.8866)*(14,100*0.85 + 0.40*60)) + 0.0625$
= 0.2166"
Small End design thickness (t = 0.1994") does not govern.

Maximum allowable working pressure, (Corroded at 980 ° F) App 1-4(e) (Large End)

P = $2*S*E*t*\cos(\alpha) / (D_o - 0.80*t*\cos(\alpha)) - P_s$
= $2*14,100*0.85*0.25*\cos(28.8866) / (54 - 0.80*0.25*\cos(28.8866)) - 0$
= 97.48 psi

Small End MAWP (109.71 psi) does not govern.

Maximum allowable pressure, (New at 70 ° F) App 1-4(e) (Large End)

P = $2*S*E*t*\cos(\alpha) / (D_o - 0.80*t*\cos(\alpha))$
= $2*20,000*0.85*0.3125*\cos(28.8866) / (54 - 0.80*0.3125*\cos(28.8866))$
= 172.98 psi

Small End MAP (194.7 psi) does not govern.

External Pressure, (Corroded & at 0 ° F) UG-33(f)

D_L = 54"
L_e = $(L_c / 2)*(1 + D_s / D_L)$
= $(4.8725 / 2)*(1 + 48.6234 / 54)$
= 4.6299"

$t_e = t*\cos(\alpha) = 0.0535*\cos(28.8866) = 0.0468$"
$L_e / D_L = 4.6299 / 54 = 0.0857$

D_L / t_e = 54 / 0.0468 = 1153.5173

Experimental basin formula

P_a = $[2.42*E / (1 - \mu^2)^{0.75}]*[(t_e / D_L)^{2.50} / (L / D_o - 0.45*(t_e / D_L)^{0.50})] / 3$
= $[2.42*28000000 / (1 - 0.30^2)^{0.75}]*[(0.0468 / 54)^{2.50} / (4.6299 / 54 - 0.45*(0.0468 / 54)^{0.50})] / 3$
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = $t_e / \cos(\alpha)$ + Corrosion = 0.0468 / cos(28.8866) + 0.0625 = 0.116"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-33(f)

t_e = $t*\cos(\alpha)$ = 0.25*cos(28.8866) = 0.2189"
L_e / D_L = 4.6299 / 54 = 0.0857
D_L / t_e = 54 / 0.2189 = 246.694
From table G: A = 0.005775
From table HA-1: B = 13,294.8918 psi

P_a = $4*B / (3*(D_L / t_e))$
= 4*13,294.89 / (3*(54 / 0.2189))
= 71.86 psi

% Forming strain - UHA-44(a)(2)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*0.3569 / 23.8215)*(1 - 23.8215 / \infty)$
= 0.7491%

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = $[W / (2*\pi*R_m) + M / (\pi*R_m^2)] / \cos(\alpha)$
= $[7,396.2 / (2*\pi*26.8572) + 59,153 / (\pi*26.8572^2)] / \cos(28.8866)$
= 79.8707 lb/in
α = $P_v / (P_e*D_o)$
= 79.8707 / (7.4*54)
= 0.1999
n = 13
m = $1.23 / (L / D_o)^2$
= $1.23 / (4.6299 / 54)^2$
= 167.3182
Ratio P_e = $(n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
= $(13^2 - 1 + 167.3182 + 167.3182*0.1999) / (13^2 - 1 + 167.3182)$
= 1.0997

Ratio P_e * P_e ≤ MAEP
(1.0997 * 7.4 = 8.14) ≤ 71.86
Transition design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = $[(1 + 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m^2)] / \cos(\alpha)$
= $[1.04*7,396.2 / (2*\pi*26.8572) + 63,743 / (\pi*26.8572^2)] / \cos(28.8866)$
= 84.4269 lb/in

$\alpha = P_v / (P_e * D_o)$
$= 84.4269 / (7.4 * 54)$
$= 0.2113$
$n = 13$
$m = 1.23 / (L / D_o)^2$
$= 1.23 / (4.6299 / 54)^2$
$= 167.3182$
Ratio $P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (13^2 - 1 + 167.3182 + 167.3182*0.2113) / (13^2 - 1 + 167.3182)$
$= 1.1054$
Ratio P_e * $P_e \leq$ MAEP
$(1.1054 * 7.4 = 8.18) \leq 71.86$
Transition design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads									
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Location	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c						
Operating, Hot & Corroded	60	14,100	4.741	980	0.0625	Top	Wind	0.0636	0.058
							Seismic	0.0639	0.0577
						Bottom	Wind	0.0568	0.0497
							Seismic	0.0573	0.0492
Operating, Hot & New	60	14,100	5.003	980	0	Top	Wind	0.0634	0.0578
							Seismic	0.0637	0.0574
						Bottom	Wind	0.0566	0.0494
							Seismic	0.0572	0.0489
Hot Shut Down, Corroded	0	14,100	4.741	980	0.0625	Top	Wind	0	0.014
							Seismic	0.0003	0.0148
						Bottom	Wind	0.0004	0.0171
							Seismic	0.0009	0.0183
Hot Shut Down, New	0	14,100	5.003	980	0	Top	Wind	0.0001	0.0135
							Seismic	0.0003	0.0144
						Bottom	Wind	0.0003	0.0164
							Seismic	0.0009	0.0178
Empty, Corroded	0	20,000	9.004	70	0.0625	Top	Wind	0.0011	0.0063
							Seismic	0.0004	0.0082
						Bottom	Wind	0.0009	0.0075
							Seismic	0.0009	0.0102
Empty, New	0	20,000	9.880	70	0	Top	Wind	0.0011	0.0059
							Seismic	0.0004	0.0076
						Bottom	Wind	0.0009	0.007
							Seismic	0.0009	0.0095
Vacuum	-7.4	20,000	9.004	0	0.0625	Top	Wind	0.0105	0.0178
							Seismic	0.01	0.0183
						Bottom	Wind	0.0088	0.0183
							Seismic	0.0081	0.0189
	0	14,100	4.741	980	0.0625	Top	Weight	0.0072	0.0139

Hot Shut Down, Corroded, Weight & Eccentric Moments Only						Bottom	Weight	0.0078	0.0163

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = 0.125 / (R_o / t_e)
= 0.125 / (27 / 0.2189)
= 0.001013
B = 4,741 psi
S = 14,100 / 1.00 = 14,100 psi
S_{cHC} = min(B, S) = 4,741 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = 0.125 / (R_o / t_e)
= 0.125 / (27 / 0.2736)
= 0.001267
B = 5,003 psi
S = 14,100 / 1.00 = 14,100 psi
S_{cHN} = min(B, S) = 5,003 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = 0.125 / (R_o / t_e)
= 0.125 / (27 / 0.2736)
= 0.001267
B = 9,880 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCN} = min(B, S) = 9,880 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = 0.125 / (R_o / t_e)
= 0.125 / (27 / 0.2189)
= 0.001013
B = 9,004 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCC} = min(B, S) = 9,004 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = 0.125 / (R_o / t_e)
= 0.125 / (27 / 0.2189)
= 0.001013
B = 9,004 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cVC} = min(B, S) = 9,004 psi

Operating, Hot & Corroded, Wind, Top Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*26.7145 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(28.8866)]
= 0.0636"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 59,153 / [(π*26.8572²*14,100*1.20*0.85)*cos(28.8866)]
= 0.0021"

t_w = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.60*7,396.2 / [(2*π*26.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.0021"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0636 + 0.0021 - (0.0021)
= 0.0636"
t_{wc} = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 7,396.2 / [(2*π*26.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.0035"
t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0021 + (0.0035) - (0.0636)|
= 0.058"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.25 - 0.0021 + (0.0021)) / ((26.7145 - 0.40*(0.25 - 0.0021 + (0.0021)))*cos(28.8866))
= 308.61 psi

Operating, Hot & New, Wind, Top Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*26.6431 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(28.8866)]
= 0.0634"
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 59,149 / [(π*26.8215²*14,100*1.20*0.85)*cos(28.8866)]
= 0.0021"
t_w = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.60*7,572.4 / [(2*π*26.8215*14,100*1.20*0.85)*cos(28.8866)]
= 0.0021"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0634 + 0.0021 - (0.0021)
= 0.0634"
t_{wc} = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 7,572.4 / [(2*π*26.8215*14,100*1.20*0.85)*cos(28.8866)]
= 0.0036"
t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0021 + (0.0036) - (0.0634)|
= 0.0578"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.3125 - 0.0021 + (0.0021)) / ((26.6431 - 0.40*(0.3125 - 0.0021 + (0.0021)))*cos(28.8866))
= 387.21 psi

Hot Shut Down, Corroded, Wind, Top Seam

t_p = 0" (Pressure)
t_m = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= 59,153 / [(π*26.8572²*4,740.96*1.20)*cos(28.8866)]
= 0.0052"
t_w = $0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= 0.60*7,396.2 / [(2*π*26.8572*4,740.96*1.20)*cos(28.8866)]
= 0.0053"
t_t = $|t_p + t_m - t_w|$ (total, net

compressive)

$= |0 + 0.0052 - (0.0053)|$

$= 0"$

$t_{wc} = W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 7,396.2 / [(2*\pi*26.8572*4,740.96*1.20)*\cos(28.8866)]$

$= 0.0088"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0052 + (0.0088) - (0)$

$= 0.014"$

Hot Shut Down, New, Wind, Top Seam

$t_p = 0"$ (Pressure)

$t_m = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 59,149 / [(\pi*26.8215^2*5,003.35*1.20)*\cos(28.8866)]$

$= 0.005"$

$t_w = 0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 0.60*7,572.4 / [(2*\pi*26.8215*5,003.35*1.20)*\cos(28.8866)]$

$= 0.0051"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.005 - (0.0051)|$

$= 0.0001"$

$t_{wc} = W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 7,572.4 / [(2*\pi*26.8215*5,003.35*1.20)*\cos(28.8866)]$

$= 0.0085"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.005 + (0.0085) - (0)$

$= 0.0135"$

Empty, Corroded, Wind, Top Seam

$t_p = 0"$ (Pressure)

$t_m = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 36,240 / [(\pi*26.8572^2*9,004.3*1.20)*\cos(28.8866)]$

$= 0.0017"$

$t_w = 0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 0.60*7,396.2 / [(2*\pi*26.8572*9,004.3*1.20)*\cos(28.8866)]$

$= 0.0028"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.0017 - (0.0028)|$

$= 0.0011"$

$t_{wc} = W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 7,396.2 / [(2*\pi*26.8572*9,004.3*1.20)*\cos(28.8866)]$

$= 0.0046"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0017 + (0.0046) - (0)$

$= 0.0063"$

Empty, New, Wind, Top Seam

$t_p = 0"$ (Pressure)

$t_m = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 36,236 / [(\pi*26.8215^2*9,880.26*1.20)*\cos(28.8866)]$
$= 0.0015"$

$t_w = 0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 0.60*7,572.4 / [(2*\pi*26.8215*9,880.26*1.20)*\cos(28.8866)]$
$= 0.0026"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0015 - (0.0026)|$
$= 0.0011"$

$t_{wc} = W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 7,572.4 / [(2*\pi*26.8215*9,880.26*1.20)*\cos(28.8866)]$
$= 0.0043"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0015 + (0.0043) - (0)$
$= 0.0059"$

Vacuum, Wind, Top Seam

$t_p = P*R / [(2*S_c*K_s + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
$= -7.4*26.7145 / [(2*9,004.3*1.20 + 0.40*|7.4|)*\cos(28.8866)]$
$= -0.0104"$

$t_m = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
$= 59,153 / [(\pi*26.8572^2*9,004.3*1.20)*\cos(28.8866)]$
$= 0.0028"$

$t_w = 0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 0.60*7,396.2 / [(2*\pi*26.8572*9,004.3*1.20)*\cos(28.8866)]$
$= 0.0028"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |-0.0104 + 0.0028 - (0.0028)|$
$= 0.0105"$

$t_{wc} = W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 7,396.2 / [(2*\pi*26.8572*9,004.3*1.20)*\cos(28.8866)]$
$= 0.0046"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0028 + (0.0046) - (-0.0104)$
$= 0.0178"$

Maximum Allowable External Pressure, Longitudinal Stress

$P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$
$= 2*9,004.3*1.20*(0.25 - 0.0028 - 0.0046) / ((26.7145 - 0.40*(0.25 - 0.0028 - 0.0046))*\cos(28.8866))$
$= 224.96$ psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Top Seam

$t_p = 0"$ (Pressure)

$t_m = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
$= 31,848 / [(\pi*26.8572^2*4,740.96*1.00)*\cos(28.8866)]$
$= 0.0034"$

$t_w = W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 7,396.2 / [(2*\pi*26.8572*4,740.96*1.00)*\cos(28.8866)]$
$= 0.0106"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

= |0 + 0.0034 - (0.0106)|
= 0.0072"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0034 + (0.0106) - (0)
= 0.0139"

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*23.7145 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(28.8866)]
= 0.0564"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 62,418 / [(π*23.8572²*14,100*1.20*0.85)*cos(28.8866)]
= 0.0028"

t_w = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.60*7,502.5 / [(2*π*23.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.0024"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0564 + 0.0028 - (0.0024)
= 0.0568"

t_{wc} = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 7,502.5 / [(2*π*23.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.004"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0028 + (0.004) - (0.0564)|
= 0.0497"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.25 - 0.0028 + (0.0024)) / ((23.7145 - 0.40*(0.25 - 0.0028 + (0.0024)))*cos(28.8866))
= 347.25 psi

Operating, Hot & New, Wind, Bottom Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*23.6431 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(28.8866)]
= 0.0563"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 62,414 / [(π*23.8215²*14,100*1.20*0.85)*cos(28.8866)]
= 0.0028"

t_w = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.60*7,696.5 / [(2*π*23.8215*14,100*1.20*0.85)*cos(28.8866)]
= 0.0025"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0563 + 0.0028 - (0.0025)
= 0.0566"

t_{wc} = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 7,696.5 / [(2*π*23.8215*14,100*1.20*0.85)*cos(28.8866)]
= 0.0041"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0028 + (0.0041) - (0.0563)|
= 0.0494"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
$= 2*14,100*1.20*0.85*(0.3125 - 0.0028 + (0.0025)) / ((23.6431 - 0.40*(0.3125 - 0.0028 + (0.0025)))*\cos(28.8866))$
= 436.05 psi

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $62,418 / [(\pi*23.8572^2*14,100*1.20*0.85)*\cos(28.8866)]$
= 0.0028"
t_w = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $0.60*7,502.5 / [(2*\pi*23.8572*14,100*1.20*0.85)*\cos(28.8866)]$
= 0.0024"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0028 - (0.0024)
= 0.0004"
t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $62,418 / [(\pi*23.8572^2*4,740.96*1.20)*\cos(28.8866)]$
= 0.007"
t_{wc} = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $7,502.5 / [(2*\pi*23.8572*4,740.96*1.20)*\cos(28.8866)]$
= 0.01"
t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.007 + (0.01) - (0)
= 0.0171"

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $62,414 / [(\pi*23.8215^2*14,100*1.20*0.85)*\cos(28.8866)]$
= 0.0028"
t_w = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $0.60*7,696.5 / [(2*\pi*23.8215*14,100*1.20*0.85)*\cos(28.8866)]$
= 0.0025"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0028 - (0.0025)
= 0.0003"
t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $62,414 / [(\pi*23.8215^2*5,003.35*1.20)*\cos(28.8866)]$
= 0.0067"
t_{wc} = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $7,696.5 / [(2*\pi*23.8215*5,003.35*1.20)*\cos(28.8866)]$
= 0.0098"
t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0067 + (0.0098) - (0)
= 0.0164"

Empty, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $37,690 / [(\pi*23.8572^2*9,004.3*1.20)*\cos(28.8866)]$
= 0.0022"

t_w = $0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.60*7,502.5 / [(2*\pi*23.8572*9,004.3*1.20)*\cos(28.8866)]$
= 0.0032"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|0 + 0.0022 - (0.0032)|$
= 0.0009"

t_{wc} = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $7,502.5 / [(2*\pi*23.8572*9,004.3*1.20)*\cos(28.8866)]$
= 0.0053"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= $0.0022 + (0.0053) - (0)$
= 0.0075"

Empty, New, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $37,687 / [(\pi*23.8215^2*9,880.26*1.20)*\cos(28.8866)]$
= 0.002"

t_w = $0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.60*7,696.5 / [(2*\pi*23.8215*9,880.26*1.20)*\cos(28.8866)]$
= 0.003"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|0 + 0.002 - (0.003)|$
= 0.0009"

t_{wc} = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $7,696.5 / [(2*\pi*23.8215*9,880.26*1.20)*\cos(28.8866)]$
= 0.005"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= $0.002 + (0.005) - (0)$
= 0.007"

Vacuum, Wind, Bottom Seam

t_p = $P*R / [(2*S_c*K_s + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= $-7.4*23.7145 / [(2*9,004.3*1.20 + 0.40*|7.4|)*\cos(28.8866)]$
= -0.0093"

t_m = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $62,418 / [(\pi*23.8572^2*9,004.3*1.20)*\cos(28.8866)]$
= 0.0037"

t_w = $0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.60*7,502.5 / [(2*\pi*23.8572*9,004.3*1.20)*\cos(28.8866)]$
= 0.0032"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|-0.0093 + 0.0037 - (0.0032)|$
= 0.0088"

t_{wc} = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= 7,502.5 / [(2*π*23.8572*9,004.3*1.20)*cos(28.8866)]
= 0.0053"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0037 + (0.0053) - (-0.0093)
= 0.0183"

Maximum Allowable External Pressure, Longitudinal Stress

P = $2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$
= 2*9,004.3*1.20*(0.25 - 0.0037 - 0.0053) / ((23.7145 - 0.40*(0.25 - 0.0037 - 0.0053))*cos(28.8866))
= 251.87 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= 31,848 / [(π*23.8572²*4,740.96*1.00)*cos(28.8866)]
= 0.0043"
t_w = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= 7,502.5 / [(2*π*23.8572*4,740.96*1.00)*cos(28.8866)]
= 0.0121"
t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0043 - (0.0121)|
= 0.0078"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0043 + (0.0121) - (0)
= 0.0163"

Operating, Hot & Corroded, Seismic, Top Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*26.7145 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(28.8866)]
= 0.0636"
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 63,743 / [(π*26.8572²*14,100*1.20*0.85)*cos(28.8866)]
= 0.0022"
t_w = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.56*7,396.2 / [(2*π*26.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.0019"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0636 + 0.0022 - (0.0019)
= 0.0639"
t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 1.04*7,396.2 / [(2*π*26.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.0036"
t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0022 + (0.0036) - (0.0636)|
= 0.0577"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
$= 2*14{,}100*1.20*0.85*(0.25 - 0.0022 + (0.0019)) / ((26.7145 - 0.40*(0.25 - 0.0022 + (0.0019)))*\cos(28.8866))$
$= 308.21$ psi

Operating, Hot & New, Seismic, Top Seam

t_p	=	$P*R / [(2*S_t*K_s*E_c + 0.40*\|P\|)*\cos(\alpha)]$	(Pressure)
	=	$60*26.6431 / [(2*14{,}100*1.20*0.85 + 0.40*\|60\|)*\cos(28.8866)]$	
	=	0.0634"	
t_m	=	$M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$	(bending)
	=	$64{,}514 / [(\pi*26.8215^2*14{,}100*1.20*0.85)*\cos(28.8866)]$	
	=	0.0023"	
t_w	=	$(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$	(Weight)
	=	$0.56*7{,}572.4 / [(2*\pi*26.8215*14{,}100*1.20*0.85)*\cos(28.8866)]$	
	=	0.002"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.0634 + 0.0023 - (0.002)	
	=	0.0637"	
t_{wc}	=	$(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$	(Weight)
	=	$1.04*7{,}572.4 / [(2*\pi*26.8215*14{,}100*1.20*0.85)*\cos(28.8866)]$	
	=	0.0037"	
t_c	=	$\|t_{mc} + t_{wc} - t_{pc}\|$	(total, net tensile)
	=	$\|0.0023 + (0.0037) - (0.0634)\|$	
	=	0.0574"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
$= 2*14{,}100*1.20*0.85*(0.3125 - 0.0023 + (0.002)) / ((26.6431 - 0.40*(0.3125 - 0.0023 + (0.002)))*\cos(28.8866))$
$= 386.78$ psi

Hot Shut Down, Corroded, Seismic, Top Seam

t_p	=	0"	(Pressure)
t_m	=	$M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$	(bending)
	=	$63{,}743 / [(\pi*26.8572^2*14{,}100*1.20*0.85)*\cos(28.8866)]$	
	=	0.0022"	
t_w	=	$(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$	(Weight)
	=	$0.56*7{,}396.2 / [(2*\pi*26.8572*14{,}100*1.20*0.85)*\cos(28.8866)]$	
	=	0.0019"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0 + 0.0022 - (0.0019)	
	=	0.0003"	
t_{mc}	=	$M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$	(bending)
	=	$63{,}743 / [(\pi*26.8572^2*4{,}740.96*1.20)*\cos(28.8866)]$	
	=	0.0056"	
t_{wc}	=	$(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$	(Weight)
	=	$1.04*7{,}396.2 / [(2*\pi*26.8572*4{,}740.96*1.20)*\cos(28.8866)]$	
	=	0.0092"	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required,

compressive)

= 0.0056 + (0.0092) - (0)
= 0.0148"

Hot Shut Down, New, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $64,514 / [(\pi*26.8215^2*14,100*1.20*0.85)*\cos(28.8866)]$
= 0.0023"

t_w = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $0.56*7,572.4 / [(2*\pi*26.8215*14,100*1.20*0.85)*\cos(28.8866)]$
= 0.002"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0023 - (0.002)
= 0.0003"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $64,514 / [(\pi*26.8215^2*5,003.35*1.20)*\cos(28.8866)]$
= 0.0054"

t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $1.04*7,572.4 / [(2*\pi*26.8215*5,003.35*1.20)*\cos(28.8866)]$
= 0.0089"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0054 + (0.0089) - (0)
= 0.0144"

Empty, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $72,296 / [(\pi*26.8572^2*20,000*1.20*0.85)*\cos(28.8866)]$
= 0.0018"

t_w = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $0.56*7,396.2 / [(2*\pi*26.8572*20,000*1.20*0.85)*\cos(28.8866)]$
= 0.0014"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0018 - (0.0014)
= 0.0004"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $72,296 / [(\pi*26.8572^2*9,004.3*1.20)*\cos(28.8866)]$
= 0.0034"

t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $1.04*7,396.2 / [(2*\pi*26.8572*9,004.3*1.20)*\cos(28.8866)]$
= 0.0048"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0034 + (0.0048) - (0)
= 0.0082"

Empty, New, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $72,989 / [(\pi*26.8215^2*20,000*1.20*0.85)*\cos(28.8866)]$

$= 0.0018"$

$t_w = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)

$= 0.56*7,572.4 / [(2*\pi*26.8215*20,000*1.20*0.85)*\cos(28.8866)]$

$= 0.0014"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0018 - (0.0014)$

$= 0.0004"$

$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 72,989 / [(\pi*26.8215^2*9,880.26*1.20)*\cos(28.8866)]$

$= 0.0031"$

$t_{wc} = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 1.04*7,572.4 / [(2*\pi*26.8215*9,880.26*1.20)*\cos(28.8866)]$

$= 0.0045"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0031 + (0.0045) - (0)$

$= 0.0076"$

Vacuum, Seismic, Top Seam

$t_p = P*R / [(2*S_c*K_s + 0.40*|P|)*\cos(\alpha)]$ (Pressure)

$= -7.4*26.7145 / [(2*9,004.3*1.20 + 0.40*|7.4|)*\cos(28.8866)]$

$= -0.0104"$

$t_m = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 63,743 / [(\pi*26.8572^2*9,004.3*1.20)*\cos(28.8866)]$

$= 0.003"$

$t_w = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 0.56*7,396.2 / [(2*\pi*26.8572*9,004.3*1.20)*\cos(28.8866)]$

$= 0.0026"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |-0.0104 + 0.003 - (0.0026)|$

$= 0.01"$

$t_{wc} = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 1.04*7,396.2 / [(2*\pi*26.8572*9,004.3*1.20)*\cos(28.8866)]$

$= 0.0048"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.003 + (0.0048) - (-0.0104)$

$= 0.0183"$

Maximum Allowable External Pressure, Longitudinal Stress

$P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$

$= 2*9,004.3*1.20*(0.25 - 0.003 - 0.0048) / ((26.7145 - 0.40*(0.25 - 0.003 - 0.0048))*\cos(28.8866))$

$= 224.57$ psi

Operating, Hot & Corroded, Seismic, Bottom Seam

$t_p = P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)

$= 60*23.7145 / [(2*14,100*1.20*0.85 + 0.40*|60|)*\cos(28.8866)]$

$= 0.0564"$

$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)

$= 69,682 / [(\pi*23.8572^2*14,100*1.20*0.85)*\cos(28.8866)]$

$= 0.0031"$

t_w = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.56*7,502.5 / [(2*π*23.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.0022"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0564 + 0.0031 - (0.0022)
= 0.0573"

t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 1.04*7,502.5 / [(2*π*23.8572*14,100*1.20*0.85)*cos(28.8866)]
= 0.0042"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0031 + (0.0042) - (0.0564)|
= 0.0492"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.25 - 0.0031 + (0.0022)) / ((23.7145 - 0.40*(0.25 - 0.0031 + (0.0022)))*cos(28.8866))
= 346.55 psi

Operating, Hot & New, Seismic, Bottom Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*23.6431 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(28.8866)]
= 0.0563"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 70,622 / [(π*23.8215²*14,100*1.20*0.85)*cos(28.8866)]
= 0.0031"

t_w = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.56*7,696.5 / [(2*π*23.8215*14,100*1.20*0.85)*cos(28.8866)]
= 0.0023"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0563 + 0.0031 - (0.0023)
= 0.0572"

t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 1.04*7,696.5 / [(2*π*23.8215*14,100*1.20*0.85)*cos(28.8866)]
= 0.0043"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0031 + (0.0043) - (0.0563)|
= 0.0489"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.3125 - 0.0031 + (0.0023)) / ((23.6431 - 0.40*(0.3125 - 0.0031 + (0.0023)))*cos(28.8866))
= 435.28 psi

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)

$= 69,682 / [(\pi*23.8572^2*14,100*1.20*0.85)*\cos(28.8866)]$
$= 0.0031"$

$t_w = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 0.56*7,502.5 / [(2*\pi*23.8572*14,100*1.20*0.85)*\cos(28.8866)]$
$= 0.0022"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0031 - (0.0022)$
$= 0.0009"$

$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
$= 69,682 / [(\pi*23.8572^2*4,740.96*1.20)*\cos(28.8866)]$
$= 0.0078"$

$t_{wc} = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 1.04*7,502.5 / [(2*\pi*23.8572*4,740.96*1.20)*\cos(28.8866)]$
$= 0.0105"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0078 + (0.0105) - (0)$
$= 0.0183"$

Hot Shut Down, New, Seismic, Bottom Seam

$t_p = 0"$ (Pressure)
$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
$= 70,622 / [(\pi*23.8215^2*14,100*1.20*0.85)*\cos(28.8866)]$
$= 0.0031"$

$t_w = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 0.56*7,696.5 / [(2*\pi*23.8215*14,100*1.20*0.85)*\cos(28.8866)]$
$= 0.0023"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0031 - (0.0023)$
$= 0.0009"$

$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
$= 70,622 / [(\pi*23.8215^2*5,003.35*1.20)*\cos(28.8866)]$
$= 0.0075"$

$t_{wc} = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 1.04*7,696.5 / [(2*\pi*23.8215*5,003.35*1.20)*\cos(28.8866)]$
$= 0.0102"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0075 + (0.0102) - (0)$
$= 0.0178"$

Empty, Corroded, Seismic, Bottom Seam

$t_p = 0"$ (Pressure)
$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
$= 79,828 / [(\pi*23.8572^2*20,000*1.20*0.85)*\cos(28.8866)]$
$= 0.0025"$

$t_w = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 0.56*7,502.5 / [(2*\pi*23.8572*20,000*1.20*0.85)*\cos(28.8866)]$
$= 0.0016"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0025 - (0.0016)$
$= 0.0009"$

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $79{,}828 / [(\pi*23.8572^2*9{,}004.3*1.20)*\cos(28.8866)]$
= 0.0047"

t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $1.04*7{,}502.5 / [(2*\pi*23.8572*9{,}004.3*1.20)*\cos(28.8866)]$
= 0.0055"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0047 + (0.0055) - (0)
= 0.0102"

Empty, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $80{,}682 / [(\pi*23.8215^2*20{,}000*1.20*0.85)*\cos(28.8866)]$
= 0.0025"

t_w = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $0.56*7{,}696.5 / [(2*\pi*23.8215*20{,}000*1.20*0.85)*\cos(28.8866)]$
= 0.0016"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0025 - (0.0016)
= 0.0009"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $80{,}682 / [(\pi*23.8215^2*9{,}880.26*1.20)*\cos(28.8866)]$
= 0.0044"

t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $1.04*7{,}696.5 / [(2*\pi*23.8215*9{,}880.26*1.20)*\cos(28.8866)]$
= 0.0052"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0044 + (0.0052) - (0)
= 0.0095"

Vacuum, Seismic, Bottom Seam

t_p = $P*R / [(2*S_c*K_s + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= $-7.4*23.7145 / [(2*9{,}004.3*1.20 + 0.40*|7.4|)*\cos(28.8866)]$
= -0.0093"

t_m = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $69{,}682 / [(\pi*23.8572^2*9{,}004.3*1.20)*\cos(28.8866)]$
= 0.0041"

t_w = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.56*7{,}502.5 / [(2*\pi*23.8572*9{,}004.3*1.20)*\cos(28.8866)]$
= 0.0029"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-0.0093 + 0.0041 - (0.0029)|
= 0.0081"

t_{wc} = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $1.04*7{,}502.5 / [(2*\pi*23.8572*9{,}004.3*1.20)*\cos(28.8866)]$
= 0.0055"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0041 + (0.0055) - (-0.0093)
= 0.0189"

Maximum Allowable External Pressure, Longitudinal Stress

$P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$
$= 2*9{,}004.3*1.20*(0.25 - 0.0041 - 0.0055) / ((23.7145 - 0.40*(0.25 - 0.0041 - 0.0055))*\cos(28.8866))$
$= 251.17$ psi

Cone juncture large end calculations, P =75.919 psi Appendix 1-5(d)								
Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2)	Status
Wind Corroded	Yes	No	-0.12	1,008.19	0.19	1.07	none	OK
Wind New	Yes	No	-0.72	1,005.21	0.18	1.58	none	OK
Seismic Corroded	Yes	No	3.89	1,012.19	0.19	1.07	none	OK
Seismic New	Yes	No	3.68	1,009.62	0.19	1.58	none	OK

Cone large end calculations per Appendix 1-5(d)(1), wind + pressure, corroded

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(26.5625*0.4375)^{0.5}$
$= 6.8179$ in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

$f_1 = -0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -0.6*7,396.16 / (\pi*2*26.7813) + 12*4,929.4 / (\pi*26.7813^2)$
$=$ -0.12 lb_f/in

$P*R_L / 2 = 1,008.31$ lb_f/in

$|f_1| <= P*R_L / 2$ so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 75.92 / (14,100*1) = 0.005384$

From table 1-5.1 $\Delta = 23.77°$

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1,008.31 + -0.12$
$=$ 1,008.19 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1,008.19*26.5625 / (14,100*1))*(1 - 23.77 / 28.8866)*\tan(28.8866)$
$=$ 0.1856 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.4375 - 0.1689)*(26.5625*0.4375)^{0.5} + (0.25 - 0.1929)*(26.5625*0.25 / \cos(28.8866))^{0.5}$
$=$ 1.0729 in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	-5,977	10,624	-5,565	9,892	42,300	42,300	-5,442	-4,746	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	-20,780	30,068	-19,347	27,994	42,300	42,300	-800	-105	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), wind + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= 4*59,152.7 / (\pi*53.5625^2) - 0.6*7,396.16 / (\pi*53.5625)$
$= -0.12$ lb_f/in

$P_e = P + 4*l / D = 75.92 + 4*-0.1202 / 53.5625$
$= 75.91$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (75.91*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ -5,977 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (75.91*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ 10,624 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (75.92*26.7813 / 0.4375)*(1 - (75.91 / 75.92)*0.2775*(26.7813 / 0.4375)^{0.5})$
$=$ -5,442 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (75.91*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) - 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ -20,780 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (75.91*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) + 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ 30,068 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$

= (75.92*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (75.91 / 75.92)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= -800 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - W / (π*D)
= - 4*59,152.7 / (π*53.5625^2) - 7,396.16 / (π*53.5625)
= -70.21 lb_f/in

P_e = P + 4*I / D = 75.92 + 4*-70.2057 / 53.5625
= 70.68 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (70.68*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= -5,565 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (70.68*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= 9,892 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.7813 / 0.4375)*(1 - (70.68 / 75.92)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= -4,746 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (70.68*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) - 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= -19,347 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (70.68*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) + 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= 27,994 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (70.68 / 75.92)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= -105 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone large end calculations per Appendix 1-5(d)(1), wind + pressure, new

L_{min} = 2*(R_L*t_s)$^{0.5}$
= 2*(26.5*0.5)$^{0.5}$
= 7.2801 in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

f_1 = -0.6*W_l / (π*2*R_m) + 12*M_l / (π*R_m^2)
= -0.6*7,572.41 / (π*2*26.75) + 12*4,929.1 / (π*26.75^2)
= -0.72 lb_f/in

$P*R_L / 2 = 1{,}005.93$ lb_f/in

$|f_1| <= P*R_L / 2$ so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 75.92 / (14{,}100*1) = 0.005384$

From table 1-5.1 $\Delta = 23.77°$

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1{,}005.93 + -0.72$
$=$ 1,005.21 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}005.21*26.5 / (14{,}100*1))*(1 - 23.77 / 28.8866)*\tan(28.8866)$
$=$ 0.1846 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.5 - 0.1685)*(26.5*0.5)^{0.5} + (0.3125 - 0.1925)*(26.5*0.3125 / \cos(28.8866))^{0.5}$
$=$ 1.5759 in^2

$A_{eL} >= A_{rL}$ therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind New	-5,254	9,313	-4,888	8,664	42,300	42,300	-3,542	-3,013	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind New	-14,937	22,354	-13,897	20,798	42,300	42,300	-182	348	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), wind + pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= 4*59,149 / (\pi*53.5^2) - 0.6*7,572.41 / (\pi*53.5)$
$= -0.72$ lb_f/in

$P_e = P + 4*l / D = 75.92 + 4*-0.7204 / 53.5$
$= 75.87$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (75.87*26.75 / 0.5)*(0.5 - 0.2453*(26.75 / 0.5)^{0.5})$
$=$ -5,254 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (75.87*26.75 / 0.5)*(0.5 + 0.2453*(26.75 / 0.5)^{0.5})$
$=$ 9,313 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (75.92*26.75 / 0.5)*(1 - (75.87 / 75.92)*0.2561*(26.75 / 0.5)^{0.5})$
$=$ -3,542 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (75.87*26.75 / 0.5)*(0.5 / (0.625*\cos(28.8866)) - 0.6281*(26.75 / 0.5)^{0.5})$
$=$ -14,937 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (75.87*26.75 / 0.5)*(0.5 / (0.625*\cos(28.8866)) + 0.6281*(26.75 / 0.5)^{0.5})$
$=$ 22,354 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$

= (75.92*26.75 / 0.5)*(1 / (0.625*cos(28.8866)) - (75.87 / 75.92)*0.2561*(26.75 / 0.5)$^{0.5}$)
= -182 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - W / (π*D)
= - 4*59,149 / (π*53.5^2) - 7,572.41 / (π*53.5)
= -71.37 lb_f/in

P_e = P + 4*I / D = 75.92 + 4*-71.3655 / 53.5
= 70.58 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (70.58*26.75 / 0.5)*(0.5 - 0.2453*(26.75 / 0.5)$^{0.5}$)
= -4,888 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (70.58*26.75 / 0.5)*(0.5 + 0.2453*(26.75 / 0.5)$^{0.5}$)
= 8,664 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.75 / 0.5)*(1 - (70.58 / 75.92)*0.2561*(26.75 / 0.5)$^{0.5}$)
= -3,013 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (70.58*26.75 / 0.5)*(0.5 / (0.625*cos(28.8866)) - 0.6281*(26.75 / 0.5)$^{0.5}$)
= -13,897 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (70.58*26.75 / 0.5)*(0.5 / (0.625*cos(28.8866)) + 0.6281*(26.75 / 0.5)$^{0.5}$)
= 20,798 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.75 / 0.5)*(1 / (0.625*cos(28.8866)) - (70.58 / 75.92)*0.2561*(26.75 / 0.5)$^{0.5}$)
= 348 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone large end calculations per Appendix 1-5(d)(1), seismic + pressure, corroded

L_{min} = 2*(R_L*t_s)$^{0.5}$
= 2*(26.5625*0.4375)$^{0.5}$
= 6.8179 in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

f_1 = -(0.6 - 0.14*S_{DS})*W_I / (π*2*R_m) + 12*M_I / (π*R_m^2)
= -(0.6 - 0.14*0.32)*7,396.16 / (π*2*26.7813) + 12*5,311.9 / (π*26.7813^2)
= 3.89 lb_f/in

$P*R_L / 2 = 1{,}008.31$ lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 75.92 / (14{,}100*1) = 0.005384$

From table 1-5.1 $\Delta = 23.77°$

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1{,}008.31 + 3.89$
$=$ 1,012.19 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}012.19*26.5625 / (14{,}100*1))*(1 - 23.77 / 28.8866)*\tan(28.8866)$
$=$ 0.1863 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.4375 - 0.1689)*(26.5625*0.4375)^{0.5} + (0.25 - 0.1929)*(26.5625*0.25 / \cos(28.8866))^{0.5}$
$=$ 1.0729 in^2

$A_{eL} >= A_{rL}$ therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-6,001	10,666	-5,542	9,850	42,300	42,300	-5,482	-4,707	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-20,862	30,186	-19,265	27,876	42,300	42,300	-840	-65	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (0.6 - 0.14*S_{DS})*W / (\pi*D)$
$= 4*63,743.2 / (\pi*53.5625^2) - (0.6 - 0.14*0.32)*7,396.16 / (\pi*53.5625)$
$= 3.89$ lb_f/in

$P_e = P + 4*l / D = 75.92 + 4*3.8862 / 53.5625$
$= 76.21$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (76.21*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ -6,001 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (76.21*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ 10,666 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (75.92*26.7813 / 0.4375)*(1 - (76.21 / 75.92)*0.2775*(26.7813 / 0.4375)^{0.5})$
$=$ -5,482 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (76.21*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) - 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ -20,862 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (76.21*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) + 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ 30,186 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$

= (75.92*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (76.21 / 75.92)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= -840 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - (1 + 0.14*S_{DS})*W / (π*D)
= - 4*63,743.2 / (π*53.5625^2) - (1 + 0.14*0.32)*7,396.16 / (π*53.5625)
= -74.21 lb_f/in

P_e = P + 4*I / D = 75.92 + 4*-74.2121 / 53.5625
= 70.38 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (70.38*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= -5,542 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (70.38*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= 9,850 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.7813 / 0.4375)*(1 - (70.38 / 75.92)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= -4,707 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (70.38*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) - 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= -19,265 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (70.38*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) + 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= 27,876 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (70.38 / 75.92)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= -65 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone large end calculations per Appendix 1-5(d)(1), seismic + pressure, new

L_{min} = 2*(R_L*t_s)$^{0.5}$
= 2*(26.5*0.5)$^{0.5}$
= 7.2801 in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

f_1 = -(0.6 - 0.14*S_{DS})*W_l / (π*2*R_m) + 12*M_l / (π*R_m^2)
= -(0.6 - 0.14*0.32)*7,572.41 / (π*2*26.75) + 12*5,376.2 / (π*26.75^2)
= 3.68 lb_f/in

$P*R_L / 2 = 1{,}005.93$ lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 75.92 / (14{,}100*1) = 0.005384$

From table 1-5.1 $\Delta = 23.77°$

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1{,}005.93 + 3.68$
$=$ 1,009.62 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}009.62*26.5 / (14{,}100*1))*(1 - 23.77 / 28.8866)*\tan(28.8866)$
$=$ 0.1854 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.5 - 0.1685)*(26.5*0.5)^{0.5} + (0.3125 - 0.1925)*(26.5*0.3125 / \cos(28.8866))^{0.5}$
$=$ 1.5759 in^2

$A_{eL} >= A_{rL}$ therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic New	-5,277	9,353	-4,865	8,624	42,300	42,300	-3,575	-2,980	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 75.919 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic New	-15,002	22,451	-13,832	20,700	42,300	42,300	-215	381	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (0.6 - 0.14*S_{DS})*W / (\pi*D)$
$= 4*64{,}513.9 / (\pi*53.5^2) - (0.6 - 0.14*0.32)*7{,}572.41 / (\pi*53.5)$
$= 3.68$ lb_f/in

$P_e = P + 4*l / D = 75.92 + 4*3.6845 / 53.5$
$= 76.19$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (76.19*26.75 / 0.5)*(0.5 - 0.2453*(26.75 / 0.5)^{0.5})$
$=$ -5,277 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (76.19*26.75 / 0.5)*(0.5 + 0.2453*(26.75 / 0.5)^{0.5})$
$=$ 9,353 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (75.92*26.75 / 0.5)*(1 - (76.19 / 75.92)*0.2561*(26.75 / 0.5)^{0.5})$
$=$ -3,575 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (76.19*26.75 / 0.5)*(0.5 / (0.625*\cos(28.8866)) - 0.6281*(26.75 / 0.5)^{0.5})$
$=$ -15,002 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (76.19*26.75 / 0.5)*(0.5 / (0.625*\cos(28.8866)) + 0.6281*(26.75 / 0.5)^{0.5})$
$=$ 22,451 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$

= (75.92*26.75 / 0.5)*(1 / (0.625*cos(28.8866)) - (76.19 / 75.92)*0.2561*(26.75 / 0.5)$^{0.5}$)
= -215 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - (1 + 0.14*S_{DS})*W / (π*D)
= - 4*64,513.9 / (π*53.5^2) - (1 + 0.14*0.32)*7,572.41 / (π*53.5)
= -75.77 lb_f/in

P_e = P + 4*I / D = 75.92 + 4*-75.7704 / 53.5
= 70.25 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (70.25*26.75 / 0.5)*(0.5 - 0.2453*(26.75 / 0.5)$^{0.5}$)
= -4,865 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (70.25*26.75 / 0.5)*(0.5 + 0.2453*(26.75 / 0.5)$^{0.5}$)
= 8,624 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.75 / 0.5)*(1 - (70.25 / 75.92)*0.2561*(26.75 / 0.5)$^{0.5}$)
= -2,980 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (70.25*26.75 / 0.5)*(0.5 / (0.625*cos(28.8866)) - 0.6281*(26.75 / 0.5)$^{0.5}$)
= -13,832 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (70.25*26.75 / 0.5)*(0.5 / (0.625*cos(28.8866)) + 0.6281*(26.75 / 0.5)$^{0.5}$)
= 20,700 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) - (P_e / P)*Y*(R / t)$^{0.5}$)
= (75.92*26.75 / 0.5)*(1 / (0.625*cos(28.8866)) - (70.25 / 75.92)*0.2561*(26.75 / 0.5)$^{0.5}$)
= 381 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone juncture small end calculations, P =75.919 psi Appendix 1-5(e)								
Loading	**Area check required**	**U-2(g) analysis required**	**f_2 (lbf/in)**	**Q_s (lbf/in)**	**A_{rs} (in2)**	**A_{es} (in2)**	**Ring area (in^2) 3/8x2 Flat Bar**	**Status**
Wind Corroded	Yes	No	-30.03	870.17	0.95	0.2	0.75	OK
Wind New	Yes	No	-30.85	866.63	0.94	0.41	0.75	OK
Seismic Corroded	Yes	No	-27.79	872.41	0.95	0.2	0.75	OK
Seismic New	Yes	No	-28.55	868.94	0.95	0.41	0.75	OK

Cone small end calculations per Appendix 1-5(e)(2), wind + pressure, corroded

Cylinder is not present at the small end.

$f_2 = -0.6*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -0.6*7{,}502.48 / (\pi*2*23.8572) + 12*0 / (\pi*23.8572^2)$
$= -30.03$ lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 900.2 + -30.03$
$= 870.17$ lb_f/in

$k = \max[S_c*E_c / (S_r*E_r) , 1]$
$= \max[14{,}100*22.94E+06 / (14{,}100*22.94E+06) , 1]$
$= 1$

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*870.17*23.7145*\tan(28.8866) / (14{,}100*0.85)$
$= 0.9499$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.25 - 0.1722)*(23.7145*0.25 / \cos(28.8866))^{0.5}$
$= 0.2024$ in^2

Additional reinforcement area required = $A_{rs} - A_{es} = 0.7476$ in^2
Area provided by a 3/8x2 Flat Bar = 0.75 in^2
The maximum ring centroid to juncture distance is $0.25*(R_s*t_s)^{0.5} = 0.6087$ in

The actual distance of ring centroid to juncture is -0.565 in

The small end is adequately reinforced per Appendix 1-5(e).

Cone small end calculations per Appendix 1-5(e)(2), wind + pressure, new

Cylinder is not present at the small end.

$f_2 = -0.6*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -0.6*7{,}696.54 / (\pi*2*23.8215) + 12*0 / (\pi*23.8215^2)$
$= -30.85$ lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 897.49 + -30.85$

= 866.63 lb_f/in

$k = \max[S_c*E_c / (S_r*E_r) , 1]$
$= \max[14{,}100*22.94E+06 / (14{,}100*22.94E+06) , 1]$
$= 1$

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*866.63*23.6431*\tan(28.8866) / (14{,}100*0.85)$
$= 0.9432$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.1717)*(23.6431*0.3125 / \cos(28.8866))^{0.5}$
$= 0.409$ in^2

Additional reinforcement area required = $A_{rs} - A_{es}$ = 0.5342 in^2
Area provided by a 3/8x2 Flat Bar = 0.75 in^2
The maximum ring centroid to juncture distance is $0.25*(R_s*t_s)^{0.5}$ = 0.6795 in

The actual distance of ring centroid to juncture is -0.565 in

The small end is adequately reinforced per Appendix 1-5(e).

Cone small end calculations per Appendix 1-5(e)(2), seismic + pressure, corroded

Cylinder is not present at the small end.

$f_2 = -(0.6 - 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -(0.6 - 0.14*0.32)*7{,}502.48 / (\pi*2*23.8572) + 12*0 / (\pi*23.8572^2)$
$= -27.79$ lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 900.2 + -27.79$
$= 872.41$ lb_f/in

$k = \max[S_c*E_c / (S_r*E_r) , 1]$
$= \max[14{,}100*22.94E+06 / (14{,}100*22.94E+06) , 1]$
$= 1$

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*872.41*23.7145*\tan(28.8866) / (14{,}100*0.85)$
$= 0.9524$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.25 - 0.1722)*(23.7145*0.25 / \cos(28.8866))^{0.5}$
$= 0.2024$ in^2

Additional reinforcement area required = $A_{rs} - A_{es}$ = 0.75 in^2
Area provided by a 3/8x2 Flat Bar = 0.75 in^2
The maximum ring centroid to juncture distance is $0.25*(R_s*t_s)^{0.5}$ = 0.6087 in

The actual distance of ring centroid to juncture is -0.565 in

The small end is adequately reinforced per Appendix 1-5(e).

Cone small end calculations per Appendix 1-5(e)(2), seismic + pressure, new

Cylinder is not present at the small end.

$f_2 = -(0.6 - 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -(0.6 - 0.14*0.32)*7{,}696.54 / (\pi*2*23.8215) + 12*0 / (\pi*23.8215^2)$
$= -28.55$ lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 897.49 + -28.55$
$= 868.94$ lb_f/in

$k = \max[S_c*E_c / (S_r*E_r) , 1]$
$= \max[14{,}100*22.94E+06 / (14{,}100*22.94E+06) , 1]$
$= 1$

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*868.94*23.6431*\tan(28.8866) / (14{,}100*0.85)$
$= 0.9458$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.1717)*(23.6431*0.3125 / \cos(28.8866))^{0.5}$
$= 0.409$ in^2

Additional reinforcement area required = $A_{rs} - A_{es} = 0.5368$ in^2
Area provided by a 3/8x2 Flat Bar = 0.75 in^2
The maximum ring centroid to juncture distance is $0.25*(R_s*t_s)^{0.5} = 0.6795$ in

The actual distance of ring centroid to juncture is -0.565 in

The small end is adequately reinforced per Appendix 1-5(e).

Cone large end calculations for external pressure of 43.259 psi Appendix 1-8(b)											
Loading	Area check req'd $\Delta < \alpha$	U-2(g) analysis req'd	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2)	Area status	I'_s (in^4)	I' (in^4)	I status
Wind Corroded	Yes	No	70.21	657.07	0.55	1.93	none	OK	0.4112	0.4113	OK
Seismic Corroded	Yes	No	74.21	658.21	0.56	1.93	none	OK	0.411	0.4113	OK

Cone large end calculations per Appendix 1-8(b)(1), wind + external pressure

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(27*0.4375)^{0.5}$
$= 6.8739$ in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

$f_1 = W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= 7,396.16 / (\pi*2*26.7813) + 12*4,929.4 / (\pi*26.7813^2)$
$= 70.21$ lb_f/in

$P*R_L / 2 = 586.8669$ lb_f/in

$f_1 + P*R_L / 2$ is in compression so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 43.26 / (20,000*0.85) = 0.002545$

From table 1-8.1 $\Delta = 5.36°$

As $\Delta < \alpha$ reinforcement is required.

$Q_L = P*R_L / 2 + f_1$
$= 586.87 + 70.21$
$= 657.07$ lb_f/in

$A_{rL} = (k*Q_L*R_L*\tan(\alpha) / (S_s*E_1))*[1 - 0.25*((P*R_L-Q_L) / Q_L)*(\Delta / \alpha)]$
$= (1*657.07*27*\tan(28.8866) / (20,000*0.85))*[1 - 0.25*((43.26*27-657.07) / 657.07)*(5.36 / 28.8866)]$
$= 0.5547$ in^2

$A_{eL} = 0.55*(D_L*t_s)^{0.5}*(t_s + t_c / \cos(\alpha))$
$= 0.55*(54*0.4375)^{0.5}*(0.4375 + 0.25 / \cos(28.8866))$
$= 1.9329$ in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Cone large end calculations per Appendix 1-8(b)(3), wind + external pressure

$L_{min} = 1.4*(R_L*t_s)^{0.5}$
$= 1.4*(27*0.4375)^{0.5}$
$= 4.8117$ in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

$M = -R_L*\tan(\alpha) / 2 + L_L / 2 + (R_L^2 - R_s^2) / (3*R_L*\tan(\alpha))$
$= -27*\tan(28.8866) / 2 + 30.7962 / 2 + (27^2 - 24^2) / (3*27*\tan(28.8866))$

= 11.3734 in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (5.4375^2 + (27 - 24)^2)^{0.5}$
= 6.2102 in

$A_{TL} = L_L * t_s / 2 + L_c * t_c / 2 + A_s$
$= 30.7962 * 0.4375 / 2 + 6.2102 * 0.25 / 2 + 0$
$= 7.5129$ in^2

$F_L = P*M + f_1*\tan(\alpha)$
$= 43.26*11.3734 + 70.21*\tan(28.8866)$
$= 533.16$ lb$_f$/in

$B = 0.75*F_L*D_L / A_{TL}$
$= 0.75*533.16*54 / 7.5129$
= 2,874 psi

From Table HA-1: A = 0.000205 (shell, 0° F)

$I'_s = A*D_L^2*A_{TL} / 10.9$
$= 0.000205*54^2*7.5129 / 10.9$
= 0.4112 in^4

The calculated I' for the combined shell-cone cross section is 0.4113 in^4

As $I' >= I'_s$ the large end is adequately stiffened per Appendix 1-8(b).

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cylinder External pressure = 43.259 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	3,424	-6,085	3,836	-6,818	60,000	60,000	3,118	3,814	30,000

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cone External pressure = 43.259 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	11,902	-17,222	13,335	-19,295	60,000	60,000	460	1,156	30,000

Appendix 1-8(e), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), wind + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= 4*59{,}152.7 / (\pi*53.5625^2) - 0.6*7{,}396.16 / (\pi*53.5625)$
$= -0.12$ lb_f/in

$P_e = P + 4*l / D = -43.26 + 4*-0.1202 / 53.5625$
$= -43.27$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-43.27*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ 3,407 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-43.27*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ -6,056 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (-43.26*26.7813 / 0.4375)*(1 - (-43.27 / -43.26)*0.2775*(26.7813 / 0.4375)^{0.5})$
$=$ 3,103 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-43.27*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) - 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ 11,844 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-43.27*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) + 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ -17,138 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$

= (-43.26*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (-43.27 / -43.26)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= 458 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - W / (π*D)
= - 4*59,152.7 / (π*53.5625^2) - 7,396.16 / (π*53.5625)
= -70.21 lb_f/in

P_e = P + 4*I / D = -43.26 + 4*-70.2057 / 53.5625
= -48.5 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (-48.5*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= 3,819 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (-48.5*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= -6,788 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)$^{0.5}$)
= (-43.26*26.7813 / 0.4375)*(1 - (-48.5 / -43.26)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= 3,798 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (-48.5*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) - 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= 13,277 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (-48.5*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) + 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= -19,211 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) - (P_e / P)*Y*(R / t)$^{0.5}$)
= (-43.26*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (-48.5 / -43.26)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= 1,154 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Cone large end calculations per Appendix 1-8(b)(1), seismic + external pressure

L_{min} = 2*(R_L*t_s)$^{0.5}$
= 2*(27*0.4375)$^{0.5}$
= 6.8739 in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

f_1 = (1 + 0.14*S_{DS})*W_I / (π*2*R_m) + 12*M_I / (π*R_m^2)
= (1 + 0.14*0.32)*7,396.16 / (π*2*26.7813) + 12*5,311.9 / (π*26.7813^2)
= 74.21 lb_f/in

P*R_L / 2 = 584.0013 lb_f/in

$f_1 + P*R_L / 2$ is in compression so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 43.26 / (20{,}000*0.85) = 0.002545$

From table 1-8.1 $\Delta = 5.36°$

As $\Delta < \alpha$ reinforcement is required.

$Q_L = P*R_L / 2 + f_1$
$= 584 + 74.21$
$= 658.21$ lb_f/in

$A_{rL} = (k*Q_L*R_L*\tan(\alpha) / (S_s*E_1))*[1 - 0.25*((P*R_L - Q_L) / Q_L)*(\Delta / \alpha)]$
$= (1*658.21*27*\tan(28.8866) / (20{,}000*0.85))*[1 - 0.25*((43.26*27-658.21) / 658.21)*(5.36 / 28.8866)]$
$= 0.556$ in^2

$A_{eL} = 0.55*(D_L*t_s)^{0.5}*(t_s + t_c / \cos(\alpha))$
$= 0.55*(54*0.4375)^{0.5}*(0.4375 + 0.25 / \cos(28.8866))$
$= 1.9329$ in^2

$A_{eL} >= A_{rL}$ therefore the large end juncture is adequately reinforced.

Cone large end calculations per Appendix 1-8(b)(3), seismic + external pressure

$L_{min} = 1.4*(R_L*t_s)^{0.5}$
$= 1.4*(27*0.4375)^{0.5}$
$= 4.8117$ in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

$M = -R_L*\tan(\alpha) / 2 + L_L / 2 + (R_L^2 - R_s^2) / (3*R_L*\tan(\alpha))$
$= -27*\tan(28.8866) / 2 + 30.7962 / 2 + (27^2 - 24^2) / (3*27*\tan(28.8866))$
$= 11.3734$ in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (5.4375^2 + (27 - 24)^2)^{0.5}$
$= 6.2102$ in

$A_{TL} = L_L*t_s / 2 + L_c * t_c / 2 + A_s$
$= 30.7962*0.4375 / 2 + 6.2102 * 0.25 / 2 + 0$
$= 7.5129$ in^2

$F_L = P*M + f_1*\tan(\alpha)$
$= 43.26*11.3734 + 74.21*\tan(28.8866)$
$= 532.95$ lb_f/in

$B = 0.75*F_L*D_L / A_{TL}$
$= 0.75*532.95*54 / 7.5129$
$= 2{,}873$ psi

From Table HA-1: A = 0.000204 (shell, 0° F)

$I'_s = A*D_L^2*A_{TL} / 10.9$
$= 0.000204*54^2*7.5129 / 10.9$
$= 0.411$ in^4

The calculated I' for the combined shell-cone cross section is 0.4113 in^4

As $I' >= I'_s$ the large end is adequately stiffened per Appendix 1-8(b).

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cylinder External pressure = 43.259 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	3,383	-6,014	3,843	-6,830	60,000	60,000	3,063	3,838	30,000

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cone External pressure = 43.259 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	11,762	-17,020	13,359	-19,330	60,000	60,000	418	1,193	30,000

Appendix 1-8(e), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (0.6 - 0.14*S_{DS})*W / (\pi*D)$
$= 4*63,743.2 / (\pi*53.5625^2) - (0.6 - 0.14*0.32)*7,396.16 / (\pi*53.5625)$
$= 3.89$ lb_f/in

$P_e = P + 4*l / D = -43.26 + 4*3.8862 / 53.5625$
$= -42.97$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-42.97*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ 3,383 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-42.97*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)^{0.5})$
$=$ -6,014 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (-43.26*26.7813 / 0.4375)*(1 - (-42.97 / -43.26)*0.2775*(26.7813 / 0.4375)^{0.5})$
$=$ 3,063 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-42.97*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) - 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ 11,762 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-42.97*26.7813 / 0.4375)*(0.5 / (0.5714*\cos(28.8866)) + 0.6993*(26.7813 / 0.4375)^{0.5})$
$=$ -17,020 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$

= (-43.26*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (-42.97 / -43.26)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= 418 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Equivalent pressure leeward side, P_e:

l = - 4*M / (π*D^2) - (1 + 0.14*S_{DS})*W / (π*D)
= - 4*63,743.2 / (π*53.5625^2) - (1 + 0.14*0.32)*7,396.16 / (π*53.5625)
= -74.21 lb_f/in

P_e = P + 4*l / D = -43.26 + 4*-74.2121 / 53.5625
= -48.8 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (-48.8*26.7813 / 0.4375)*(0.5 - 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= 3,843 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (-48.8*26.7813 / 0.4375)*(0.5 + 0.2283*(26.7813 / 0.4375)$^{0.5}$)
= -6,830 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)$^{0.5}$)
= (-43.26*26.7813 / 0.4375)*(1 - (-48.8 / -43.26)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= 3,838 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (-48.8*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) - 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= 13,359 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (-48.8*26.7813 / 0.4375)*(0.5 / (0.5714*cos(28.8866)) + 0.6993*(26.7813 / 0.4375)$^{0.5}$)
= -19,330 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) - (P_e / P)*Y*(R / t)$^{0.5}$)
= (-43.26*26.7813 / 0.4375)*(1 / (0.5714*cos(28.8866)) - (-48.8 / -43.26)*0.2775*(26.7813 / 0.4375)$^{0.5}$)
= 1,193 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Cone small end calculations for external pressure of 43.259 psi Appendix 1-8(c)										
Loading	U-2(g) analysis req'd	f_2 (lbf/in)	Q_s (lbf/in)	A_{rs} (in2)	A_{es} (in2)	Ring area (in^2) 3/8x2 Flat Bar	Area status	$I's$ (in^4)	I' (in^4)	I status
Wind Corroded	No	50.05	569.16	0.38	0.22	0.75	OK	0.4107	0.6834	OK
Seismic Corroded	No	52.29	571.4	0.38	0.22	0.75	OK	0.4135	0.6834	OK

Cone small end calculations per Appendix 1-8(c)(2), wind + external pressure

Cylinder is not present at the small end.

$f_2 = W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= 7{,}502.48 / (\pi*2*23.8572) + 12*0 / (\pi*23.8572^2)$
$=$ 50.05 lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 519.11 + 50.05$
$=$ 569.16 lb_f/in

$k = \max[S_c*E_c / (S_r*E_r) , 1]$
$= \max[20{,}000*28.67E+06 / (20{,}000*28.67E+06) , 1]$
$= 1$

$A_{rs} = k*Q_s*D_s*\tan(\alpha) / (2*S_c*E_2)$
$= 1*569.16*48*\tan(28.8866) / (2*20{,}000*1)$
$=$ 0.3768 in^2

$A_{es} = 0.55*(D_s*t_c)^{0.5}*(t_c - t_r) / \cos(\alpha)$
$= 0.55*(48*0.25)^{0.5}*(0.25 - 0.1472) / \cos(28.8866)$
$=$ 0.2237 in^2

Additional reinforcement area required = $A_{rs} - A_{es} = 0.1531$ in^2
Area provided by a 3/8x2 Flat Bar = 0.75 in^2
The maximum ring centroid to juncture distance is $0.25*(R_s*t_s)^{0.5} = 0.6124$ in

The actual distance of ring centroid to juncture is -0.565 in

The small end is adequately reinforced per Appendix 1-8(c).

Cone small end calculations per Appendix 1-8(c)(3), wind + external pressure

$N = R_s*\tan(\alpha) / 2 + L_s / 2 + (R_L^2 - R_s^2) / (6*R_s*\tan(\alpha))$
$= 24*\tan(28.8866) / 2 + 0 / 2 + (27^2 - 24^2) / (6*24*\tan(28.8866))$
$= 8.5465$ in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (5.4375^2 + (27 - 24)^2)^{0.5}$
$= 6.2102$ in

$A_{TS} = L_s*t_s / 2 + L_c * t_c / 2 + A_s$
$= 0*0.25 / 2 + 6.2102 * 0.25 / 2 + 0.75$
$= 1.53$

$F_s = P*N + f_2*\tan(\alpha)$
$= 43.26*8.5465 + 50.05*\tan(28.8866)$
$= 397.33$ lb_f/in

$B = 0.75*F_s*D_s / A_{TS}$
$= 0.75*397.33*48 / 1.5263$
$= 9{,}372$ psi

From Table HA-1: A = 0.001273 (shell, 0° F)

$I'_s = A*D_s^2*A_{TS} / 10.9$
$= 0.001273*48^2*1.5263 / 10.9$
$= 0.4107$ in^4

The calculated I' for the combined ring-shell-cone cross section is 0.6834 in^4

As $I' >= I'_s$ the small end is adequately stiffened per Appendix 1-8(c).

Cone small end calculations per Appendix 1-8(c)(2), seismic + external pressure

Cylinder is not present at the small end.

$f_2 = (1 + 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= (1 + 0.14*0.32)*7{,}502.48 / (\pi*2*23.8572) + 12*0 / (\pi*23.8572^2)$
$= 52.29$ lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 519.11 + 52.29$
$= 571.4$ lb_f/in

$k = \max[S_c*E_c / (S_r*E_r) , 1]$
$= \max[20{,}000*28.67E+06 / (20{,}000*28.67E+06) , 1]$
$= 1$

$A_{rs} = k*Q_s*D_s*\tan(\alpha) / (2*S_c*E_2)$
$= 1*571.4*48*\tan(28.8866) / (2*20{,}000*1)$
$= 0.3783$ in^2

$A_{es} = 0.55*(D_s*t_c)^{0.5}*(t_c - t_r) / \cos(\alpha)$
$= 0.55*(48*0.25)^{0.5}*(0.25 - 0.1472) / \cos(28.8866)$
$= 0.2237$ in^2

Additional reinforcement area required = $A_{rs} - A_{es} = 0.1546$ in^2
Area provided by a 3/8x2 Flat Bar = 0.75 in^2
The maximum ring centroid to juncture distance is $0.25*(R_s*t_s)^{0.5} = 0.6124$ in

The actual distance of ring centroid to juncture is -0.565 in

The small end is adequately reinforced per Appendix 1-8(c).

Cone small end calculations per Appendix 1-8(c)(3), seismic + external pressure

$N = R_s*\tan(\alpha) / 2 + L_s / 2 + (R_L^2 - R_s^2) / (6*R_s*\tan(\alpha))$
$= 24*\tan(28.8866) / 2 + 0 / 2 + (27^2 - 24^2) / (6*24*\tan(28.8866))$
$= 8.5465$ in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (5.4375^2 + (27 - 24)^2)^{0.5}$
$= 6.2102$ in

$A_{TS} = L_s * t_s / 2 + L_c * t_c / 2 + A_s$
$= 0 * 0.25 / 2 + 6.2102 * 0.25 / 2 + 0.75$
$= 1.53$

$F_s = P * N + f_2 * \tan(\alpha)$
$= 43.26 * 8.5465 + 52.29 * \tan(28.8866)$
$= 398.57$ lb_f/in

$B = 0.75 * F_s * D_s / A_{TS}$
$= 0.75 * 398.57 * 48 / 1.5263$
$= 9{,}401$ psi

From Table HA-1: A = 0.001282 (shell, 0° F)

$I'_s = A * D_s^2 * A_{TS} / 10.9$
$= 0.001282 * 48^2 * 1.5263 / 10.9$
$= 0.4135$ in^4

The calculated I' for the combined ring-shell-cone cross section is 0.6834 in^4

As $I' >= I'_s$ the small end is adequately stiffened per Appendix 1-8(c).

MAP Cone juncture large end calculations, P =120.963 psi Appendix 1-5(d)								
Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2)	Status
Pressure	Yes	No	0	1,602.76	0.15	1.43	none	OK

Cone large end calculations per Appendix 1-5(d)(1), pressure, new

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(26.5*0.5)^{0.5}$
$= 7.2801$ in

The length of the attached cylinder (26.1275 in) ≥ L_{min}.

$f_1 = -0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -0.6*0 / (\pi*2*26.75) + 12*0 / (\pi*26.75^2)$
$= 0$ lb_f/in

$P*R_L / 2 = 1{,}602.76$ lb_f/in

$|f_1| <= P*R_L / 2$ so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 120.96 / (20{,}000*1) = 0.006048$

From table 1-5.1 $\Delta = 25.1°$

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1{,}602.76 + 0$
$= 1{,}602.76$ lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}602.76*26.5 / (20{,}000*1))*(1 - 25.1 / 28.8866)*\tan(28.8866)$
$= 0.1536$ in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.5 - 0.1894)*(26.5*0.5)^{0.5} + (0.3125 - 0.2163)*(26.5*0.3125 / \cos(28.8866))^{0.5}$
$= 1.4266$ in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 120.963 psi (MAP)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Pressure	-8,377	14,849	0	0	60,000	60,000	-5,652	0	30,000

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 120.963 psi (MAP)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Pressure	-23,816	35,642	0	0	60,000	60,000	-298	0	30,000

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= 4*0 / (\pi*53.5^2) - 0.6*0 / (\pi*53.5)$
$= 0$ lb_f/in

$P_e = P + 4*l / D = 120.96 + 4*0 / 53.5$
$= 120.96$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (120.96*26.75 / 0.5)*(0.5 - 0.2453*(26.75 / 0.5)^{0.5})$
$=$ -8,377 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (120.96*26.75 / 0.5)*(0.5 + 0.2453*(26.75 / 0.5)^{0.5})$
$=$ 14,849 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (120.96*26.75 / 0.5)*(1 - (120.96 / 120.96)*0.2561*(26.75 / 0.5)^{0.5})$
$=$ -5,652 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (120.96*26.75 / 0.5)*(0.5 / (0.625*\cos(28.8866)) - 0.6281*(26.75 / 0.5)^{0.5})$
$=$ -23,816 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (120.96*26.75 / 0.5)*(0.5 / (0.625*\cos(28.8866)) + 0.6281*(26.75 / 0.5)^{0.5})$
$=$ 35,642 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) - (P_e / P)*Y*(R / t)$^{0.5}$)
= (120.96*26.75 / 0.5)*(1 / (0.625*cos(28.8866)) - (120.96 / 120.96)*0.2561*(26.75 / 0.5)$^{0.5}$)
= -298 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

MAP Cone juncture small end calculations, P =120.963 psi Appendix 1-5(e)								
Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_2 (lbf/in)	Q_s (lbf/in)	A_{rs} (in2)	A_{es} (in2)	Ring area (in^2) 3/8x2 Flat Bar	Status
Pressure	Yes	No	0	1,429.97	1.1	0.35	0.75	OK

Cone small end calculations per Appendix 1-5(e)(2), pressure, new

Cylinder is not present at the small end.

$f_2 = -0.6*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -0.6*0 / (\pi*2*23.8215) + 12*0 / (\pi*23.8215^2)$
$= 0$ lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 1{,}429.97 + 0$
$= 1{,}429.97$ lb_f/in

$k = \max[S_c*E_c / (S_r*E_r) , 1]$
$= \max[20{,}000*28.3E+06 / (20{,}000*28.3E+06) , 1]$
$= 1$

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*1{,}429.97*23.6431*\tan(28.8866) / (20{,}000*0.85)$
$= 1.0972$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.193)*(23.6431*0.3125 / \cos(28.8866))^{0.5}$
$= 0.3472$ in^2

Additional reinforcement area required = $A_{rs} - A_{es} = 0.75$ in^2
Area provided by a 3/8x2 Flat Bar = 0.75 in^2
The maximum ring centroid to juncture distance is $0.25*(R_s*t_s)^{0.5} = 0.6795$ in

The actual distance of ring centroid to juncture is -0.565 in

The small end is adequately reinforced per Appendix 1-5(e).

Upper Body Flange

ASME B16.47-2011 Flange	
Description	NPS 48 Class 300 WN A182 F304 Series B
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

Lower Body Flange

ASME B16.47-2011 Flange	
Description	NPS 48 Class 300 WN A182 F304 Series B
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

Vessel Body Vacuum Ring

ASME Section VIII Division 1, 2013 Edition	
Attached to	Vessel Body Upper Shell
Ring type	Flat bar
Description	3/8x4 Flat Bar
Material	SA-479 304 Bar (II-D p. 94, ln. 39)
External design pressure	7.4 psi
External design temperature	0° F
Corrosion allowance	0"
Distance from ring neutral axis to datum	84.3125"
Distance to previous support	80.9375"
Distance to next support	72"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.25"
Vessel thickness at weld location, new	0.3125"
Vessel corrosion allowance at weld location	0.0625"
Stiffener thickness at weld location	0.375"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	2"
Ring area	1.5 in^2
Ring inertia	2 in^4

External Pressure, (Corroded & at 0° F) UG-29(a)

L / D_o = 80.9375 / 48 = 1.6862
D_o / t = 48 / 0.1444 = 332.3179
From Table G: A = 1.3126E-04
From Table HA-1: B = 1,844.96 psi

P_a = 4*B / (3*(D_o / t))
= 4*1,844.96 / (3*(48 / 0.14444))
= 7.4 psi

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*7.4*48 / (0.1444 + 1.5 / 76.4688)
= 1,624 psi

From Table HA-1: A = 0.00011555 (ring, 0° F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[48^2 * 76.4688 * (0.1444 + 1.5 / 76.4688) * 0.00011555] / 10.9$
= 0.3063 in^4

I' for the composite corroded shell-ring cross section is 4.6358 in^4

As $I' >= I_s'$ a 3/8x4 Flat Bar stiffener is adequate for an external pressure of 7.4 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.25 in is adequate per UG-30(f)(1).

Radial pressure load, $P * L_s$ = 7.4*76.4688 = 565.87 lb_f/in
Radial shear load, V = 0.01*P*L_s*D_o = 0.01*7.4*76.4688*48 = 271.62 lb_f
First moment of area, Q = 0.95*1.2996 = 1.2381 in^3

Weld shear flow, q = V*Q / I' = 72.5388 lb_f/in
Combined weld load, f_w = Sqr(565.8688^2 + 72.5388^2) = 570.5 lb_f/in

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*20,000 = 11,000 psi

Fillet weld size required to resist radial pressure and shear

t_w = $f_w * (d_{weld\ segment} + d_{toe}) / (S_w * d_{weld\ total})$ + corrosion
= 570.5*(1 + 0) / (11,000*2) + 0
= 0.0259 in

The fillet weld size of 0.25 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 0° F) UG-29(a)

L / D_o = 80.9375 / 48 = 1.6862
D_o / t = 48 / 0.25 = 192
From Table G: A = 2.9486E-04
From Table HA-1: B = 4,141.23 psi

P_a = 4*B / (3*(D_o / t))
= 4*4,141.23 / (3*(48 / 0.25))
= 28.76 psi

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*28.76*48 / (0.25 + 1.5 / 76.4688)
= 3,840 psi

From Table HA-1: A = 0.00027339 (ring, 0° F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[48^2 * 76.4688 * (0.25 + 1.5 / 76.4688) * 0.00027339] / 10.9$
= 1.1914 in^4

I' for the composite corroded shell-ring cross section is 4.6358 in^4

As $I' >= I_s'$ a 3/8x4 Flat Bar stiffener is adequate for an external pressure of 28.76 psi.

Check the stiffener ring attachment welds per UG-30

Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.25 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 28.76*76.4688 = 2,199.13\ lb_f/in$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*28.76*76.4688*48 = 1,055.58\ lb_f$
First moment of area, $Q = 0.95*1.2996 = 1.2381\ in^3$

Weld shear flow, $q = V*Q / I' = 281.9066\ lb_f/in$
Combined weld load, $f_w = Sqr(2,199.1281^2 + 281.9066^2) = 2,217.12\ lb_f/in$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*20,000 = 11,000$ psi

Fillet weld size required to resist radial pressure and shear

$$\begin{aligned} t_w &= f_w*(d_{\text{weld segment}} + d_{toe}) / (S_w*d_{\text{weld total}}) + \text{corrosion} \\ &= 2,217.12*(1 + 0) / (11,000*2) + 0 \\ &= 0.1008 \text{ in} \end{aligned}$$

The fillet weld size of 0.25 in is adequate to resist radial pressure and shear.

Vessel Body Upper Shell

ASME Section VIII Division 1, 2013 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		2.11	58.5151	1
Dimensions				
Outer Diameter		48"		
Length		97.94"		
Nominal Thickness		0.3125"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		1,328.12		747.37
Corroded		1,063.89		751.32
Radiography				
Longitudinal seam		Spot UW-11(b) Type 1		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.1825"
Design thickness due to external pressure (t_e)	0.2069"
Design thickness due to combined loadings + corrosion	0.1234"
Maximum allowable working pressure (MAWP)	125.37 psi
Maximum allowable pressure (MAP)	222.51 psi
Maximum allowable external pressure (MAEP)	28.76 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 61.16*24 / (20,000*0.85 + 0.4*61.16) =	0.0862"
Stress ratio = t_r*E* / (t_n - c) = 0.0862*0.85 / (0.3125 - 0.0625) =	0.2931
Impact test exempt per UHA-51(g) (coincident ratio = 0.2931)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) Appendix 1-1

t = P*R_o / (S*E + 0.40*P) + Corrosion
= 60*24 / (14,100*0.85 + 0.40*60) + 0.0625
= 0.1825"

Maximum allowable working pressure, (at 980 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 14,100*0.85*0.25 / (24 - 0.40*0.25) - 0
= 125.37 psi

Maximum allowable pressure, (at 70 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t)
= 20,000*0.85*0.3125 / (24 - 0.40*0.3125)
= 222.51 psi

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 80.9375 / 48 = 1.6862
D_o / t = 48 / 0.1444 = 332.3638
From table G: A = 0.000131
From table HA-1: B = 1,844.6279 psi

P_a = 4*B / (3*(D_o / t))
= 4*1,844.63 / (3*(48 / 0.1444))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t + Corrosion = 0.1444 + 0.0625 = 0.2069"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 80.9375 / 48 = 1.6862
D_o / t = 48 / 0.25 = 192.0000
From table G: A = 0.000295
From table HA-1: B = 4,141.2349 psi

P_a = 4*B / (3*(D_o / t))
= 4*4,141.23 / (3*(48 / 0.25))
= 28.76 psi

% Forming strain - UHA-44(a)(2)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.3125 / 23.8438)*(1 - 23.8438 / ∞)
= 0.6553%

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = W / (2*π*R_m) + M / (π*R_m^2)
= 15,319.1 / (2*π*23.875) + 107,476 / (π*23.875^2)
= 162.1363 lb/in
α = P_v / (P_e*D_o)
= 162.1363 / (7.4*48)
= 0.4565
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (80.9375 / 48)^2
= 0.4326
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (4^2 - 1 + 0.4326 + 0.4326*0.4565) / (4^2 - 1 + 0.4326)
= 1.0128

Ratio P_e * P_e ≤ MAEP
(1.0128 * 7.4 = 7.49) ≤ 28.76
Cylinder design thickness is satisfactory.

External Pressure + Weight + Wind Loading Check at Bottom Seam (Bergman, ASME paper 54-A-104)

P_v = 0.6*W / (2*π*R_m) + M / (π*R_m^2)
= 0.60*-9,225.7 / (2*π*23.875) + 293,309 / (π*23.875^2)
= 126.8903 lb/in
α = P_v / (P_e*D_o)
= 126.8903 / (7.4*48)
= 0.3572
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (80.9375 / 48)^2
= 0.4326
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)

$= (4^2 - 1 + 0.4326 + 0.4326*0.3572) / (4^2 - 1 + 0.4326)$
$= 1.01$

Ratio $P_e * P_e \leq$ MAEP

$(1.01 * 7.4 = 7.47) \leq 28.76$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$P_v = (1 + 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m^2)$
$= 1.04*15,319.1 / (2*\pi*23.875) + 149,414 / (\pi*23.875^2)$
$= 190.1308$ lb/in

$\alpha = P_v / (P_e*D_o)$
$= 190.1308 / (7.4*48)$
$= 0.5353$

$n = 4$

$m = 1.23 / (L / D_o)^2$
$= 1.23 / (80.9375 / 48)^2$
$= 0.4326$

Ratio $P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (4^2 - 1 + 0.4326 + 0.4326*0.5353) / (4^2 - 1 + 0.4326)$
$= 1.015$

Ratio $P_e * P_e \leq$ MAEP

$(1.015 * 7.4 = 7.51) \leq 28.76$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check at Bottom Seam(Bergman, ASME paper 54-A-104)

$P_v = (0.6 - 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m^2)$
$= 0.56*-9,225.7 / (2*\pi*23.875) + 448,252 / (\pi*23.875^2)$
$= 216.1696$ lb/in

$\alpha = P_v / (P_e*D_o)$
$= 216.1696 / (7.4*48)$
$= 0.6086$

$n = 4$

$m = 1.23 / (L / D_o)^2$
$= 1.23 / (80.9375 / 48)^2$
$= 0.4326$

Ratio $P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (4^2 - 1 + 0.4326 + 0.4326*0.6086) / (4^2 - 1 + 0.4326)$
$= 1.0171$

Ratio $P_e * P_e \leq$ MAEP

$(1.0171 * 7.4 = 7.53) \leq 28.76$

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads									
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Location	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c						
Operating, Hot & Corroded	60	14,100	5,037	980	0.0625	Top	Wind	0.042	0.0325
							Seismic	0.0437	0.0308
						Bottom	Wind	0.0554	0.0346
							Seismic	0.0607	0.0293
Operating, Hot & New	60	14,100	5,286	980	0	Top	Wind	0.0418	0.0323
							Seismic	0.0436	0.0305
						Bottom	Wind	0.0555	0.0346
							Seismic	0.0609	0.0291
Hot Shut Down, Corroded	0	14,100	5,037	980	0.0625	Top	Wind	0.0002	0.0268
							Seismic	0.0016	0.0315
						Bottom	Wind	0.0133	0.021
							Seismic	0.0186	0.0358
Hot Shut Down, New	0	14,100	5,286	980	0	Top	Wind	0.0004	0.0259
							Seismic	0.0016	0.0306
						Bottom	Wind	0.0135	0.0198
							Seismic	0.0189	0.0343
Empty, Corroded	0	20,000	9,994	70	0.0625	Top	Wind	0.0021	0.0116
							Seismic	0.0019	0.0173
						Bottom	Wind	0.0035	0.0034
							Seismic	0.0034	0.0032
Empty, New	0	20,000	10,848	70	0	Top	Wind	0.002	0.0108
							Seismic	0.0019	0.0163
						Bottom	Wind	0.0036	0.003
							Seismic	0.0036	0.003
Vacuum	-7.4	20,000	9,994	0	0.0625	Top	Wind	0.0074	0.0208
							Seismic	0.0051	0.0232
						Bottom	Wind	0.0057	0.0179
							Seismic	0.0094	0.0254
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,100	5,037	980	0.0625	Top	Weight	0.0168	0.0238
						Bottom	Weight	0.0138	0.0142

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t)$

= $0.125 / (24 / 0.25)$

= 0.001302

B = 5,037 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHC} = min(B, S) = 5,037 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (24 / 0.3125)
= 0.001628

B = 5,286 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHN} = min(B, S) = 5,286 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (24 / 0.3125)
= 0.001628

B = 10,848 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCN} = min(B, S) = 10,848 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (24 / 0.25)
= 0.001302

B = 9,994 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCC} = min(B, S) = 9,994 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (24 / 0.25)
= 0.001302

B = 9,994 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cVC} = min(B, S) = 9,994 psi

Operating, Hot & Corroded, Wind, Above Support Point

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*23.75 / (2*14,100*1.20*1.00 + 0.40*|60|)
= 0.0421"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 107,476 / (π*23.875^2*14,100*1.20*1.00)
= 0.0035"

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.60*15,319.1 / (2*π*23.875*14,100*1.20*1.00)
= 0.0036"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0421 + 0.0035 - (0.0036)

= 0.042"

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 15,319.1 / (2*π*23.875*14,100*1.20*1.00)
= 0.006"

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |0.0035 + (0.006) - (0.0421)|
= 0.0325"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*1.00*(0.25 - 0.0035 + (0.0036)) / (23.75 - 0.40*(0.25 - 0.0035 + (0.0036)))
= 357.82 psi

Operating, Hot & New, Wind, Above Support Point

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*23.6875 / (2*14,100*1.20*1.00 + 0.40*|60|)
= 0.042"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 107,415 / (π*23.8438^2*14,100*1.20*1.00)
= 0.0036"

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.60*15,624.5 / (2*π*23.8438*14,100*1.20*1.00)
= 0.0037"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.042 + 0.0036 - (0.0037)
= 0.0418"

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 15,624.5 / (2*π*23.8438*14,100*1.20*1.00)
= 0.0062"

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |0.0036 + (0.0062) - (0.042)|
= 0.0323"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*1.00*(0.3125 - 0.0036 + (0.0037)) / (23.6875 - 0.40*(0.3125 - 0.0036 + (0.0037)))
= 449.01 psi

Hot Shut Down, Corroded, Wind, Above Support Point

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 107,476 / (π*23.875^2*5,036.69*1.20)
= 0.0099"

t_w = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)

= 0.60*15,319.1 / (2*π*23.875*5,036.69*1.20)
= 0.0101"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0099 - (0.0101)|
= 0.0002"

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= 15,319.1 / (2*π*23.875*5,036.69*1.20)
= 0.0169"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0099 + (0.0169) - (0)
= 0.0268"

Hot Shut Down, New, Wind, Above Support Point

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $107,415 / (\pi*23.8438^2*5,286.41*1.20)$
= 0.0095"

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= 0.60*15,624.5 / (2*π*23.8438*5,286.41*1.20)
= 0.0099"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0095 - (0.0099)|
= 0.0004"

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= 15,624.5 / (2*π*23.8438*5,286.41*1.20)
= 0.0164"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0095 + (0.0164) - (0)
= 0.0259"

Empty, Corroded, Wind, Above Support Point

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $65,223 / (\pi*23.875^2*9,994*1.20)$
= 0.003"

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= 0.60*15,319.1 / (2*π*23.875*9,994*1.20)
= 0.0051"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.003 - (0.0051)|
= 0.0021"

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= 15,319.1 / (2*π*23.875*9,994*1.20)
= 0.0085"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.003 + (0.0085) - (0)
= 0.0116"

Empty, New, Wind, Above Support Point

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $65,163 / (\pi * 23.8438^2 * 10,848.01 * 1.20)$
= 0.0028"
t_w = $0.6 * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $0.60 * 15,624.5 / (2 * \pi * 23.8438 * 10,848.01 * 1.20)$
= 0.0048"
t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0028 - (0.0048)|
= 0.002"
t_{wc} = $W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $15,624.5 / (2 * \pi * 23.8438 * 10,848.01 * 1.20)$
= 0.008"
t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0028 + (0.008) - (0)
= 0.0108"

Vacuum, Wind, Above Support Point

t_p = $P * R / (2 * S_c * K_s + 0.40 * |P|)$ (Pressure)
= $-7.4 * 23.75 / (2 * 9,994 * 1.20 + 0.40 * |7.4|)$
= -0.0073"
t_m = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $107,476 / (\pi * 23.875^2 * 9,994 * 1.20)$
= 0.005"
t_w = $0.6 * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $0.60 * 15,319.1 / (2 * \pi * 23.875 * 9,994 * 1.20)$
= 0.0051"
t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-0.0073 + 0.005 - (0.0051)|
= 0.0074"
t_{wc} = $W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $15,319.1 / (2 * \pi * 23.875 * 9,994 * 1.20)$
= 0.0085"
t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.005 + (0.0085) - (-0.0073)
= 0.0208"

Maximum Allowable External Pressure, Longitudinal Stress

$P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))$
$= 2*9,994*1.20*(0.25 - 0.005 - 0.0085) / (23.75 - 0.40*(0.25 - 0.005 - 0.0085))$
$=$ 239.78 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Above Support Point

t_p = 0" (Pressure)

$t_m = M / (\pi*R_m^2*S_c*K_s)$ (bending)
$= 31,451 / (\pi*23.875^2*5,036.69*1.00)$
$=$ 0.0035"

$t_w = W / (2*\pi*R_m*S_c*K_s)$ (Weight)
$= 15,319.1 / (2*\pi*23.875*5,036.69*1.00)$
$=$ 0.0203"

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0035 - (0.0203)|$
$=$ 0.0168"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0035 + (0.0203) - (0)$
$=$ 0.0238"

Operating, Hot & Corroded, Wind, Below Support Point

$t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
$= 60*23.75 / (2*14,100*1.20*1.00 + 0.40*|60|)$
$=$ 0.0421"

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 293,309 / (\pi*23.875^2*14,100*1.20*1.00)$
$=$ 0.0097"

$t_w = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= -9,225.7 / (2*\pi*23.875*14,100*1.20*1.00)$
$=$ -0.0036"

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0.0421 + 0.0097 - (-0.0036)$
$=$ 0.0554"

$t_{wc} = 0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= 0.60*-9,225.7 / (2*\pi*23.875*14,100*1.20*1.00)$
$=$ -0.0022"

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
$= |0.0097 + (-0.0022) - (0.0421)|$
$=$ 0.0346"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}100*1.20*1.00*(0.25 - 0.0097 + (-0.0036)) / (23.75 - 0.40*(0.25 - 0.0097 + (-0.0036)))$
$= 338.59$ psi

Operating, Hot & New, Wind, Below Support Point

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\|P\|)$	(Pressure)
	=	$60*23.6875 / (2*14{,}100*1.20*1.00 + 0.40*\|60\|)$	
	=	0.042"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$292{,}997 / (\pi*23.8438^2*14{,}100*1.20*1.00)$	
	=	0.0097"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$-9{,}617.2 / (2*\pi*23.8438*14{,}100*1.20*1.00)$	
	=	-0.0038"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.042 + 0.0097 - (-0.0038)	
	=	0.0555"	
t_{wc}	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$0.60*-9{,}617.2 / (2*\pi*23.8438*14{,}100*1.20*1.00)$	
	=	-0.0023"	
t_c	=	$\|t_{mc} + t_{wc} - t_{pc}\|$	(total, net tensile)
	=	$\|0.0097 + (-0.0023) - (0.042)\|$	
	=	0.0346"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}100*1.20*1.00*(0.3125 - 0.0097 + (-0.0038)) / (23.6875 - 0.40*(0.3125 - 0.0097 + (-0.0038)))$
$= 429.33$ psi

Hot Shut Down, Corroded, Wind, Below Support Point

t_p	=	0"	(Pressure)
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$293{,}309 / (\pi*23.875^2*14{,}100*1.20*1.00)$	
	=	0.0097"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$-9{,}225.7 / (2*\pi*23.875*14{,}100*1.20*1.00)$	
	=	-0.0036"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0 + 0.0097 - (-0.0036)	
	=	0.0133"	
t_{mc}	=	$M / (\pi*R_m^2*S_c*K_s)$	(bending)

= 293,309 / (π*23.875^2*5,036.69*1.20)
= 0.0271"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-9,225.7 / (2*π*23.875*5,036.69*1.20)
= -0.0061"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0271 + (-0.0061) - (0)
= 0.021"

Hot Shut Down, New, Wind, Below Support Point

t_p = 0" (Pressure)
t_m = M / (π*R_m^{2}*S_t*K_s*E_c) (bending)
= 292,997 / (π*23.8438^2*14,100*1.20*1.00)
= 0.0097"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -9,617.2 / (2*π*23.8438*14,100*1.20*1.00)
= -0.0038"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0097 - (-0.0038)
= 0.0135"

t_{mc} = M / (π*R_m^{2}*S_c*K_s) (bending)
= 292,997 / (π*23.8438^2*5,286.41*1.20)
= 0.0259"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-9,617.2 / (2*π*23.8438*5,286.41*1.20)
= -0.0061"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0259 + (-0.0061) - (0)
= 0.0198"

Empty, Corroded, Wind, Below Support Point

t_p = 0" (Pressure)
t_m = M / (π*R_m^{2}*S_t*K_s*E_c) (bending)
= 102,394 / (π*23.875^2*20,000*1.20*1.00)
= 0.0024"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,069.8 / (2*π*23.875*20,000*1.20*1.00)
= -0.0011"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0024 - (-0.0011)
= 0.0035"

t_{mc} = M / (π*R_m^{2}*S_c*K_s) (bending)
= 102,394 / (π*23.875^2*9,994*1.20)
= 0.0048"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-4,069.8 / (2*π*23.875*9,994*1.20)
= -0.0014"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0048 + (-0.0014) - (0)
= 0.0034"

Empty, New, Wind, Below Support Point

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 102,433 / (π*23.8438^2*20,000*1.20*1.00)
= 0.0024"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,468.1 / (2*π*23.8438*20,000*1.20*1.00)
= -0.0012"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0024 - (-0.0012)
= 0.0036"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 102,433 / (π*23.8438^2*10,848.01*1.20)
= 0.0044"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-4,468.1 / (2*π*23.8438*10,848.01*1.20)
= -0.0014"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0044 + (-0.0014) - (0)
= 0.003"

Vacuum, Wind, Below Support Point

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*20,000*1.20*1.00 + 0.40*|7.4|)
= -0.0037"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 293,309 / (π*23.875^2*20,000*1.20*1.00)
= 0.0068"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -9,225.7 / (2*π*23.875*20,000*1.20*1.00)
= -0.0026"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0037 + 0.0068 - (-0.0026)
= 0.0057"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*9,994*1.20 + 0.40*|7.4|)
= -0.0073"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 293,309 / (π*23.875^2*9,994*1.20)
= 0.0137"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-9,225.7 / (2*π*23.875*9,994*1.20)
= -0.0031"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0137 + (-0.0031) - (-0.0073)
= 0.0179"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*9,994*1.20*(0.25 - 0.0137 - -0.0031) / (23.75 - 0.40*(0.25 - 0.0137 - -0.0031))
= 242.77 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Below Support Point

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 238,175 / (π*23.875^2*14,100*1.00*1.00)
= 0.0094"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -9,225.7 / (2*π*23.875*14,100*1.00*1.00)
= -0.0044"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0094 - (-0.0044)
= 0.0138"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 238,175 / (π*23.875^2*5,036.69*1.00)
= 0.0264"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= -9,225.7 / (2*π*23.875*5,036.69*1.00)
= -0.0122"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0264 + (-0.0122) - (0)
= 0.0142"

Operating, Hot & Corroded, Seismic, Above Support Point

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*23.75 / (2*14,100*1.20*1.00 + 0.40*|60|)
= 0.0421"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 149,414 / (π*23.875^2*14,100*1.20*1.00)
= 0.0049"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)

= 0.56*15,319.1 / (2*π*23.875*14,100*1.20*1.00)
= 0.0034"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0421 + 0.0049 - (0.0034)
= 0.0437"

t_{wc} = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 1.04*15,319.1 / (2*π*23.875*14,100*1.20*1.00)
= 0.0063"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0049 + (0.0063) - (0.0421)|
= 0.0308"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= 2*14,100*1.20*1.00*(0.25 - 0.0049 + (0.0034)) / (23.75 - 0.40*(0.25 - 0.0049 + (0.0034)))
= 355.45 psi

Operating, Hot & New, Seismic, Above Support Point

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*23.6875 / (2*14,100*1.20*1.00 + 0.40*|60|)
= 0.042"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 152,546 / (π*23.8438²*14,100*1.20*1.00)
= 0.005"

t_w = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*15,624.5 / (2*π*23.8438*14,100*1.20*1.00)
= 0.0034"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.042 + 0.005 - (0.0034)
= 0.0436"

t_{wc} = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 1.04*15,624.5 / (2*π*23.8438*14,100*1.20*1.00)
= 0.0064"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.005 + (0.0064) - (0.042)|
= 0.0305"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= 2*14,100*1.20*1.00*(0.3125 - 0.005 + (0.0034)) / (23.6875 - 0.40*(0.3125 - 0.005 + (0.0034)))
= 446.46 psi

Hot Shut Down, Corroded, Seismic, Above Support Point

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $149,414 / (\pi * 23.875^2 * 14,100 * 1.20 * 1.00)$
= 0.0049"

t_w = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $0.56 * 15,319.1 / (2 * \pi * 23.875 * 14,100 * 1.20 * 1.00)$
= 0.0034"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0049 - (0.0034)
= 0.0016"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $149,414 / (\pi * 23.875^2 * 5,036.69 * 1.20)$
= 0.0138"

t_{wc} = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $1.04 * 15,319.1 / (2 * \pi * 23.875 * 5,036.69 * 1.20)$
= 0.0177"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0138 + (0.0177) - (0)
= 0.0315"

Hot Shut Down, New, Seismic, Above Support Point

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $152,546 / (\pi * 23.8438^2 * 14,100 * 1.20 * 1.00)$
= 0.005"

t_w = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $0.56 * 15,624.5 / (2 * \pi * 23.8438 * 14,100 * 1.20 * 1.00)$
= 0.0034"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.005 - (0.0034)
= 0.0016"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $152,546 / (\pi * 23.8438^2 * 5,286.41 * 1.20)$
= 0.0135"

t_{wc} = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $1.04 * 15,624.5 / (2 * \pi * 23.8438 * 5,286.41 * 1.20)$
= 0.0172"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0135 + (0.0172) - (0)
= 0.0306"

Empty, Corroded, Seismic, Above Support Point

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $181,048 / (\pi * 23.875^2 * 20,000 * 1.20 * 1.00)$
= 0.0042"

t_w = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $0.56 * 15,319.1 / (2 * \pi * 23.875 * 20,000 * 1.20 * 1.00)$
= 0.0024"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0042 - (0.0024)
= 0.0019"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $181,048 / (\pi * 23.875^2 * 9,994 * 1.20)$
= 0.0084"

t_{wc} = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $1.04 * 15,319.1 / (2 * \pi * 23.875 * 9,994 * 1.20)$
= 0.0089"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0084 + (0.0089) - (0)
= 0.0173"

Empty, New, Seismic, Above Support Point

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $183,975 / (\pi * 23.8438^2 * 20,000 * 1.20 * 1.00)$
= 0.0043"

t_w = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $0.56 * 15,624.5 / (2 * \pi * 23.8438 * 20,000 * 1.20 * 1.00)$
= 0.0024"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0043 - (0.0024)
= 0.0019"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $183,975 / (\pi * 23.8438^2 * 10,848.01 * 1.20)$
= 0.0079"

t_{wc} = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $1.04 * 15,624.5 / (2 * \pi * 23.8438 * 10,848.01 * 1.20)$
= 0.0084"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0079 + (0.0084) - (0)
= 0.0163"

Vacuum, Seismic, Above Support Point

t_p = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*9,994*1.20 + 0.40*|7.4|)
= -0.0073"

t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 149,414 / (π*23.875^2*9,994*1.20)
= 0.007"

t_w = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*15,319.1 / (2*π*23.875*9,994*1.20)
= 0.0047"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |-0.0073 + 0.007 - (0.0047)|
= 0.0051"

t_{wc} = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 1.04*15,319.1 / (2*π*23.875*9,994*1.20)
= 0.0089"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.007 + (0.0089) - (-0.0073)
= 0.0232"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*9,994*1.20*(0.25 - 0.007 - 0.0089) / (23.75 - 0.40*(0.25 - 0.007 - 0.0089))
= 237.41 psi

Operating, Hot & Corroded, Seismic, Below Support Point

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*23.75 / (2*14,100*1.20*1.00 + 0.40*|60|)
= 0.0421"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 448,252 / (π*23.875^2*14,100*1.20*1.00)
= 0.0148"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-9,225.7 / (2*π*23.875*14,100*1.20*1.00)
= -0.0038"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0421 + 0.0148 - (-0.0038)
= 0.0607"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 0.56*-9,225.7 / (2*π*23.875*14,100*1.20*1.00)
= -0.002"

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)

= |0.0148 + (-0.002) - (0.0421)|
= 0.0293"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*1.00*(0.25 - 0.0148 + (-0.0038)) / (23.75 - 0.40*(0.25 - 0.0148 + (-0.0038)))
= 331.01 psi

Operating, Hot & New, Seismic, Below Support Point

t_p	=	P*R / (2*S_t*K_s*E_c + 0.40*|P|)	(Pressure)
	=	60*23.6875 / (2*14,100*1.20*1.00 + 0.40*|60|)	
	=	0.042"	
t_m	=	M / (π*R_m^2*S_t*K_s*E_c)	(bending)
	=	452,535 / (π*23.8438^2*14,100*1.20*1.00)	
	=	0.015"	
t_w	=	(1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c)	(Weight)
	=	1.04*-9,617.2 / (2*π*23.8438*14,100*1.20*1.00)	
	=	-0.004"	
t_t	=	t_p + t_m - t_w	(total required, tensile)
	=	0.042 + 0.015 - (-0.004)	
	=	0.0609"	
t_{wc}	=	(0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c)	(Weight)
	=	0.56*-9,617.2 / (2*π*23.8438*14,100*1.20*1.00)	
	=	-0.0021"	
t_c	=	|t_{mc} + t_{wc} - t_{pc}|	(total, net tensile)
	=	|0.015 + (-0.0021) - (0.042)|	
	=	0.0291"	

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*1.00*(0.3125 - 0.015 + (-0.004)) / (23.6875 - 0.40*(0.3125 - 0.015 + (-0.004)))
= 421.47 psi

Hot Shut Down, Corroded, Seismic, Below Support Point

t_p	=	0"	(Pressure)
t_m	=	M / (π*R_m^2*S_t*K_s*E_c)	(bending)
	=	448,252 / (π*23.875^2*14,100*1.20*1.00)	
	=	0.0148"	
t_w	=	(1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c)	(Weight)
	=	1.04*-9,225.7 / (2*π*23.875*14,100*1.20*1.00)	
	=	-0.0038"	
t_t	=	t_p + t_m - t_w	(total required, tensile)

= 0 + 0.0148 - (-0.0038)
= 0.0186"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 448,252 / (π*23.875^2*5,036.69*1.20)
= 0.0414"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-9,225.7 / (2*π*23.875*5,036.69*1.20)
= -0.0056"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0414 + (-0.0056) - (0)
= 0.0358"

Hot Shut Down, New, Seismic, Below Support Point

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 452,535 / (π*23.8438^2*14,100*1.20*1.00)
= 0.015"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-9,617.2 / (2*π*23.8438*14,100*1.20*1.00)
= -0.004"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.015 - (-0.004)
= 0.0189"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 452,535 / (π*23.8438^2*5,286.41*1.20)
= 0.0399"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-9,617.2 / (2*π*23.8438*5,286.41*1.20)
= -0.0056"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0399 + (-0.0056) - (0)
= 0.0343"

Empty, Corroded, Seismic, Below Support Point

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 95,299 / (π*23.875^2*20,000*1.20*1.00)
= 0.0022"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,069.8 / (2*π*23.875*20,000*1.20*1.00)
= -0.0012"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0022 - (-0.0012)
= 0.0034"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 95,299 / (π*23.875^2*9,994*1.20)
= 0.0044"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,069.8 / (2*π*23.875*9,994*1.20)
= -0.0013"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0044 + (-0.0013) - (0)
= 0.0032"

Empty, New, Seismic, Below Support Point

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 100,192 / (π*23.8438^2*20,000*1.20*1.00)
= 0.0023"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,468.1 / (2*π*23.8438*20,000*1.20*1.00)
= -0.0013"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0023 - (-0.0013)
= 0.0036"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 100,192 / (π*23.8438^2*10,848.01*1.20)
= 0.0043"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,468.1 / (2*π*23.8438*10,848.01*1.20)
= -0.0013"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0043 + (-0.0013) - (0)
= 0.003"

Vacuum, Seismic, Below Support Point

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*20,000*1.20*1.00 + 0.40*|7.4|)
= -0.0037"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 448,252 / (π*23.875^2*20,000*1.20*1.00)
= 0.0104"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-9,225.7 / (2*π*23.875*20,000*1.20*1.00)
= -0.0027"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0037 + 0.0104 - (-0.0027)
= 0.0094"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*9,994*1.20 + 0.40*|7.4|)
= -0.0073"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 448,252 / (π*23.875^2*9,994*1.20)
= 0.0209"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-9,225.7 / (2*π*23.875*9,994*1.20)
= -0.0028"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0209 + (-0.0028) - (-0.0073)
= 0.0254"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*9,994*1.20*(0.25 - 0.0209 - -0.0028) / (23.75 - 0.40*(0.25 - 0.0209 - -0.0028))
= 235.2 psi

Vessel Body Mid Shell

ASME Section VIII Division 1, 2013 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		0.11	7.75	0.385
Test horizontal		2.11	58.3276	1
Dimensions				
Outer Diameter		48"		
Length		30"		
Nominal Thickness		0.5"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		568.98	225.32	
Corroded		498.6	226.52	
Radiography				
Longitudinal seam		Spot UW-11(b) Type 1		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.1827"
Design thickness due to external pressure (t_e)	0.1998"
Design thickness due to combined loadings + corrosion	0.127"
Maximum allowable working pressure (MAWP)	219.97 psi
Maximum allowable pressure (MAP)	357.14 psi
Maximum allowable external pressure (MAEP)	97.82 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 61.26*24 / (20,000*0.85 + 0.4*61.26) =	0.0864"
Stress ratio = t_r*E* / (t_n - c) = 0.0864*0.85 / (0.5 - 0.0625) =	0.1678
Impact test exempt per UHA-51(g) (coincident ratio = 0.1678)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 60.11*24 / (14,100*0.85 + 0.40*60.11) + 0.0625
= 0.1827"

Maximum allowable working pressure, (at 980 ° F) Appendix 1-1

P = $S*E*t / (R_o - 0.40*t) - P_s$
= 14,100*0.85*0.4375 / (24 - 0.40*0.4375) - 0.11
= 219.97 psi

Maximum allowable pressure, (at 70 ° F) Appendix 1-1

P = $S*E*t / (R_o - 0.40*t)$
= 20,000*0.85*0.5 / (24 - 0.40*0.5)
= 357.14 psi

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 72 / 48 = 1.5000
D_o / t = 48 / 0.1373 = 349.6062
From table G: A = 0.000138
From table HA-1: B = 1,940.3189 psi

P_a = $4*B / (3*(D_o / t))$
= 4*1,940.32 / (3*(48 / 0.1373))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t + Corrosion = 0.1373 + 0.0625 = 0.1998"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 72 / 48 = 1.5000
D_o / t = 48 / 0.4375 = 109.7143
From table G: A = 0.000774
From table HA-1: B = 8,049.2353 psi

P_a = 4*B / (3*(D_o / t))
= 4*8,049.24 / (3*(48 / 0.4375))
= 97.82 psi

% Forming strain - UHA-44(a)(2)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.5 / 23.75)*(1 - 23.75 / ∞)
= 1.0526%

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = 0.6*W / (2*π*R_m) + M / (π*R_m^2)
= 0.60*-8,096.5 / (2*π*23.7813) + 195,763 / (π*23.7813^2)
= 77.6708 lb/in
α = P_v / (P_e*D_o)
= 77.6708 / (7.4*48)
= 0.2187
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (72 / 48)^2
= 0.5467
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (4^2 - 1 + 0.5467 + 0.5467*0.2187) / (4^2 - 1 + 0.5467)
= 1.0077

Ratio P_e * P_e ≤ MAEP
(1.0077 * 7.4 = 7.46) ≤ 97.82
Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = (0.6 - 0.14*S_{DS})*W / (2*π*R_m) + M / (π*R_m^2)
= 0.56*-8,096.5 / (2*π*23.7813) + 290,418 / (π*23.7813^2)
= 133.3733 lb/in
α = P_v / (P_e*D_o)
= 133.3733 / (7.4*48)
= 0.3755
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (72 / 48)^2
= 0.5467

Ratio P_e = $(n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
= $(4^2 - 1 + 0.5467 + 0.5467*0.3755) / (4^2 - 1 + 0.5467)$
= 1.0132

Ratio P_e * P_e ≤ MAEP

(1.0132 * 7.4 = 7.5) ≤ 97.82

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	60	14,100	5,593	980	0.0625	Wind	0.0605	0.0437
						Seismic	0.0644	0.0398
Operating, Hot & New	60	14,100	5,711	980	0	Wind	0.0605	0.0436
						Seismic	0.0645	0.0397
Hot Shut Down, Corroded	0	14,100	5,593	980	0.0625	Wind	0.0114	0.0116
						Seismic	0.0153	0.0199
Hot Shut Down, New	0	14,100	5,711	980	0	Wind	0.0115	0.0112
						Seismic	0.0155	0.0195
Empty, Corroded	0	20,000	11,813	70	0.0625	Wind	0.0027	0.0017
						Seismic	0.0027	0.0017
Empty, New	0	20,000	12,142	70	0	Wind	0.0028	0.0016
						Seismic	0.0028	0.0016
Vacuum	-7.4	20,000	11,813	0	0.0625	Wind	0.0038	0.0116
						Seismic	0.0065	0.0156
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,100	5,593	980	0.0625	Weight	0.0129	0.0083

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t)$
= $0.125 / (24 / 0.4375)$
= 0.002279

B = 5,593 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHC} = min(B, S) = 5,593 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = $0.125 / (R_o / t)$
= $0.125 / (24 / 0.5)$
= 0.002604

B = 5,711 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHN} = min(B, S) = 5,711 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (24 / 0.5)
= 0.002604

B = 12,142 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCN} = min(B, S) = 12,142 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (24 / 0.4375)
= 0.002279

B = 11,813 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCC} = min(B, S) = 11,813 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (24 / 0.4375)
= 0.002279

B = 11,813 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cVC} = min(B, S) = 11,813 psi

Operating, Hot & Corroded, Wind, Top Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*23.5625 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0491"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 195,763 / (π*23.7813^2*14,100*1.20*0.85)
= 0.0077"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= -8,096.5 / (2*π*23.7813*14,100*1.20*0.85)
= -0.0038"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0491 + 0.0077 - (-0.0038)
= 0.0605"

t_{wc} = $0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.60*-8,096.5 / (2*π*23.7813*14,100*1.20*0.85)
= -0.0023"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0077 + (-0.0023) - (0.0491)|

= 0.0437"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14,100*1.20*0.85*(0.4375 - 0.0077 + (-0.0038)) / (23.5625 - 0.40*(0.4375 - 0.0077 + (-0.0038)))$
$= 523.92$ psi

Operating, Hot & New, Wind, Top Seam

$t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
$= 60*23.5 / (2*14,100*1.20*0.85 + 0.40*|60|)$
$= 0.049"$

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 195,457 / (\pi*23.75^2*14,100*1.20*0.85)$
$= 0.0077"$

$t_w = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= -8,322.4 / (2*\pi*23.75*14,100*1.20*0.85)$
$= -0.0039"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0.049 + 0.0077 - (-0.0039)$
$= 0.0605"$

$t_{wc} = 0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= 0.60*-8,322.4 / (2*\pi*23.75*14,100*1.20*0.85)$
$= -0.0023"$

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
$= |0.0077 + (-0.0023) - (0.049)|$
$= 0.0436"$

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14,100*1.20*0.85*(0.5 - 0.0077 + (-0.0039)) / (23.5 - 0.40*(0.5 - 0.0077 + (-0.0039)))$
$= 602.88$ psi

Hot Shut Down, Corroded, Wind, Top Seam

$t_p = 0"$ (Pressure)
$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 195,763 / (\pi*23.7813^2*14,100*1.20*0.85)$
$= 0.0077"$

$t_w = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= -8,096.5 / (2*\pi*23.7813*14,100*1.20*0.85)$
$= -0.0038"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0077 - (-0.0038)$
$= 0.0114"$

$t_{mc} = M / (\pi*R_m^2*S_c*K_s)$ (bending)

= 195,763 / (π*23.7813^2*5,592.93*1.20)
= 0.0164"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-8,096.5 / (2*π*23.7813*5,592.93*1.20)
= -0.0048"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0164 + (-0.0048) - (0)
= 0.0116"

Hot Shut Down, New, Wind, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 195,457 / (π*23.75^2*14,100*1.20*0.85)
= 0.0077"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -8,322.4 / (2*π*23.75*14,100*1.20*0.85)
= -0.0039"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0077 - (-0.0039)
= 0.0115"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 195,457 / (π*23.75^2*5,711.25*1.20)
= 0.0161"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-8,322.4 / (2*π*23.75*5,711.25*1.20)
= -0.0049"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0161 + (-0.0049) - (0)
= 0.0112"

Empty, Corroded, Wind, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 63,997 / (π*23.7813^2*20,000*1.20*0.85)
= 0.0018"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -2,949.1 / (2*π*23.7813*20,000*1.20*0.85)
= -0.001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0018 - (-0.001)
= 0.0027"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 63,997 / (π*23.7813^2*11,812.64*1.20)
= 0.0025"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-2,949.1 / (2*π*23.7813*11,812.64*1.20)
= -0.0008"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0025 + (-0.0008) - (0)
= 0.0017"

Empty, New, Wind, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 64,035 / (π*23.75^2*20,000*1.20*0.85)
= 0.0018"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -3,181.3 / (2*π*23.75*20,000*1.20*0.85)
= -0.001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0018 - (-0.001)
= 0.0028"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 64,035 / (π*23.75^2*12,141.51*1.20)
= 0.0025"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-3,181.3 / (2*π*23.75*12,141.51*1.20)
= -0.0009"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0025 + (-0.0009) - (0)
= 0.0016"

Vacuum, Wind, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*23.5625 / (2*20,000*1.20*0.85 + 0.40*|7.4|)
= -0.0043"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 195,763 / (π*23.7813^2*20,000*1.20*0.85)
= 0.0054"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -8,096.5 / (2*π*23.7813*20,000*1.20*0.85)
= -0.0027"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0043 + 0.0054 - (-0.0027)
= 0.0038"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*23.5625 / (2*11,812.64*1.20 + 0.40*|7.4|)
= -0.0061"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 195,763 / (π*23.7813^2*11,812.64*1.20)
= 0.0078"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-8,096.5 / (2*π*23.7813*11,812.64*1.20)
= -0.0023"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0078 + (-0.0023) - (-0.0061)
= 0.0116"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*11,812.64*1.20*(0.4375 - 0.0078 - -0.0023) / (23.5625 - 0.40*(0.4375 - 0.0078 - -0.0023))
= 523.65 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 179,031 / (π*23.7813^2*14,100*1.00*0.85)
= 0.0084"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -8,096.5 / (2*π*23.7813*14,100*1.00*0.85)
= -0.0045"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0084 - (-0.0045)
= 0.0129"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 179,031 / (π*23.7813^2*5,592.93*1.00)
= 0.018"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= -8,096.5 / (2*π*23.7813*5,592.93*1.00)
= -0.0097"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.018 + (-0.0097) - (0)
= 0.0083"

Operating, Hot & Corroded, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*23.5625 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0491"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 290,418 / (π*23.7813^2*14,100*1.20*0.85)
= 0.0114"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)

= 1.04*-8,096.5 / (2*π*23.7813*14,100*1.20*0.85)
= -0.0039"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0491 + 0.0114 - (-0.0039)
= 0.0644"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*-8,096.5 / (2*π*23.7813*14,100*1.20*0.85)
= -0.0021"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0114 + (-0.0021) - (0.0491)|
= 0.0398"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= 2*14,100*1.20*0.85*(0.4375 - 0.0114 + (-0.0039)) / (23.5625 - 0.40*(0.4375 - 0.0114 + (-0.0039)))
= 519.12 psi

Operating, Hot & New, Seismic, Top Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*23.5 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.049"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 292,003 / (π*23.75²*14,100*1.20*0.85)
= 0.0115"

t_w = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 1.04*-8,322.4 / (2*π*23.75*14,100*1.20*0.85)
= -0.0041"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.049 + 0.0115 - (-0.0041)
= 0.0645"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*-8,322.4 / (2*π*23.75*14,100*1.20*0.85)
= -0.0022"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0115 + (-0.0022) - (0.049)|
= 0.0397"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= 2*14,100*1.20*0.85*(0.5 - 0.0115 + (-0.0041)) / (23.5 - 0.40*(0.5 - 0.0115 + (-0.0041)))
= 597.95 psi

Hot Shut Down, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 290,418 / (π*23.7813^2*14,100*1.20*0.85)
= 0.0114"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-8,096.5 / (2*π*23.7813*14,100*1.20*0.85)
= -0.0039"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0114 - (-0.0039)
= 0.0153"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 290,418 / (π*23.7813^2*5,592.93*1.20)
= 0.0244"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-8,096.5 / (2*π*23.7813*5,592.93*1.20)
= -0.0045"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0244 + (-0.0045) - (0)
= 0.0199"

Hot Shut Down, New, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 292,003 / (π*23.75^2*14,100*1.20*0.85)
= 0.0115"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-8,322.4 / (2*π*23.75*14,100*1.20*0.85)
= -0.0041"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0115 - (-0.0041)
= 0.0155"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 292,003 / (π*23.75^2*5,711.25*1.20)
= 0.024"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-8,322.4 / (2*π*23.75*5,711.25*1.20)
= -0.0045"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.024 + (-0.0045) - (0)
= 0.0195"

Empty, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $61,215 / (\pi * 23.7813^2 * 20,000 * 1.20 * 0.85)$
= 0.0017"

t_w = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $1.04 * -2,949.1 / (2 * \pi * 23.7813 * 20,000 * 1.20 * 0.85)$
= -0.001"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0017 - (-0.001)
= 0.0027"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $61,215 / (\pi * 23.7813^2 * 11,812.64 * 1.20)$
= 0.0024"

t_{wc} = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $0.56 * -2,949.1 / (2 * \pi * 23.7813 * 11,812.64 * 1.20)$
= -0.0008"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0024 + (-0.0008) - (0)
= 0.0017"

Empty, New, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $62,981 / (\pi * 23.75^2 * 20,000 * 1.20 * 0.85)$
= 0.0017"

t_w = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= $1.04 * -3,181.3 / (2 * \pi * 23.75 * 20,000 * 1.20 * 0.85)$
= -0.0011"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0017 - (-0.0011)
= 0.0028"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $62,981 / (\pi * 23.75^2 * 12,141.51 * 1.20)$
= 0.0024"

t_{wc} = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $0.56 * -3,181.3 / (2 * \pi * 23.75 * 12,141.51 * 1.20)$
= -0.0008"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0024 + (-0.0008) - (0)
= 0.0016"

Vacuum, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*23.5625 / (2*20,000*1.20*0.85 + 0.40*|7.4|)
= -0.0043"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 290,418 / (π*23.7813^2*20,000*1.20*0.85)
= 0.008"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-8,096.5 / (2*π*23.7813*20,000*1.20*0.85)
= -0.0028"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0043 + 0.008 - (-0.0028)
= 0.0065"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*23.5625 / (2*11,812.64*1.20 + 0.40*|7.4|)
= -0.0061"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 290,418 / (π*23.7813^2*11,812.64*1.20)
= 0.0115"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-8,096.5 / (2*π*23.7813*11,812.64*1.20)
= -0.0021"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0115 + (-0.0021) - (-0.0061)
= 0.0156"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*11,812.64*1.20*(0.4375 - 0.0115 - -0.0021) / (23.5625 - 0.40*(0.4375 - 0.0115 - -0.0021))
= 518.85 psi

Vessel Body Lower Shell

ASME Section VIII Division 1, 2013 Edition				
Component		Cylinder		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		0.34	24.5	0.385
Test horizontal		2.11	58.5151	1
Dimensions				
Outer Diameter		48"		
Length		16.75"		
Nominal Thickness		0.3125"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		224.29	127.82	
Corroded		179.67	128.49	
Radiography				
Longitudinal seam		Spot UW-11(b) Type 1		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.1831"
Design thickness due to external pressure (t_e)	0.1998"
Design thickness due to combined loadings + corrosion	0.123"
Maximum allowable working pressure (MAWP)	125.03 psi
Maximum allowable pressure (MAP)	222.51 psi
Maximum allowable external pressure (MAEP)	32.51 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 61.5*24 / (20,000*0.85 + 0.4*61.5) =	0.0867"
Stress ratio = t_r*E* / (t_n - c) = 0.0867*0.85 / (0.3125 - 0.0625) =	0.2948
Impact test exempt per UHA-51(g) (coincident ratio = 0.2948)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) Appendix 1-1

t = P*R_o / (S*E + 0.40*P) + Corrosion
= 60.34*24 / (14,100*0.85 + 0.40*60.34) + 0.0625
= 0.1831"

Maximum allowable working pressure, (at 980 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 14,100*0.85*0.25 / (24 - 0.40*0.25) - 0.34
= 125.03 psi

Maximum allowable pressure, (at 70 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t)
= 20,000*0.85*0.3125 / (24 - 0.40*0.3125)
= 222.51 psi

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 72 / 48 = 1.5000
D_o / t = 48 / 0.1373 = 349.6062
From table G: A = 0.000138
From table HA-1: B = 1,940.3189 psi

P_a = 4*B / (3*(D_o / t))
= 4*1,940.32 / (3*(48 / 0.1373))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t + Corrosion = 0.1373 + 0.0625 = 0.1998"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 72 / 48 = 1.5000
D_o / t = 48 / 0.25 = 192.0000
From table G: A = 0.000333
From table HA-1: B = 4,681.5984 psi

P_a = 4*B / (3*(D_o / t))
= 4*4,681.6 / (3*(48 / 0.25))
= 32.51 psi

% Forming strain - UHA-44(a)(2)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.3125 / 23.8438)*(1 - 23.8438 / ∞)
= 0.6553%

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = 0.6*W / (2*π*R_m) + M / (π*R_m^2)
= 0.60*-5,840.6 / (2*π*23.875) + 147,776 / (π*23.875^2)
= 59.1606 lb/in
α = P_v / (P_e*D_o)
= 59.1606 / (7.4*48)
= 0.1666
n = 5
m = 1.23 / (L / D_o)^2
= 1.23 / (72 / 48)^2
= 0.5467
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (5^2 - 1 + 0.5467 + 0.5467*0.1666) / (5^2 - 1 + 0.5467)
= 1.0037

Ratio P_e * P_e ≤ MAEP
(1.0037 * 7.4 = 7.43) ≤ 32.51
Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = (0.6 - 0.14*S_{DS})*W / (2*π*R_m) + M / (π*R_m^2)
= 0.56*-5,840.6 / (2*π*23.875) + 209,475 / (π*23.875^2)
= 95.3591 lb/in
α = P_v / (P_e*D_o)
= 95.3591 / (7.4*48)
= 0.2685
n = 5
m = 1.23 / (L / D_o)^2
= 1.23 / (72 / 48)^2
= 0.5467

Ratio P_e = $(n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
= $(5^2 - 1 + 0.5467 + 0.5467*0.2685) / (5^2 - 1 + 0.5467)$
= 1.006

Ratio P_e * P_e ≤ MAEP

(1.006 * 7.4 = 7.44) ≤ 32.51

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	60	14,100	5,037	980	0.0625	Wind	0.0579	0.0454
						Seismic	0.0605	0.0429
Operating, Hot & New	60	14,100	5,286	980	0	Wind	0.0579	0.0453
						Seismic	0.0604	0.0427
Hot Shut Down, Corroded	0	14,100	5,037	980	0.0625	Wind	0.0084	0.0098
						Seismic	0.011	0.0158
Hot Shut Down, New	0	14,100	5,286	980	0	Wind	0.0085	0.0093
						Seismic	0.0111	0.015
Empty, Corroded	0	20,000	9,994	70	0.0625	Wind	0.0005	0.0003
						Seismic	0.0005	0.0002
Empty, New	0	20,000	10,848	70	0	Wind	0.0006	0.0002
						Seismic	0.0005	0.0002
Vacuum	-7.4	20,000	9,994	0	0.0625	Wind	0.0016	0.0123
						Seismic	0.0034	0.0153
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,100	5,037	980	0.0625	Weight	0.0098	0.008

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t)$
= $0.125 / (24 / 0.25)$
= 0.001302

B = 5,037 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHC} = min(B, S) = 5,037 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = $0.125 / (R_o / t)$
= $0.125 / (24 / 0.3125)$
= 0.001628

B = 5,286 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHN} = min(B, S) = 5,286 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (24 / 0.3125)
= 0.001628

B = 10,848 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCN} = min(B, S) = 10,848 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (24 / 0.25)
= 0.001302

B = 9,994 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCC} = min(B, S) = 9,994 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (24 / 0.25)
= 0.001302

B = 9,994 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cVC} = min(B, S) = 9,994 psi

Operating, Hot & Corroded, Wind, Top Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*23.75 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0495"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 147,776 / (π*23.875^2*14,100*1.20*0.85)
= 0.0057"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= -5,840.6 / (2*π*23.875*14,100*1.20*0.85)
= -0.0027"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0495 + 0.0057 - (-0.0027)
= 0.0579"

t_{wc} = $0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.60*-5,840.6 / (2*π*23.875*14,100*1.20*0.85)
= -0.0016"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0057 + (-0.0016) - (0.0495)|

= 0.0454"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14,100*1.20*0.85*(0.25 - 0.0057 + (-0.0027)) / (23.75 - 0.40*(0.25 - 0.0057 + (-0.0027)))$
$= 293.75$ psi

Operating, Hot & New, Wind, Top Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\|P\|)$	(Pressure)
	=	$60*23.6875 / (2*14,100*1.20*0.85 + 0.40*\|60\|)$	
	=	0.0494"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$147,420 / (\pi*23.8438^2*14,100*1.20*0.85)$	
	=	0.0057"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$-5,955.8 / (2*\pi*23.8438*14,100*1.20*0.85)$	
	=	-0.0028"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.0494 + 0.0057 - (-0.0028)	
	=	0.0579"	
t_{wc}	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$0.60*-5,955.8 / (2*\pi*23.8438*14,100*1.20*0.85)$	
	=	-0.0017"	
t_c	=	$\|t_{mc} + t_{wc} - t_{pc}\|$	(total, net tensile)
	=	$\|0.0057 + (-0.0017) - (0.0494)\|$	
	=	0.0453"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14,100*1.20*0.85*(0.3125 - 0.0057 + (-0.0028)) / (23.6875 - 0.40*(0.3125 - 0.0057 + (-0.0028)))$
$= 371.05$ psi

Hot Shut Down, Corroded, Wind, Top Seam

t_p	=	0"	(Pressure)
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$147,776 / (\pi*23.875^2*14,100*1.20*0.85)$	
	=	0.0057"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$-5,840.6 / (2*\pi*23.875*14,100*1.20*0.85)$	
	=	-0.0027"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0 + 0.0057 - (-0.0027)	

= 0.0084"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 147,776 / (π*23.875^2*5,036.69*1.20)
= 0.0137"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-5,840.6 / (2*π*23.875*5,036.69*1.20)
= -0.0039"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0137 + (-0.0039) - (0)
= 0.0098"

Hot Shut Down, New, Wind, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 147,420 / (π*23.8438^2*14,100*1.20*0.85)
= 0.0057"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -5,955.8 / (2*π*23.8438*14,100*1.20*0.85)
= -0.0028"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0057 - (-0.0028)
= 0.0085"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 147,420 / (π*23.8438^2*5,286.41*1.20)
= 0.013"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-5,955.8 / (2*π*23.8438*5,286.41*1.20)
= -0.0038"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.013 + (-0.0038) - (0)
= 0.0093"

Empty, Corroded, Wind, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 10,638 / (π*23.875^2*20,000*1.20*0.85)
= 0.0003"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -693.2 / (2*π*23.875*20,000*1.20*0.85)
= -0.0002"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0003 - (-0.0002)
= 0.0005"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)

= 10,638 / (π*23.875^2*9,994*1.20)
= 0.0005"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-693.2 / (2*π*23.875*9,994*1.20)
= -0.0002"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0005 + (-0.0002) - (0)
= 0.0003"

Empty, New, Wind, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 10,994 / (π*23.8438^2*20,000*1.20*0.85)
= 0.0003"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -814.7 / (2*π*23.8438*20,000*1.20*0.85)
= -0.0003"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0003 - (-0.0003)
= 0.0006"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 10,994 / (π*23.8438^2*10,848.01*1.20)
= 0.0005"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-814.7 / (2*π*23.8438*10,848.01*1.20)
= -0.0003"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0005 + (-0.0003) - (0)
= 0.0002"

Vacuum, Wind, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*20,000*1.20*0.85 + 0.40*|7.4|)
= -0.0043"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 147,776 / (π*23.875^2*20,000*1.20*0.85)
= 0.004"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -5,840.6 / (2*π*23.875*20,000*1.20*0.85)
= -0.0019"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0043 + 0.004 - (-0.0019)
= 0.0016"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)

= -7.4*23.75 / (2*9,994*1.20 + 0.40*|7.4|)
= -0.0073"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 147,776 / (π*23.875^2*9,994*1.20)
= 0.0069"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-5,840.6 / (2*π*23.875*9,994*1.20)
= -0.0019"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0069 + (-0.0019) - (-0.0073)
= 0.0123"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*9,994*1.20*(0.25 - 0.0069 - -0.0019) / (23.75 - 0.40*(0.25 - 0.0069 - -0.0019))
= 248.52 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 141,569 / (π*23.875^2*14,100*1.00*0.85)
= 0.0066"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -5,840.6 / (2*π*23.875*14,100*1.00*0.85)
= -0.0032"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0066 - (-0.0032)
= 0.0098"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 141,569 / (π*23.875^2*5,036.69*1.00)
= 0.0157"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= -5,840.6 / (2*π*23.875*5,036.69*1.00)
= -0.0077"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0157 + (-0.0077) - (0)
= 0.008"

Operating, Hot & Corroded, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*23.75 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0495"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 209,475 / (π*23.875^2*14,100*1.20*0.85)

= 0.0081"

t_w = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 1.04*-5,840.6 / (2*π*23.875*14,100*1.20*0.85)
= -0.0028"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0495 + 0.0081 - (-0.0028)
= 0.0605"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*-5,840.6 / (2*π*23.875*14,100*1.20*0.85)
= -0.0015"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0081 + (-0.0015) - (0.0495)|
= 0.0429"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= 2*14,100*1.20*0.85*(0.25 - 0.0081 + (-0.0028)) / (23.75 - 0.40*(0.25 - 0.0081 + (-0.0028)))
= 290.67 psi

Operating, Hot & New, Seismic, Top Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 60*23.6875 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0494"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 209,938 / (π*23.8438²*14,100*1.20*0.85)
= 0.0082"

t_w = $(1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 1.04*-5,955.8 / (2*π*23.8438*14,100*1.20*0.85)
= -0.0029"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0494 + 0.0082 - (-0.0029)
= 0.0604"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 0.56*-5,955.8 / (2*π*23.8438*14,100*1.20*0.85)
= -0.0015"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0082 + (-0.0015) - (0.0494)|
= 0.0427"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}100*1.20*0.85*(0.3125 - 0.0082 + (-0.0029)) / (23.6875 - 0.40*(0.3125 - 0.0082 + (-0.0029)))$
$= 367.91$ psi

Hot Shut Down, Corroded, Seismic, Top Seam

$t_p = 0"$ (Pressure)

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 209{,}475 / (\pi*23.875^2*14{,}100*1.20*0.85)$
$= 0.0081"$

$t_w = (1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= 1.04*-5{,}840.6 / (2*\pi*23.875*14{,}100*1.20*0.85)$
$= -0.0028"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0081 - (-0.0028)$
$= 0.011"$

$t_{mc} = M / (\pi*R_m^2*S_c*K_s)$ (bending)
$= 209{,}475 / (\pi*23.875^2*5{,}036.69*1.20)$
$= 0.0194"$

$t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_c*K_s)$ (Weight)
$= 0.56*-5{,}840.6 / (2*\pi*23.875*5{,}036.69*1.20)$
$= -0.0036"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0194 + (-0.0036) - (0)$
$= 0.0158"$

Hot Shut Down, New, Seismic, Top Seam

$t_p = 0"$ (Pressure)

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 209{,}938 / (\pi*23.8438^2*14{,}100*1.20*0.85)$
$= 0.0082"$

$t_w = (1 + 0.14*S_{DS})*W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= 1.04*-5{,}955.8 / (2*\pi*23.8438*14{,}100*1.20*0.85)$
$= -0.0029"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0082 - (-0.0029)$
$= 0.0111"$

$t_{mc} = M / (\pi*R_m^2*S_c*K_s)$ (bending)
$= 209{,}938 / (\pi*23.8438^2*5{,}286.41*1.20)$
$= 0.0185"$

$t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*\pi*R_m*S_c*K_s)$ (Weight)
$= 0.56*-5{,}955.8 / (2*\pi*23.8438*5{,}286.41*1.20)$
$= -0.0035"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= 0.0185 + (-0.0035) - (0)
= 0.015"

Empty, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $8,085 / (\pi * 23.875^2 * 20,000 * 1.20 * 0.85)$
= 0.0002"

t_w = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= 1.04*-693.2 / (2*π*23.875*20,000*1.20*0.85)
= -0.0002"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0002 - (-0.0002)
= 0.0005"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $8,085 / (\pi * 23.875^2 * 9,994 * 1.20)$
= 0.0004"

t_{wc} = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.56*-693.2 / (2*π*23.875*9,994*1.20)
= -0.0002"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0004 + (-0.0002) - (0)
= 0.0002"

Empty, New, Seismic, Top Seam

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= $9,067 / (\pi * 23.8438^2 * 20,000 * 1.20 * 0.85)$
= 0.0002"

t_w = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= 1.04*-814.7 / (2*π*23.8438*20,000*1.20*0.85)
= -0.0003"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0002 - (-0.0003)
= 0.0005"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $9,067 / (\pi * 23.8438^2 * 10,848.01 * 1.20)$
= 0.0004"

t_{wc} = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.56*-814.7 / (2*π*23.8438*10,848.01*1.20)
= -0.0002"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0004 + (-0.0002) - (0)
= 0.0002"

Vacuum, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*20,000*1.20*0.85 + 0.40*|7.4|)
= -0.0043"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 209,475 / (π*23.875^2*20,000*1.20*0.85)
= 0.0057"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-5,840.6 / (2*π*23.875*20,000*1.20*0.85)
= -0.002"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0043 + 0.0057 - (-0.002)
= 0.0034"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*23.75 / (2*9,994*1.20 + 0.40*|7.4|)
= -0.0073"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 209,475 / (π*23.875^2*9,994*1.20)
= 0.0098"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-5,840.6 / (2*π*23.875*9,994*1.20)
= -0.0018"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0098 + (-0.0018) - (-0.0073)
= 0.0153"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*9,994*1.20*(0.25 - 0.0098 - -0.0018) / (23.75 - 0.40*(0.25 - 0.0098 - -0.0018))
= 245.45 psi

Vessel Cone Upper Stiffening Ring

ASME Section VIII Division 1, 2013 Edition	
Attached to	Vessel Body Lower Shell
Ring type	Flat bar
Description	3/8x4 Flat Bar
Material	SA-240 304 (II-D p. 94, ln. 8)
External design pressure	7.4 psi
External design temperature	0° F
Corrosion allowance	0"
Distance from ring neutral axis to datum	156.3125"
Distance to previous support	72"
Distance to next support	0.5625"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.25"
Vessel thickness at weld location, new	0.3125"
Vessel corrosion allowance at weld location	0.0625"
Stiffener thickness at weld location	0.375"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	2"
Ring area	1.5 in^2
Ring inertia	2 in^4

External Pressure, (Corroded & at 0° F) UG-29(a)

L / D_o = 72 / 48 = 1.5
D_o / t = 48 / 0.1373 = 349.602
From Table G: A = 1.3806E-04
From Table HA-1: B = 1,940.35 psi

P_a = $4*B / (3*(D_o / t))$
= 4*1,940.35 / (3*(48 / 0.137299))
= 7.4 psi

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*7.4*48 / (0.1373 + 1.5 / 36.2813)
= 1,491 psi

From Table HA-1: A = 0.00010608 (ring, 0° F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[48^2 * 36.2813 * (0.1373 + 1.5 / 36.2813) * 0.00010608] / 10.9$
= 0.1453 in^4

I' for the composite corroded shell-ring-cone cross section is 5.7035 in^4

As $I' >= I_s'$ a 3/8x4 Flat Bar stiffener is adequate for an external pressure of 7.4 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.25 in is adequate per UG-30(f)(1).

Radial pressure load, $P * L_s$ = 7.4*36.2813 = 268.48 lb_f/in
Radial shear load, V = 0.01*P*L_s*D_o = 0.01*7.4*36.2813*48 = 128.87 lb_f
First moment of area, Q = 1.03*1.1422 = 1.1721 in^3

Weld shear flow, q = V*Q / I' = 26.4848 lb_f/in
Combined weld load, f_w = Sqr(268.4813^2 + 26.4848^2) = 269.78 lb_f/in

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*20,000 = 11,000 psi

Fillet weld size required to resist radial pressure and shear

t_w = $f_w * (d_{weld\ segment} + d_{toe}) / (S_w * d_{weld\ total})$ + corrosion
= 269.78*(1 + 0) / (11,000*2) + 0
= 0.0123 in

The fillet weld size of 0.25 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 0° F) UG-29(a)

L / D_o = 72 / 48 = 1.5
D_o / t = 48 / 0.25 = 192
From Table G: A = 3.3337E-04
From Table HA-1: B = 4,681.6 psi

P_a = 4*B / (3*(D_o / t))
= 4*4,681.6 / (3*(48 / 0.25))
= 32.51 psi

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*32.51*48 / (0.25 + 1.5 / 36.2813)
= 4,017 psi

From Table HA-1: A = 0.00028602 (ring, 0° F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[48^2 * 36.2813 * (0.25 + 1.5 / 36.2813) * 0.00028602] / 10.9$
= 0.6391 in^4

I' for the composite corroded shell-ring-cone cross section is 5.7035 in^4

As $I' >= I_s'$ a 3/8x4 Flat Bar stiffener is adequate for an external pressure of 32.51 psi.

Check the stiffener ring attachment welds per UG-30

Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.25 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 32.51*36.2813 = 1{,}179.54$ lb_f/in
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*32.51*36.2813*48 = 566.18$ lb_f
First moment of area, $Q = 1.03*1.1422 = 1.1721$ in^3

Weld shear flow, $q = V*Q / I' = 116.3579$ lb_f/in
Combined weld load, $f_w = Sqr(1{,}179.5411^2 + 116.3579^2) = 1{,}185.27$ lb_f/in

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*20{,}000 = 11{,}000$ psi

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{\text{weld segment}} + d_{\text{toe}}) / (S_w*d_{\text{weld total}}) + \text{corrosion}$$
$$= 1{,}185.27*(1 + 0) / (11{,}000*2) + 0$$
$$= 0.0539 \text{ in}$$

The fillet weld size of 0.25 in is adequate to resist radial pressure and shear.

Vessel Body Cone

ASME Section VIII Division 1, 2013 Edition				
Component		Cone		
Material		SA-240 304 (II-D p. 94, ln. 8)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating	**Large**	0.34	24.5	0.385
	Small	0.77	55.0625	
Test horizontal	**Large**	2.11	58.4668	1
	Small	1.47	40.8418	
Dimensions				
Outer Diameter	**Large**	48"		
	Small	12.75"		
Length		30.5625"		
Nominal Thickness		0.3125"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		301.48	102.13	
Corroded		241.76	103.02	
Radiography				
Longitudinal seam		Spot UW-11(b) Type 1		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	Hot Shut Down, Corroded
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.2017"
Design thickness due to external pressure (t_e)	0.1559"
Design thickness due to combined loadings + corrosion	0.2335"
Maximum allowable working pressure (MAWP)	89.28 psi
Maximum allowable pressure (MAP)	192.62 psi
Maximum allowable external pressure (MAEP)	55.62 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 61.5*48 / (2*0.8663*(20,000*0.85 + 0.4*61.5)) =	0.1001"
Stress ratio = t_r*E* / (t_n - c) = 0.1001*0.85 / (0.3125 - 0.0625) =	0.3403
Impact test exempt per UHA-51(g) (coincident ratio = 0.3403)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) App 1-4(e) (Large End)

t = $P*D_o$ / (2*cos(α)*(S*E + 0.40*P)) + Corrosion
= 60.34*48 / (2*cos(29.9715)*(14,100*0.85 + 0.40*60.34)) + 0.0625
= 0.2017"
Small End design thickness (t = 0.0997") does not govern.

Maximum allowable working pressure, (Corroded at 980 ° F) App 1-4(e) (Large End)

P = $2*S*E*t*\cos(\alpha) / (D_o - 0.80*t*\cos(\alpha)) - P_s$
= 2*14,100*0.85*0.25*cos(29.9715) / (48 - 0.80*0.25*cos(29.9715)) - 0.34
= 108.2 psi

Small End MAWP (411.99 psi) does not govern.

Maximum allowable pressure, (New at 70 ° F) App 1-4(e) (Large End)

P = $2*S*E*t*\cos(\alpha) / (D_o - 0.80*t*\cos(\alpha))$
= 2*20,000*0.85*0.3125*cos(29.9715) / (48 - 0.80*0.3125*cos(29.9715))
= 192.62 psi

Small End MAP (734.37 psi) does not govern.

External Pressure, (Corroded & at 0 ° F) UG-33(f)

D_L = 48"
L_e = $(L_c / 2)*(1 + D_s / D_L)$

= (30.5625 / 2)*(1 + 12.75 / 48)
= 19.3403"

t_e = t*cos(α) = 0.0934*cos(29.9715) = 0.0809"
L_e / D_L = 19.3403 / 48 = 0.4029
D_L / t_e = 48 / 0.0809 = 593.0879
From table G: A = 0.000234
From table HA-1: B = 3,291.6516 psi

P_a = 4*B / (3*(D_L / t_e))
= 4*3,291.65 / (3*(48 / 0.0809))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t_e / cos(α) + Corrosion = 0.0809 / cos(29.9715) + 0.0625 = 0.1559"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-33(f)

t_e = t*cos(α) = 0.25*cos(29.9715) = 0.2166"
L_e / D_L = 19.3403 / 48 = 0.4029
D_L / t_e = 48 / 0.2166 = 221.639
From table G: A = 0.001080
From table HA-1: B = 9,245.8533 psi

P_a = 4*B / (3*(D_L / t_e))
= 4*9,245.85 / (3*(48 / 0.2166))
= 55.62 psi

% Forming strain - UHA-44(a)(2)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.3607 / 6.1946)*(1 - 6.1946 / ∞)
= 2.9117%

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = [0.6*W / (2*π*R_m) + M / (π*R_m^2)] / cos(α)
= [0.60*-5,462.7 / (2*π*23.8557) + 131,983 / (π*23.8557^2)] / cos(29.9715)
= 59.9752 lb/in
α = P_v / (P_e*D_o)
= 59.9752 / (7.4*48)
= 0.1688
n = 8
m = 1.23 / (L / D_o)^2
= 1.23 / (19.3403 / 48)^2
= 7.5763
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (8^2 - 1 + 7.5763 + 7.5763*0.1688) / (8^2 - 1 + 7.5763)
= 1.0181

Ratio P_e * P_e ≤ MAEP
(1.0181 * 7.4 = 7.53) ≤ 55.62
Transition design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = $[(0.6 - 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m^2)] / \cos(\alpha)$
= $[0.56*-5{,}462.7 / (2*\pi*23.8557) + 176{,}761 / (\pi*23.8557^2)] / \cos(29.9715)$
= 90.7719 lb/in
α = $P_v / (P_e*D_o)$
= 90.7719 / (7.4*48)
= 0.2556
n = 8
m = $1.23 / (L / D_o)^2$
= $1.23 / (19.3403 / 48)^2$
= 7.5763
Ratio P_e = $(n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
= $(8^2 - 1 + 7.5763 + 7.5763*0.2556) / (8^2 - 1 + 7.5763)$
= 1.0274
Ratio P_e * P_e ≤ MAEP
(1.0274 * 7.4 = 7.6) ≤ 55.62
Transition design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads									
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Location	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c						
Operating, Hot & Corroded	60	14,100	4,865	980	0.0625	Top	Wind	0.0659	0.0529
							Seismic	0.068	0.0507
						Bottom	Wind	0.0887	0.111
							Seismic	0.0984	0.1349
Operating, Hot & New	60	14,100	5,134	980	0	Top	Wind	0.0658	0.0527
							Seismic	0.0679	0.0505
						Bottom	Wind	0.0894	0.1073
							Seismic	0.0992	0.1303
Hot Shut Down, Corroded	0	14,100	4,865	980	0.0625	Top	Wind	0.0089	0.0103
							Seismic	0.011	0.0155
						Bottom	Wind	0.0741	0.1471
							Seismic	0.0838	0.171
Hot Shut Down, New	0	14,100	5,134	980	0	Top	Wind	0.0089	0.0097
							Seismic	0.0111	0.0148
						Bottom	Wind	0.0749	0.141
							Seismic	0.0848	0.1641
Empty, Corroded	0	20,000	9,415	70	0.0625	Top	Wind	0.0002	0
							Seismic	0.0002	0
						Bottom	Wind	0.0002	0.0001
							Seismic	0.0002	0.0001
Empty, New	0	20,000	10,330	70	0	Top	Wind	0.0002	0
							Seismic	0.0002	0
						Bottom	Wind	0.0002	0
							Seismic	0.0002	0.0001
Vacuum	-7.4	20,000	9,415	0	0.0625	Top	Wind	0.0013	0.0143

							Seismic	0.0028	0.017
						Bottom	Wind	0.0509	0.0783
							Seismic	0.0578	0.0907
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,100	4,865	980	0.0625	Top	Weight	0.0105	0.0085
						Bottom	Weight	0.0887	0.1655

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t_e)$
= 0.125 / (24 / 0.2166)
= 0.001128
B = 4,865 psi
S = 14,100 / 1.00 = 14,100 psi
S_{cHC} = min(B, S) = 4,865 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = $0.125 / (R_o / t_e)$
= 0.125 / (24 / 0.2707)
= 0.001410
B = 5,134 psi
S = 14,100 / 1.00 = 14,100 psi
S_{cHN} = min(B, S) = 5,134 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = $0.125 / (R_o / t_e)$
= 0.125 / (24 / 0.2707)
= 0.001410
B = 10,330 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCN} = min(B, S) = 10,330 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = $0.125 / (R_o / t_e)$
= 0.125 / (24 / 0.2166)
= 0.001128
B = 9,415 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCC} = min(B, S) = 9,415 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = $0.125 / (R_o / t_e)$
= 0.125 / (24 / 0.2166)
= 0.001128
B = 9,415 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cVC} = min(B, S) = 9,415 psi

Operating, Hot & Corroded, Wind, Top Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*23.7114 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(29.9715)]
= 0.057"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $131,983 / [(\pi*23.8557^2*14,100*1.20*0.85)*\cos(29.9715)]$
= 0.0059"

t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= -5,462.7 / [(2*π*23.8557*14,100*1.20*0.85)*cos(29.9715)]
= -0.0029"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.057 + 0.0059 - (-0.0029)
= 0.0659"

t_{wc} = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.60*-5,462.7 / [(2*π*23.8557*14,100*1.20*0.85)*cos(29.9715)]
= -0.0018"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0059 + (-0.0018) - (0.057)|
= 0.0529"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.25 - 0.0059 + (-0.0029)) / ((23.7114 - 0.40*(0.25 - 0.0059 + (-0.0029)))*cos(29.9715))
= 339.07 psi

Operating, Hot & New, Wind, Top Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*23.6393 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(29.9715)]
= 0.0569"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 131,983 / [(π*23.8196²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0059"

t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= -5,523 / [(2*π*23.8196*14,100*1.20*0.85)*cos(29.9715)]
= -0.003"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0569 + 0.0059 - (-0.003)
= 0.0658"

t_{wc} = $0.6*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.60*-5,523 / [(2*π*23.8196*14,100*1.20*0.85)*cos(29.9715)]
= -0.0018"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0059 + (-0.0018) - (0.0569)|
= 0.0527"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.3125 - 0.0059 + (-0.003)) / ((23.6393 - 0.40*(0.3125 - 0.0059 + (-0.003)))*cos(29.9715))
= 428.64 psi

Hot Shut Down, Corroded, Wind, Top Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 131,983 / [(π*23.8557²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0059"

t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= -5,462.7 / [(2*π*23.8557*14,100*1.20*0.85)*cos(29.9715)]
= -0.0029"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0059 - (-0.0029)
= 0.0089"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= 131,983 / [(π*23.8557²*4,865.13*1.20)*cos(29.9715)]
= 0.0146"

t_{wc} = $0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= 0.60*-5,462.7 / [(2*π*23.8557*4,865.13*1.20)*cos(29.9715)]
= -0.0043"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0146 + (-0.0043) - (0)
= 0.0103"

Hot Shut Down, New, Wind, Top Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 131,983 / [(π*23.8196²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0059"

t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= -5,523 / [(2*π*23.8196*14,100*1.20*0.85)*cos(29.9715)]
= -0.003"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0059 - (-0.003)
= 0.0089"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= 131,983 / [(π*23.8196²*5,134.4*1.20)*cos(29.9715)]
= 0.0139"

t_{wc} = $0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= 0.60*-5,523 / [(2*π*23.8196*5,134.4*1.20)*cos(29.9715)]
= -0.0041"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0139 + (-0.0041) - (0)
= 0.0097"

Empty, Corroded, Wind, Top Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 2,733 / [(π*23.8557²*20,000*1.20*0.85)*cos(29.9715)]
= 0.0001"

t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= -315.2 / [(2*π*23.8557*20,000*1.20*0.85)*cos(29.9715)]
= -0.0001"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

= 2,733 / [(π*23.8557²*9,414.59*1.20)*cos(29.9715)]
= 0.0002"

t_{wc} = 0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)] (Weight)
= 0.60*-315.2 / [(2*π*23.8557*9,414.59*1.20)*cos(29.9715)]
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0002 + (-0.0001) - (0)
= 0"

Empty, New, Wind, Top Seam

t_p = 0" (Pressure)

t_m = M / [(π*R_m²*S_t*K_s*E_c)*cos(α)] (bending)
= 2,733 / [(π*23.8196²*20,000*1.20*0.85)*cos(29.9715)]
= 0.0001"

t_w = W / [(2*π*R_m*S_t*K_s*E_c)*cos(α)] (Weight)
= -381.9 / [(2*π*23.8196*20,000*1.20*0.85)*cos(29.9715)]
= -0.0001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = M / [(π*R_m²*S_c*K_s)*cos(α)] (bending)
= 2,733 / [(π*23.8196²*10,330.46*1.20)*cos(29.9715)]
= 0.0001"

t_{wc} = 0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)] (Weight)
= 0.60*-381.9 / [(2*π*23.8196*10,330.46*1.20)*cos(29.9715)]
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Vacuum, Wind, Top Seam

t_p = P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*cos(α)] (Pressure)
= -7.4*23.7114 / [(2*20,000*1.20*0.85 + 0.40*|7.4|)*cos(29.9715)]
= -0.005"

t_m = M / [(π*R_m²*S_t*K_s*E_c)*cos(α)] (bending)
= 131,983 / [(π*23.8557²*20,000*1.20*0.85)*cos(29.9715)]
= 0.0042"

t_w = W / [(2*π*R_m*S_t*K_s*E_c)*cos(α)] (Weight)
= -5,462.7 / [(2*π*23.8557*20,000*1.20*0.85)*cos(29.9715)]
= -0.0021"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.005 + 0.0042 - (-0.0021)
= 0.0013"

t_{pc} = P*R / [(2*S_c*K_s + 0.40*|P|)*cos(α)] (Pressure)
= -7.4*23.7114 / [(2*9,414.59*1.20 + 0.40*|7.4|)*cos(29.9715)]
= -0.009"

t_{mc} = M / [(π*R_m²*S_c*K_s)*cos(α)] (bending)
= 131,983 / [(π*23.8557²*9,414.59*1.20)*cos(29.9715)]
= 0.0075"

t_{wc} = 0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)] (Weight)

= 0.60*-5,462.7 / [(2*π*23.8557*9,414.59*1.20)*cos(29.9715)]
= -0.0022"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0075 + (-0.0022) - (-0.009)
= 0.0143"

Maximum Allowable External Pressure, Longitudinal Stress

P = $2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$
= 2*9,414.59*1.20*(0.25 - 0.0075 - -0.0022) / ((23.7114 - 0.40*(0.25 - 0.0075 - -0.0022))*cos(29.9715))
= 270.28 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Top Seam

t_p = 0" (Pressure)
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 129,250 / [(π*23.8557²*14,100*1.00*0.85)*cos(29.9715)]
= 0.007"
t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= -5,462.7 / [(2*π*23.8557*14,100*1.00*0.85)*cos(29.9715)]
= -0.0035"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.007 - (-0.0035)
= 0.0105"
t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= 129,250 / [(π*23.8557²*4,865.13*1.00)*cos(29.9715)]
= 0.0172"
t_{wc} = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= -5,462.7 / [(2*π*23.8557*4,865.13*1.00)*cos(29.9715)]
= -0.0086"
t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0172 + (-0.0086) - (0)
= 0.0085"

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*6.0864 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(29.9715)]
= 0.0146"
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 98,894 / [(π*6.2307²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0651"
t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= -4,378.5 / [(2*π*6.2307*14,100*1.20*0.85)*cos(29.9715)]
= -0.009"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0146 + 0.0651 - (-0.009)
= 0.0887"
t_{pc} = $P*R / [(2*S_c*K_s + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*6.0864 / [(2*4,865.13*1.20 + 0.40*|60|)*cos(29.9715)]
= 0.036"
t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

= 98,894 / [(π*6.2307²*4,865.13*1.20)*cos(29.9715)]
= 0.1603"

t_{wc} = 0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)] (Weight)
= 0.60*-4,378.5 / [(2*π*6.2307*4,865.13*1.20)*cos(29.9715)]
= -0.0133"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1603 + (-0.0133) - (0.036)
= 0.111"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*cos(α))
= 2*14,100*1.20*0.85*(0.25 - 0.0651 + (-0.009)) / ((6.0864 - 0.40*(0.25 - 0.0651 + (-0.009)))*cos(29.9715))
= 971.06 psi

Operating, Hot & New, Wind, Bottom Seam

t_p = P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*cos(α)] (Pressure)
= 60*6.0143 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(29.9715)]
= 0.0145"

t_m = M / [(π*R_m²*S_t*K_s*E_c)*cos(α)] (bending)
= 98,894 / [(π*6.1946²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0658"

t_w = W / [(2*π*R_m*S_t*K_s*E_c)*cos(α)] (Weight)
= -4,383.2 / [(2*π*6.1946*14,100*1.20*0.85)*cos(29.9715)]
= -0.009"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0145 + 0.0658 - (-0.009)
= 0.0894"

t_{pc} = P*R / [(2*S_c*K_s + 0.40*|P|)*cos(α)] (Pressure)
= 60*6.0143 / [(2*5,134.4*1.20 + 0.40*|60|)*cos(29.9715)]
= 0.0337"

t_{mc} = M / [(π*R_m²*S_c*K_s)*cos(α)] (bending)
= 98,894 / [(π*6.1946²*5,134.4*1.20)*cos(29.9715)]
= 0.1537"

t_{wc} = 0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)] (Weight)
= 0.60*-4,383.2 / [(2*π*6.1946*5,134.4*1.20)*cos(29.9715)]
= -0.0127"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1537 + (-0.0127) - (0.0337)
= 0.1073"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*cos(α))
= 2*14,100*1.20*0.85*(0.3125 - 0.0658 + (-0.009)) / ((6.0143 - 0.40*(0.3125 - 0.0658 + (-0.009)))*cos(29.9715))
= 1,332.93 psi

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = M / [(π*R_m²*S_t*K_s*E_c)*cos(α)] (bending)
= 98,894 / [(π*6.2307²*14,100*1.20*0.85)*cos(29.9715)]

$= 0.0651"$

$t_w = W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)

$= -4,378.5 / [(2*\pi*6.2307*14,100*1.20*0.85)*\cos(29.9715)]$

$= -0.009"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0651 - (-0.009)$

$= 0.0741"$

$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 98,894 / [(\pi*6.2307^2*4,865.13*1.20)*\cos(29.9715)]$

$= 0.1603"$

$t_{wc} = 0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 0.60*-4,378.5 / [(2*\pi*6.2307*4,865.13*1.20)*\cos(29.9715)]$

$= -0.0133"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.1603 + (-0.0133) - (0)$

$= 0.1471"$

Hot Shut Down, New, Wind, Bottom Seam

$t_p = 0"$ (Pressure)

$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)

$= 98,894 / [(\pi*6.1946^2*14,100*1.20*0.85)*\cos(29.9715)]$

$= 0.0658"$

$t_w = W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)

$= -4,383.2 / [(2*\pi*6.1946*14,100*1.20*0.85)*\cos(29.9715)]$

$= -0.009"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0658 - (-0.009)$

$= 0.0749"$

$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 98,894 / [(\pi*6.1946^2*5,134.4*1.20)*\cos(29.9715)]$

$= 0.1537"$

$t_{wc} = 0.6*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 0.60*-4,383.2 / [(2*\pi*6.1946*5,134.4*1.20)*\cos(29.9715)]$

$= -0.0127"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.1537 + (-0.0127) - (0)$

$= 0.141"$

Empty, Corroded, Wind, Bottom Seam

$t_p = 0"$ (Pressure)

$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)

$= 207 / [(\pi*6.2307^2*20,000*1.20*0.85)*\cos(29.9715)]$

$= 0.0001"$

$t_w = W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)

$= -73.5 / [(2*\pi*6.2307*20,000*1.20*0.85)*\cos(29.9715)]$

$= -0.0001"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0001 - (-0.0001)$

$= 0.0002"$

$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

$= 207 / [(\pi*6.2307^2*9,414.59*1.20)*\cos(29.9715)]$

	=	0.0002"	
t_{wc}	=	0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)]	(Weight)
	=	0.60*-73.5 / [(2*π*6.2307*9,414.59*1.20)*cos(29.9715)]	
	=	-0.0001"	
t_c	=	t_{mc} + t_{wc} - t_{pc}	(total required, compressive)
	=	0.0002 + (-0.0001) - (0)	
	=	0.0001"	

Empty, New, Wind, Bottom Seam

t_p	=	0"	(Pressure)
t_m	=	M / [(π*R_m^2*S_t*K_s*E_c)*cos(α)]	(bending)
	=	207 / [(π*6.1946^2*20,000*1.20*0.85)*cos(29.9715)]	
	=	0.0001"	
t_w	=	W / [(2*π*R_m*S_t*K_s*E_c)*cos(α)]	(Weight)
	=	-80.4 / [(2*π*6.1946*20,000*1.20*0.85)*cos(29.9715)]	
	=	-0.0001"	
t_t	=	t_p + t_m - t_w	(total required, tensile)
	=	0 + 0.0001 - (-0.0001)	
	=	0.0002"	
t_{mc}	=	M / [(π*R_m^2*S_c*K_s)*cos(α)]	(bending)
	=	207 / [(π*6.1946^2*10,330.46*1.20)*cos(29.9715)]	
	=	0.0002"	
t_{wc}	=	0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)]	(Weight)
	=	0.60*-80.4 / [(2*π*6.1946*10,330.46*1.20)*cos(29.9715)]	
	=	-0.0001"	
t_c	=	t_{mc} + t_{wc} - t_{pc}	(total required, compressive)
	=	0.0002 + (-0.0001) - (0)	
	=	0"	

Vacuum, Wind, Bottom Seam

t_p	=	P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*cos(α)]	(Pressure)
	=	-7.4*6.0864 / [(2*20,000*1.20*0.85 + 0.40*|7.4|)*cos(29.9715)]	
	=	-0.0013"	
t_m	=	M / [(π*R_m^2*S_t*K_s*E_c)*cos(α)]	(bending)
	=	98,894 / [(π*6.2307^2*20,000*1.20*0.85)*cos(29.9715)]	
	=	0.0459"	
t_w	=	W / [(2*π*R_m*S_t*K_s*E_c)*cos(α)]	(Weight)
	=	-4,378.5 / [(2*π*6.2307*20,000*1.20*0.85)*cos(29.9715)]	
	=	-0.0063"	
t_t	=	t_p + t_m - t_w	(total required, tensile)
	=	-0.0013 + 0.0459 - (-0.0063)	
	=	0.0509"	
t_{pc}	=	P*R / [(2*S_c*K_s + 0.40*|P|)*cos(α)]	(Pressure)
	=	-7.4*6.0864 / [(2*9,414.59*1.20 + 0.40*|7.4|)*cos(29.9715)]	
	=	-0.0023"	
t_{mc}	=	M / [(π*R_m^2*S_c*K_s)*cos(α)]	(bending)
	=	98,894 / [(π*6.2307^2*9,414.59*1.20)*cos(29.9715)]	
	=	0.0829"	
t_{wc}	=	0.6*W / [(2*π*R_m*S_c*K_s)*cos(α)]	(Weight)
	=	0.60*-4,378.5 / [(2*π*6.2307*9,414.59*1.20)*cos(29.9715)]	

= -0.0069"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= 0.0829 + (-0.0069) - (-0.0023)

= 0.0783"

Maximum Allowable External Pressure, Longitudinal Stress

P = $2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$

= $2*9,414.59*1.20*(0.25 - 0.0829 - -0.0069) / ((6.0864 - 0.40*(0.25 - 0.0829 - -0.0069))*\cos(29.9715))$

= 754.31 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)

= $98,688 / [(\pi*6.2307^2*14,100*1.00*0.85)*\cos(29.9715)]$

= 0.0779"

t_w = $W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)

= $-4,378.5 / [(2*\pi*6.2307*14,100*1.00*0.85)*\cos(29.9715)]$

= -0.0108"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= 0 + 0.0779 - (-0.0108)

= 0.0887"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)

= $98,688 / [(\pi*6.2307^2*4,865.13*1.00)*\cos(29.9715)]$

= 0.192"

t_{wc} = $W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

= $-4,378.5 / [(2*\pi*6.2307*4,865.13*1.00)*\cos(29.9715)]$

= -0.0265"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= 0.192 + (-0.0265) - (0)

= 0.1655"

Operating, Hot & Corroded, Seismic, Top Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)

= $60*23.7114 / [(2*14,100*1.20*0.85 + 0.40*|60|)*\cos(29.9715)]$

= 0.057"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)

= $176,761 / [(\pi*23.8557^2*14,100*1.20*0.85)*\cos(29.9715)]$

= 0.0079"

t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)

= $1.04*-5,462.7 / [(2*\pi*23.8557*14,100*1.20*0.85)*\cos(29.9715)]$

= -0.0031"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= 0.057 + 0.0079 - (-0.0031)

= 0.068"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)

= $0.56*-5,462.7 / [(2*\pi*23.8557*14,100*1.20*0.85)*\cos(29.9715)]$

= -0.0016"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0079 + (-0.0016) - (0.057)|
= 0.0507"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.25 - 0.0079 + (-0.0031)) / ((23.7114 - 0.40*(0.25 - 0.0079 + (-0.0031)))*cos(29.9715))
= 336.05 psi

Operating, Hot & New, Seismic, Top Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= 60*23.6393 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(29.9715)]
= 0.0569"
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 177,197 / [(π*23.8196²*14,100*1.20*0.85)*cos(29.9715)]
= 0.008"
t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 1.04*-5,523 / [(2*π*23.8196*14,100*1.20*0.85)*cos(29.9715)]
= -0.0031"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.0569 + 0.008 - (-0.0031)
= 0.0679"
t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 0.56*-5,523 / [(2*π*23.8196*14,100*1.20*0.85)*cos(29.9715)]
= -0.0016"
t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.008 + (-0.0016) - (0.0569)|
= 0.0505"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
= 2*14,100*1.20*0.85*(0.3125 - 0.008 + (-0.0031)) / ((23.6393 - 0.40*(0.3125 - 0.008 + (-0.0031)))*cos(29.9715))
= 425.56 psi

Hot Shut Down, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= 176,761 / [(π*23.8557²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0079"
t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 1.04*-5,462.7 / [(2*π*23.8557*14,100*1.20*0.85)*cos(29.9715)]
= -0.0031"
t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0079 - (-0.0031)
= 0.011"
t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= 176,761 / [(π*23.8557²*4,865.13*1.20)*cos(29.9715)]
= 0.0195"
t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)

$= 0.56*-5{,}462.7 / [(2*\pi*23.8557*4{,}865.13*1.20)*\cos(29.9715)]$
$= -0.004"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0195 + (-0.004) - (0)$
$= 0.0155"$

Hot Shut Down, New, Seismic, Top Seam

$t_p = 0"$ (Pressure)
$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
$= 177{,}197 / [(\pi*23.8196^2*14{,}100*1.20*0.85)*\cos(29.9715)]$
$= 0.008"$
$t_w = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 1.04*-5{,}523 / [(2*\pi*23.8196*14{,}100*1.20*0.85)*\cos(29.9715)]$
$= -0.0031"$
$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.008 - (-0.0031)$
$= 0.0111"$
$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
$= 177{,}197 / [(\pi*23.8196^2*5{,}134.4*1.20)*\cos(29.9715)]$
$= 0.0186"$
$t_{wc} = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 0.56*-5{,}523 / [(2*\pi*23.8196*5{,}134.4*1.20)*\cos(29.9715)]$
$= -0.0038"$
$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0186 + (-0.0038) - (0)$
$= 0.0148"$

Empty, Corroded, Seismic, Top Seam

$t_p = 0"$ (Pressure)
$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
$= 1{,}647 / [(\pi*23.8557^2*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= 0.0001"$
$t_w = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 1.04*-315.2 / [(2*\pi*23.8557*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= -0.0001"$
$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0001 - (-0.0001)$
$= 0.0002"$
$t_{wc} = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 0.56*-315.2 / [(2*\pi*23.8557*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= -0.0001"$
$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
$= |0.0001 + (-0.0001) - (0)|$
$= 0"$

Empty, New, Seismic, Top Seam

$t_p = 0"$ (Pressure)
$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)

$= 1{,}906 / [(\pi*23.8196^2*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= 0.0001"$

$t_w = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 1.04*-381.9 / [(2*\pi*23.8196*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= -0.0002"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0001 - (-0.0002)$
$= 0.0002"$

$t_{wc} = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 0.56*-381.9 / [(2*\pi*23.8196*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= -0.0001"$

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
$= |0.0001 + (-0.0001) - (0)|$
$= 0"$

Vacuum, Seismic, Top Seam

$t_p = P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
$= -7.4*23.7114 / [(2*20{,}000*1.20*0.85 + 0.40*|7.4|)*\cos(29.9715)]$
$= -0.005"$

$t_m = M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
$= 176{,}761 / [(\pi*23.8557^2*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= 0.0056"$

$t_w = (1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
$= 1.04*-5{,}462.7 / [(2*\pi*23.8557*20{,}000*1.20*0.85)*\cos(29.9715)]$
$= -0.0022"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= -0.005 + 0.0056 - (-0.0022)$
$= 0.0028"$

$t_{pc} = P*R / [(2*S_c*K_s + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
$= -7.4*23.7114 / [(2*9{,}414.59*1.20 + 0.40*|7.4|)*\cos(29.9715)]$
$= -0.009"$

$t_{mc} = M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
$= 176{,}761 / [(\pi*23.8557^2*9{,}414.59*1.20)*\cos(29.9715)]$
$= 0.0101"$

$t_{wc} = (0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
$= 0.56*-5{,}462.7 / [(2*\pi*23.8557*9{,}414.59*1.20)*\cos(29.9715)]$
$= -0.0021"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0101 + (-0.0021) - (-0.009)$
$= 0.017"$

Maximum Allowable External Pressure, Longitudinal Stress

$P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$
$= 2*9{,}414.59*1.20*(0.25 - 0.0101 - -0.0021) / ((23.7114 - 0.40*(0.25 - 0.0101 - -0.0021))*\cos(29.9715))$
$= 267.26$ psi

Operating, Hot & Corroded, Seismic, Bottom Seam

$t_p = P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)

= 60*6.0864 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(29.9715)]
= 0.0146"

t_m = M / [(π*R_m^2*S_t*K_s*E_c)*cos(α)] (bending)
= 113,036 / [(π*6.2307²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0744"

t_w = (1 + 0.14*S_{DS})*W / [(2*π*R_m*S_t*K_s*E_c)*cos(α)] (Weight)
= 1.04*-4,378.5 / [(2*π*6.2307*14,100*1.20*0.85)*cos(29.9715)]
= -0.0094"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0146 + 0.0744 - (-0.0094)
= 0.0984"

t_{pc} = P*R / [(2*S_c*K_s + 0.40*|P|)*cos(α)] (Pressure)
= 60*6.0864 / [(2*4,865.13*1.20 + 0.40*|60|)*cos(29.9715)]
= 0.036"

t_{mc} = M / [(π*R_m^2*S_c*K_s)*cos(α)] (bending)
= 113,036 / [(π*6.2307²*4,865.13*1.20)*cos(29.9715)]
= 0.1833"

t_{wc} = (0.6 - 0.14*S_{DS})*W / [(2*π*R_m*S_c*K_s)*cos(α)] (Weight)
= 0.56*-4,378.5 / [(2*π*6.2307*4,865.13*1.20)*cos(29.9715)]
= -0.0123"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1833 + (-0.0123) - (0.036)
= 0.1349"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*cos(α))
= 2*14,100*1.20*0.85*(0.25 - 0.0744 + (-0.0094)) / ((6.0864 - 0.40*(0.25 - 0.0744 + (-0.0094)))*cos(29.9715))
= 916.88 psi

Operating, Hot & New, Seismic, Bottom Seam

t_p = P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*cos(α)] (Pressure)
= 60*6.0143 / [(2*14,100*1.20*0.85 + 0.40*|60|)*cos(29.9715)]
= 0.0145"

t_m = M / [(π*R_m^2*S_t*K_s*E_c)*cos(α)] (bending)
= 113,118 / [(π*6.1946²*14,100*1.20*0.85)*cos(29.9715)]
= 0.0753"

t_w = (1 + 0.14*S_{DS})*W / [(2*π*R_m*S_t*K_s*E_c)*cos(α)] (Weight)
= 1.04*-4,383.2 / [(2*π*6.1946*14,100*1.20*0.85)*cos(29.9715)]
= -0.0094"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0145 + 0.0753 - (-0.0094)
= 0.0992"

t_{pc} = P*R / [(2*S_c*K_s + 0.40*|P|)*cos(α)] (Pressure)
= 60*6.0143 / [(2*5,134.4*1.20 + 0.40*|60|)*cos(29.9715)]
= 0.0337"

t_{mc} = M / [(π*R_m^2*S_c*K_s)*cos(α)] (bending)
= 113,118 / [(π*6.1946²*5,134.4*1.20)*cos(29.9715)]
= 0.1758"

t_{wc} = (0.6 - 0.14*S_{DS})*W / [(2*π*R_m*S_c*K_s)*cos(α)] (Weight)
= 0.56*-4,383.2 / [(2*π*6.1946*5,134.4*1.20)*cos(29.9715)]
= -0.0117"

t_c = t_{mc} + t_{wc} - t_{pc} (total required,

compressive)

= 0.1758 + (-0.0117) - (0.0337)
= 0.1303"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / ((R - 0.40*(t - t_m + t_w))*\cos(\alpha))$
$= 2*14{,}100*1.20*0.85*(0.3125 - 0.0753 + (-0.0094)) / ((6.0143 - 0.40*(0.3125 - 0.0753 + (-0.0094)))*\cos(29.9715))$
= 1,276.68 psi

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $113{,}036 / [(\pi*6.2307^2*14{,}100*1.20*0.85)*\cos(29.9715)]$
= 0.0744"

t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $1.04*-4{,}378.5 / [(2*\pi*6.2307*14{,}100*1.20*0.85)*\cos(29.9715)]$
= -0.0094"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0744 - (-0.0094)
= 0.0838"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $113{,}036 / [(\pi*6.2307^2*4{,}865.13*1.20)*\cos(29.9715)]$
= 0.1833"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.56*-4{,}378.5 / [(2*\pi*6.2307*4{,}865.13*1.20)*\cos(29.9715)]$
= -0.0123"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.1833 + (-0.0123) - (0)
= 0.171"

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $113{,}118 / [(\pi*6.1946^2*14{,}100*1.20*0.85)*\cos(29.9715)]$
= 0.0753"

t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $1.04*-4{,}383.2 / [(2*\pi*6.1946*14{,}100*1.20*0.85)*\cos(29.9715)]$
= -0.0094"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0753 - (-0.0094)
= 0.0848"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $113{,}118 / [(\pi*6.1946^2*5{,}134.4*1.20)*\cos(29.9715)]$
= 0.1758"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.56*-4{,}383.2 / [(2*\pi*6.1946*5{,}134.4*1.20)*\cos(29.9715)]$
= -0.0117"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.1758 + (-0.0117) - (0)
= 0.1641"

Empty, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $214 / [(\pi*6.2307^2*20{,}000*1.20*0.85)*\cos(29.9715)]$
= 0.0001"

t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $1.04*-73.5 / [(2*\pi*6.2307*20{,}000*1.20*0.85)*\cos(29.9715)]$
= -0.0001"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $214 / [(\pi*6.2307^2*9{,}414.59*1.20)*\cos(29.9715)]$
= 0.0002"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.56*-73.5 / [(2*\pi*6.2307*9{,}414.59*1.20)*\cos(29.9715)]$
= -0.0001"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0002 + (-0.0001) - (0)
= 0.0001"

Empty, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $227 / [(\pi*6.1946^2*20{,}000*1.20*0.85)*\cos(29.9715)]$
= 0.0001"

t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= $1.04*-80.4 / [(2*\pi*6.1946*20{,}000*1.20*0.85)*\cos(29.9715)]$
= -0.0001"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= $227 / [(\pi*6.1946^2*10{,}330.46*1.20)*\cos(29.9715)]$
= 0.0002"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= $0.56*-80.4 / [(2*\pi*6.1946*10{,}330.46*1.20)*\cos(29.9715)]$
= -0.0001"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0002 + (-0.0001) - (0)
= 0.0001"

Vacuum, Seismic, Bottom Seam

t_p = $P*R / [(2*S_t*K_s*E_c + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= $-7.4*6.0864 / [(2*20{,}000*1.20*0.85 + 0.40*|7.4|)*\cos(29.9715)]$
= -0.0013"

t_m = $M / [(\pi*R_m^2*S_t*K_s*E_c)*\cos(\alpha)]$ (bending)
= $113{,}036 / [(\pi*6.2307^2*20{,}000*1.20*0.85)*\cos(29.9715)]$
= 0.0524"

t_w = $(1 + 0.14*S_{DS})*W / [(2*\pi*R_m*S_t*K_s*E_c)*\cos(\alpha)]$ (Weight)
= 1.04*-4,378.5 / [(2*π*6.2307*20,000*1.20*0.85)*cos(29.9715)]
= -0.0066"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= -0.0013 + 0.0524 - (-0.0066)
= 0.0578"

t_{pc} = $P*R / [(2*S_c*K_s + 0.40*|P|)*\cos(\alpha)]$ (Pressure)
= -7.4*6.0864 / [(2*9,414.59*1.20 + 0.40*|7.4|)*cos(29.9715)]
= -0.0023"

t_{mc} = $M / [(\pi*R_m^2*S_c*K_s)*\cos(\alpha)]$ (bending)
= 113,036 / [(π*6.2307²*9,414.59*1.20)*cos(29.9715)]
= 0.0947"

t_{wc} = $(0.6 - 0.14*S_{DS})*W / [(2*\pi*R_m*S_c*K_s)*\cos(\alpha)]$ (Weight)
= 0.56*-4,378.5 / [(2*π*6.2307*9,414.59*1.20)*cos(29.9715)]
= -0.0063"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0947 + (-0.0063) - (-0.0023)
= 0.0907"

Maximum Allowable External Pressure, Longitudinal Stress

P = $2*S_c*K_s*(t - t_{mc} - t_{wc}) / ((R - 0.40*(t - t_{mc} - t_{wc}))*\cos(\alpha))$
= 2*9,414.59*1.20*(0.25 - 0.0947 - -0.0063) / ((6.0864 - 0.40*(0.25 - 0.0947 - -0.0063))*cos(29.9715))
= 700.15 psi

Cone juncture large end calculations, P =89.621 psi (MAWP = 89.28 psi) Appendix 1-5(d)								
Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2) 3/8x4 Flat Bar	Status
Wind Corroded	Yes	No	106.12	1,170.36	0.16	0.29	1.5	OK
Wind New	Yes	No	106.77	1,168.22	0.16	0.68	1.5	OK
Seismic Corroded	Yes	No	132.57	1,196.82	0.17	0.29	1.5	OK
Seismic New	Yes	No	133.56	1,195.01	0.16	0.68	1.5	OK

Cone large end calculations per Appendix 1-5(d)(1), wind + pressure, corroded

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(23.75*0.25)^{0.5}$
$= 4.8734$ in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$f_1 = -W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= --4,862.3 / (\pi*2*23.875) + 12*10,998.6 / (\pi*23.875^2)$
$=$ 106.12 lb_f/in

$P*R_L / 2 = 1,064.24$ lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 89.62 / (14,100*1) = 0.006356$

From table 1-5.1 $\Delta = 25.71°$

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1,064.24 + 106.12$
$=$ 1,170.36 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1,170.36*23.75 / (14,100*1))*(1 - 25.71 / 29.9715)*\tan(29.9715)$
$=$ 0.1616 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.25 - 0.1784)*(23.75*0.25)^{0.5} + (0.25 - 0.2059)*(23.75*0.25 / \cos(29.9715))^{0.5}$
$=$ 0.2898 in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	-25,129	34,537	-21,702	29,827	42,300	42,300	-5,562	-4,349	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	-24,403	35,263	-21,075	30,454	42,300	42,300	988	2,201	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), wind + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - W / (\pi*D)$
$= 4*131,983 / (\pi*47.75^2) - -4,862.3 / (\pi*47.75)$
$= 106.12$ lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*106.1153 / 47.75$
$= 98.51$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (98.51*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ -25,129 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (98.51*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
$=$ 34,537 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
$= 0.3925$ in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 - (98.51 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$
$=$ -5,562 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (98.51*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ -24,403 psi [longitudinal stress, large end, cone outside surface]

Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (98.51*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= 35,263 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (98.51 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= 988 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

$l = - 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= - 4*131,983 / (\pi*47.75^2) - 0.6*-4,862.3 / (\pi*47.75)$
= -54.25 lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*-54.2546 / 47.75$
= 85.08 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (85.08*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
= -21,702 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (85.08*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
= 29,827 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
= 0.3925 in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 - (85.08 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= -4,349 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (85.08*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
= -21,075 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (85.08*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= 30,454 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (85.08 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$

= 2,201 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone large end calculations per Appendix 1-5(d)(1), wind + pressure, new

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(23.6875*0.3125)^{0.5}$
= 5.4415 in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$f_1 = -W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= --4,925.77 / (\pi*2*23.8438) + 12*10,998.6 / (\pi*23.8438^2)$
= 106.77 lb_f/in

$P*R_L / 2$ = 1,061.44 lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 89.62 / (14,100*1) = 0.006356$

From table 1-5.1 Δ = 25.71°

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1,061.44 + 106.77$
= 1,168.22 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1,168.22*23.6875 / (14,100*1))*(1 - 25.71 / 29.9715)*\tan(29.9715)$
= 0.1609 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.1779)*(23.6875*0.3125)^{0.5} + (0.3125 - 0.2054)*(23.6875*0.3125 / \cos(29.9715))^{0.5}$
= 0.6792 in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind New	-17,558	25,080	-15,154	21,645	42,300	42,300	-4,051	-3,055	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind New	-16,978	25,660	-14,653	22,146	42,300	42,300	623	1,619	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), wind + pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - W / (\pi*D)$
$= 4*131,983 / (\pi*47.6875^2) - -4,925.77 / (\pi*47.6875)$
$= 106.77$ lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*106.7747 / 47.6875$
$= 98.58$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (98.58*23.8438 / 0.3125)*(0.5 - 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ -17,558 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (98.58*23.8438 / 0.3125)*(0.5 + 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ 25,080 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.3125)^{0.5})$
$= 0.3511$ in

Equivalent thickness t = 0.3125 + 0.3511 = 0.6636 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 - (98.58 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
$=$ -4,051 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (98.58*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ -16,978 psi [longitudinal stress, large end, cone outside surface]

Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (98.58*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.8438 / 0.3125)^{0.5})$
= 25,660 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 / (0.4709*\cos(29.9715)) - (98.58 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
= 623 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

$l = - 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= - 4*131,983 / (\pi*47.6875^2) - 0.6*-4,925.77 / (\pi*47.6875)$
= -54.17 lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*-54.1682 / 47.6875$
= 85.08 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (85.08*23.8438 / 0.3125)*(0.5 - 0.3245*(23.8438 / 0.3125)^{0.5})$
= -15,154 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (85.08*23.8438 / 0.3125)*(0.5 + 0.3245*(23.8438 / 0.3125)^{0.5})$
= 21,645 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.3125)^{0.5})$
= 0.3511 in

Equivalent thickness t = 0.3125 + 0.3511 = 0.6636 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 - (85.08 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
= -3,055 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (85.08*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.8438 / 0.3125)^{0.5})$
= -14,653 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (85.08*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.8438 / 0.3125)^{0.5})$
= 22,146 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 / (0.4709*\cos(29.9715)) - (85.08 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$

= 1,619 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone large end calculations per Appendix 1-5(d)(1), seismic + pressure, corroded

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(23.75*0.25)^{0.5}$
= 4.8734 in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$f_1 = -(1 + 0.14*S_{DS})*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -(1 + 0.14*0.32)*-4,862.3 / (\pi*2*23.875) + 12*14,730.1 / (\pi*23.875^2)$
= 132.57 lb_f/in

$P*R_L / 2$ = 1,064.24 lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 89.62 / (14,100*1) = 0.006356$

From table 1-5.1 Δ = 25.71°

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1,064.24 + 132.57$
= 1,196.82 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1,196.82*23.75 / (14,100*1))*(1 - 25.71 / 29.9715)*\tan(29.9715)$
= 0.1653 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.25 - 0.1784)*(23.75*0.25)^{0.5} + (0.25 - 0.2059)*(23.75*0.25 / \cos(29.9715))^{0.5}$
= 0.2898 in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-25,694	35,314	-21,137	29,050	42,300	42,300	-5,762	-4,149	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-24,952	36,056	-20,526	29,660	42,300	42,300	788	2,401	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (1 + 0.14*S_{DS})*W / (\pi*D)$
$= 4*176{,}761.3 / (\pi*47.75^2) - (1 + 0.14*0.32)*-4{,}862.3 / (\pi*47.75)$
$= 132.57$ lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*132.5726 / 47.75$
$= 100.73$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (100.73*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ -25,694 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (100.73*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
$=$ 35,314 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
$= 0.3925$ in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 - (100.73 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$
$=$ -5,762 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (100.73*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ -24,952 psi [longitudinal stress, large end, cone outside surface]

Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (100.73*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= 36,056 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (100.73 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= 788 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

$l = - 4*M / (\pi*D^2) - (0.6 - 0.14*S_{DS})*W / (\pi*D)$
$= - 4*176{,}761.3 / (\pi*47.75^2) - (0.6 - 0.14*0.32)*-4{,}862.3 / (\pi*47.75)$
= -80.71 lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*-80.7119 / 47.75$
= 82.86 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (82.86*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
= -21,137 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (82.86*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
= 29,050 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
= 0.3925 in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 - (82.86 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= -4,149 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (82.86*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
= -20,526 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (82.86*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= 29,660 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (82.86 / 89.62)*0.3985*(23.875 / 0.6425)^{0.5})$

= 2,401 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone large end calculations per Appendix 1-5(d)(1), seismic + pressure, new

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(23.6875*0.3125)^{0.5}$
= 5.4415 in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$f_1 = -(1 + 0.14*S_{DS})*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -(1 + 0.14*0.32)*-4{,}925.77 / (\pi*2*23.8438) + 12*14{,}766.4 / (\pi*23.8438^2)$
= 133.56 lb_f/in

$P*R_L / 2$ = 1,061.44 lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 89.62 / (14{,}100*1) = 0.006356$

From table 1-5.1 $\Delta = 25.71°$

As $\Delta < \alpha$ a reinforcement check is required.

$Q_L = P*R_L / 2 + f_1$
$= 1{,}061.44 + 133.56$
= 1,195.01 lb_f/in

$A_{rL} = (k*Q_L*R_L / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}195.01*23.6875 / (14{,}100*1))*(1 - 25.71 / 29.9715)*\tan(29.9715)$
= 0.1646 in^2

$A_{eL} = (t_s - t)*(R_L*t_s)^{0.5} + (t_c - t_r)*(R_L*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.1779)*(23.6875*0.3125)^{0.5} + (0.3125 - 0.2054)*(23.6875*0.3125 / \cos(29.9715))^{0.5}$
= 0.6792 in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic New	-17,959	25,652	-14,754	21,074	42,300	42,300	-4,217	-2,889	21,150

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 89.621 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic New	-17,365	26,245	-14,266	21,561	42,300	42,300	457	1,784	21,150

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (1 + 0.14*S_{DS})*W / (\pi*D)$
$= 4*177,197.1 / (\pi*47.6875^2) - (1 + 0.14*0.32)*-4,925.77 / (\pi*47.6875)$
$= 133.56$ lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*133.5626 / 47.6875$
$= 100.82$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (100.82*23.8438 / 0.3125)*(0.5 - 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ -17,959 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (100.82*23.8438 / 0.3125)*(0.5 + 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ 25,652 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.3125)^{0.5})$
$= 0.3511$ in

Equivalent thickness t = 0.3125 + 0.3511 = 0.6636 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 - (100.82 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
$=$ -4,217 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (100.82*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ -17,365 psi [longitudinal stress, large end, cone outside surface]

Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (100.82*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.8438 / 0.3125)^{0.5})$
= 26,245 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 / (0.4709*\cos(29.9715)) - (100.82 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
= 457 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

$l = - 4*M / (\pi*D^2) - (0.6 - 0.14*S_{DS})*W / (\pi*D)$
$= - 4*177,197.1 / (\pi*47.6875^2) - (0.6 - 0.14*0.32)*-4,925.77 / (\pi*47.6875)$
= -80.96 lb_f/in

$P_e = P + 4*l / D = 89.62 + 4*-80.956 / 47.6875$
= 82.83 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (82.83*23.8438 / 0.3125)*(0.5 - 0.3245*(23.8438 / 0.3125)^{0.5})$
= -14,754 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (82.83*23.8438 / 0.3125)*(0.5 + 0.3245*(23.8438 / 0.3125)^{0.5})$
= 21,074 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.3125)^{0.5})$
= 0.3511 in

Equivalent thickness t = 0.3125 + 0.3511 = 0.6636 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 - (82.83 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
= -2,889 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (82.83*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.8438 / 0.3125)^{0.5})$
= -14,266 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (82.83*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.8438 / 0.3125)^{0.5})$
= 21,561 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (89.62*23.8438 / 0.6636)*(1 / (0.4709*\cos(29.9715)) - (82.83 / 89.62)*0.3425*(23.8438 / 0.6636)^{0.5})$

= 1,784 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone juncture small end calculations, P =90.045 psi (MAWP = 89.28 psi) Appendix 1-5(e)								
Loading	Area check required	U-2(g) analysis required	f_2 (lbf/in)	Q_s (lbf/in)	A_{rs} (in2)	A_{es} (in2)	Ring area (in2)	Status
Wind Corroded	Yes	No	923.77	1,196.72	0.3	0.52	none	OK
Wind New	Yes	No	932.74	1,202.88	0.35	0.38	none	OK
Seismic Corroded	Yes	No	1,045.09	1,318.04	0.33	0.52	none	OK
Seismic New	Yes	No	1,055.95	1,326.08	0.38	0.38	none	OK

Cone small end calculations per Appendix 1-5(e)(1), wind + pressure, corroded

$L_{min} = 1.4*(R_S*t_s)^{0.5}$
$= 1.4*(6.0625*0.3125)^{0.5}$
$= 1.927$ in

The length of the attached cylinder (2.0575 in) ≥ L_{min}.

$f_2 = -W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= --4,289.79 / (\pi*2*6.2188) + 12*8,241.2 / (\pi*6.2188^2)$
$=$ 923.77 lb_f/in

$P*R_s / 2 = 272.95$ lb_f/in

f_2 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 90.05 / (12,000*0.85) = 0.008828$

From table 1-5.2 $\Delta = 8.3°$

As $\Delta < \alpha$ reinforcement is required.

$Q_s = P*R_s / 2 + f_2$
$= 272.95 + 923.77$
$=$ 1,196.72 lb_f/in

$A_{rs} = (k*Q_s*R_s / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1,196.72*6.0625 / (12,000*0.85))*(1 - 8.3 / 29.9715)*\tan(29.9715)$
$=$ 0.2966 in^2

$A_{es} = 0.78*(R_s*t_s)^{0.5}*[(t_s - t) + (t_c - t_r) / \cos(\alpha)]$
$= 0.78*(6.0625*0.3125)^{0.5}*[(0.3125 - 0.0538) + (0.25 - 0.0528) / \cos(29.9715)]$
$=$ 0.5221 in^2

A_{es} >= A_{rs} therefore the small end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cylinder Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Wind Corroded	-6,400	14,104	2,489	-5,485	36,000	36,000	9,167	-1,076	18,000

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cone Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Wind Corroded	-10,461	21,577	4,068	-8,391	42,300	42,300	9,961	-283	21,150

Appendix 1-5(g), U-2(g) small end cone to shell juncture analysis (Bednar 8.6), wind + pressure, corroded

Equivalent pressure windward side, P_e:

$I = 4*M / (\pi*D^2) - W / (\pi*D)$
$= 4*98,894.4 / (\pi*12.4375^2) - -4,289.79 / (\pi*12.4375)$
$= 923.77$ lb_f/in

$P_e = P + 4*I / D = 90.05 + 4*923.7714 / 12.4375$
$= 387.14$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (387.14*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ -6,400 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (387.14*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ 14,104 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.2188 / 0.3125)*(1 + (387.14 / 90.05)*0.2146*(6.2188 / 0.3125)^{0.5})$
$=$ 9,167 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (387.14*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) - 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ -10,461 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (387.14*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) + 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ 21,577 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$

= (90.05*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (387.14 / 90.05)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= 9,961 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

l = - 4*M / (π*D^2) - 0.6*W / (π*D)
= - 4*98,894.4 / (π*12.4375^2) - 0.6*-4,289.79 / (π*12.4375)
= -748.11 lb_f/in

P_e = P + 4*l / D = 90.05 + 4*-748.1112 / 12.4375
= -150.55 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (-150.55*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= 2,489 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (-150.55*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= -5,485 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

σ_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)$^{0.5}$)
= (90.05*6.2188 / 0.3125)*(1 + (-150.55 / 90.05)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -1,076 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (-150.55*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) - 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= 4,068 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (-150.55*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) + 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= -8,391 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) + (P_e / P)*Y*(R / t)$^{0.5}$)
= (90.05*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (-150.55 / 90.05)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -283 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone small end calculations per Appendix 1-5(e)(2), wind + pressure, new

L_{min} = 1.4*(R_S*t_s)$^{0.5}$
= 1.4*(6*0.375)$^{0.5}$
= 2.1 in

The length of the attached cylinder (2.0575 in) < L_{min}.

f_2 = -W_s / (π*2*R_m) + 12*M_s / (π*R_m^2)
= --4,296.41 / (π*2*6.1875) + 12*8,241.2 / (π*6.1875^2)
= 932.74 lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 270.14 + 932.74$
$= 1,202.88$ lb_f/in

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*1,202.88*6*\tan(29.9715) / (14,100*0.85)$
$= 0.3473$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.0523)*(6*0.3125 / \cos(29.9715))^{0.5}$
$= 0.3828$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cylinder Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Wind New	0	0	0	0	0	0	0	0	0

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cone Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Wind New	0	0	0	0	0	0	0	0	0

Appendix 1-5(g), U-2(g) small end cone to shell juncture analysis (Bednar 8.6), wind + pressure, new

Equivalent pressure windward side, P_e:

$I = 4*M / (\pi*D^2) - W / (\pi*D)$
$= 4*98,894.4 / (\pi*12.375^2) - -4,296.41 / (\pi*12.375)$
$= 932.74$ lb_f/in

$P_e = P + 4*I / D = 90.05 + 4*932.7389 / 12.375$
$= 391.54$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (391.54*6.1875 / 0.375)*(0.5 - 0.3041*(6.1875 / 0.375)^{0.5})$
$=$ -4,751 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (391.54*6.1875 / 0.375)*(0.5 + 0.3041*(6.1875 / 0.375)^{0.5})$
$=$ 11,211 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 + (391.54 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
$=$ 6,924 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (391.54*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) - 0.438*(6.1875 / 0.375)^{0.5})$
$=$ -7,019 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (391.54*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) + 0.438*(6.1875 / 0.375)^{0.5})$

= 15,968 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 / (0.8333*\cos(29.9715)) + (391.54 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
= 7,497 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

$I = - 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= - 4*98,894.4 / (\pi*12.375^2) - 0.6*-4,296.41 / (\pi*12.375)$
$= -755.92$ lb$_f$/in

$P_e = P + 4*I / D = 90.05 + 4*-755.9192 / 12.375$
= -154.29 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-154.29*6.1875 / 0.375)*(0.5 - 0.3041*(6.1875 / 0.375)^{0.5})$
= 1,872 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-154.29*6.1875 / 0.375)*(0.5 + 0.3041*(6.1875 / 0.375)^{0.5})$
= -4,418 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 + (-154.29 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
= -657 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-154.29*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) - 0.438*(6.1875 / 0.375)^{0.5})$
= 2,766 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-154.29*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) + 0.438*(6.1875 / 0.375)^{0.5})$
= -6,293 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 / (0.8333*\cos(29.9715)) + (-154.29 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
= -85 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone small end calculations per Appendix 1-5(e)(1), seismic + pressure, corroded

$L_{min} = 1.4*(R_S*t_s)^{0.5}$
$= 1.4*(6.0625*0.3125)^{0.5}$
= 1.927 in

The length of the attached cylinder (2.0575 in) ≥ L_{min}.

$f_2 = -(1 + 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -(1 + 0.14*0.32)*-4{,}289.79 / (\pi*2*6.2188) + 12*9{,}419.7 / (\pi*6.2188^2)$
$= 1{,}045.09$ lb_f/in

$P*R_s / 2 = 272.95$ lb_f/in

f_2 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 90.05 / (12{,}000*0.85) = 0.008828$

From table 1-5.2 $\Delta = 8.3°$

As $\Delta < \alpha$ reinforcement is required.

$Q_s = P*R_s / 2 + f_2$
$= 272.95 + 1{,}045.09$
$= 1{,}318.04$ lb_f/in

$A_{rs} = (k*Q_s*R_s / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}318.04*6.0625 / (12{,}000*0.85))*(1 - 8.3 / 29.9715)*\tan(29.9715)$
$= 0.3267$ in^2

$A_{es} = 0.78*(R_s*t_s)^{0.5}*[(t_s - t) + (t_c - t_r) / \cos(\alpha)]$
$= 0.78*(6.0625*0.3125)^{0.5}*[(0.3125 - 0.0538) + (0.25 - 0.0528) / \cos(29.9715)]$
$= 0.5221$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cylinder Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-7,045	15,526	3,134	-6,906	36,000	36,000	9,911	-1,820	18,000

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cone Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-11,515	23,752	5,122	-10,566	42,300	42,300	10,704	-1,026	21,150

Appendix 1-5(g), U-2(g) small end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (1 + 0.14*S_{DS})*W / (\pi*D)$
$= 4*113,035.9 / (\pi*12.4375^2) - (1 + 0.14*0.32)*-4,289.79 / (\pi*12.4375)$
$= 1,045.09$ lb$_f$/in

$P_e = P + 4*l / D = 90.05 + 4*1,045.0864 / 12.4375$
$= 426.15$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (426.15*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ -7,045 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (426.15*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ 15,526 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.2188 / 0.3125)*(1 + (426.15 / 90.05)*0.2146*(6.2188 / 0.3125)^{0.5})$
$=$ 9,911 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (426.15*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) - 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ -11,515 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (426.15*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) + 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ 23,752 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$

= (90.05*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (426.15 / 90.05)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= 10,704 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - (0.6 - 0.14*S_{DS})*W / (π*D)
= - 4*113,035.9 / (π*12.4375^2) - (0.6 - 0.14*0.32)*-4,289.79 / (π*12.4375)
= -869.43 lb_f/in

P_e = P + 4*I / D = 90.05 + 4*-869.4262 / 12.4375
= -189.57 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (-189.57*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= 3,134 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (-189.57*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= -6,906 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

σ_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)$^{0.5}$)
= (90.05*6.2188 / 0.3125)*(1 + (-189.57 / 90.05)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -1,820 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (-189.57*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) - 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= 5,122 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (-189.57*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) + 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= -10,566 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) + (P_e / P)*Y*(R / t)$^{0.5}$)
= (90.05*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (-189.57 / 90.05)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -1,026 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone small end calculations per Appendix 1-5(e)(2), seismic + pressure, new

L_{min} = 1.4*(R_S*t_s)$^{0.5}$
= 1.4*(6*0.375)$^{0.5}$
= 2.1 in

The length of the attached cylinder (2.0575 in) < L_{min}.

f_2 = -(1 + 0.14*S_{DS})*W_s / (π*2*R_m) + 12*M_s / (π*R_m^2)
= -(1 + 0.14*0.32)*-4,296.41 / (π*2*6.1875) + 12*9,426.5 / (π*6.1875^2)
= 1,055.95 lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 270.14 + 1,055.95$
$= 1,326.08$ lb_f/in

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*1,326.08*6*\tan(29.9715) / (14,100*0.85)$
$= 0.3828$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.0523)*(6*0.3125 / \cos(29.9715))^{0.5}$
$= 0.3828$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cylinder Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Seismic New	0	0	0	0	36,000	36,000	0	0	18,000

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cone Internal pressure = 90.045 psi (MAWP = 89.28 psi)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Seismic New	0	0	0	0	42,300	42,300	0	0	21,150

Appendix 1-5(g), U-2(g) small end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (1 + 0.14*S_{DS})*W / (\pi*D)$
$= 4*113,118.1 / (\pi*12.375^2) - (1 + 0.14*0.32)*-4,296.41 / (\pi*12.375)$
$= 1,055.95$ lb$_f$/in

$P_e = P + 4*l / D = 90.05 + 4*1,055.948 / 12.375$
$= 431.36$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (431.36*6.1875 / 0.375)*(0.5 - 0.3041*(6.1875 / 0.375)^{0.5})$
$=$ -5,234 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (431.36*6.1875 / 0.375)*(0.5 + 0.3041*(6.1875 / 0.375)^{0.5})$
$=$ 12,351 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 + (431.36 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
$=$ 7,477 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (431.36*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) - 0.438*(6.1875 / 0.375)^{0.5})$
$=$ -7,733 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (431.36*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) + 0.438*(6.1875 / 0.375)^{0.5})$

= 17,592 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 / (0.8333*\cos(29.9715)) + (431.36 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
= 8,050 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Equivalent pressure leeward side, P_e:

$l = - 4*M / (\pi*D^2) - (0.6 - 0.14*S_{DS})*W / (\pi*D)$
$= - 4*113,118.1 / (\pi*12.375^2) - (0.6 - 0.14*0.32)*-4,296.41 / (\pi*12.375)$
$= -879.13$ lb$_f$/in

$P_e = P + 4*l / D = 90.05 + 4*-879.1282 / 12.375$
= -194.12 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-194.12*6.1875 / 0.375)*(0.5 - 0.3041*(6.1875 / 0.375)^{0.5})$
= 2,355 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-194.12*6.1875 / 0.375)*(0.5 + 0.3041*(6.1875 / 0.375)^{0.5})$
= -5,558 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 36,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 + (-194.12 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
= -1,210 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 18,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-194.12*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) - 0.438*(6.1875 / 0.375)^{0.5})$
= 3,480 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-194.12*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) + 0.438*(6.1875 / 0.375)^{0.5})$
= -7,917 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 42,300 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$
$= (90.05*6.1875 / 0.375)*(1 / (0.8333*\cos(29.9715)) + (-194.12 / 90.05)*0.2072*(6.1875 / 0.375)^{0.5})$
= -638 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 21,150 psi.

Cone large end calculations for external pressure of 55.621 psi Appendix 1-8(b)											
Loading	Area check req'd $\Delta < \alpha$	U-2(g) analysis req'd	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2) 3/8x4 Flat Bar	Area status	l'_s (in^4)	l' (in^4)	I status
Wind Corroded	Yes	No	51.85	719.31	0.56	1.03	1.5	OK	1.3554	5.7035	OK
Seismic Corroded	Yes	No	78.49	745.94	0.58	1.03	1.5	OK	1.3748	5.7035	OK

Cone large end calculations per Appendix 1-8(b)(1), wind + external pressure

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(24*0.25)^{0.5}$
$= 4.899$ in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$f_1 = 0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= 0.6*-5,462.65 / (\pi*2*23.875) + 12*10,998.6 / (\pi*23.875^2)$
$=$ 51.85 lb_f/in

$P*R_L / 2 = 667.4536$ lb_f/in

$f_1 + P*R_L / 2$ is in compression so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 55.62 / (20,000*0.85) = 0.003272$

From table 1-8.1 $\Delta = 5.85°$

As $\Delta < \alpha$ reinforcement is required.

$Q_L = P*R_L / 2 + f_1$
$= 667.45 + 51.85$
$=$ 719.31 lb_f/in

$A_{rL} = (k*Q_L*R_L*\tan(\alpha) / (S_s*E_1))*[1 - 0.25*((P*R_L-Q_L) / Q_L)*(\Delta / \alpha)]$
$= (1*719.31*24*\tan(29.9715) / (20,000*0.85))*[1 - 0.25*((55.62*24-719.31) / 719.31)*(5.85 / 29.9715)]$
$=$ 0.5612 in^2

$A_{eL} = 0.55*(D_L*t_s)^{0.5}*(t_s + t_c / \cos(\alpha))$
$= 0.55*(48*0.25)^{0.5}*(0.25 + 0.25 / \cos(29.9715))$
$=$ 1.0262 in^2

$A_{eL} >= A_{rL}$ therefore the large end juncture is adequately reinforced.

Cone large end calculations per Appendix 1-8(b)(3), wind + external pressure

$L_{min} = 1.4*(R_L*t_s)^{0.5}$
$= 1.4*(24*0.25)^{0.5}$
$= 3.4293$ in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$M = -R_L*\tan(\alpha) / 2 + L_L / 2 + (R_L^2 - R_s^2) / (3*R_L*\tan(\alpha))$
$= -24*\tan(29.9715) / 2 + 72.5625 / 2 + (24^2 - 6.375^2) / (3*24*\tan(29.9715))$

= 42.2546 in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (30.5625^2 + (24 - 6.375)^2)^{0.5}$
= 35.2804 in

$A_{TL} = L_L * t_s / 2 + L_c * t_c / 2 + A_s$
$= 72.5625*0.25 / 2 + 35.2804 * 0.25 / 2 + 1.5$
= 14.9804 in^2

$F_L = P*M + f_1*\tan(\alpha)$
$= 55.62*42.2546 + 51.85*\tan(29.9715)$
= 2,380.15 lb_f/in

$B = 0.75*F_L*D_L / A_{TL}$
$= 0.75*2,380.15*48 / 14.9804$
= 5,720 psi

From Table HA-1: A = 0.000428 (shell, 0° F)

$I'_s = A*D_L^2*A_{TL} / 10.9$
$= 0.000428*48^2*14.9804 / 10.9$
= 1.3554 in^4

The calculated I' for the combined ring-shell-cone cross section is 5.7035 in^4

As $I' >= I'_s$ the large end is adequately stiffened per Appendix 1-8(b).

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cylinder External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	11,835	-16,266	15,296	-21,023	60,000	60,000	2,121	3,346	30,000

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cone External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Wind Corroded	11,493	-16,608	14,854	-21,465	60,000	60,000	-1,944	-719	30,000

Appendix 1-8(e), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), wind + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - W / (\pi*D)$
$= 4*131,983 / (\pi*47.75^2) - -5,462.65 / (\pi*47.75)$
$= 110.12$ lb_f/in

$P_e = P + 4*l / D = -55.62 + 4*110.1174 / 47.75$
$= -46.4$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-46.4*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ 11,835 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-46.4*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
$=$ -16,266 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
$= 0.3925$ in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 - (-46.4 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$
$=$ 2,121 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-46.4*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ 11,493 psi [longitudinal stress, large end, cone outside surface]

Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-46.4*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= -16,608 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (-46.4 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= -1,944 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Equivalent pressure leeward side, P_e:

$l = - 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= - 4*131,983 / (\pi*47.75^2) - 0.6*-5,462.65 / (\pi*47.75)$
= -51.85 lb_f/in

$P_e = P + 4*l / D = -55.62 + 4*-51.8533 / 47.75$
= -59.96 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-59.96*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
= 15,296 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-59.96*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
= -21,023 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
= 0.3925 in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 - (-59.96 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= 3,346 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-59.96*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
= 14,854 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-59.96*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= -21,465 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (-59.96 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$

= -719 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Cone large end calculations per Appendix 1-8(b)(1), seismic + external pressure

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(24*0.25)^{0.5}$
= 4.899 in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$f_1 = (0.6 - 0.14*S_{DS})*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= (0.6 - 0.14*0.32)*-5,462.65 / (\pi*2*23.875) + 12*14,730.1 / (\pi*23.875^2)$
= 78.49 lb_f/in

$P*R_L / 2$ = 667.4536 lb_f/in

$f_1 + P*R_L / 2$ is in compression so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 55.62 / (20,000*0.85) = 0.003272$

From table 1-8.1 Δ = 5.85°

As $\Delta < \alpha$ reinforcement is required.

$Q_L = P*R_L / 2 + f_1$
$= 667.45 + 78.49$
= 745.94 lb_f/in

$A_{rL} = (k*Q_L*R_L*\tan(\alpha) / (S_s*E_1))*[1 - 0.25*((P*R_L-Q_L) / Q_L)*(\Delta / \alpha)]$
$= (1*745.94*24*\tan(29.9715) / (20,000*0.85))*[1 - 0.25*((55.62*24-745.94) / 745.94)*(5.85 / 29.9715)]$
= 0.5839 in^2

$A_{eL} = 0.55*(D_L*t_s)^{0.5}*(t_s + t_c / \cos(\alpha))$
$= 0.55*(48*0.25)^{0.5}*(0.25 + 0.25 / \cos(29.9715))$
= 1.0262 in^2

A_{eL} >= A_{rL} therefore the large end juncture is adequately reinforced.

Cone large end calculations per Appendix 1-8(b)(3), seismic + external pressure

$L_{min} = 1.4*(R_L*t_s)^{0.5}$
$= 1.4*(24*0.25)^{0.5}$
= 3.4293 in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$M = -R_L*\tan(\alpha) / 2 + L_L / 2 + (R_L^2 - R_s^2) / (3*R_L*\tan(\alpha))$
$= -24*\tan(29.9715) / 2 + 72.5625 / 2 + (24^2 - 6.375^2) / (3*24*\tan(29.9715))$
= 42.2546 in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (30.5625^2 + (24 - 6.375)^2)^{0.5}$
= 35.2804 in

$A_{TL} = L_L*t_s / 2 + L_c * t_c / 2 + A_s$
$= 72.5625*0.25 / 2 + 35.2804 * 0.25 / 2 + 1.5$

= 14.9804 in^2

$F_L = P*M + f_1*\tan(\alpha)$
= 55.62*42.2546 + 78.49*tan(29.9715)
= 2,395.51 lb_f/in

$B = 0.75*F_L*D_L / A_{TL}$
= 0.75*2,395.51*48 / 14.9804
= 5,757 psi

From Table HA-1: A = 0.000434 (shell, 0° F)

$I'_s = A*D_L^2*A_{TL} / 10.9$
= $0.000434*48^2*14.9804 / 10.9$
= 1.3748 in^4

The calculated I' for the combined ring-shell-cone cross section is 5.7035 in^4

As $I' >= I'_s$ the large end is adequately stiffened per Appendix 1-8(b).

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cylinder External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	11,266	-15,484	15,866	-21,805	60,000	60,000	1,920	3,547	30,000

Appendix 1-8(e), U-2(g) analysis of large end juncture, stress in the cone External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Seismic Corroded	10,941	-15,809	15,407	-22,264	60,000	60,000	-2,145	-518	30,000

Appendix 1-8(e), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (1 + 0.14*S_{DS})*W / (\pi*D)$
$= 4*176{,}761.3 / (\pi*47.75^2) - (1 + 0.14*0.32)*-5{,}462.65 / (\pi*47.75)$
$= 136.75$ lb_f/in

$P_e = P + 4*l / D = -55.62 + 4*136.754 / 47.75$
$= -44.17$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-44.17*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ 11,266 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-44.17*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
$=$ -15,484 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
$= 0.3925$ in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 - (-44.17 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$
$=$ 1,920 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-44.17*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
$=$ 10,941 psi [longitudinal stress, large end, cone outside surface]

Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-44.17*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= -15,809 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (-44.17 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= -2,145 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Equivalent pressure leeward side, P_e:

$l = - 4*M / (\pi*D^2) - (0.6 - 0.14*S_{DS})*W / (\pi*D)$
$= - 4*176{,}761.3 / (\pi*47.75^2) - (0.6 - 0.14*0.32)*-5{,}462.65 / (\pi*47.75)$
= -78.49 lb_f/in

$P_e = P + 4*l / D = -55.62 + 4*-78.49 / 47.75$
= -62.2 psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (-62.2*23.875 / 0.25)*(0.5 - 0.3245*(23.875 / 0.25)^{0.5})$
= 15,866 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (-62.2*23.875 / 0.25)*(0.5 + 0.3245*(23.875 / 0.25)^{0.5})$
= -21,805 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.25)^{0.5})$
= 0.3925 in

Equivalent thickness t = 0.25 + 0.3925 = 0.6425 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 - (-62.2 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$
= 3,547 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (-62.2*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.875 / 0.25)^{0.5})$
= 15,407 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (-62.2*23.875 / 0.25)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.875 / 0.25)^{0.5})$
= -22,264 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*23.875 / 0.6425)*(1 / (0.3891*\cos(29.9715)) - (-62.2 / -55.62)*0.3985*(23.875 / 0.6425)^{0.5})$

= -518 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Cone small end calculations for external pressure of 55.621 psi Appendix 1-8(c)										
Loading	U-2(g) analysis req'd	f_2 (lbf/in)	Q_s (lbf/in)	A_{rs} (in2)	A_{es} (in2)	Ring area (in^2)	Area status	$I's$ (in^4)	I' (in^4)	I status
Wind Corroded	No	746.75	924.04	0.2	0.46	none	OK	0.0231	0.0311	OK
Seismic Corroded	No	868.17	1,045.46	0.23	0.46	none	OK	0.0238	0.0311	OK

Cone small end calculations per Appendix 1-8(c)(1), wind + external pressure

$L_{min} = 1.4*(R_S*t_s)^{0.5}$
$= 1.4*(6.375*0.3125)^{0.5}$
$= 1.976$ in

The length of the attached cylinder (2.0575 in) ≥ L_{min}.

$f_2 = 0.6*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= 0.6*-4,378.54 / (\pi*2*6.2188) + 12*8,241.2 / (\pi*6.2188^2)$
$=$ 746.75 lb_f/in

$P*R_s / 2 = 177.2924$ lb_f/in

$f_2 + P*R_s / 2$ is in compression so a U-2(g) analysis is not required.

$Q_s = P*R_s / 2 + f_2$
$= 177.29 + 746.75$
$=$ 924.04 lb_f/in

$A_{rs} = (k*Q_s*R_s*\tan(\alpha) / (S_s*E_1))$
$= (1*924.04*6.375*\tan(29.9715) / (17,000*1))$
$=$ 0.1998 in^2

$A_{es} = 0.55*(D_s*t_s)^{0.5}*((t_s - t) + (t_c - t_r) / \cos(\alpha))$
$= 0.55*(12.75*0.3125)^{0.5}*((0.3125 - 0.0751) + (0.25 - 0.0959) / \cos(29.9715))$
$=$ 0.4559 in^2

A_{es} >= A_{rs} therefore the small end juncture is adequately reinforced.

Cone small end calculations per Appendix 1-8(c)(3), wind + external pressure

$N = R_s*\tan(\alpha) / 2 + L_s / 2 + (R_L^2 - R_s^2) / (6*R_s*\tan(\alpha))$
$= 6.375*\tan(29.9715) / 2 + 13.9375 / 2 + (24^2 - 6.375^2) / (6*6.375*\tan(29.9715))$
$= 33.0772$ in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (30.5625^2 + (24 - 6.375)^2)^{0.5}$
$= 35.2804$ in

$A_{TS} = L_s*t_s / 2 + L_c * t_c / 2 + A_s$
$= 13.9375*0.3125 / 2 + 35.2804 * 0.25 / 2 + 0$
$= 6.59$

$F_s = P*N + f_2*\tan(\alpha)$
$= 55.62*33.0772 + 746.75*\tan(29.9715)$
$= 2,270.43$ lb_f/in

$B = 0.75*F_s*D_s / A_{TS}$
$= 0.75*2{,}270.43*12.75 / 6.5878$
$= 3{,}296$ psi

From Table HA-1: A = 0.000235 (shell, 0° F)

$I'_s = A*D_s^2*A_{TS} / 10.9$
$= 0.000235*12.75^2*6.5878 / 10.9$
$= 0.0231$ in^4

The calculated I' for the combined shell-cone cross section is 0.0311 in^4

As $I' >= I'_s$ the small end is adequately stiffened per Appendix 1-8(c).

Appendix 1-8(e), U-2(g) analysis of small end juncture, stress in the cylinder External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Wind Corroded	-4,004	8,824	4,890	-10,776	60,000	60,000	3,507	-6,742	25,500

Appendix 1-8(e), U-2(g) analysis of small end juncture, stress in the cone External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Wind Corroded	-6,544	13,499	7,992	-16,486	60,000	60,000	3,017	-7,232	30,000

Appendix 1-8(e), U-2(g) small end cone to shell juncture analysis (Bednar 8.6), wind + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - W / (\pi*D)$
$= 4*98,894.4 / (\pi*12.4375^2) - -4,378.54 / (\pi*12.4375)$
$= 926.04$ lb_f/in

$P_e = P + 4*l / D = -55.62 + 4*926.0426 / 12.4375$
$= 242.2$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (242.2*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ -4,004 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (242.2*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ 8,824 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*6.2188 / 0.3125)*(1 + (242.2 / -55.62)*0.2146*(6.2188 / 0.3125)^{0.5})$
$=$ 3,507 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 25,500 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (242.2*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) - 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ -6,544 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (242.2*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) + 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ 13,499 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$

= (-55.62*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (242.2 / -55.62)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= 3,017 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - 0.6*W / (π*D)
= - 4*98,894.4 / (π*12.4375^2) - 0.6*-4,378.54 / (π*12.4375)
= -746.75 lb_f/in

P_e = P + 4*I / D = -55.62 + 4*-746.7485 / 12.4375
= -295.78 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (-295.78*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= 4,890 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (-295.78*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= -10,776 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

σ_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)$^{0.5}$)
= (-55.62*6.2188 / 0.3125)*(1 + (-295.78 / -55.62)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -6,742 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 25,500 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (-295.78*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) - 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= 7,992 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (-295.78*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) + 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= -16,486 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) + (P_e / P)*Y*(R / t)$^{0.5}$)
= (-55.62*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (-295.78 / -55.62)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -7,232 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Cone small end calculations per Appendix 1-8(c)(1), seismic + external pressure

L_{min} = 1.4*(R_S*t_s)$^{0.5}$
= 1.4*(6.375*0.3125)$^{0.5}$
= 1.976 in

The length of the attached cylinder (2.0575 in) ≥ L_{min}.

f_2 = (0.6 - 0.14*S_{DS})*W_s / (π*2*R_m) + 12*M_s / (π*R_m^2)
= (0.6 - 0.14*0.32)*-4,378.54 / (π*2*6.2188) + 12*9,419.7 / (π*6.2188^2)
= 868.17 lb_f/in

P*R_s / 2 = 177.2924 lb_f/in

$f_2 + P*R_s / 2$ is in compression so a U-2(g) analysis is not required.

$Q_s = P*R_s / 2 + f_2$
$= 177.29 + 868.17$
$= 1,045.46$ lb_f/in

$A_{rs} = (k*Q_s*R_s*\tan(\alpha) / (S_s*E_1))$
$= (1*1,045.46*6.375*\tan(29.9715) / (17,000*1))$
$= 0.2261$ in^2

$A_{es} = 0.55*(D_s*t_s)^{0.5}*((t_s - t) + (t_c - t_r) / \cos(\alpha))$
$= 0.55*(12.75*0.3125)^{0.5}*((0.3125 - 0.0751) + (0.25 - 0.0959) / \cos(29.9715))$
$= 0.4559$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Cone small end calculations per Appendix 1-8(c)(3), seismic + external pressure

$N = R_s*\tan(\alpha) / 2 + L_s / 2 + (R_L^2 - R_s^2) / (6*R_s*\tan(\alpha))$
$= 6.375*\tan(29.9715) / 2 + 13.9375 / 2 + (24^2 - 6.375^2) / (6*6.375*\tan(29.9715))$
$= 33.0772$ in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (30.5625^2 + (24 - 6.375)^2)^{0.5}$
$= 35.2804$ in

$A_{TS} = L_s*t_s / 2 + L_c * t_c / 2 + A_s$
$= 13.9375*0.3125 / 2 + 35.2804 * 0.25 / 2 + 0$
$= 6.59$

$F_s = P*N + f_2*\tan(\alpha)$
$= 55.62*33.0772 + 868.17*\tan(29.9715)$
$= 2,340.45$ lb_f/in

$B = 0.75*F_s*D_s / A_{TS}$
$= 0.75*2,340.45*12.75 / 6.5878$
$= 3,397$ psi

From Table HA-1: A = 0.000242 (shell, 0° F)

$I'_s = A*D_s^2*A_{TS} / 10.9$
$= 0.000242*12.75^2*6.5878 / 10.9$
$= 0.0238$ in^4

The calculated I' for the combined shell-cone cross section is 0.0311 in^4

As $I' >= I'_s$ the small end is adequately stiffened per Appendix 1-8(c).

Appendix 1-8(e), U-2(g) analysis of small end juncture, stress in the cylinder External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-4,650	10,247	5,535	-12,199	60,000	60,000	4,251	-7,486	25,500

Appendix 1-8(e), U-2(g) analysis of small end juncture, stress in the cone External pressure = 55.621 psi									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Seismic Corroded	-7,600	15,676	9,047	-18,662	60,000	60,000	3,761	-7,976	30,000

Appendix 1-8(e), U-2(g) small end cone to shell juncture analysis (Bednar 8.6), seismic + pressure, corroded

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - (1 + 0.14*S_{DS})*W / (\pi*D)$
$= 4*113,035.9 / (\pi*12.4375^2) - (1 + 0.14*0.32)*-4,378.54 / (\pi*12.4375)$
$= 1,047.46$ lb$_f$/in

$P_e = P + 4*l / D = -55.62 + 4*1,047.4594 / 12.4375$
$= 281.25$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (281.25*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ -4,650 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (281.25*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)^{0.5})$
$=$ 10,247 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (-55.62*6.2188 / 0.3125)*(1 + (281.25 / -55.62)*0.2146*(6.2188 / 0.3125)^{0.5})$
$=$ 4,251 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 25,500 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (281.25*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) - 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ -7,600 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (281.25*6.2188 / 0.3125)*(0.5 / (0.8*\cos(29.9715)) + 0.4661*(6.2188 / 0.3125)^{0.5})$
$=$ 15,676 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) + (P_e / P)*Y*(R / t)^{0.5})$

= (-55.62*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (281.25 / -55.62)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= 3,761 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Equivalent pressure leeward side, P_e:

I = - 4*M / (π*D^2) - (0.6 - 0.14*S_{DS})*W / (π*D)
= - 4*113,035.9 / (π*12.4375^2) - (0.6 - 0.14*0.32)*-4,378.54 / (π*12.4375)
= -868.17 lb_f/in

P_e = P + 4*I / D = -55.62 + 4*-868.1652 / 12.4375
= -334.83 psi

σ_L = (P_e*R / t)*(0.5 - X*(R / t)$^{0.5}$)
= (-334.83*6.2188 / 0.3125)*(0.5 - 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= 5,535 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 + X*(R / t)$^{0.5}$)
= (-334.83*6.2188 / 0.3125)*(0.5 + 0.2983*(6.2188 / 0.3125)$^{0.5}$)
= -12,199 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

σ_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)$^{0.5}$)
= (-55.62*6.2188 / 0.3125)*(1 + (-334.83 / -55.62)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -7,486 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 25,500 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) - U*(R / t)$^{0.5}$)
= (-334.83*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) - 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= 9,047 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_L = (P_e*R / t)*(0.5 / (n*cos(α)) + U*(R / t)$^{0.5}$)
= (-334.83*6.2188 / 0.3125)*(0.5 / (0.8*cos(29.9715)) + 0.4661*(6.2188 / 0.3125)$^{0.5}$)
= -18,662 psi [longitudinal stress, small end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) + (P_e / P)*Y*(R / t)$^{0.5}$)
= (-55.62*6.2188 / 0.3125)*(1 / (0.8*cos(29.9715)) + (-334.83 / -55.62)*0.2146*(6.2188 / 0.3125)$^{0.5}$)
= -7,976 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

MAP Cone juncture large end calculations, P =192.622 psi Appendix 1-5(d)								
Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2) 3/8x4 Flat Bar	Status
Pressure	No	No	0	2,281.37	0	0.12	1.5	OK

Cone large end calculations per Appendix 1-5(d)(1), pressure, new

$L_{min} = 2*(R_L*t_s)^{0.5}$
$= 2*(23.6875*0.3125)^{0.5}$
$= 5.4415$ in

The length of the attached cylinder (16.75 in) ≥ L_{min}.

$f_1 = -0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -0.6*0 / (\pi*2*23.8438) + 12*0 / (\pi*23.8438^2)$
$= 0$ lb_f/in

$P*R_L / 2 = 2{,}281.37$ lb_f/in

$|f_1| <= P*R_L / 2$ so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 192.62 / (20{,}000*1) = 0.009631$

From table 1-5.1 $\Delta = 30°$

As $\Delta >= \alpha$ no additional reinforcement is required.

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cylinder Internal pressure = 192.622 psi (MAP)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Pressure	-34,310	49,007	0	0	60,000	60,000	-7,287	0	30,000

Appendix 1-5(g), U-2(g) analysis of large end juncture, stress in the cone Internal pressure = 192.622 psi (MAP)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	outer	inner	outer	inner	compressive	tensile	windward	leeward	allowable
Pressure	-33,175	50,141	0	0	60,000	60,000	2,759	0	30,000

Appendix 1-5(g), U-2(g) large end cone to shell juncture analysis (Bednar 8.6), pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= 4*0 / (\pi*47.6875^2) - 0.6*0 / (\pi*47.6875)$
$= 0$ lb_f/in

$P_e = P + 4*l / D = 192.62 + 4*0 / 47.6875$
$= 192.62$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (192.62*23.8438 / 0.3125)*(0.5 - 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ -34,310 psi [longitudinal stress, large end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (192.62*23.8438 / 0.3125)*(0.5 + 0.3245*(23.8438 / 0.3125)^{0.5})$
$=$ 49,007 psi [longitudinal stress, large end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

3/8x4 Flat Bar ring reduces stress σ_{tm}

$t_e = A_s / (1.56*(R_o*t)^{0.5})$
$= 1.5 / (1.56*(24*0.3125)^{0.5})$
$= 0.3511$ in

Equivalent thickness t = 0.3125 + 0.3511 = 0.6636 in

$\sigma_{tm} = (P*R / t)*(1 - (P_e / P)*Y*(R / t)^{0.5})$
$= (192.62*23.8438 / 0.6636)*(1 - (192.62 / 192.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
$=$ -7,287 psi [membrane hoop stress, large end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (192.62*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) - 0.3245*(23.8438 / 0.3125)^{0.5})$

= -33,175 psi [longitudinal stress, large end, cone outside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (192.62*23.8438 / 0.3125)*(0.5 / (1*\cos(29.9715)) + 0.3245*(23.8438 / 0.3125)^{0.5})$
= 50,141 psi [longitudinal stress, large end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 / (n*\cos(\alpha)) - (P_e / P)*Y*(R / t)^{0.5})$
$= (192.62*23.8438 / 0.6636)*(1 / (0.4709*\cos(29.9715)) - (192.62 / 192.62)*0.3425*(23.8438 / 0.6636)^{0.5})$
= 2,759 psi [membrane hoop stress, large end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

MAP Cone juncture small end calculations, P =192.622 psi Appendix 1-5(e)								
Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_2 (lbf/in)	Q_s (lbf/in)	A_{rs} (in2)	A_{es} (in2)	Ring area (in^2)	Status
Pressure	Yes	No	0	577.87	0.12	0.34	none	OK

Cone small end calculations per Appendix 1-5(e)(2), pressure, new

$L_{min} = 1.4*(R_S*t_s)^{0.5}$
$= 1.4*(6*0.375)^{0.5}$
$= 2.1$ in

The length of the attached cylinder (2.0575 in) < L_{min}.

$f_2 = -0.6*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -0.6*0 / (\pi*2*6.1875) + 12*0 / (\pi*6.1875^2)$
$= 0$ lb_f/in

$Q_s = P*R_s / 2 + f_2$
$= 577.87 + 0$
$= 577.87$ lb_f/in

$A_{rs} = k*Q_s*R_s*\tan(\alpha) / (S_c*E_2)$
$= 1*577.87*6*\tan(29.9715) / (20{,}000*0.85)$
$= 0.1176$ in^2

$A_{es} = (t_c - t_r)*(R_s*t_c / \cos(\alpha))^{0.5}$
$= (0.3125 - 0.079)*(6*0.3125 / \cos(29.9715))^{0.5}$
$= 0.3435$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cylinder Internal pressure = 192.622 psi (MAP)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Pressure	0	0	0	0	0	0	0	0	0

Appendix 1-5(g), U-2(g) analysis of small end juncture, stress in the cone Internal pressure = 192.622 psi (MAP)									
Loading	σ_L (windward, psi)		σ_L (leeward, psi)		Allowable σ_L (psi)		σ_{tm} (psi)		
	inner	outer	inner	outer	compressive	tensile	windward	leeward	allowable
Pressure	0	0	0	0	0	0	0	0	0

Appendix 1-5(g), U-2(g) small end cone to shell juncture analysis (Bednar 8.6), pressure, new

Equivalent pressure windward side, P_e:

$l = 4*M / (\pi*D^2) - 0.6*W / (\pi*D)$
$= 4*0 / (\pi*12.375^2) - 0.6*0 / (\pi*12.375)$
$= 0$ lb_f/in

$P_e = P + 4*l / D = 192.62 + 4*0 / 12.375$
$= 192.62$ psi

$\sigma_L = (P_e*R / t)*(0.5 - X*(R / t)^{0.5})$
$= (192.62*6.1875 / 0.375)*(0.5 - 0.3041*(6.1875 / 0.375)^{0.5})$
$=$ -2,337 psi [longitudinal stress, small end, cylinder inside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 + X*(R / t)^{0.5})$
$= (192.62*6.1875 / 0.375)*(0.5 + 0.3041*(6.1875 / 0.375)^{0.5})$
$=$ 5,515 psi [longitudinal stress, small end, cylinder outside surface]
Membrane + bending stress σ_L does not exceed 2*Sy = 60,000 psi.

$\sigma_{tm} = (P*R / t)*(1 + (P_e / P)*Y*(R / t)^{0.5})$
$= (192.62*6.1875 / 0.375)*(1 + (192.62 / 192.62)*0.2072*(6.1875 / 0.375)^{0.5})$
$=$ 5,854 psi [membrane hoop stress, small end, in cylinder]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 25,500 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) - U*(R / t)^{0.5})$
$= (192.62*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) - 0.438*(6.1875 / 0.375)^{0.5})$
$=$ -3,453 psi [longitudinal stress, small end, cone inside surface]
Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

$\sigma_L = (P_e*R / t)*(0.5 / (n*\cos(\alpha)) + U*(R / t)^{0.5})$
$= (192.62*6.1875 / 0.375)*(0.5 / (0.8333*\cos(29.9715)) + 0.438*(6.1875 / 0.375)^{0.5})$
$=$ 7,856 psi [longitudinal stress, small end, cone outside surface]

Membrane + bending stress σ_L does not exceed 3*S = 60,000 psi.

σ_{tm} = (P*R / t)*(1 / (n*cos(α)) + (P_e / P)*Y*(R / t)$^{0.5}$)
= (192.62*6.1875 / 0.375)*(1 / (0.8333*cos(29.9715)) + (192.62 / 192.62)*0.2072*(6.1875 / 0.375)$^{0.5}$)
= 7.078 psi [membrane hoop stress, small end, in cone]
Membrane hoop + discontinuity hoop stress σ_{tm} does not exceed 1.5*S = 30,000 psi.

Cone Outlet Neck

ASME Section VIII Division 1, 2013 Edition				
Component		Cylinder		
Material		SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)		
Pipe NPS and Schedule		NPS 12 Sch 40S (Std)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		0.79	57.12	0.385
Test horizontal		1.47	40.8276	1
Dimensions				
Outer Diameter		12.75"		
Length		2.0575"		
Nominal Thickness		0.375"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		8.7	1.01	
Corroded		7.29	1.03	
Radiography				
Longitudinal seam		Welded pipe		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	Hot Shut Down, Corroded
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.1005"
Design thickness due to external pressure (t_e)	0.0949"
Design thickness due to combined loadings + corrosion	0.178"
Maximum allowable working pressure (MAWP)	431.41 psi
Maximum allowable pressure (MAP)	759.38 psi
Maximum allowable external pressure (MAEP)	354.74 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 61.95*6.375 / (17,000*0.85 + 0.4*61.95) =	0.0273"
Stress ratio = t_r*E* / (t_n - c) = 0.0273*0.85 / (0.3281 - 0.0625) =	0.0873
Impact test exempt per UHA-51(g) (coincident ratio = 0.0873)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 60.79*6.375 / (12,000*0.85 + 0.40*60.79) + 0.0625
= 0.1005"

Maximum allowable working pressure, (at 980 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 12,000*0.85*(0.375*0.875 - 0.0625) / (6.375 - 0.40*(0.375*0.875 - 0.0625)) - 0.79
= 431.41 psi

Maximum allowable pressure, (at 70 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t)
= 17,000*0.85*(0.375*0.875) / (6.375 - 0.40*(0.375*0.875))
= 759.38 psi

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 13.9375 / 12.75 = 1.0931
D_o / t = 12.75 / 0.0324 = 393.8361
From table G: A = 0.000156
From table HA-1: B = 2,185.7967 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,185.8 / (3*(12.75 / 0.0324))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t + Corrosion = 0.0324 + 0.0625 = 0.0949"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 13.9375 / 12.75 = 1.0931
D_o / t = 12.75 / (0.375*0.875 - 0.0625) = 48.0000
From table G: A = 0.003766
From table HA-1: B = 12,770.5725 psi

P_a = 4*B / (3*(D_o / t))
= 4*12,770.57 / (3*(12.75 / (0.375*0.875 - 0.0625)))
= 354.74 psi

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = 0.6*W / (2*π*R_m) + M / (π*R_m^2)
= 0.60*-4,378.2 / (2*π*6.2188) + 98,894 / (π*6.2188^2)
= 746.7544 lb/in
α = P_v / (P_e*D_o)
= 746.7544 / (7.4*12.75)
= 7.9147
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (13.9375 / 12.75)^2
= 1.0293
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (4^2 - 1 + 1.0293 + 1.0293*7.9147) / (4^2 - 1 + 1.0293)
= 1.5082

Ratio P_e * P_e ≤ MAEP
(1.5082 * 7.4 = 11.16) ≤ 354.74
Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = (0.6 - 0.14*S_{DS})*W / (2*π*R_m) + M / (π*R_m^2)
= 0.56*-4,378.2 / (2*π*6.2188) + 113,036 / (π*6.2188^2)
= 868.1707 lb/in
α = P_v / (P_e*D_o)
= 868.1707 / (7.4*12.75)
= 9.2016
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (13.9375 / 12.75)^2
= 1.0293
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (4^2 - 1 + 1.0293 + 1.0293*9.2016) / (4^2 - 1 + 1.0293)
= 1.5909

Ratio P_e * P_e ≤ MAEP
(1.5909 * 7.4 = 11.77) ≤ 354.74
Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	60	14,118	6,263	980	0.0625	Wind	0.0769	0.0752
						Seismic	0.0854	0.0914
Operating, Hot & New	60	14,118	6,417	980	0	Wind	0.0774	0.0747
						Seismic	0.086	0.0907
Hot Shut Down, Corroded	0	14,118	6,263	980	0.0625	Wind	0.0643	0.0994
						Seismic	0.0727	0.1155
Hot Shut Down, New	0	14,118	6,417	980	0	Wind	0.0649	0.098
						Seismic	0.0735	0.114
Empty, Corroded	0	20,000	13,166	70	0.0625	Wind	0.0002	0
						Seismic	0.0002	0
Empty, New	0	20,000	13,431	70	0	Wind	0.0002	0
						Seismic	0.0002	0
Vacuum	-7.4	20,000	13,166	0	0.0625	Wind	0.0443	0.0487
						Seismic	0.0502	0.0564
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,118	6,263	980	0.0625	Weight	0.077	0.1118

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (6.375 / (0.375*0.875 - 0.0625))
= 0.005208

B = 6,263 psi

S = 12,000 / 0.85 = 14,118 psi

S_{cHC} = min(B, S) = 6,263 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (6.375 / (0.375*0.875))
= 0.006434

B = 6,417 psi

S = 12,000 / 0.85 = 14,118 psi

S_{cHN} = min(B, S) = 6,417 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (6.375 / (0.375*0.875))
= 0.006434

B = 13,431 psi

S = 17,000 / 0.85 = 20,000 psi

S_{cCN} = min(B, S) = 13,431 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (6.375 / (0.375*0.875 - 0.0625))
= 0.005208

B = 13,166 psi

S = 17,000 / 0.85 = 20,000 psi

S_{cCC} = min(B, S) = 13,166 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (6.375 / (0.375*0.875 - 0.0625))
= 0.005208

B = 13,166 psi

S = 17,000 / 0.85 = 20,000 psi

S_{cVC} = min(B, S) = 13,166 psi

Operating, Hot & Corroded, Wind, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*6.0625 / (2*14,117.65*1.20*0.85 + 0.40*|60|)
= 0.0126"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 98,894 / (π*6.2188^2*14,117.65*1.20*0.85)
= 0.0565"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,378.2 / (2*π*6.2188*14,117.65*1.20*0.85)
= -0.0078"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0126 + 0.0565 - (-0.0078)
= 0.0769"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= 60*6.0625 / (2*6,262.74*1.20 + 0.40*|60|)
= 0.0242"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 98,894 / (π*6.2188^2*6,262.74*1.20)
= 0.1083"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-4,378.2 / (2*π*6.2188*6,262.74*1.20)
= -0.0089"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1083 + (-0.0089) - (0.0242)
= 0.0752"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}117.65*1.20*0.85*((0.375*0.875 - 0.0625) - 0.0565 + (-0.0078)) / (6.0625 - 0.40*((0.375*0.875 - 0.0625) - 0.0565 + (-0.0078)))$
$= 969.23$ psi

Operating, Hot & New, Wind, Top Seam

$t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
$= 60*6 / (2*14{,}117.65*1.20*0.85 + 0.40*|60|)$
$= 0.0125"$

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 98{,}894 / (\pi*6.1875^2*14{,}117.65*1.20*0.85)$
$= 0.0571"$

$t_w = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= -4{,}383 / (2*\pi*6.1875*14{,}117.65*1.20*0.85)$
$= -0.0078"$

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0.0125 + 0.0571 - (-0.0078)$
$= 0.0774"$

$t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|)$ (Pressure)
$= 60*6 / (2*6{,}417.27*1.20 + 0.40*|60|)$
$= 0.0233"$

$t_{mc} = M / (\pi*R_m^2*S_c*K_s)$ (bending)
$= 98{,}894 / (\pi*6.1875^2*6{,}417.27*1.20)$
$= 0.1068"$

$t_{wc} = 0.6*W / (2*\pi*R_m*S_c*K_s)$ (Weight)
$= 0.60*-4{,}383 / (2*\pi*6.1875*6{,}417.27*1.20)$
$= -0.0088"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.1068 + (-0.0088) - (0.0233)$
$= 0.0747"$

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}117.65*1.20*0.85*((0.375*0.875) - 0.0571 + (-0.0078)) / (6 - 0.40*((0.375*0.875) - 0.0571 + (-0.0078)))$
$= 1{,}285.91$ psi

Hot Shut Down, Corroded, Wind, Top Seam

$t_p = 0"$ (Pressure)

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 98{,}894 / (\pi*6.2188^2*14{,}117.65*1.20*0.85)$
$= 0.0565"$

$t_w = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= -4{,}378.2 / (2*\pi*6.2188*14{,}117.65*1.20*0.85)$

= -0.0078"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0565 - (-0.0078)
= 0.0643"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= 98,894 / (π*6.2188^2*6,262.74*1.20)
= 0.1083"

t_{wc} = $0.6 * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.60*-4,378.2 / (2*π*6.2188*6,262.74*1.20)
= -0.0089"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.1083 + (-0.0089) - (0)
= 0.0994"

Hot Shut Down, New, Wind, Top Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= 98,894 / (π*6.1875^2*14,117.65*1.20*0.85)
= 0.0571"

t_w = $W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= -4,383 / (2*π*6.1875*14,117.65*1.20*0.85)
= -0.0078"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0571 - (-0.0078)
= 0.0649"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= 98,894 / (π*6.1875^2*6,417.27*1.20)
= 0.1068"

t_{wc} = $0.6 * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.60*-4,383 / (2*π*6.1875*6,417.27*1.20)
= -0.0088"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.1068 + (-0.0088) - (0)
= 0.098"

Empty, Corroded, Wind, Top Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= 207 / (π*6.2188^2*20,000*1.20*0.85)
= 0.0001"

t_w = $W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= -73.5 / (2*π*6.2188*20,000*1.20*0.85)
= -0.0001"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 207 / (π*6.2188^2*13,166.22*1.20)
= 0.0001"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-73.5 / (2*π*6.2188*13,166.22*1.20)
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Empty, New, Wind, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 207 / (π*6.1875^2*20,000*1.20*0.85)
= 0.0001"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -80.4 / (2*π*6.1875*20,000*1.20*0.85)
= -0.0001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 207 / (π*6.1875^2*13,430.72*1.20)
= 0.0001"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-80.4 / (2*π*6.1875*13,430.72*1.20)
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Vacuum, Wind, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*6.0625 / (2*20,000*1.20*0.85 + 0.40*|7.4|)
= -0.0011"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 98,894 / (π*6.2188^2*20,000*1.20*0.85)
= 0.0399"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,378.2 / (2*π*6.2188*20,000*1.20*0.85)
= -0.0055"

t_t = t_p + t_m - t_w (total required, tensile)

= -0.0011 + 0.0399 - (-0.0055)
= 0.0443"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*6.0625 / (2*13,166.22*1.20 + 0.40*|7.4|)
= -0.0014"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 98,894 / (π*6.2188^2*13,166.22*1.20)
= 0.0515"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-4,378.2 / (2*π*6.2188*13,166.22*1.20)
= -0.0043"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0515 + (-0.0043) - (-0.0014)
= 0.0487"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*13,166.22*1.20*((0.375*0.875 - 0.0625) - 0.0515 - -0.0043) / (6.0625 - 0.40*((0.375*0.875 - 0.0625) - 0.0515 - -0.0043))
= 1,154.77 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 98,688 / (π*6.2188^2*14,117.65*1.00*0.85)
= 0.0677"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,378.2 / (2*π*6.2188*14,117.65*1.00*0.85)
= -0.0093"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0677 - (-0.0093)
= 0.077"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 98,688 / (π*6.2188^2*6,262.74*1.00)
= 0.1297"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= -4,378.2 / (2*π*6.2188*6,262.74*1.00)
= -0.0179"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1297 + (-0.0179) - (0)
= 0.1118"

Operating, Hot & Corroded, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)

= 60*6.0625 / (2*14,117.65*1.20*0.85 + 0.40*|60|)
= 0.0126"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 113,036 / (π*6.2188^2*14,117.65*1.20*0.85)
= 0.0646"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,378.2 / (2*π*6.2188*14,117.65*1.20*0.85)
= -0.0081"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0126 + 0.0646 - (-0.0081)
= 0.0854"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= 60*6.0625 / (2*6,262.74*1.20 + 0.40*|60|)
= 0.0242"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 113,036 / (π*6.2188^2*6,262.74*1.20)
= 0.1238"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,378.2 / (2*π*6.2188*6,262.74*1.20)
= -0.0083"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1238 + (-0.0083) - (0.0242)
= 0.0914"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,117.65*1.20*0.85*((0.375*0.875 - 0.0625) - 0.0646 + (-0.0081)) / (6.0625 - 0.40*((0.375*0.875 - 0.0625) - 0.0646 + (-0.0081)))
= 928.12 psi

Operating, Hot & New, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*6 / (2*14,117.65*1.20*0.85 + 0.40*|60|)
= 0.0125"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 113,118 / (π*6.1875^2*14,117.65*1.20*0.85)
= 0.0653"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,383 / (2*π*6.1875*14,117.65*1.20*0.85)
= -0.0082"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0125 + 0.0653 - (-0.0082)
= 0.086"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)

= 60*6 / (2*6,417.27*1.20 + 0.40*|60|)
= 0.0233"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 113,118 / (π*6.1875^2*6,417.27*1.20)
= 0.1221"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,383 / (2*π*6.1875*6,417.27*1.20)
= -0.0081"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1221 + (-0.0081) - (0.0233)
= 0.0907"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,117.65*1.20*0.85*((0.375*0.875) - 0.0653 + (-0.0082)) / (6 - 0.40*((0.375*0.875) - 0.0653 + (-0.0082)))
= 1,243.35 psi

Hot Shut Down, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 113,036 / (π*6.2188^2*14,117.65*1.20*0.85)
= 0.0646"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,378.2 / (2*π*6.2188*14,117.65*1.20*0.85)
= -0.0081"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0646 - (-0.0081)
= 0.0727"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 113,036 / (π*6.2188^2*6,262.74*1.20)
= 0.1238"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,378.2 / (2*π*6.2188*6,262.74*1.20)
= -0.0083"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1238 + (-0.0083) - (0)
= 0.1155"

Hot Shut Down, New, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 113,118 / (π*6.1875^2*14,117.65*1.20*0.85)
= 0.0653"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)

= 1.04*-4,383 / (2*π*6.1875*14,117.65*1.20*0.85)
= -0.0082"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0653 - (-0.0082)
= 0.0735"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= 113,118 / (π*6.1875²*6,417.27*1.20)
= 0.1221"

t_{wc} = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.56*-4,383 / (2*π*6.1875*6,417.27*1.20)
= -0.0081"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.1221 + (-0.0081) - (0)
= 0.114"

Empty, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= 214 / (π*6.2188²*20,000*1.20*0.85)
= 0.0001"

t_w = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= 1.04*-73.5 / (2*π*6.2188*20,000*1.20*0.85)
= -0.0001"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= 214 / (π*6.2188²*13,166.22*1.20)
= 0.0001"

t_{wc} = $(0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.56*-73.5 / (2*π*6.2188*13,166.22*1.20)
= -0.0001"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Empty, New, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= 227 / (π*6.1875²*20,000*1.20*0.85)
= 0.0001"

t_w = $(1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= 1.04*-80.4 / (2*π*6.1875*20,000*1.20*0.85)
= -0.0001"

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0 + 0.0001 - (-0.0001)$
$=$ 0.0002"

$t_{mc} = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 227 / (\pi * 6.1875^2 * 13{,}430.72 * 1.20)$
$= 0.0001$"

$t_{wc} = (0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 0.56 * -80.4 / (2 * \pi * 6.1875 * 13{,}430.72 * 1.20)$
$= -0.0001$"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0001 + (-0.0001) - (0)$
$=$ 0"

Vacuum, Seismic, Top Seam

$t_p = P * R / (2 * S_t * K_s * E_c + 0.40 * |P|)$ (Pressure)
$= -7.4 * 6.0625 / (2 * 20{,}000 * 1.20 * 0.85 + 0.40 * |7.4|)$
$= -0.0011$"

$t_m = M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
$= 113{,}036 / (\pi * 6.2188^2 * 20{,}000 * 1.20 * 0.85)$
$= 0.0456$"

$t_w = (1 + 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
$= 1.04 * -4{,}378.2 / (2 * \pi * 6.2188 * 20{,}000 * 1.20 * 0.85)$
$= -0.0057$"

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= -0.0011 + 0.0456 - (-0.0057)$
$=$ 0.0502"

$t_{pc} = P * R / (2 * S_c * K_s + 0.40 * |P|)$ (Pressure)
$= -7.4 * 6.0625 / (2 * 13{,}166.22 * 1.20 + 0.40 * |7.4|)$
$= -0.0014$"

$t_{mc} = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 113{,}036 / (\pi * 6.2188^2 * 13{,}166.22 * 1.20)$
$= 0.0589$"

$t_{wc} = (0.6 - 0.14 * S_{DS}) * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 0.56 * -4{,}378.2 / (2 * \pi * 6.2188 * 13{,}166.22 * 1.20)$
$= -0.0039$"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0589 + (-0.0039) - (-0.0014)$
$=$ 0.0564"

Maximum Allowable External Pressure, Longitudinal Stress

$P = 2 * S_c * K_s * (t - t_{mc} - t_{wc}) / (R - 0.40 * (t - t_{mc} - t_{wc}))$
$= 2 * 13{,}166.22 * 1.20 * ((0.375 * 0.875 - 0.0625) - 0.0589 - -0.0039) / (6.0625 - 0.40 * ((0.375 * 0.875 - 0.0625) - 0.0589 - -0.0039))$
$=$ 1,113.56 psi

Cone Outlet 12"x6" Sch 80s Reducer

ASME Section VIII Division 1, 2013 Edition				
Component		Cylinder		
Material		SA-403 304 (II-D p. 94, ln. 34)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (° F)**	**Design MDMT (° F)**
Internal		60	980	-20
External		7.4	0	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		0.91	65.12	0.385
Test horizontal		1.48	40.8744	1
Dimensions				
Outer Diameter		12.75"		
Length		8"		
Nominal Thickness		0.3281"		
Corrosion	**Inner**	0.0625"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		29.71	3.98	
Corroded		24.17	4.06	
Radiography				
Longitudinal seam		Seamless No RT		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Spot UW-11(b) Type 1		

Results Summary	
Governing condition	Hot Shut Down, Corroded
Minimum thickness per UG-16	0.0625" + 0.0625" = 0.125"
Design thickness due to internal pressure (t)	0.0949"
Design thickness due to external pressure (t_e)	0.0949"
Design thickness due to combined loadings + corrosion	0.1726"
Maximum allowable working pressure (MAWP)	506.93 psi
Maximum allowable pressure (MAP)	893.39 psi
Maximum allowable external pressure (MAEP)	354.74 psi
Rated MDMT	-320 ° F

UHA-51 Material Toughness Requirements	
t_r = 62.06*6.375 / (20,000*0.85 + 0.4*62.06) =	0.0232"
Stress ratio = t_r*E* / (t_n - c) = 0.0232*0.85 / (0.3281 - 0.0625) =	0.0744
Impact test exempt per UHA-51(g) (coincident ratio = 0.0744)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Design thickness, (at 980 ° F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 60.9*6.375 / (14,100*0.85 + 0.40*60.9) + 0.0625
= 0.0949"

Maximum allowable working pressure, (at 980 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 14,100*0.85*0.2656 / (6.375 - 0.40*0.2656) - 0.9
= 506.93 psi

Maximum allowable pressure, (at 70 ° F) Appendix 1-1

P = S*E*t / (R_o - 0.40*t)
= 20,000*0.85*0.3281 / (6.375 - 0.40*0.3281)
= 893.39 psi

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 13.9375 / 12.75 = 1.0931
D_o / t = 12.75 / 0.0324 = 393.8361
From table G: A = 0.000156
From table HA-1: B = 2,185.7967 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,185.8 / (3*(12.75 / 0.0324))
= 7.4 psi

Design thickness for external pressure P_a = 7.4 psi

t_a = t + Corrosion = 0.0324 + 0.0625 = 0.0949"

Maximum Allowable External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 13.9375 / 12.75 = 1.0931
D_o / t = 12.75 / 0.2656 = 48.0000
From table G: A = 0.003766
From table HA-1: B = 12,770.5725 psi

P_a = 4*B / (3*(D_o / t))
= 4*12,770.57 / (3*(12.75 / 0.2656))
= 354.74 psi

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = 0.6*W / (2*π*R_m) + M / (π*R_m^2)
= 0.60*-4,370.9 / (2*π*6.2422) + 96,780 / (π*6.2422^2)
= 723.747 lb/in
α = P_v / (P_e*D_o)
= 723.747 / (7.4*12.75)
= 7.6709
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (13.9375 / 12.75)^2
= 1.0293
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (4^2 - 1 + 1.0293 + 1.0293*7.6709) / (4^2 - 1 + 1.0293)
= 1.4926

Ratio P_e * P_e ≤ MAEP
(1.4926 * 7.4 = 11.05) ≤ 354.74
Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = (0.6 - 0.14*S_{DS})*W / (2*π*R_m) + M / (π*R_m^2)
= 0.56*-4,370.9 / (2*π*6.2422) + 108,832 / (π*6.2422^2)
= 827.1912 lb/in
α = P_v / (P_e*D_o)
= 827.1912 / (7.4*12.75)
= 8.7673
n = 4
m = 1.23 / (L / D_o)^2
= 1.23 / (13.9375 / 12.75)^2
= 1.0293
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (4^2 - 1 + 1.0293 + 1.0293*8.7673) / (4^2 - 1 + 1.0293)
= 1.563

Ratio P_e * P_e ≤ MAEP
(1.563 * 7.4 = 11.57) ≤ 354.74
Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (° F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	60	14,100	6,263	980	0.0625	Wind	0.0755	0.072
						Seismic	0.0826	0.0857
Operating, Hot & New	60	14,100	6,417	980	0	Wind	0.0759	0.0714
						Seismic	0.0832	0.0851
Hot Shut Down, Corroded	0	14,100	6,263	980	0.0625	Wind	0.0627	0.0963
						Seismic	0.0699	0.1101
Hot Shut Down, New	0	14,100	6,417	980	0	Wind	0.0633	0.095
						Seismic	0.0706	0.1086
Empty, Corroded	0	20,000	13,166	70	0.0625	Wind	0.0001	0
						Seismic	0.0002	0
Empty, New	0	20,000	13,431	70	0	Wind	0.0002	0
						Seismic	0.0002	0
Vacuum	-7.4	20,000	13,166	0	0.0625	Wind	0.0431	0.0472
						Seismic	0.0482	0.0538
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	14,100	6,263	980	0.0625	Weight	0.0752	0.1083

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (6.375 / 0.2656)
= 0.005208

B = 6,263 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHC} = min(B, S) = 6,263 psi

Allowable Compressive Stress, Hot and New- S_{cHN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (6.375 / 0.3281)
= 0.006434

B = 6,417 psi

S = 14,100 / 1.00 = 14,100 psi

S_{cHN} = min(B, S) = 6,417 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table HA-1)

A = $0.125 / (R_o / t)$
= 0.125 / (6.375 / 0.3281)
= 0.006434

B = 13,431 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCN} = min(B, S) = 13,431 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (6.375 / 0.2656)
= 0.005208

B = 13,166 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cCC} = min(B, S) = 13,166 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table HA-1)

A = 0.125 / (R_o / t)
= 0.125 / (6.375 / 0.2656)
= 0.005208

B = 13,166 psi

S = 20,000 / 1.00 = 20,000 psi

S_{cVC} = min(B, S) = 13,166 psi

Operating, Hot & Corroded, Wind, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*6.1094 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0127"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 96,780 / (π*6.2422^2*14,100*1.20*0.85)
= 0.055"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,370.9 / (2*π*6.2422*14,100*1.20*0.85)
= -0.0077"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0127 + 0.055 - (-0.0077)
= 0.0755"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= 60*6.1094 / (2*6,262.74*1.20 + 0.40*|60|)
= 0.0243"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 96,780 / (π*6.2422^2*6,262.74*1.20)
= 0.1052"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-4,370.9 / (2*π*6.2422*6,262.74*1.20)
= -0.0089"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1052 + (-0.0089) - (0.0243)
= 0.072"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}100*1.20*0.85*(0.2656 - 0.055 + (-0.0077)) / (6.1094 - 0.40*(0.2656 - 0.055 + (-0.0077)))$
$= 968.17$ psi

Operating, Hot & New, Wind, Top Seam

$t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
$= 60*6.0469 / (2*14{,}100*1.20*0.85 + 0.40*|60|)$
$= 0.0126$"

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 96{,}780 / (\pi*6.2109^2*14{,}100*1.20*0.85)$
$= 0.0555$"

$t_w = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= -4{,}374.3 / (2*\pi*6.2109*14{,}100*1.20*0.85)$
$= -0.0078$"

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 0.0126 + 0.0555 - (-0.0078)$
$= 0.0759$"

$t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|)$ (Pressure)
$= 60*6.0469 / (2*6{,}417.27*1.20 + 0.40*|60|)$
$= 0.0235$"

$t_{mc} = M / (\pi*R_m^2*S_c*K_s)$ (bending)
$= 96{,}780 / (\pi*6.2109^2*6{,}417.27*1.20)$
$= 0.1037$"

$t_{wc} = 0.6*W / (2*\pi*R_m*S_c*K_s)$ (Weight)
$= 0.60*-4{,}374.3 / (2*\pi*6.2109*6{,}417.27*1.20)$
$= -0.0087$"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.1037 + (-0.0087) - (0.0235)$
$= 0.0714$"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*14{,}100*1.20*0.85*(0.3281 - 0.0555 + (-0.0078)) / (6.0469 - 0.40*(0.3281 - 0.0555 + (-0.0078)))$
$= 1{,}282.09$ psi

Hot Shut Down, Corroded, Wind, Top Seam

$t_p = 0$" (Pressure)
$t_m = M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
$= 96{,}780 / (\pi*6.2422^2*14{,}100*1.20*0.85)$
$= 0.055$"

$t_w = W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
$= -4{,}370.9 / (2*\pi*6.2422*14{,}100*1.20*0.85)$
$= -0.0077$"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.055 - (-0.0077)
= 0.0627"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= 96,780 / (π*6.2422^2*6,262.74*1.20)
= 0.1052"

t_{wc} = $0.6 * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.60*-4,370.9 / (2*π*6.2422*6,262.74*1.20)
= -0.0089"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.1052 + (-0.0089) - (0)
= 0.0963"

Hot Shut Down, New, Wind, Top Seam

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= 96,780 / (π*6.2109^2*14,100*1.20*0.85)
= 0.0555"

t_w = $W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= -4,374.3 / (2*π*6.2109*14,100*1.20*0.85)
= -0.0078"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0555 - (-0.0078)
= 0.0633"

t_{mc} = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= 96,780 / (π*6.2109^2*6,417.27*1.20)
= 0.1037"

t_{wc} = $0.6 * W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= 0.60*-4,374.3 / (2*π*6.2109*6,417.27*1.20)
= -0.0087"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.1037 + (-0.0087) - (0)
= 0.095"

Empty, Corroded, Wind, Top Seam

t_p = 0" (Pressure)

t_m = $M / (\pi * R_m^2 * S_t * K_s * E_c)$ (bending)
= 150 / (π*6.2422^2*20,000*1.20*0.85)
= 0.0001"

t_w = $W / (2 * \pi * R_m * S_t * K_s * E_c)$ (Weight)
= -66.2 / (2*π*6.2422*20,000*1.20*0.85)
= -0.0001"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0 + 0.0001 - (-0.0001)

= 0.0001"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 150 / (π*6.2422^2*13,166.22*1.20)
= 0.0001"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-66.2 / (2*π*6.2422*13,166.22*1.20)
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Empty, New, Wind, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 150 / (π*6.2109^2*20,000*1.20*0.85)
= 0.0001"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -71.7 / (2*π*6.2109*20,000*1.20*0.85)
= -0.0001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 150 / (π*6.2109^2*13,430.72*1.20)
= 0.0001"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-71.7 / (2*π*6.2109*13,430.72*1.20)
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Vacuum, Wind, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*6.1094 / (2*20,000*1.20*0.85 + 0.40*|7.4|)
= -0.0011"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 96,780 / (π*6.2422^2*20,000*1.20*0.85)
= 0.0388"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,370.9 / (2*π*6.2422*20,000*1.20*0.85)
= -0.0055"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0011 + 0.0388 - (-0.0055)

= 0.0431"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*6.1094 / (2*13,166.22*1.20 + 0.40*|7.4|)
= -0.0014"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 96,780 / (π*6.2422^2*13,166.22*1.20)
= 0.05"

t_{wc} = 0.6*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.60*-4,370.9 / (2*π*6.2422*13,166.22*1.20)
= -0.0042"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.05 + (-0.0042) - (-0.0014)
= 0.0472"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*13,166.22*1.20*(0.2656 - 0.05 - -0.0042) / (6.1094 - 0.40*(0.2656 - 0.05 - -0.0042))
= 1,153.54 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Top Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 96,630 / (π*6.2422^2*14,100*1.00*0.85)
= 0.0659"

t_w = W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= -4,370.9 / (2*π*6.2422*14,100*1.00*0.85)
= -0.0093"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0659 - (-0.0093)
= 0.0752"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 96,630 / (π*6.2422^2*6,262.74*1.00)
= 0.126"

t_{wc} = W / (2*π*R_m*S_c*K_s) (Weight)
= -4,370.9 / (2*π*6.2422*6,262.74*1.00)
= -0.0178"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.126 + (-0.0178) - (0)
= 0.1083"

Operating, Hot & Corroded, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*6.1094 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0127"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 108,832 / (π*6.2422^2*14,100*1.20*0.85)
= 0.0618"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,370.9 / (2*π*6.2422*14,100*1.20*0.85)
= -0.0081"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0127 + 0.0618 - (-0.0081)
= 0.0826"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= 60*6.1094 / (2*6,262.74*1.20 + 0.40*|60|)
= 0.0243"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 108,832 / (π*6.2422^2*6,262.74*1.20)
= 0.1183"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,370.9 / (2*π*6.2422*6,262.74*1.20)
= -0.0082"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1183 + (-0.0082) - (0.0243)
= 0.0857"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*0.85*(0.2656 - 0.0618 + (-0.0081)) / (6.1094 - 0.40*(0.2656 - 0.0618 + (-0.0081)))
= 933.4 psi

Operating, Hot & New, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= 60*6.0469 / (2*14,100*1.20*0.85 + 0.40*|60|)
= 0.0126"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 108,901 / (π*6.2109^2*14,100*1.20*0.85)
= 0.0625"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,374.3 / (2*π*6.2109*14,100*1.20*0.85)
= -0.0081"

t_t = t_p + t_m - t_w (total required, tensile)
= 0.0126 + 0.0625 - (-0.0081)
= 0.0832"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= 60*6.0469 / (2*6,417.27*1.20 + 0.40*|60|)
= 0.0235"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)

= 108,901 / (π*6.2109^2*6,417.27*1.20)
= 0.1167"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,374.3 / (2*π*6.2109*6,417.27*1.20)
= -0.0081"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1167 + (-0.0081) - (0.0235)
= 0.0851"

Maximum allowable working pressure, Longitudinal Stress

P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))
= 2*14,100*1.20*0.85*(0.3281 - 0.0625 + (-0.0081)) / (6.0469 - 0.40*(0.3281 - 0.0625 + (-0.0081)))
= 1,246.12 psi

Hot Shut Down, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^{2}*S_t*K_s*E_c) (bending)
= 108,832 / (π*6.2422^2*14,100*1.20*0.85)
= 0.0618"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,370.9 / (2*π*6.2422*14,100*1.20*0.85)
= -0.0081"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0618 - (-0.0081)
= 0.0699"

t_{mc} = M / (π*R_m^{2}*S_c*K_s) (bending)
= 108,832 / (π*6.2422^2*6,262.74*1.20)
= 0.1183"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,370.9 / (2*π*6.2422*6,262.74*1.20)
= -0.0082"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1183 + (-0.0082) - (0)
= 0.1101"

Hot Shut Down, New, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^{2}*S_t*K_s*E_c) (bending)
= 108,901 / (π*6.2109^2*14,100*1.20*0.85)
= 0.0625"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,374.3 / (2*π*6.2109*14,100*1.20*0.85)
= -0.0081"

t_t = t_p + t_m - t_w (total required, tensile)

= 0 + 0.0625 - (-0.0081)
= 0.0706"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 108,901 / (π*6.2109^2*6,417.27*1.20)
= 0.1167"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,374.3 / (2*π*6.2109*6,417.27*1.20)
= -0.0081"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.1167 + (-0.0081) - (0)
= 0.1086"

Empty, Corroded, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 171 / (π*6.2422^2*20,000*1.20*0.85)
= 0.0001"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-66.2 / (2*π*6.2422*20,000*1.20*0.85)
= -0.0001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 171 / (π*6.2422^2*13,166.22*1.20)
= 0.0001"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-66.2 / (2*π*6.2422*13,166.22*1.20)
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Empty, New, Seismic, Top Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 180 / (π*6.2109^2*20,000*1.20*0.85)
= 0.0001"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-71.7 / (2*π*6.2109*20,000*1.20*0.85)
= -0.0001"

t_t = t_p + t_m - t_w (total required, tensile)
= 0 + 0.0001 - (-0.0001)
= 0.0002"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 180 / (π*6.2109^2*13,430.72*1.20)
= 0.0001"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-71.7 / (2*π*6.2109*13,430.72*1.20)
= -0.0001"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0001 + (-0.0001) - (0)
= 0"

Vacuum, Seismic, Top Seam

t_p = P*R / (2*S_t*K_s*E_c + 0.40*|P|) (Pressure)
= -7.4*6.1094 / (2*20,000*1.20*0.85 + 0.40*|7.4|)
= -0.0011"

t_m = M / (π*R_m^2*S_t*K_s*E_c) (bending)
= 108,832 / (π*6.2422^2*20,000*1.20*0.85)
= 0.0436"

t_w = (1 + 0.14*S_{DS})*W / (2*π*R_m*S_t*K_s*E_c) (Weight)
= 1.04*-4,370.9 / (2*π*6.2422*20,000*1.20*0.85)
= -0.0057"

t_t = t_p + t_m - t_w (total required, tensile)
= -0.0011 + 0.0436 - (-0.0057)
= 0.0482"

t_{pc} = P*R / (2*S_c*K_s + 0.40*|P|) (Pressure)
= -7.4*6.1094 / (2*13,166.22*1.20 + 0.40*|7.4|)
= -0.0014"

t_{mc} = M / (π*R_m^2*S_c*K_s) (bending)
= 108,832 / (π*6.2422^2*13,166.22*1.20)
= 0.0563"

t_{wc} = (0.6 - 0.14*S_{DS})*W / (2*π*R_m*S_c*K_s) (Weight)
= 0.56*-4,370.9 / (2*π*6.2422*13,166.22*1.20)
= -0.0039"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0563 + (-0.0039) - (-0.0014)
= 0.0538"

Maximum Allowable External Pressure, Longitudinal Stress

P = 2*S_c*K_s*(t - t_{mc} - t_{wc}) / (R - 0.40*(t - t_{mc} - t_{wc}))
= 2*13,166.22*1.20*(0.2656 - 0.0563 - -0.0039) / (6.1094 - 0.40*(0.2656 - 0.0563 - -0.0039))
= 1,118.69 psi

Nozzle 'B2' Applied Radial Load

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Vertical Load
Elevation Above Datum	201.375"
Direction Angle	0.00°
Distance from Center of Vessel	0"
Magnitude of Force	4,200 lb
Loading Conditions	
Present When Operating	Yes
Included in Vessel Lift Weight	No
Present When Vessel is Empty	No
Present During Hydrotest	No

Nozzle 'B2' Applied Resultant Moment (1000 lbf @ 84.75" moment arm = 84750 lbf-in [7062 lbf-ft])

ASME Section VIII Division 1, 2013 Edition	
Inputs	
Load Orientation	Lateral Force
Elevation Above Datum	286.125"
Magnitude of Force	1,000 lb_f
Direction Angle	0.00°
Loading Conditions	
Present When Operating	Yes
Present When Vessel is Empty	No
Present During Hydrotest	No

ASME B16.5-2009 Flange	
Description	NPS 6 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0.96 psi
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

Building Code: ASCE 7-10		
Elevation of base above grade		123.5000 ft
Increase effective outer diameter by		0.5000 ft
Wind Force Coefficient, Cf		0.7100
Risk Category (Table 1.5-1)		III
Basic Wind Speed, V		115.0000 mph
Exposure category		C
Wind Directionality Factor, Kd		0.9500
Topographic Factor, Kzt		1.0000
Enforce min. loading of 16 psf		Yes
Vessel Characteristics		
Height, h		8.4172 ft
Minimum Diameter, b	Operating, Corroded	4.0000 ft
	Empty, Corroded	4.0000 ft
	Hydrotest, Corroded, Field	4.0000 ft
Fundamental Frequency, n_1	Operating, Corroded	22.6310 Hz
	Empty, Corroded	40.3754 Hz
	Hydrotest, Corroded, Field	35.7882 Hz
	Vacuum, Corroded	25.3003 Hz
Damping coefficient, β	Operating, Corroded	0.0231
	Empty, Corroded	0.0200
	Hydrotest, Corroded, Field	0.0250
	Vacuum, Corroded	0.0251

Table Lookup Values

2.4.1 Basic Load Combinations for Allowable Stress Design	
Load combinations considered in accordance with ASCE section 2.4.1:	
5.	$D + P + P_s + 0.6W$
7.	$0.6D + P + P_s + 0.6W$
Parameter Description	
D	= Dead load
P	= Internal or external pressure load
P_s	= Static head load
W	= Wind load

Wind Deflection Reports:

Operating, Corroded
Empty, Corroded
Vacuum, Corroded
Hydrotest, Corroded, field
Wind Pressure Calculations

Wind Deflection Report: Operating, Corroded								
Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb_f)	Total Wind Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)	Deflection at Top (in)
Top Head	89.75	5.00	22.9	*	311	375	3,924	0.0015
Bonnet Shell	63.6225	5.00	22.9	1.273	311	559	4,929	0.0012
Bonnet Cone	49.375	4.75	22.9	*	311	663	5,663	0.0007
Tube Sheet Thk Spacer (No Print)	46	4.50	22.9	0.5155	311	684	5,852	0.0005
Vessel Body Upper Shell (top)	0	4.50	22.9	0.5155	311	976	8,956	0.0004
Vessel Body Upper Shell (bottom)	0	4.50	22.9	0.5155	0	1,824	24,442	0.0019
Vessel Body Mid Shell	-60.75	4.50	22.9	0.8915	0	1,443	16,314	0.0039
Vessel Body Lower Shell	-90.75	4.50	22.9	0.5155	0	1,259	12,315	0.0052
Vessel Body Cone	-107.5	3.03	22.9	*	0	1,156	10,999	0.0085
Cone Outlet Neck	-138.0625	1.56	22.9	0.01139	0	1,030	8,241	0.0089
Cone Outlet 12"x6" Sch 80s Reducer	-140.12	1.56	22.9	0.009793	0	1,025	8,065	0.013
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Empty, Corroded								
Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb_f)	Total Wind Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)	Deflection at Top (in)
Top Head	89.75	5.00	28.3	*	0	64	2,682	0.0007
Bonnet Shell	63.6225	5.00	28.3	1.273	0	248	3,020	0.0006
Bonnet Cone	49.375	4.75	28.3	*	0	352	3,375	0.0003
Tube Sheet Thk Spacer (No Print)	46	4.50	28.3	0.5155	0	374	3,477	0.0002
Vessel Body Upper Shell (top)	0	4.50	28.3	0.5155	0	665	5,435	0.0002
Vessel Body Upper Shell (bottom)	0	4.50	28.3	0.5155	0	824	8,533	0.0005
Vessel Body Mid Shell	-60.75	4.50	28.3	0.8915	0	443	5,333	0.0011
Vessel Body Lower Shell	-90.75	4.50	28.3	0.5155	0	259	887	0.0014
Vessel Body Cone	-107.5	3.03	28.3	*	0	156	228	0.002
Cone Outlet Neck	-138.0625	1.56	28.3	0.01139	0	30	17	0.002
Cone Outlet 12"x6" Sch 80s Reducer	-140.12	1.56	28.3	0.009793	0	25	13	0.0022
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Vacuum, Corroded								
Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb_f)	Total Wind Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)	Deflection at Top (in)
Top Head	89.75	5.00	28.7	*	311	375	3,924	0.0012
Bonnet Shell	63.6225	5.00	28.7	1.273	311	559	4,929	0.001
Bonnet Cone	49.375	4.75	28.7	*	311	663	5,663	0.0006
Tube Sheet Thk Spacer (No Print)	46	4.50	28.7	0.5155	311	684	5,852	0.0004
Vessel Body Upper Shell (top)	0	4.50	28.7	0.5155	311	976	8,956	0.0003
Vessel Body Upper Shell (bottom)	0	4.50	28.7	0.5155	0	1,824	24,442	0.0016
Vessel Body Mid Shell	-60.75	4.50	28.7	0.8915	0	1,443	16,314	0.0032
Vessel Body Lower Shell	-90.75	4.50	28.7	0.5155	0	1,259	12,315	0.0042
Vessel Body Cone	-107.5	3.03	28.7	*	0	1,156	10,999	0.0068
Cone Outlet Neck	-138.0625	1.56	28.7	0.01139	0	1,030	8,241	0.0071
Cone Outlet 12"x6" Sch 80s Reducer	-140.12	1.56	28.7	0.009793	0	1,025	8,065	0.0104
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Field Hydrotest, Corroded								
Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb_f)	Total Wind Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)	Deflection at Top (in)
Top Head	89.75	5.00	28.3	*	186	225	3,417	0.0009
Bonnet Shell	63.6225	5.00	28.3	1.273	186	335	4,019	0.0007
Bonnet Cone	49.375	4.75	28.3	*	186	398	4,460	0.0004
Tube Sheet Thk Spacer (No Print)	46	4.50	28.3	0.5155	186	411	4,573	0.0003
Vessel Body Upper Shell (top)	0	4.50	28.3	0.5155	186	586	6,422	0.0002
Vessel Body Upper Shell (bottom)	0	4.50	28.3	0.5155	0	494	6,695	0.0004
Vessel Body Mid Shell	-60.75	4.50	28.3	0.8915	0	266	4,775	0.0009
Vessel Body Lower Shell	-90.75	4.50	28.3	0.5155	0	155	680	0.0011
Vessel Body Cone	-107.5	3.03	28.3	*	0	94	137	0.0016
Cone Outlet Neck	-138.0625	1.56	28.3	0.01139	0	18	10	0.0017
Cone Outlet 12"x6" Sch 80s Reducer	-140.12	1.56	28.3	0.009793	0	15	8	0.0019
*Moment of Inertia I varies over the length of the component								

Wind Pressure (WP) Calculations

Gust Factor ($\bar{G}$) Calculations

$Kz = 2.01 * (Z/Zg)^{2/\alpha}$

$= 2.01 * (Z/900.0000)^{0.2105}$

$qz = 0.00256 * Kz * Kzt * Kd * V^2$

$= 0.00256 * Kz * 1.0000 * 0.9500 * 115.0000^2$

$= 32.1632 * Kz$

$WP = 0.6 * qz * G * Cf$ (Minimum 16 lb/ft^2)

$= 0.6 * qz * G * 0.7100$ (Minimum 16 lb/ft^2)

Design Wind Pressures							
Height Z (')	Kz	qz (psf)	WP (psf)				
			Operating	Empty	Hydrotest New	Hydrotest Corroded	Vacuum
15.0	0.8489	27.30	10.56	10.56	N.A.	9.60	10.56
20.0	0.9019	29.01	11.22	11.22	N.A.	9.60	11.22
25.0	0.9453	30.40	11.76	11.76	N.A.	9.60	11.76
30.0	0.9823	31.59	12.22	12.22	N.A.	9.60	12.22
40.0	1.0436	33.56	12.98	12.98	N.A.	9.60	12.98
50.0	1.0938	35.18	13.61	13.61	N.A.	9.60	13.61
60.0	1.1366	36.56	14.14	14.14	N.A.	9.60	14.14
70.0	1.1741	37.76	14.61	14.61	N.A.	9.60	14.61
80.0	1.2075	38.84	15.02	15.02	N.A.	9.60	15.02
90.0	1.2379	39.81	15.40	15.40	N.A.	9.60	15.40
100.0	1.2656	40.71	15.75	15.75	N.A.	9.60	15.75
120.0	1.3151	42.30	16.36	16.36	N.A.	9.82	16.36
140.0	1.3585	43.69	16.90	16.90	N.A.	10.14	16.90
Design Wind Force determined from: F = Pressure * Af , where Af is the projected area.							

Gust Factor Calculations

Operating, Corroded
Empty, Corroded
Vacuum, Corroded
Hydrotest, Corroded, field

Gust Factor Calculations: Operating, Corroded

Vessel is considered a rigid structure as n_1 = 22.6310 Hz ≥ 1 Hz.

$\bar{z}$ = max (0.60 * h , z_{min})
= max (0.60 * 8.4172 , 15.0000)
= 15.0000

$I_{\bar{z}}$ = c * $(33 / \bar{z})^{1/6}$
= 0.2000 * $(33 / 15.0000)^{1/6}$
= 0.2281

$L_{\bar{z}}$ = l * $(\bar{z} / 33)^{ep}$
= 500.0000 * $(15.0000 / 33)^{0.2000}$
= 427.0566

Q = Sqr(1 / (1 + 0.63 * ((b + h) / $L_{\bar{z}}$)$^{0.63}$))
= Sqr(1 / (1 + 0.63 * ((4.0000 + 8.4172) / 427.0566)$^{0.63}$))
= 0.9677

G = 0.925 * (1 + 1.7 * g_Q * $I_{\bar{z}}$ * Q) / (1 + 1.7 * g_v * $I_{\bar{z}}$)
= 0.925 * (1 + 1.7 * 3.40* 0.2281 * 0.9677) / (1 + 1.7 * 3.40 * 0.2281)

= 0.9080

Gust Factor Calculations: Empty, Corroded

Vessel is considered a rigid structure as n_1 = 40.3754 Hz ≥ 1 Hz.

$\bar{z}$ = max (0.60 * h , z_{min})
= max (0.60 * 8.4172 , 15.0000)
= 15.0000
I_{z^-} = c * $(33 / \bar{z})^{1/6}$
= 0.2000 * $(33 / 15.0000)^{1/6}$
= 0.2281
L_{z^-} = l * $(\bar{z} / 33)^{ep}$
= 500.0000 * $(15.0000 / 33)^{0.2000}$
= 427.0566
Q = Sqr(1 / (1 + 0.63 * ((b + h) / L_{z^-})$^{0.63}$))
= Sqr(1 / (1 + 0.63 * ((4.0000 + 8.4172) / 427.0566)$^{0.63}$))
= 0.9677
G = 0.925 * (1 + 1.7 * g_Q * I_{z^-} * Q) / (1 + 1.7 * g_v * I_{z^-})
= 0.925 * (1 + 1.7 * 3.40* 0.2281 * 0.9677) / (1 + 1.7 * 3.40 * 0.2281)
= 0.9080

Gust Factor Calculations: Vacuum, Corroded

Vessel is considered a rigid structure as n_1 = 25.3003 Hz ≥ 1 Hz.

$\bar{z}$ = max (0.60 * h , z_{min})
= max (0.60 * 8.4172 , 15.0000)
= 15.0000
I_{z^-} = c * $(33 / \bar{z})^{1/6}$
= 0.2000 * $(33 / 15.0000)^{1/6}$
= 0.2281
L_{z^-} = l * $(\bar{z} / 33)^{ep}$
= 500.0000 * $(15.0000 / 33)^{0.2000}$
= 427.0566
Q = Sqr(1 / (1 + 0.63 * ((b + h) / L_{z^-})$^{0.63}$))
= Sqr(1 / (1 + 0.63 * ((4.0000 + 8.4172) / 427.0566)$^{0.63}$))
= 0.9677
G = 0.925 * (1 + 1.7 * g_Q * I_{z^-} * Q) / (1 + 1.7 * g_v * I_{z^-})
= 0.925 * (1 + 1.7 * 3.40* 0.2281 * 0.9677) / (1 + 1.7 * 3.40 * 0.2281)
= 0.9080

Gust Factor Calculations: Hydrotest, Corroded, field

Vessel is considered a rigid structure as n_1 = 35.7882 Hz ≥ 1 Hz.

$\bar{z}$ = max (0.60 * h , z_{min})

$= \max (0.60 * 8.4172 , 15.0000)$

$= 15.0000$

$I_{z^-} = c * (33 / z^-)^{1/6}$

$= 0.2000 * (33 / 15.0000)^{1/6}$

$= 0.2281$

$L_{z^-} = l * (z^- / 33)^{ep}$

$= 500.0000 * (15.0000 / 33)^{0.2000}$

$= 427.0566$

$Q = Sqr(1 / (1 + 0.63 * ((b + h) / L_{z^-})^{0.63}))$

$= Sqr(1 / (1 + 0.63 * ((4.0000 + 8.4172) / 427.0566)^{0.63}))$

$= 0.9677$

$G = 0.925 * (1 + 1.7 * g_Q * I_{z^-} * Q) / (1 + 1.7 * g_v * I_{z^-})$

$= 0.925 * (1 + 1.7 * 3.40* 0.2281 * 0.9677) / (1 + 1.7 * 3.40 * 0.2281)$

$= 0.9080$

Table Lookup Values	
$\alpha = 9.5000$, $z_g = 900.0000$ ft	[Table 26.9-1, page 256]
c = 0.2000, l = 500.0000, ep = 0.2000	[Table 26.9-1, page 256]
$a^- = 0.1538$, $b^- = 0.6500$	[Table 26.9-1, page 256]
$z_{min} = 15.0000$ ft	[Table 26.9-1, page 256]
$g_Q = 3.40$	[26.9.4 page 254]
$g_v = 3.40$	[26.9.4 page 254]

Building Code: ASCE 7-10 building mounted		
Site Class		C
Spectral Response Acceleration at short period (% g), S_s		40.00%
Spectral Response Acceleration at period of 1 sec (% g), S_1		15.30%
Response Modification Factor from Table 13.6-1, R_p		2.5000
Importance Factor, I_p		1.5000
Amplification factor from Table 13.6-1, a_p		1.0000
z/h Ratio		0.6740
Acceleration-based Site Coefficient, F_a		1.2000
Velocity-based Site Coefficient, F_v		1.6470
Redundancy factor, ρ		1.0000
Risk Category (Table 1.5-1)		III
User Defined Vertical Accelerations Considered		No
Vessel Characteristics		
Height		8.4172 ft
Weight	Operating, Corroded	24,873 lb
	Empty, Corroded	19,718 lb
	Vacuum, Corroded	24,873 lb
Period of Vibration Calculation		
Fundamental Period, T	Operating, Corroded	0.044 sec (f = 22.6 Hz)
	Empty, Corroded	0.025 sec (f = 40.4 Hz)
	Vacuum, Corroded	0.040 sec (f = 25.3 Hz)

The fundamental period of vibration T (above) is calculated using the Rayleigh method of approximation

$T = 2 * PI * Sqr(\{Sum(W_i * y_i^2)\} / \{g * Sum(W_i * y_i)\})$, where

W_i is the weight of the i^{th} lumped mass, and
y_i is its deflection when the system is treated as a cantilever beam.

12.4.2.3 Basic Load Combinations for Allowable Stress Design			
Load combinations considered in accordance with ASCE section 2.4.1:			
5.	$D + P + P_s + 0.7E$	$= (1.0 + 0.14S_{DS})D + P + P_s + 0.7\rho Q_E$	
8.	$0.6D + P + P_s + 0.7E$	$= (0.6 - 0.14S_{DS})D + P + P_s + 0.7\rho Q_E$	
Parameter description			
D	= Dead load		
P	= Internal or external pressure load		
P_s	= Static head load		
E	= Seismic load	$= E_h$ +/- E_v	$= \rho Q_E$ +/- $0.2S_{DS}D$

Seismic Shear Reports:

Operating, Corroded
Empty, Corroded
Vacuum, Corroded
Base Shear Calculations

Seismic Shear Report: Operating, Corroded					
Component	**Elevation of Bottom above Base (in)**	**Elastic Modulus E (10^6 psi)**	**Inertia I (ft^4)**	**Seismic Shear at Bottom (lb_f)**	**Bending Moment at Bottom (lb_f-ft)**
Top Head	89.75	22.9	*	678	3,267
Bonnet Shell	63.6225	22.9	1.2733	1,088	5,312
Bonnet Cone	49.375	22.9	*	1,245	6,669
Tube Sheet Thk Spacer (No Print)	46	22.9	0.5155	1,248	7,019
Vessel Body Upper Shell (top)	0	22.9	0.5155	1,519	12,451
Vessel Body Upper Shell (bottom)	0	22.9	0.5155	2,644	37,354
Vessel Body Mid Shell	-60.75	22.9	0.8915	2,589	24,201
Vessel Body Lower Shell	-90.75	22.9	0.5155	2,279	17,456
Vessel Body Cone	-107.5	22.9	*	2,153	14,730
Cone Outlet Neck	-138.0625	22.9	0.0114	2,044	9,420
Cone Outlet 12"x6" Sch 80s Reducer	-140.12	22.9	0.0098	2,042	9,069
*Moment of Inertia I varies over the length of the component					

Seismic Shear Report: Empty, Corroded					
Component	Elevation of Bottom above Base (in)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Seismic Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)
Top Head	89.75	28.3	*	860	3,431
Bonnet Shell	63.6225	28.3	1.2733	1,380	6,025
Bonnet Cone	49.375	28.3	*	1,579	7,745
Tube Sheet Thk Spacer (No Print)	46	28.3	0.5155	1,582	8,190
Vessel Body Upper Shell (top)	0	28.3	0.5155	1,926	15,087
Vessel Body Upper Shell (bottom)	0	28.3	0.5155	586	7,942
Vessel Body Mid Shell	-60.75	28.3	0.8915	517	5,101
Vessel Body Lower Shell	-90.75	28.3	0.5155	157	674
Vessel Body Cone	-107.5	28.3	*	81	137
Cone Outlet Neck	-138.0625	28.3	0.0114	22	18
Cone Outlet 12"x6" Sch 80s Reducer	-140.12	28.3	0.0098	20	14
*Moment of Inertia I varies over the length of the component					

Seismic Shear Report: Vacuum, Corroded					
Component	Elevation of Bottom above Base (in)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Seismic Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)
Top Head	89.75	28.7	*	678	3,267
Bonnet Shell	63.6225	28.7	1.2733	1,088	5,312
Bonnet Cone	49.375	28.7	*	1,245	6,669
Tube Sheet Thk Spacer (No Print)	46	28.7	0.5155	1,248	7,019
Vessel Body Upper Shell (top)	0	28.7	0.5155	1,519	12,451
Vessel Body Upper Shell (bottom)	0	28.7	0.5155	2,644	37,354
Vessel Body Mid Shell	-60.75	28.7	0.8915	2,589	24,201
Vessel Body Lower Shell	-90.75	28.7	0.5155	2,279	17,456
Vessel Body Cone	-107.5	28.7	*	2,153	14,730
Cone Outlet Neck	-138.0625	28.7	0.0114	2,044	9,420
Cone Outlet 12"x6" Sch 80s Reducer	-140.12	28.7	0.0098	2,042	9,069
*Moment of Inertia I varies over the length of the component					

11.4.3: Maximum considered earthquake spectral response acceleration

The maximum considered earthquake spectral response acceleration at short period, S_{MS}

$S_{MS} = F_a * S_s = 1.2000 * 40.00 / 100 = 0.4800$

The maximum considered earthquake spectral response acceleration at 1 s period, S_{M1}

$S_{M1} = F_v * S_1 = 1.6470 * 15.30 / 100 = 0.2520$

11.4.4: Design spectral response acceleration parameters

Design earthquake spectral response acceleration at short period, S_{DS}

$S_{DS} = 2 / 3 * S_{MS} = 2 / 3 * 0.4800 = 0.3200$

Design earthquake spectral response acceleration at 1 s period, S_{D1}

$S_{D1} = 2 / 3 * S_{M1} = 2 / 3 * 0.2520 = 0.1680$

11.6 Seismic Design Category

The Risk Category is III.
From Table 11.6-1, the Seismic Design Category based on S_{Ds} = 0.3200 is B.
From Table 11.6-2, the Seismic Design Category based on S_{D1} = 0.1680 is C.
This vessel is assigned to Seismic Design Category C.

12.4.2.3: Seismic Load Combinations: Vertical Term

Factor is applied to dead load.

Compressive Side: $= 1.0 + 0.14 * S_{DS}$
$= 1.0 + 0.14 * 0.3200$
$= 1.0448$
Tensile Side: $= 0.6 - 0.14 * S_{DS}$
$= 0.6 - 0.14 * 0.3200$
$= 0.5552$

Note: Seismic base shears used in calculation of V_{Accel} Term do not include lateral forces.

Base Shear Calculations

Operating, Corroded
Empty, Corroded
Vacuum, Corroded

Base Shear Calculations: Operating, Corroded

The base shear F_p is as per Equation 13.3-1 below, provided its value is between F_{pMin} and F_{pMax}

$F_p = 0.40 * a_p * S_{DS} * W_p / (R_p / I_p) * (1 + 2 * z / h)$
$= 0.40 * 1.0000 * 0.3200 * 24,872.5215/ (2.5000 / 1.5000) * (1 + 2 * 0.6740)$
$= 4,485.1724$ lb

$F_{pMin} = 0.30 * S_{DS} * I_p * W_p$
$= 0.30 * 0.3200 * 1.5000 * 24,872.5215$
$= 3,581.64$ lb

$F_{pMax} = 1.60 * S_{DS} * I_p * W_p$
$= 1.60 * 0.3200 * 1.5000 * 24,872.5215$
$= 19,102.10$ lb

$F_p = 4,485.17$ lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h
$Q_E = F_p$
$E_h = 0.7 * \rho * Q_E$ (Only 70% of seismic load considered as per Section 2.4.1)
$= 0.70 * 1.0000 * 4,485.17$
$= 3,139.62$ lb

Base Shear Calculations: Empty, Corroded

The base shear F_p is as per Equation 13.3-1 below, provided its value is between F_{pMin} and F_{pMax}

$F_p = 0.40 * a_p * S_{DS} * W_p / (R_p / I_p) * (1 + 2 * z / h)$
$= 0.40 * 1.0000 * 0.3200 * 19,717.5137 / (2.5000 / 1.5000) * (1 + 2 * 0.6740)$
$= 3,555.5881$ lb

$F_{pMin} = 0.30 * S_{DS} * I_p * W_p$
$= 0.30 * 0.3200 * 1.5000 * 19,717.5137$
$= 2,839.32$ lb

$F_{pMax} = 1.60 * S_{DS} * I_p * W_p$
$= 1.60 * 0.3200 * 1.5000 * 19,717.5137$
$= 15,143.05$ lb

$F_p = 3,555.59$ lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h

$Q_E = F_p$
$E_h = 0.7 * \rho * Q_E$ (Only 70% of seismic load considered as per Section 2.4.1)
$= 0.70 * 1.0000 * 3,555.59$
$= 2,488.91$ lb

Base Shear Calculations: Vacuum, Corroded

The base shear F_p is as per Equation 13.3-1 below, provided its value is between F_{pMin} and F_{pMax}

$F_p = 0.40 * a_p * S_{DS} * W_p / (R_p / I_p) * (1 + 2 * z / h)$
$= 0.40 * 1.0000 * 0.3200 * 24,872.5215 / (2.5000 / 1.5000) * (1 + 2 * 0.6740)$
$= 4,485.1724$ lb

$F_{pMin} = 0.30 * S_{DS} * I_p * W_p$
$= 0.30 * 0.3200 * 1.5000 * 24,872.5215$
$= 3,581.64$ lb

$F_{pMax} = 1.60 * S_{DS} * I_p * W_p$
$= 1.60 * 0.3200 * 1.5000 * 24,872.5215$
$= 19,102.0957$ lb

$F_p = 4,485.17$ lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h

$Q_E = F_p$
$E_h = 0.7 * \rho * Q_E$ (Only 70% of seismic load considered as per Section 2.4.1)
$= 0.70 * 1.0000 * 4,485.17$
$= 3,139.62$ lb

Support Lugs

Inputs	
Support material	SA-240 304/304L
This support is attached to	Vessel Body Upper Shell
Distance from baseplate to datum	49.375"
Lug allowable stress, S_b	14,100 psi
Shell to center of load bearing area, d	10"
Lug length, circumferential direction, L	10"
Lug attachment fillet weld size	0.25"
Radial/bending lug stiffness ratio	2
Number of support lugs	4
Local Shell	
Outer Diameter	48"
Thickness	0.3125"
Inner Corrosion	0.0625"
Outer Corrosion	0"
Top Plate	
Width, W_p	3.5"
Thickness, t_a	0.625"
Base Plate	
Width, b	12"
Thickness, t_b	1.125"
Load Bearing Width, L_b	4"
Gusset	
Height, h	10"
Thickness, t_g	0.5"
Separation, L_g	7.5"
Reinforcing Pad	
Width, Circumferential Direction	14"
Length, Longitudinal Direction	16"
Thickness, t_e	0.25"
Attachment Fillet Weld Size	0.25"

Stresses in Shell at Lug Supports

Condition	Total Weight (lb)	Shear V (lb_f)	Moment M (lb_f-ft)	Lug orient	Lug Loading						Stress in Shell (psi)		
					W (lb)	P_r (lb_f)	V_L (lb_f)	M_L (lb_f-ft)	V_c (lb_f)	M_c (lb_f-ft)	Primary Circ (P_L)	Primary Long (P_L)	Combined P_L+P_b+Q
Wind, operating, corroded Attack angle = 0°	24,873	2,800	15,634	0°	3,731	-933	972	809.88	0	0.00	7,720	3,969	11,655
				90°	6,218	0	6,218	5,181.78	467	388.86	10,866	5,911	17,068
				180°	6,218	933	8,977	7,480.96	0	0.00	11,990	6,875	20,276
				270°	6,218	0	6,218	5,181.78	-467	-388.86	10,866	5,911	17,068
Wind, operating, corroded Attack angle = 45°	24,873	2,800	15,634	0°	3,731	-495	1,780	1,483.29	-495	-412.45	7,851	4,346	12,328
				90°	3,731	-495	1,780	1,483.29	495	412.45	7,851	4,346	12,328
				180°	6,218	495	8,169	6,807.55	495	412.45	11,859	6,658	19,655
				270°	6,218	495	8,169	6,807.55	-495	-412.45	11,859	6,658	19,655
Wind, operating, new Attack angle = 0°	25,570	2,800	15,617	0°	3,835	-933	1,079	899.56	0	0.00	6,044	3,064	8,779
				90°	6,392	0	6,392	5,326.99	467	388.86	8,355	4,564	13,347
				180°	6,392	933	9,148	7,623.62	0	0.00	9,178	5,248	15,768
				270°	6,392	0	6,392	5,326.99	-467	-388.86	8,355	4,564	13,347
Wind, operating, new Attack angle = 45°	25,570	2,800	15,617	0°	3,835	-495	1,887	1,572.23	-495	-412.45	6,147	3,306	9,123
				90°	3,835	-495	1,887	1,572.23	495	412.45	6,147	3,306	9,123
				180°	6,392	495	8,341	6,950.95	495	412.45	9,076	5,098	15,298
				270°	6,392	495	8,341	6,950.95	-495	-412.45	9,076	5,098	15,298
Wind, empty, corroded Attack angle = 0°	19,718	1,489	6,899	0°	2,958	-496	1,740	1,450.13	0	0.00	2,011	1,038	4,582
				90°	4,929	0	4,929	4,107.82	248	206.84	-4,008	-2,383	10,006
				180°	4,929	496	6,147	5,122.38	0	0.00	-5,594	-3,169	-13,527
				270°	4,929	0	4,929	4,107.82	-248	-206.84	-4,008	-2,383	10,006
Wind, empty, corroded Attack angle = 45°	19,718	1,489	6,899	0°	2,958	-263	2,097	1,747.29	-263	-219.39	2,021	1,118	4,815
				90°	2,958	-263	2,097	1,747.29	263	219.39	2,021	1,118	4,815
				180°	4,929	263	5,790	4,825.22	263	219.39	-5,024	-2,903	-12,309
				270°	4,929	263	5,790	4,825.22	-263	-219.39	-5,024	-2,903	-12,309
Wind, empty, new Attack angle = 0°	20,421	1,489	6,919	0°	3,063	-496	1,842	1,535.12	0	0.00	1,487	799	3,665
				90°	5,105	0	5,105	4,254.45	248	206.84	-2,970	-1,794	-7,965
				180°	5,105	496	6,326	5,271.99	0	0.00	-4,096	-2,375	-10,661
				270°	5,105	0	5,105	4,254.45	-248	-206.84	-2,970	-1,794	-7,965
Wind, empty, new Attack angle = 45°	20,421	1,489	6,919	0°	3,063	-263	2,200	1,833.15	-263	-219.39	1,500	853	3,854
				90°	3,063	-263	2,200	1,833.15	263	219.39	1,500	853	3,854
				180°	5,105	263	5,969	4,973.96	263	219.39	-3,693	-2,177	-9,732
				270°	5,105	263	5,969	4,973.96	-263	-219.39	-3,693	-2,177	-9,732
Wind, test, corroded Attack angle = 0°	34,380	1,080	4,075	0°	5,157	-360	4,438	3,698.33	0	0.00	14,884	7,711	19,564
				90°	8,595	0	8,595	7,162.54	180	149.98	17,832	9,577	26,400
				180°	8,595	360	9,314	7,761.74	0	0.00	17,985	9,782	27,014
				270°	8,595	0	8,595	7,162.54	-180	-149.98	17,832	9,577	26,400
Wind, test, corroded Attack angle = 45°	34,380	1,080	4,075	0°	5,157	-191	4,649	3,873.83	-191	-159.08	14,852	7,745	19,622
				90°	5,157	-191	4,649	3,873.83	191	159.08	14,852	7,745	19,622

				180°	8,595	191	9,103	7,586.24	191	159.08	18,016	9,747	26,955
				270°	8,595	191	9,103	7,586.24	-191	-159.08	18,016	9,747	26,955
Wind, vacuum, corroded Attack angle = 0°	24,873	2,800	15,634	0°	3,731	-933	972	809.88	0	0.00	1,207	712	-5,867
				90°	6,218	0	6,218	5,181.78	467	388.86	-5,759	-3,358	-12,977
				180°	6,218	933	8,977	7,480.96	0	0.00	-9,123	-5,062	-20,547
				270°	6,218	0	6,218	5,181.78	-467	-388.86	-5,759	-3,358	-12,977
Wind, vacuum, corroded Attack angle = 45°	24,873	2,800	15,634	0°	3,731	-495	1,780	1,483.29	-495	-412.45	-1,556	1,089	-6,428
				90°	3,731	-495	1,780	1,483.29	495	412.45	-1,556	1,089	-6,428
				180°	6,218	495	8,169	6,807.55	495	412.45	-7,940	-4,497	-17,982
				270°	6,218	495	8,169	6,807.55	-495	-412.45	-7,940	-4,497	-17,982
Seismic, operating, corroded Attack angle = 0°	24,873	3,164	24,903	0°	3,452	-1,055	-942	-785.31	0	0.00	7,841	4,107	12,415
				90°	6,497	0	6,497	5,413.92	527	439.42	11,093	6,046	17,573
				180°	6,497	1,055	10,891	9,076.15	0	0.00	13,401	7,751	23,509
				270°	6,497	0	6,497	5,413.92	-527	-439.42	11,093	6,046	17,573
Seismic, operating, corroded Attack angle = 45°	24,873	3,164	24,903	0°	3,452	-559	345	287.33	-559	-466.08	6,761	4,534	13,166
				90°	3,452	-559	345	287.33	559	466.08	6,761	4,534	13,166
				180°	6,497	559	9,604	8,003.51	559	466.08	12,949	7,326	22,133
				270°	6,497	559	9,604	8,003.51	-559	-466.08	12,949	7,326	22,133
Seismic, operating, new Attack angle = 0°	25,570	3,257	24,999	0°	3,549	-1,086	-863	-718.79	0	0.00	6,045	3,186	9,454
				90°	6,679	0	6,679	5,565.64	543	452.35	8,522	4,665	13,739
				180°	6,679	1,086	11,090	9,241.97	0	0.00	10,181	5,883	18,197
				270°	6,679	0	6,679	5,565.64	-543	-452.35	8,522	4,665	13,739
Seismic, operating, new Attack angle = 45°	25,570	3,257	24,999	0°	3,549	-576	430	357.98	-576	-479.79	5,367	3,466	9,845
				90°	3,549	-576	430	357.98	576	479.79	5,367	3,466	9,845
				180°	6,679	576	9,798	8,165.20	576	479.79	9,855	5,585	17,172
				270°	6,679	576	9,798	8,165.20	-576	-479.79	9,855	5,585	17,172
Seismic, empty, corroded Attack angle = 0°	19,718	2,513	7,146	0°	2,737	-838	1,476	1,229.82	0	0.00	2,205	1,045	5,262
				90°	5,150	0	5,150	4,291.85	419	349.05	-4,188	-2,490	10,457
				180°	5,150	838	6,411	5,342.69	0	0.00	-6,218	-3,432	-14,786
				270°	5,150	0	5,150	4,291.85	-419	-349.05	-4,188	-2,490	10,457
Seismic, empty, corroded Attack angle = 45°	19,718	2,513	7,146	0°	2,737	-444	1,845	1,537.60	-444	-370.22	2,033	1,294	5,867
				90°	2,737	-444	1,845	1,537.60	444	370.22	2,033	1,294	5,867
				180°	5,150	444	6,042	5,034.90	444	370.22	-5,446	-3,097	-13,205
				270°	5,150	444	6,042	5,034.90	-444	-370.22	-5,446	-3,097	-13,205
Seismic, empty, new Attack angle = 0°	20,421	2,607	6,982	0°	2,834	-869	1,602	1,335.31	0	0.00	1,658	828	3,886
				90°	5,334	0	5,334	4,445.05	435	362.10	-3,103	-1,874	8,323
				180°	5,334	869	6,566	5,471.80	0	0.00	-4,546	-2,572	-11,629
				270°	5,334	0	5,334	4,445.05	-435	-362.10	-3,103	-1,874	8,323
Seismic, empty, new Attack angle = 45°	20,421	2,607	6,982	0°	2,834	-461	1,963	1,636.04	-461	-384.06	1,527	919	4,192
				90°	2,834	-461	1,963	1,636.04	461	384.06	1,527	919	4,192
				180°	5,334	461	6,205	5,171.07	461	384.06	-3,995	-2,321	-10,417
				270°	5,334	461	6,205	5,171.07	-461	-384.06	-3,995	-2,321	-10,417

Seismic, vacuum, corroded Attack angle = 0°	24,873	3,164	24,903	0°	3,452	-1,055	-942	-785.31	0	0.00	1,328	850	-6,536
				90°	6,497	0	6,497	5,413.92	527	439.42	-5,986	-3,493	-13,544
				180°	6,497	1,055	10,891	9,076.15	0	0.00	-10,824	-6,036	-24,689
				270°	6,497	0	6,497	5,413.92	-527	-439.42	-5,986	-3,493	-13,544
Seismic, vacuum, corroded Attack angle = 45°	24,873	3,164	24,903	0°	3,452	-559	345	287.33	-559	-466.08	-742	1,277	-7,161
				90°	3,452	-559	345	287.33	559	466.08	-742	1,277	-7,161
				180°	6,497	559	9,604	8,003.51	559	466.08	-9,184	-5,217	-21,032
				270°	6,497	559	9,604	8,003.51	-559	-466.08	-9,184	-5,217	-21,032

Applied Loads (Seismic, operating, corroded, Attack angle = 0° , lug orientation = 180°)	
Radial load, P_r	1,054.62 lb_f
Circumferential moment, M_c	0 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	108,913.8 lb_f-in
Longitudinal shear, V_L	10,891.38 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	61.16 psi
Mean shell radius, R_m	23.875"
Local shell thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 23.875 / 0.25 = 95.5$

$C_1 = 7$, $C_2 = 8$ in

Local circumferential pressure stress = $P*R_i / T$ =5,810 psi

Local longitudinal pressure stress = $P*R_i / (2*T)$ =2,905 psi

Maximum combined stress (P_L+P_b+Q) = 23,509 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 13,401 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**	**β**	**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	2.1827	0.3385	0	0	0	0	-386	-386	-386	-386
4C*	7.1614	0.3239	-1,265	-1,265	-1,265	-1,265	0	0	0	0
1C	0.0614	0.3072	0	0	0	0	-6,216	6,216	-6,216	6,216
2C-1	0.0074	0.3072	-749	749	-749	749	0	0	0	0
3A*	2.201	0.3065	0	0	0	0	0	0	0	0
1A	0.0525	0.327	0	0	0	0	0	0	0	0
3B*	4.2252	0.3205	-8,856	-8,856	8,856	8,856	0	0	0	0
1B-1	0.0077	0.3106	-10,857	10,857	10,857	-10,857	0	0	0	0
Pressure stress*			5,810	5,810	5,810	5,810	5,810	5,810	5,810	5,810
Total circumferential stress			-15,917	7,295	23,509	3,293	-792	11,640	-792	11,640
Primary membrane circumferential stress*			-4,311	-4,311	13,401	13,401	5,424	5,424	5,424	5,424
3C*	2.3689	0.3239	-419	-419	-419	-419	0	0	0	0
4C*	6.8021	0.3385	0	0	0	0	-1,202	-1,202	-1,202	-1,202
1C-1	0.0179	0.3265	-1,812	1,812	-1,812	1,812	0	0	0	0
2C	0.03	0.3265	0	0	0	0	-3,037	3,037	-3,037	3,037
4A*	8.5965	0.3065	0	0	0	0	0	0	0	0
2A	0.0203	0.3506	0	0	0	0	0	0	0	0
4B*	2.3073	0.3205	-5,265	-5,265	5,265	5,265	0	0	0	0
2B-1	0.013	0.3381	-16,841	16,841	16,841	-16,841	0	0	0	0
Pressure stress*			2,905	2,905	2,905	2,905	2,905	2,905	2,905	2,905
Total longitudinal stress			-21,432	15,874	22,780	-7,278	-1,334	4,740	-1,334	4,740
Primary membrane longitudinal stress*			-2,779	-2,779	7,751	7,751	1,703	1,703	1,703	1,703
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	-1,361	-1,361	1,361	1,361
Total Shear stress			0	0	0	0	-1,361	-1,361	1,361	1,361
Combined stress (P_L+P_b+Q)			-21,432	15,874	23,509	-10,571	2,775	11,899	2,775	11,899
* denotes primary stress.										

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / T = 23.875 / 0.5 = 47.75$

$C_1 = 5$, $C_2 = 5.875$ in

Local circumferential pressure stress = $P*R_i / T$ =5,810 psi

Local longitudinal pressure stress = $P*R_i / (2*T)$ =2,905 psi

Maximum combined stress (P_L+P_b+Q) = 19,885 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 11,508 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the lug edge per WRC Bulletin 107										
Figure	**value**	**β**	**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	3.046	0.2486	0	0	0	0	-269	-269	-269	-269
4C*	5.9793	0.236	-528	-528	-528	-528	0	0	0	0
1C	0.0629	0.2216	0	0	0	0	-1,592	1,592	-1,592	1,592
2C-1	0.0262	0.2216	-663	663	-663	663	0	0	0	0
3A*	1.9294	0.221	0	0	0	0	0	0	0	0
1A	0.0661	0.2452	0	0	0	0	0	0	0	0
3B*	4.3097	0.2332	-6,226	-6,226	6,226	6,226	0	0	0	0
1B-1	0.019	0.2301	-9,040	9,040	9,040	-9,040	0	0	0	0
Pressure stress*			5,810	5,810	5,810	5,810	5,810	5,810	5,810	5,810
Total circumferential stress			-10,647	8,759	19,885	3,131	3,949	7,133	3,949	7,133
Primary membrane circumferential stress*			-944	-944	11,508	11,508	5,541	5,541	5,541	5,541
3C*	3.3104	0.236	-292	-292	-292	-292	0	0	0	0
4C*	5.7884	0.2486	0	0	0	0	-511	-511	-511	-511
1C-1	0.0492	0.2383	-1,245	1,245	-1,245	1,245	0	0	0	0
2C	0.0328	0.2383	0	0	0	0	-830	830	-830	830
4A*	4.1705	0.221	0	0	0	0	0	0	0	0
2A	0.0276	0.2636	0	0	0	0	0	0	0	0
4B*	1.943	0.2332	-3,216	-3,216	3,216	3,216	0	0	0	0
2B-1	0.0285	0.2509	-12,435	12,435	12,435	-12,435	0	0	0	0
Pressure stress*			2,905	2,905	2,905	2,905	2,905	2,905	2,905	2,905
Total longitudinal stress			-14,283	13,077	17,019	-5,361	1,564	3,224	1,564	3,224
Primary membrane longitudinal stress*			-603	-603	5,829	5,829	2,394	2,394	2,394	2,394
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	-927	-927	927	927
Total Shear stress			0	0	0	0	-927	-927	927	927
Combined stress (P_L+P_b+Q)			-14,283	13,077	19,885	-8,492	4,267	7,342	4,267	7,342
* denotes primary stress.										

Lug top plate required thickness, Bednar 5.2

$t_a = 0.75*(V_L*d*L)/(S_b*W_p^2*h)$
$= 0.75*(11{,}090.37*10*10)/(14{,}100*3.5^2*10)$
$= 0.4816$ in

The top plate thickness of 0.625 in is adequate.

Gusset plate required thickness, Bednar 5.2

$S_c = 10{,}575 / (1 + (1/10{,}575)*(h/(0.289*t_g))^2)$
$= 10{,}575 / (1 + (1/10{,}575)*(10/(0.289*0.5))^2)$
$= 7{,}279$ psi

$t_g = V_L*(3*d - b)/(S_c*b^2*\mathrm{Sin}(\alpha)^2)$
$= 11{,}090.37*(3*10 - 12)/(7{,}279*12^2*\mathrm{Sin}(49.635)^2)$
$= 0.3281$ in

The gusset thickness of 0.5 in is adequate.

Lug base plate required thickness

From Escoe table 4-8 (l/b = 1.6)

$C_x = 0.1246$, $C_y = -0.1242$

$f_c = V_L/(L_b*L)$
$= 11{,}090.37/(4*10)$
$= 277$ psi

$M_x = C_x*f_c*L_g^2$
$= 0.1246*277*7.5^2$
$= 1{,}943.24$ in-lb$_f$/in

$M_y = C_y*f_c*L_b^2$
$= -0.1242*277*4^2$
$= -550.97$ in-lb$_f$/in

$M = \mathrm{Max}[\mathrm{Abs}(M_x), \mathrm{Abs}(M_y)]$
$= \mathrm{Max}[\mathrm{Abs}(1{,}943.24), \mathrm{Abs}(-550.97)]$
$= 1{,}943.24$ in-lb$_f$/in

$t_b = \mathrm{Sqr}(6*M / S_b)$
$= \mathrm{Sqr}(6*1{,}943.2 / 14{,}100)$
$= 0.9093$ in

The base plate thickness of 1.125 in is adequate.

Support Lug to Pad Fillet Weld Sizing - Bednar chapters 5.2 and 10.3

Note: continuous welding is assumed for all support lug fillet welds.

$d_h = t_a + h + t_b$

$L_w = 2*(b + d_h) = 2*(10 + 11.75) = 43.5$ in
$Z_w = b*d_h + d_h^2/3 = 10*11.75 + 11.75^2/3 = 163.52$ in^2
$Z_z = d_h*b + b^2/3 = 11.75*10 + 10^2/3 = 150.83$ in^2

Shear $f_1 = V_L/L_w = 11{,}090.37/43.5 = 255$ lb_f/in
Shear $f_2 = V_c/L_w = 0/43.5 = 0$ lb_f/in
Bending f_3 = larger absolute value of M_L/Z_w or M_c/Z_z
$= M_L/Z_w$
$= 110{,}903.7/163.52$
$= 678.22$ lb_f/in

Resultant load $f = (f_1^2 + f_2^2 + f_3^2)^{1/2}$

$= (254.95^2 + 0^2 + 678.22^2)^{1/2}$
$= 724.56$ lb_f/in

Required weld size $w = F/(0.707*0.55*S_a)$

$= 724.56/(0.707*0.55*14{,}100)$
$= 0.1322$ in

The support lug fillet weld size of 0.25 in is adequate.

Support Lug Pad to Shell Fillet Weld Sizing - Bednar chapters 5.2 and 10.3

$L_w = 2*(b + d_h) = 2*(14 + 16) = 60$ in
$Z_w = b*d_h + d_h^2/3 = 14*14 + 16^2/3 = 309.33$ in^2
$Z_z = d_h*b + b^2/3 = 16*14 + 14^2/3 = 289.33$ in^2

Shear $f_1 = V_L/L_w = 11{,}090.37/60 = 185$ lb_f/in
Shear $f_2 = V_c/L_w = 0/60 = 0$ lb_f/in
Bending f_3 = larger absolute value of M_L/Z_w or M_c/Z_z
$= M_L/Z_w$
$= 110{,}903.7/309.33$
$= 358.52$ lb_f/in

Resultant load $f = (f_1^2 + f_2^2 + f_3^2)^{1/2}$

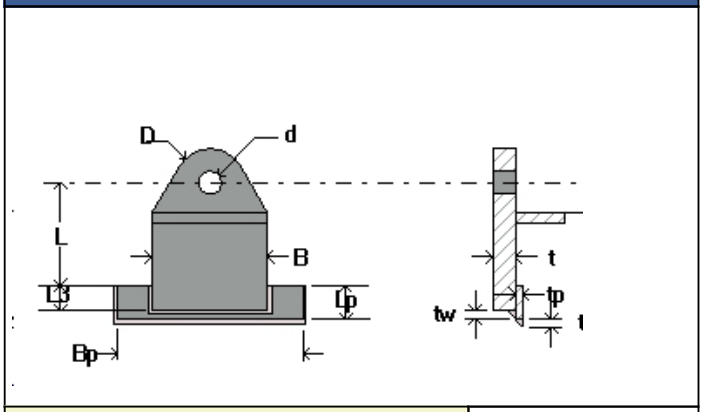
$= (184.84^2 + 0^2 + 358.52^2)^{1/2}$
$= 403.37$ lb_f/in

Required weld size $w = F/(0.707*0.55*S_a)$

$= 403.37/(0.707*0.55*14{,}100)$
$= 0.0736$ in

The support lug pad fillet weld size of 0.25 in is adequate.

Lift Lugs

Geometry Inputs	
	
Attached To	Bonnet Shell
Material	SA-240 304/304L
Distance of Lift Point From Datum	-48.875"
Angular Position	90° and 270°
Length, L	8.5"
Width, B	10"
Thickness, t	1"
Hole Diameter, d	2"
Pin Diameter, Dp	1.5"
Diameter at Pin, D	6"
Length to Brace Plate, L_1	2.5"
Load Angle from Vertical, ϕ	0°
Has Brace Plate	Yes
Welds	
Size, t_w	0.3125"
Reinforcement Pad	
Width, B_p	16"
Length, L_p	3"
Thickness, t_p	0.3125"
Weld Size, t_{wp}	0.3125"
Weld Length, L_3	2.5"

Intermediate Values	
Load Factor	2.0000
Vessel Weight (new, incl. Load Factor), W	40,842.7 lb
Lug Weight (new), W_{lug}	89.2 lb (Qty=2)
Distance from Center of Gravity to Top Lug, l_1	60.5743"
Distance from Center of Gravity to Tail Lug, l_2	111.4257"
Distance from Vessel Center Line to Tail Lug, l_3	28.0625"
Allowable Stress, Tensile, σ_t	10,000 psi
Allowable Stress, Shear, σ_s	6,667 psi
Allowable Stress, Bearing, σ_p	15,000 psi
Allowable Stress, Bending, σ_b	11,112 psi
Allowable Stress, Weld Shear, $\tau_{allowable}$	11,000 psi
Allowable Stress set to 1/3 Sy per ASME B30.20	No

Summary Values	
Required Lift Pin Diameter, d_{reqd}	1.3964"
Required Lug Thickness, t_{reqd}	0.9076"
Estimated Brace Plate Length	2.1055"
Lug Stress Ratio, σ_{ratio}	0.64
Weld Shear Stress Ratio, τ_{ratio}	0.6
Lug Design	Acceptable
Local Stresses WRC 107	Acceptable
Maximum Out of Plane Lift Angle - Weak Axis Bending	19.94°

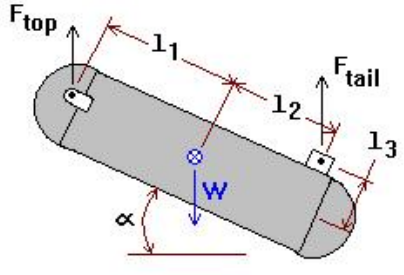
COMPRESS recommends a spreader beam be used to prevent weak axis bending of the top lugs.
Ear lug brace plate should be removed before vessel is put in service.

Lift Forces

Lift force on lugs during rotational lift ($0° \le \alpha \le 90°$):

$2*F_{top} = W*(l_2*\cos(\alpha) + l_3*\sin(\alpha)) / (l_1*\cos(\alpha) + l_2*\cos(\alpha) + l_3*\sin(\alpha))$

$F_{tail} = W - (2*F)$



α [°]	F_{top}[lbf]	F_{tail}[lbf]
0	13,229	14,384
15	13,531	13,781
30	13,849	13,146
45	14,238	12,366
60	14,814	11,215
75	15,951	8,940
90	20,421	0
17[1]	13,571	13,700
17[2]	13,571	13,700
20[3]	13,633	13,578
[1]Lift angle at maximum lug stress.		
[2]Lift angle at maximum weld stress.		
[3]Lift angle at maximum pad weld stress.		
Shell angle at lift lug	0.00°	

Lug Pin Diameter - Shear stress

$d_{reqd} = (2*F_v / (\pi*\sigma_s))^{0.5}$
$= (2*20,421 / (\pi*6,667))^{0.5} = 1.3964"$

$d_{reqd} / D_p = 1.3964 / 1.5 = 0.93$ Acceptable

$\sigma = F_v / A$
$= F_v / (2*(0.25*\pi*D_p^2))$
$= 20,421 / (2*(0.25*\pi*1.5^2)) = 5,778$ psi

$\sigma / \sigma_s = 5,778 / 6,667 = 0.87$ Acceptable

Lug Thickness - Tensile stress

$t_{reqd} = F_v / ((D - d)*\sigma_t)$
$= 20,421 / ((6 - 2)*10,000) = 0.5105"$

$t_{reqd} / t = 0.5105 / 1 = 0.51$ Acceptable

$\sigma = F_v / A$
$= F_v / ((D - d)*t)$
$= 20,421 / ((6 - 2)*1) = 5,105$ psi

$\sigma / \sigma_t = 5,105 / 10,000 = 0.51$ Acceptable

Lug Thickness - Bearing stress

t_{reqd} = $F_v / (D_p * \sigma_p)$
= 20,421 / (1.5*15,000) = 0.9076"

t_{reqd} / t = 0.9076 / 1 = 0.91 Acceptable

σ = $F_v / A_{bearing}$
= $F_v / (D_p * (t))$
= 20,421 / (1.5*(1)) = 13,614 psi

σ / σ_p = 13,614 / 15,000 = 0.91 Acceptable

Lug Thickness - Shear stress

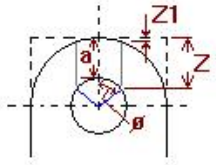
t_{reqd} = $[F_v / \sigma_s] / (2 * L_{shear})$
= (20,421 / 6,667) / (2*2.1451) = 0.714"

t_{reqd} / t = 0.714 / 1 = 0.71 Acceptable

τ = F_v / A_{shear}
= $F_v / (2 * t * L_{shear})$
= 20,421 / (2*1*2.1451) = 4,760 psi

τ / σ_s = 4,760 / 6,667 = 0.71 Acceptable

Shear stress length (per Pressure Vessel and Stacks, A. Keith Escoe)



ϕ = $55 * D_p / d$
= 55*1.5 / 2
= 41.25°

Z = $0.5*(D - d) + 0.5*D_p*(1 - \cos(\phi))$
= 0.5*(6 - 2) + 0.5*1.5*(1 - cos(41.25))
= 2.1861"

Z1 = $0.5*D - \text{sqr}(0.25*D*D - (0.5*D_p*\sin(\phi))^2)$
= $0.5*6 - \text{sqr}(0.25*6*6 - (0.5*1.5*\sin(41.25))^2)$
= 0.041"

L_{shear} = Z - Z1
= 2.1451"

Lug Plate Stress

Lug stress, tensile + bending, during rotational lift:

σ_{ratio} = $[F_{ten} / (A_{ten}*\sigma_t)] + [M_{bend} / (Z_{bend}*\sigma_b)] \le 1$

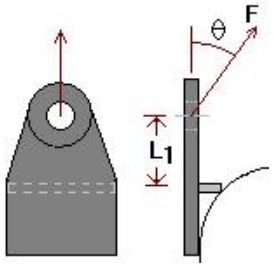
= $[(F_{top}(\alpha)*\sin(\alpha)) / (t*B*\sigma_t)] + [(6*F_{top}(\alpha)*L*\cos(\alpha)) / (t*B^2*\sigma_b)] \le 1$

= $13{,}571*\sin(17.0) / (1*10*10{,}000) + 6*(13{,}571)*8.5*\cos(17.0) / (1*10^2*11{,}112)$

= 0.64 Acceptable

Weak Axis Bending Stress

Maximum lift cable angle from vertical θ = 19.94°



σ_b = M / Z = $(F*\sin(\theta)*L_1) / Z$

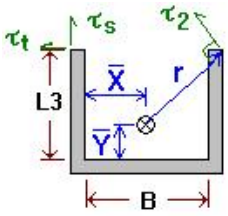
$F*\cos(\theta)$ = 0.5*W => $F = 0.5*W / \cos(\theta)$

θ = $\arctan((2*\sigma_b*Z) / (W*L_1))$

θ = $\arctan((2*11{,}112*(10*1^2/6)) / (40{,}843*2.5))$ = 19.94°

Loading on brace plate and head are not considered.

Weld Stress



Weld stress, direct and torsional shear, during rotational lift:

Direct shear:

Maximum weld shear stress occurs at lift angle 17.00° ; lift force = 13,571 lb_f

A_{weld} = $0.707*t_w*(2*L_3 + 2*B)$

= $0.707*0.3125*(2*2.5 + 2*10)$ = 5.5234 in^2

τ_t = $F_{lug}*\cos(\alpha) / A_{weld}$

= $13{,}571*\cos(17.0) / 5.5234$ = 2,350 psi

τ_s = F_{lug}*sin(α) / A_{weld}

= 13,571*sin(17.0) / 5.5234 = 718 psi

Torsional shear:

Weld centroid:

Weld areas

A_i	=	0.707*t_w*L_i	
A_1	=	0.707*0.3125*2.5	= 0.5523 in^2
A_4	=	0.707*0.3125*10	= 2.2094 in^2
A_7	=	0.707*0.3125*2.5	= 0.5523 in^2
A_8	=	0.707*0.3125*10	= 2.2094 in^2 (brace plate)
$A_{weld\ torsion}$	=	Σ A_i	= 5.5234 in^2

Weld centroid locations

x_1 = 0"
y_1 = 1.25"
x_4 = 5"
y_4 = 0"
x_7 = 10"
y_7 = 1.25"
x_8 = 5"
y_8 = 8.5"
X_{bar} = Σ (A_i*x_i) / ΣA_i
Y_{bar} = Σ (A_i*y_i) / ΣA_i
X_{bar} = (0.5523*0 + 2.2094*5 + 0.5523*10 + 2.2094*5) / 5.5234 = 5"
Y_{bar} = (0.5523*1.25 + 2.2094*0 + 0.5523*1.25 + 2.2094*8.5) / 5.5234 = 3.65"

Radius to centroid locations

r_i	=	sqr((X_{bar} - x_i)^2 + (Y_{bar} - y_i)^2)		
r_1	=	sqr((5 - 0)^2 + (3.65 - 1.25)^2)	=	5.5462"
r_4	=	sqr((5 - 5)^2 + (3.65 - 0)^2)	=	3.65"
r_7	=	sqr((5 - 10)^2 + (3.65 - 1.25)^2)	=	5.5462"
r_8	=	sqr((5 - 5)^2 + (3.65 - 8.5)^2)	=	4.85"

Polar Moment of Area

J_i = 0.707*t_w*(L_i^3) / 12

J_1 = 0.707*0.3125*(2.5^3) / 12 = 0.2877 in^4

$J_4 = \frac{0.707*0.3125*(10^3)}{12} = 18.4115\ in^4$

$J_7 = \frac{0.707*0.3125*(2.5^3)}{12} = 0.2877\ in^4$

$J_8 = \frac{0.707*0.3125*(10^3)}{12} = 18.4115\ in^4$

$J = \Sigma (J_i + A_i*r_i^2)$ Parallel axis theorem

$J = [0.2877 + 0.5523*(5.5462)^2 + (18.4115 + 2.2094*(3.65)^2) + (0.2877 + 0.5523*(5.5462)^2) + (18.4115 + 2.2094*(4.85)^2)\ ] = 152.78\ in^4$

Radial distance from centroid to weld:

$r = sqr(X_{bar}^2 + ((L_3 + L - L_1) - Y_{bar})^2)$

$= sqr(5^2 + (8.5 - 3.65)^2) = 6.9658"$

$\theta_r = arctan(((L_3 + L - L_1) - Y_{bar}) / (X_{bar}))$

$= arctan(4.85 / 5) = 44.13°$

$\tau_2 = M * r / J$

$= [F(\alpha)*cos(\alpha)*(L + L_3 - Y_{bar})] * r / J$

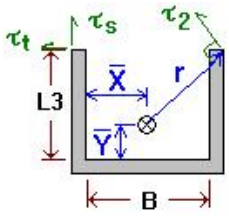
$= (13{,}571*cos(17.0)*7.35)*6.9658 / 152.7829$

$= 4{,}349\ psi$

$\tau_{ratio} = sqr((\tau_t + \tau_2*sin(\theta_r))^2 + (\tau_s + \tau_2*cos(\theta_r))^2) / \tau_{allowable} \le 1$

$= sqr ((2{,}350 + 4{,}349*sin(44.13))^2 + (718 + 4{,}349*cos(44.13))^2) / 11{,}000$

$= 0.60$ Acceptable



Pad Weld Stress

Direct shear:

Maximum weld shear stress occurs at lift angle 20.00° ; lift force = 13,633 lb_f

$A_{weld} = 0.707*t_{wp}*(2*L_p + B_p)$

$= 0.707*0.3125*(2*3 + 16) = 4.8606\ in^2$

$\tau_t = F_{lug}*cos(\alpha) / A_{weld}$

$= 13{,}633*cos(20.0) / 4.8606 = 2{,}636\ psi$

$\tau_s = F_{lug}*sin(\alpha) / A_{weld}$

$= 13{,}633*sin(20.0) / 4.8606 = 959\ psi$

Torsional shear:

Weld centroid:

$Y_{barp} = L_p^2 / (2*L_p + B_p)$
$= 3^2 / (2*3 + 16) \quad = 0.4091"$

Second polar moment of area:

$J_p = 0.707*t_{wp}*((8*L_p^3 + 6*L_p*B_p^2 + B_p^3) / 12 - L_p^4 / (2*L_p + B_p))$
$= 0.707*0.3125* ((8*3^3 + 6*3*16^2 + 16^3) / 12 - 3^4 / (2*3 + 16)) \quad = 163.42 \text{ in}^4$

Radial distance from centroid to weld:

$r_p = sqr((X_{barp})^2 + (L_p - Y_{barp})^2)$
$= sqr((0.5*16)^2 + (3 - 0.4091)^2) \quad = 8.4091"$

$\theta_r = arctan((L_p - Y_{barp}) / (X_{barp}))$
$= arctan(2.5909 / 8) \quad = 17.95°$

$\tau_2 = M * r_p / J_p$
$= [F(\alpha)*cos(\alpha)*(L + L_p - Y_{barp})] * r_p / J_p$
$= (13{,}633*cos(20.0)*11.0909)*8.4091 / 163.4168$
$= 7{,}311 \text{ psi}$

$\tau_{ratio} = sqr((\tau_t + \tau_2*sin(\theta_r))^2 + (\tau_s + \tau_2*cos(\theta_r))^2) / \tau_{allowable} \le 1$
$= sqr ((2{,}636 + 7{,}311*sin(17.95))^2 + (959 + 7{,}311*cos(17.95))^2) / 11{,}000$
$= 0.85 \quad$ Acceptable

WRC 107 Analysis

Maximum stress ratio occurs at lift angle = 90.00° with lift force = 20,421 lb_f

Geometry	
Height (radial)	1"
Width (circumferential)	10"
Length	2.5"
Fillet Weld Size:	0.3125"
Located On	Bonnet Shell (2.5" from top end)
Location Angle	90.00° and 270.00°
Reinforcement Pad	
Thickness	0.3125"
Width	16"
Length	3"
Weld Size	0.3125"

Applied Loads	
Radial load, P_r	0 lb_f
Circumferential moment, M_c	0 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	16,592.3 lb_f-in
Longitudinal shear, V_L	20,421.35 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	0 psi
Mean shell radius, R_m	26.75"
Design factor	3

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / T = 26.75 / 0.8125 = 32.9231$

$C_1 = 5.3125$, $C_2 = 1.5625$ in

Local circumferential pressure stress = $P*R_i / T = 0$ psi

Local longitudinal pressure stress = $P*R_i / (2*T) = 0$ psi

Maximum combined stress (P_L+P_b+Q) = 8,042 psi
Allowable combined stress (P_L+P_b+Q) = $\pm 3*S = \pm 60{,}000$ psi

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = -762 psi
Allowable local primary membrane stress (P_L) = $\pm 1.5*S = \pm 30{,}000$ psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the lug edge per WRC Bulletin 107										
Figure	**value**	**β**	**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	5.2077	0.1	0	0	0	0	0	0	0	0
4C*	5.08	0.1663	0	0	0	0	0	0	0	0
1C	0.0876	0.1732	0	0	0	0	0	0	0	0
2C-1	0.0537	0.1732	0	0	0	0	0	0	0	0
3A*	1.1333	0.1321	0	0	0	0	0	0	0	0
1A	0.0845	0.1807	0	0	0	0	0	0	0	0
3B*	2.9774	0.0878	-762	-762	762	762	0	0	0	0
1B-1	0.0404	0.1413	-1,612	1,612	1,612	-1,612	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			-2,374	850	2,374	-850	0	0	0	0
Primary membrane circumferential stress*			-762	-762	762	762	0	0	0	0
3C*	3.8124	0.1663	0	0	0	0	0	0	0	0
4C*	5.8194	0.1	0	0	0	0	0	0	0	0
1C-1	0.1217	0.1249	0	0	0	0	0	0	0	0
2C	0.082	0.1249	0	0	0	0	0	0	0	0
4A*	1.7596	0.1321	0	0	0	0	0	0	0	0
2A	0.0505	0.1376	0	0	0	0	0	0	0	0
4B*	0.8116	0.0878	-117	-117	117	117	0	0	0	0
2B-1	0.0763	0.1028	-4,185	4,185	4,185	-4,185	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			-4,302	4,068	4,302	-4,068	0	0	0	0
Primary membrane longitudinal stress*			-117	-117	117	117	0	0	0	0
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	-4,021	-4,021	4,021	4,021
Total Shear stress			0	0	0	0	-4,021	-4,021	4,021	4,021
Combined stress (P_L+P_b+Q)			-4,302	4,068	4,302	-4,068	8,042	8,042	8,042	8,042
* denotes primary stress.										

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 26.75 / 0.5 = 53.5$

$C_1 = 7.25$, $C_2 = 1.8125$ in

Note: Actual lug $C_1 / C_2 > 4$, $C_1 / C_2 = 4$ used as this is the maximum ratio covered by WRC 107.

Local circumferential pressure stress = $P*R_i / T = 0$ psi

Local longitudinal pressure stress = $P*R_i / (2*T) = 0$ psi

Maximum combined stress (P_L+P_b+Q) = 11,266 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±60,000 psi

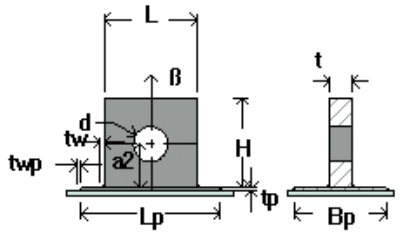
The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = -2,017 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±30,000 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**	**β**	**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	6.9156	0.1233	0	0	0	0	0	0	0	0
4C*	6.6344	0.2277	0	0	0	0	0	0	0	0
1C	0.0628	0.2385	0	0	0	0	0	0	0	0
2C-1	0.0207	0.2385	0	0	0	0	0	0	0	0
3A*	2.1653	0.1707	0	0	0	0	0	0	0	0
1A	0.0641	0.2436	0	0	0	0	0	0	0	0
3B*	6.0599	0.1076	-2,017	-2,017	2,017	2,017	0	0	0	0
1B-1	0.0255	0.177	-2,144	2,144	2,144	-2,144	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			-4,161	127	4,161	-127	0	0	0	0
Primary membrane circumferential stress*			-2,017	-2,017	2,017	2,017	0	0	0	0
3C*	3.644	0.2277	0	0	0	0	0	0	0	0
4C*	8.6371	0.1233	0	0	0	0	0	0	0	0
1C-1	0.074	0.1626	0	0	0	0	0	0	0	0
2C	0.0431	0.1626	0	0	0	0	0	0	0	0
4A*	4.1305	0.1707	0	0	0	0	0	0	0	0
2A	0.0361	0.1826	0	0	0	0	0	0	0	0
4B*	1.8183	0.1076	-254	-254	254	254	0	0	0	0
2B-1	0.0549	0.1244	-6,570	6,570	6,570	-6,570	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			-6,824	6,316	6,824	-6,316	0	0	0	0
Primary membrane longitudinal stress*			-254	-254	254	254	0	0	0	0
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	-5,633	-5,633	5,633	5,633
Total Shear stress			0	0	0	0	-5,633	-5,633	5,633	5,633
Combined stress (P_L+P_b+Q)			-6,824	6,316	6,824	-6,316	11,266	11,266	11,266	11,266
* denotes primary stress.										

Tailing Lug

Geometry Inputs	
	
Attached To	Vessel Body Mid Shell
Material	SA-240 304/304L
Orientation	Longitudinal
Distance of Lift Point From Datum	123.125"
Angular Position	0°
Length, L	8"
Height, H	7.75"
Thickness, t	1"
Hole Diameter, d	3"
Pin Diameter, Dp	2"
Load Eccentricity, a_1	0"
Distance from Load to Shell or Pad, a_2	3.75"
Load Angle Normal to Vessel, β	0°
Load Angle from Vertical, ϕ	-90°
Welds	
Size, t_w	0.375"
Reinforcement Pad	
Width, B_p	4"
Length, L_p	12"
Thickness, t_p	0.3125"
Weld Size, t_{wp}	0.3125"

Intermediate Values	
Load Factor	2.0000
Vessel Weight (new, incl. Load Factor), W	40,842.7 lb
Lug Weight (new), W_{lug}	21.1 lb
Distance from Center of Gravity to Top Lug, l_1	60.5743"
Distance from Center of Gravity to Tail Lug, l_2	111.4257"
Distance from Vessel Center Line to Tail Lug, l_3	28.0625"
Allowable Stress, Tensile, σ_t	10,000 psi
Allowable Stress, Shear, σ_s	6,667 psi
Allowable Stress, Bearing, σ_p	15,000 psi
Allowable Stress, Bending, σ_b	11,112 psi
Allowable Stress, Weld Shear, $\tau_{allowable}$	11,000 psi
Allowable Stress set to 1/3 Sy per ASME B30.20	No

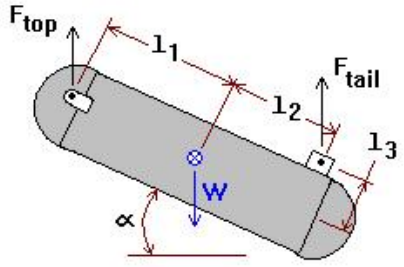
Summary Values	
Required Lift Pin Diameter, d_{reqd}	1.172"
Required Lug Thickness, t_{reqd}	0.4795"
Lug Stress Ratio, σ_{ratio}	0.39
Weld Shear Stress Ratio, τ_{ratio}	0.58
Lug Design	Acceptable
Local Stresses WRC 107	Acceptable

Lift Forces

Lift force on lugs during rotational lift ($0° \le \alpha \le 90°$):

$2*F_{top} = W*(l_2*\cos(\alpha) + l_3*\sin(\alpha)) / (l_1*\cos(\alpha) + l_2*\cos(\alpha) + l_3*\sin(\alpha))$

$F_{tail} = W - (2*F)$



α [°]	F_{top}[lbf]	F_{tail}[lbf]
0	13,229	14,384
15	13,531	13,781
30	13,849	13,146
45	14,238	12,366
60	14,814	11,215
75	15,951	8,940
90	20,421	0
50[1]	14,400	12,042
50[2]	14,400	12,042
45[3]	14,238	12,366
[1]Lift angle at maximum lug stress.		
[2]Lift angle at maximum weld stress.		
[3]Lift angle at maximum pad weld stress.		

Lug loading at α = 0°	
Total lift force	
$F = F_{top} / \cos(\phi)$	
$F = 14,384 / \cos(0.0) =$	14,384 lb_f
Tensile force (parallel to lug normal)	
$F_t = F*\cos(\beta)$	
$F_t = 14,384*\cos(0.0) =$	14,384 lb_f
Shear force (parallel to lug weld)	
$F_s = F*\sin(\beta)$	
$F_s = 14,384*\sin(0.0) =$	0 lb_f

Lug Pin Diameter - Shear stress

$d_{reqd} = (2*F / (\pi*\sigma_s))^{0.5}$
$= (2*14,384 / (\pi*6,667))^{0.5} = 1.172"$

$d_{reqd} / D_p = 1.172 / 2 = 0.59$ Acceptable

$\sigma = F / A$
$= F / (2*(0.25*\pi*D_p^2))$
$= 14,384 / (2*(0.25*\pi*2^2)) = 2,289$ psi

$\sigma / \sigma_s = 2,289 / 6,667 = 0.34$ Acceptable

Lug Thickness - Tensile stress

t_{reqd} = F_r / ((L - d)*σ_t)
= 14,384 / ((8 - 3)*10,000) = 0.2877"

t_{reqd} / t = 0.2877 / 1 = 0.29 Acceptable

σ = F_r / A
= F_r / ((L - d)*t)
= 14,384 / ((8 - 3)*1) = 2,877 psi

σ / σ_t = 2,877 / 10,000 = 0.29 Acceptable

Lug Thickness - Bearing stress

t_{reqd} = F / (D_p*σ_p)
= 14,384 / (2*15,000) = 0.4795"

t_{reqd} / t = 0.4795 / 1 = 0.48 Acceptable

σ = F / $A_{bearing}$
= F / (D_p*(t))
= 14,384 / (2*(1)) = 7,192 psi

σ / σ_p = 7,192 / 15,000 = 0.48 Acceptable

Lug Thickness - Shear stress

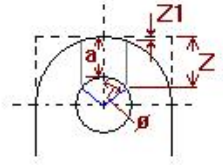
t_{reqd} = [F_v / σ_s] / (2*L_{shear})
= (14,384 / 6,667) / (2*2.6979) = 0.3998"

t_{reqd} / t = 0.3998 / 1 = 0.40 Acceptable

τ = F_v / A_{shear}
= F_v / (2*t*L_{shear})
= 14,384 / (2*1*2.6979) = 2,666 psi

τ / σ_s = 2,666 / 6,667 = 0.4 Acceptable

Shear stress length (per Pressure Vessel and Stacks, A. Keith Escoe)



ϕ = 55*D_p / d

$= 55*2 / 3$

$= 36.6667°$

$L_{shear} = (H - a2 - 0.5*d) + 0.5*D_p*(1 - \cos(\phi))$

$= (7.75 - 3.75 - 0.5*3) + 0.5*2*(1 - \cos(36.6667))$

$= 2.6979"$

Lug Plate Stress

Lug stress tensile + bending during lift:

$\sigma_{ratio} = [F_{ten} / (A_{ten}*\sigma_t)] + [M_{bend} / (Z_{bend}*\sigma_b)] \le 1$

$= [(F_{tail}(\alpha)*\cos(\alpha)) / (t*L*\sigma_t)] + [(6*abs(F_{tail}(\alpha)*\sin(\alpha)*Hght - F_{tail}(\alpha)*\cos(\alpha)*a_1)) / (t*L^2*\sigma_b)] \le 1$

$= 12,042*\cos(50.0) / (1*8*10,000) + 6*abs(12,042*\sin(50.0)*3.75 - 12,042*\cos(50.0)*0) / (1*8^2*11,112)$

$= 0.39$ Acceptable

Weld Stress

Weld stress, tensile, bending and shear during lift:

Direct shear:

Maximum shear stress occurs at lift angle 50.00° ; lift force = 12,042 lb_f

$F_{lug} = F_{top} / \cos(\phi)$

$= 12,042 / \cos(-90.0) = 12,042\ lb_f$

$A_{weld} = 2*(0.707)*t_w*(L + t)$

$= 2*(0.707)*0.375*(8 + 1) = 4.7723\ in^2$

$\tau_t = F_{tail}*\cos(\alpha) / A_{weld}$

$= 12,042*\cos(50.0) / 4.7723 = 1,622\ psi$

$\tau_s = F_{tail}*\sin(\alpha) / A_{weld}$

$= 12,042*\sin(50.0) / 4.7723 = 1,933\ psi$

$\tau_b = M * c / I$

$= 3*(F_{lug}*\sin(\beta)*Hght - F_{lug}*\cos(\beta)*a_1) / (0.707*h*L*(3*t + L))$

$= 3*abs(12,042*\sin(50.0)*3.75 - 12,042*\cos(50.0)*(0)) / (23.3310)$

$= 4,448\ psi$

$\tau_{ratio} = sqr((\tau_t + \tau_b)^2 + \tau_s^2) / \tau_{allowable} \le 1$

$= sqr ((1,622 + 4,448)^2 + (1,933)^2) / 11,000$

$= 0.58$ Acceptable

Pad Weld Stress, tensile, bending and shear during lift:

Direct shear:

Maximum shear stress occurs at lift angle 45.00° ; lift force = 12,366 lb_f

F_{lug} = F_{top} / cos(ϕ)

= 12,366 / cos(-90.0) = 12,366 lb_f

A_{weld} = 2*(0.707)*t_{wp}*(L_p + B_p)

= 2*(0.707)*0.3125*(12 + 4) = 7.07 in^2

τ_t = F_{tail}*cos(α) / A_{weld}

= 12,366*cos(45.0) / 7.07 = 1,237 psi

τ_s = F_{tail}*sin(α) / A_{weld}

= 12,366*sin(45.0) / 7.07 = 1,237 psi

τ_b = M * c / I

= 3*(F_{lug}*sin(β)*Hght - F_{lug}*cos(β)*a_1) / (0.707*h_p*L_p*(3*W_p + L_p))

= 3*abs(12,366*sin(45.0)*4.0625 - 12,366*cos(45.0)*(0)) / (63.6300)

= 1,675 psi

τ_{ratio} = sqr((τ_t + τ_b)^2 + τ_s^2) / $\tau_{allowable}$ ≤ 1

= sqr ((1,237 + 1,675)^2 + (1,237)^2) / 11,000

= 0.29 Acceptable

WRC 107 Analysis

Maximum stress ratio occurs at lift angle = 0.00° with lift force = 14,384 lb_f

Geometry	
Height (radial)	7.75"
Width (circumferential)	1"
Length	8"
Fillet Weld Size:	0.375"
Located On	Vessel Body Mid Shell (127.125" from bottom end)
Location Angle	0.00°
Reinforcement Pad	
Thickness	0.3125"
Width	4"
Length	12"

Weld Size	0.3125"

Applied Loads	
Radial load, P_r	-14,383.83 lb_f
Circumferential moment, M_c	0 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	0 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	0 psi
Mean shell radius, R_m	23.75"
Design factor	3

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / T = 23.75 / 0.8125 = 29.2308$

$C_1 = 0.875$, $C_2 = 3.5$ in

Note: Actual lug $C_1 / C_2 < 1 / 4$, $C_1 / C_2 = 1 / 4$ used as this is the minimum ratio covered by WRC 107.

Local circumferential pressure stress = $P*R_i / T = 0$ psi

Local longitudinal pressure stress = $P*R_i / (2*T) = 0$ psi

Maximum combined stress (P_L+P_b+Q) = 27,308 psi
Allowable combined stress (P_L+P_b+Q) = $\pm 3*S = \pm 60{,}000$ psi

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 3,963 psi
Allowable local primary membrane stress (P_L) = $\pm 1.5*S = \pm 30{,}000$ psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the lug edge per WRC Bulletin 107										
Figure	**value**	**β**	**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	4.5403	0.1091	0	0	0	0	3,384	3,384	3,384	3,384
4C*	5.3167	0.0884	3,963	3,963	3,963	3,963	0	0	0	0
1C	0.183	0.0648	0	0	0	0	23,924	-23,924	23,924	-23,924
2C-1	0.1445	0.0648	18,891	-18,891	18,891	-18,891	0	0	0	0
3A*	0.4233	0.0585	0	0	0	0	0	0	0	0
1A	0.1038	0.075	0	0	0	0	0	0	0	0
3B*	2.6303	0.0928	0	0	0	0	0	0	0	0
1B-1	0.0534	0.082	0	0	0	0	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			22,854	-14,928	22,854	-14,928	27,308	-20,540	27,308	-20,540
Primary membrane circumferential stress*			3,963	3,963	3,963	3,963	3,384	3,384	3,384	3,384
3C*	4.8944	0.0884	3,648	3,648	3,648	3,648	0	0	0	0
4C*	5.1298	0.1091	0	0	0	0	3,824	3,824	3,824	3,824
1C-1	0.1552	0.0921	20,289	-20,289	20,289	-20,289	0	0	0	0
2C	0.1128	0.0921	0	0	0	0	14,746	-14,746	14,746	-14,746
4A*	0.549	0.0585	0	0	0	0	0	0	0	0
2A	0.0561	0.1024	0	0	0	0	0	0	0	0
4B*	0.7189	0.0928	0	0	0	0	0	0	0	0
2B-1	0.075	0.1132	0	0	0	0	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			23,937	-16,641	23,937	-16,641	18,570	-10,922	18,570	-10,922
Primary membrane longitudinal stress*			3,648	3,648	3,648	3,648	3,824	3,824	3,824	3,824
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			23,937	-16,641	23,937	-16,641	27,308	-20,540	27,308	-20,540
* denotes primary stress.										

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 23.75 / 0.5 = 47.5$

$C_1 = 2.3125$, $C_2 = 6.3125$ in

Local circumferential pressure stress = $P*R_i / T = 0$ psi

Local longitudinal pressure stress = $P*R_i / (2*T) = 0$ psi

Maximum combined stress (P_L+P_b+Q) = 34,073 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±60,000 psi

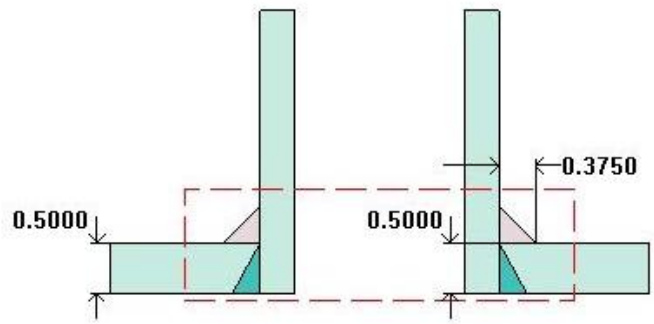
The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 8,111 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±30,000 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**	**β**	**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	3.5061	0.2261	0	0	0	0	4,247	4,247	4,247	4,247
4C*	6.6965	0.1881	8,111	8,111	8,111	8,111	0	0	0	0
1C	0.0864	0.1446	0	0	0	0	29,826	-29,826	29,826	-29,826
2C-1	0.0521	0.1446	17,986	-17,986	17,986	-17,986	0	0	0	0
3A*	1.8047	0.1361	0	0	0	0	0	0	0	0
1A	0.0805	0.159	0	0	0	0	0	0	0	0
3B*	4.8945	0.1902	0	0	0	0	0	0	0	0
1B-1	0.0283	0.1712	0	0	0	0	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			26,097	-9,875	26,097	-9,875	34,073	-25,579	34,073	-25,579
Primary membrane circumferential stress*			8,111	8,111	8,111	8,111	4,247	4,247	4,247	4,247
3C*	4.3991	0.1881	5,328	5,328	5,328	5,328	0	0	0	0
4C*	6.1012	0.2261	0	0	0	0	7,390	7,390	7,390	7,390
1C-1	0.0649	0.1949	22,404	-22,404	22,404	-22,404	0	0	0	0
2C	0.0369	0.1949	0	0	0	0	12,738	-12,738	12,738	-12,738
4A*	2.9916	0.1361	0	0	0	0	0	0	0	0
2A	0.0349	0.2022	0	0	0	0	0	0	0	0
4B*	1.9676	0.1902	0	0	0	0	0	0	0	0
2B-1	0.033	0.2159	0	0	0	0	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			27,732	-17,076	27,732	-17,076	20,128	-5,348	20,128	-5,348
Primary membrane longitudinal stress*			5,328	5,328	5,328	5,328	7,390	7,390	7,390	7,390
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			27,732	-17,076	27,732	-17,076	34,073	-25,579	34,073	-25,579
* denotes primary stress.										

Spare Conn (T1)

ASME Section VIII Division 1, 2013 Edition

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bonnet Shell
Orientation	90°
Nozzle center line offset to datum line	-17.625"
End of nozzle to shell center	33"
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.5"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Welds	
Inner Fillet, Leg_{41}	0.375"
Nozzle to vessel groove weld	0.5"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Local stresses at the nozzle OD per WRC 107 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 220.07 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	220.07	700	2,856	0	3,696	0	0	29,368	42,300	21,150	21,150	No

Calculations for internal pressure 220.07 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 220.0712*0.9685 / ((12,000 / 0.85)*1 - 0.6*220.0712)
= 0.0152 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o$ / (S*E + 0.4*P)
= 220.0712*27 / (14,100*1 + 0.4*220.0712)
= 0.4188 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o$ / (S*E + 0.4*P)
= 220.0712*27 / (14,100*0.85 + 0.4*220.0712)
= 0.4922 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 220.0712*0.9685 / (12,000*1 - 0.6*220.0712) + 0.125
= 0.143 in

$t_{a\ UG-22}$ = 0.1872 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.143 , 0.1872]
= 0.1872 in

t_{b1} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 220.0712*27 / (14,100*1 + 0.4*220.0712) + 0.0625
= 0.4813 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.4813 , 0.1875]
= 0.4813 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.4813]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]

= max[0.1872 , 0.2598]

= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	220.07 psi
Mean shell radius, R_m	26.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 26.7813 / 0.4375 = 61.2143$

$\beta = 0.875*r_o / R_m = 0.875*1.1875 / 26.7813 = 0.0388$

Pressure stress intensity factor, I = 1.5612 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =20,859 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =10,429 psi

Maximum combined stress (P_L+P_b+Q) = 29,368 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 21,150 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	11.8113	0	0	0	0	-706	-706	-706	-706
4C*	N_ϕ / (P / R_m)	11.4327	-683	-683	-683	-683	0	0	0	0
1C	M_ϕ / P	0.2036	0	0	0	0	-4,468	4,468	-4,468	4,468
2C-1	M_ϕ / P	0.1604	-3,520	3,520	-3,520	3,520	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.8485	0	0	0	0	-199	-199	199	199
1A	M_ϕ / [M_c / (R_m*β)]	0.1038	0	0	0	0	-8,944	8,944	8,944	-8,944
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.2099	-974	-974	974	974	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0596	-6,646	6,646	6,646	-6,646	0	0	0	0
Pressure stress*			20,859	20,859	20,859	20,859	13,361	13,361	13,361	13,361
Total circumferential stress			9,036	29,368	24,276	18,024	-956	25,868	17,330	8,378
Primary membrane circumferential stress*			19,202	19,202	21,150	21,150	12,456	12,456	12,854	12,854
3C*	N_x / (P / R_m)	11.8113	-706	-706	-706	-706	0	0	0	0
4C*	N_x / (P / R_m)	11.4327	0	0	0	0	-683	-683	-683	-683
1C-1	M_x / P	0.2012	-4,415	4,415	-4,415	4,415	0	0	0	0
2C	M_x / P	0.1569	0	0	0	0	-3,443	3,443	-3,443	3,443
4A*	N_x / [M_c / (R_m^2*β)]	1.0987	0	0	0	0	-258	-258	258	258
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-5,342	5,342	5,342	-5,342
4B*	N_x / [M_L / (R_m^2*β)]	0.8681	-264	-264	264	264	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.101	-11,262	11,262	11,262	-11,262	0	0	0	0
Pressure stress*			6,680	6,680	6,680	6,680	10,429	10,429	10,429	10,429
Total longitudinal stress			-9,967	21,387	13,085	-609	703	18,273	11,903	8,105
Primary membrane longitudinal stress*			5,710	5,710	6,238	6,238	9,488	9,488	10,004	10,004
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-19,003	29,368	24,276	-18,633	1,659	25,868	17,330	8,378
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 220.07*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,503 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 373.14 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.2408	0.2625	weld size is adequate

Calculations for internal pressure 373.14 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.687, 0.8435 + (0.344 - 0) + (0.5 - 0))
= 1.6875 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.344 - 0) + 0)
= 0.86 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 373.1371*0.8435 / ((17,000 / 0.85)*1 - 0.6*373.1371)
= 0.0159 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 373.1371*27 / (20,000*1 + 0.4*373.1371)
= 0.5 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $373.1371*27 / (20,000*0.85 + 0.4*373.1371)$
= 0.5875 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.344 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.2408 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= $373.1371*0.8435 / (17,000*1 - 0.6*373.1371)$ + 0
= 0.0188 in

$t_{a\ UG-22}$ = 0.0563 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0188 , 0.0563]
= 0.0563 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= $373.1371*27 / (20,000*1 + 0.4*373.1371)$ + 0
= 0.5 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.5 , 0.0625]
= 0.5 in

t_b = min[t_{b3} , t_{b1}]
= min[0.1348 , 0.5]
= 0.1348 in

t_{UG-45} = max[t_a , t_b]
= max[0.0563 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 120.36 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2246	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

Calculations for external pressure 120.36 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-28 t_{rn} = 0.0285 in

From UG-37(d)(1) required thickness t_r = 0.4375 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.1535 in

$t_{a\ UG\text{-}22}$ = 0.1684 in

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.1535 , 0.1684]
= 0.1684 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 120.3613*27 / (20,000*1 + 0.4*120.3613) + 0.0625
= 0.2246 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.2246 , 0.1875]
= 0.2246 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.2246]
= 0.2246 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.1684 , 0.2246]
= 0.2246 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

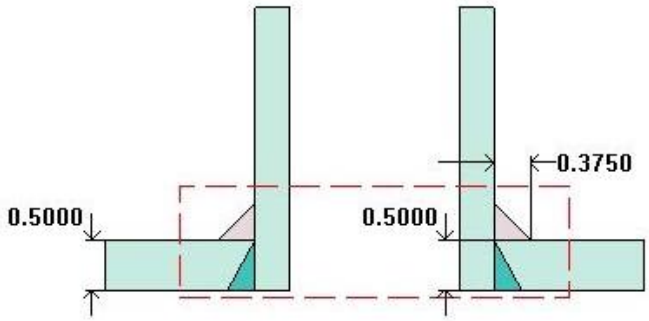
External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0261 / 2.375 = 2.5373
D_o / t = 2.375 / 0.0285 = 83.4050
From table G: A = 0.000659
From table HA-1: B = 7,529.1628 psi

P_a = $4*B / (3*(D_o / t))$
= 4*7,529.16 / (3*(2.375 / 0.0285))
= 120.36 psi

Design thickness for external pressure P_a = 120.36 psi

t_a = t + Corrosion = 0.0285 + 0.125 = 0.1535"

ASME Section VIII Division 1, 2013 Edition	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Bonnet Shell
Orientation	0°
Nozzle center line offset to datum line	-31.5"
End of nozzle to shell center	33"
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.5"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner Fillet, Leg_{41}	0.375"
Nozzle to vessel groove weld	0.5"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Local stresses at the nozzle OD per WRC 107 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 220.07 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	220.07	700	2,856	0	3,696	0	0	29,368	42,300	21,150	21,150	No

Calculations for internal pressure 220.07 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 220.0712*0.9685 / ((12,000 / 0.85)*1 - 0.6*220.0712)
= 0.0152 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o$ / (S*E + 0.4*P)
= 220.0712*27 / (14,100*1 + 0.4*220.0712)
= 0.4188 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o$ / (S*E + 0.4*P)
= 220.0712*27 / (14,100*0.85 + 0.4*220.0712)
= 0.4922 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 220.0712*0.9685 / (12,000*1 - 0.6*220.0712) + 0.125
= 0.143 in

$t_{a\ UG-22}$ = 0.1872 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.143 , 0.1872]
= 0.1872 in

t_{b1} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 220.0712*27 / (14,100*1 + 0.4*220.0712) + 0.0625
= 0.4813 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.4813 , 0.1875]
= 0.4813 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.4813]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]

= max[0.1872 , 0.2598]
= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	220.07 psi
Mean shell radius, R_m	26.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 26.7813 / 0.4375 = 61.2143$

$\beta = 0.875*r_o / R_m = 0.875*1.1875 / 26.7813 = 0.0388$

Pressure stress intensity factor, I = 1.5612 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =20,859 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =10,429 psi

Maximum combined stress (P_L+P_b+Q) = 29,368 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 21,150 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	11.8113	0	0	0	0	-706	-706	-706	-706
4C*	N_ϕ / (P / R_m)	11.4327	-683	-683	-683	-683	0	0	0	0
1C	M_ϕ / P	0.2036	0	0	0	0	-4,468	4,468	-4,468	4,468
2C-1	M_ϕ / P	0.1604	-3,520	3,520	-3,520	3,520	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.8485	0	0	0	0	-199	-199	199	199
1A	M_ϕ / [M_c / (R_m*β)]	0.1038	0	0	0	0	-8,944	8,944	8,944	-8,944
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.2099	-974	-974	974	974	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0596	-6,646	6,646	6,646	-6,646	0	0	0	0
Pressure stress*			20,859	20,859	20,859	20,859	13,361	13,361	13,361	13,361
Total circumferential stress			9,036	29,368	24,276	18,024	-956	25,868	17,330	8,378
Primary membrane circumferential stress*			19,202	19,202	21,150	21,150	12,456	12,456	12,854	12,854
3C*	N_x / (P / R_m)	11.8113	-706	-706	-706	-706	0	0	0	0
4C*	N_x / (P / R_m)	11.4327	0	0	0	0	-683	-683	-683	-683
1C-1	M_x / P	0.2012	-4,415	4,415	-4,415	4,415	0	0	0	0
2C	M_x / P	0.1569	0	0	0	0	-3,443	3,443	-3,443	3,443
4A*	N_x / [M_c / (R_m^2*β)]	1.0987	0	0	0	0	-258	-258	258	258
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-5,342	5,342	5,342	-5,342
4B*	N_x / [M_L / (R_m^2*β)]	0.8681	-264	-264	264	264	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.101	-11,262	11,262	11,262	-11,262	0	0	0	0
Pressure stress*			6,680	6,680	6,680	6,680	10,429	10,429	10,429	10,429
Total longitudinal stress			-9,967	21,387	13,085	-609	703	18,273	11,903	8,105
Primary membrane longitudinal stress*			5,710	5,710	6,238	6,238	9,488	9,488	10,004	10,004
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-19,003	29,368	24,276	-18,633	1,659	25,868	17,330	8,378
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 220.07*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,503 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 373.14 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.2408	0.2625	weld size is adequate

Calculations for internal pressure 373.14 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.687, 0.8435 + (0.344 - 0) + (0.5 - 0))
= 1.6875 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.344 - 0) + 0)
= 0.86 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 373.1371*0.8435 / ((17,000 / 0.85)*1 - 0.6*373.1371)
= 0.0159 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 373.1371*27 / (20,000*1 + 0.4*373.1371)
= 0.5 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $373.1371*27 / (20,000*0.85 + 0.4*373.1371)$
= 0.5875 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.344 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.2408 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P) + Corrosion$
= $373.1371*0.8435 / (17,000*1 - 0.6*373.1371) + 0$
= 0.0188 in

$t_{a\ UG-22}$ = 0.0563 in

t_a = $max[t_{a\ UG-27} , t_{a\ UG-22}]$
= max[0.0188 , 0.0563]
= 0.0563 in

t_{b1} = $P*R_o / (S*E + 0.4*P) + Corrosion$
= $373.1371*27 / (20,000*1 + 0.4*373.1371) + 0$
= 0.5 in

t_{b1} = $max[t_{b1} , t_{b\ UG16}]$
= max[0.5 , 0.0625]
= 0.5 in

t_b = $min[t_{b3} , t_{b1}]$
= min[0.1348 , 0.5]
= 0.1348 in

t_{UG-45} = $max[t_a , t_b]$
= max[0.0563 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 120.36 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2246	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

Calculations for external pressure 120.36 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-28 t_{rn} = 0.0285 in

From UG-37(d)(1) required thickness t_r = 0.4375 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.1535 in

$t_{a\ UG\text{-}22}$ = 0.1684 in

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.1535 , 0.1684]
= 0.1684 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 120.3613*27 / (20,000*1 + 0.4*120.3613) + 0.0625
= 0.2246 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.2246 , 0.1875]
= 0.2246 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.2246]
= 0.2246 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.1684 , 0.2246]
= 0.2246 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0261 / 2.375 = 2.5373
D_o / t = 2.375 / 0.0285 = 83.4050
From table G: A = 0.000659
From table HA-1: B = 7,529.1628 psi

P_a = $4*B / (3*(D_o / t))$
= 4*7,529.16 / (3*(2.375 / 0.0285))
= 120.36 psi

Design thickness for external pressure P_a = 120.36 psi

t_a = t + Corrosion = 0.0285 + 0.125 = 0.1535"

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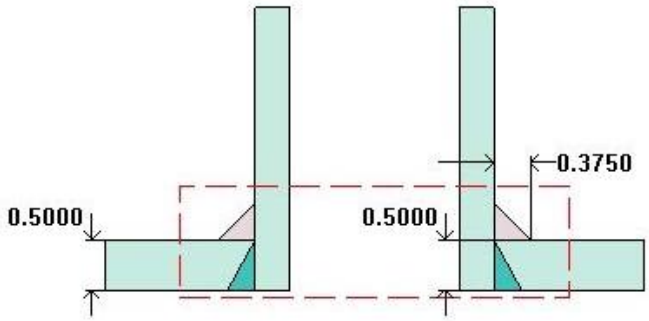

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bonnet Shell
Orientation	242°
Nozzle center line offset to datum line	-31.5"
End of nozzle to shell center	33"
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.5"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Welds	
Inner Fillet, Leg_{41}	0.375"
Nozzle to vessel groove weld	0.5"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Local stresses at the nozzle OD per WRC 107 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 220.07 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	220.07	700	2,856	0	3,696	0	0	29,368	42,300	21,150	21,150	No

Calculations for internal pressure 220.07 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 220.0712*0.9685 / ((12,000 / 0.85)*1 - 0.6*220.0712)
= 0.0152 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 220.0712*27 / (14,100*1 + 0.4*220.0712)
= 0.4188 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 220.0712*27 / (14,100*0.85 + 0.4*220.0712)
= 0.4922 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= 220.0712*0.9685 / (12,000*1 - 0.6*220.0712) + 0.125
= 0.143 in

$t_{a\ UG-22}$ = 0.1872 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.143 , 0.1872]
= 0.1872 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 220.0712*27 / (14,100*1 + 0.4*220.0712) + 0.0625
= 0.4813 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.4813 , 0.1875]
= 0.4813 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.4813]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]

= max[0.1872 , 0.2598]
= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	220.07 psi
Mean shell radius, R_m	26.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 26.7813 / 0.4375 = 61.2143$

$\beta = 0.875*r_o / R_m = 0.875*1.1875 / 26.7813 = 0.0388$

Pressure stress intensity factor, I = 1.5612 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =20,859 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =10,429 psi

Maximum combined stress (P_L+P_b+Q) = 29,368 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 21,150 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	11.8113	0	0	0	0	-706	-706	-706	-706
4C*	N_ϕ / (P / R_m)	11.4327	-683	-683	-683	-683	0	0	0	0
1C	M_ϕ / P	0.2036	0	0	0	0	-4,468	4,468	-4,468	4,468
2C-1	M_ϕ / P	0.1604	-3,520	3,520	-3,520	3,520	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.8485	0	0	0	0	-199	-199	199	199
1A	M_ϕ / [M_c / (R_m*β)]	0.1038	0	0	0	0	-8,944	8,944	8,944	-8,944
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.2099	-974	-974	974	974	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0596	-6,646	6,646	6,646	-6,646	0	0	0	0
Pressure stress*			20,859	20,859	20,859	20,859	13,361	13,361	13,361	13,361
Total circumferential stress			9,036	29,368	24,276	18,024	-956	25,868	17,330	8,378
Primary membrane circumferential stress*			19,202	19,202	21,150	21,150	12,456	12,456	12,854	12,854
3C*	N_x / (P / R_m)	11.8113	-706	-706	-706	-706	0	0	0	0
4C*	N_x / (P / R_m)	11.4327	0	0	0	0	-683	-683	-683	-683
1C-1	M_x / P	0.2012	-4,415	4,415	-4,415	4,415	0	0	0	0
2C	M_x / P	0.1569	0	0	0	0	-3,443	3,443	-3,443	3,443
4A*	N_x / [M_c / (R_m^2*β)]	1.0987	0	0	0	0	-258	-258	258	258
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-5,342	5,342	5,342	-5,342
4B*	N_x / [M_L / (R_m^2*β)]	0.8681	-264	-264	264	264	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.101	-11,262	11,262	11,262	-11,262	0	0	0	0
Pressure stress*			6,680	6,680	6,680	6,680	10,429	10,429	10,429	10,429
Total longitudinal stress			-9,967	21,387	13,085	-609	703	18,273	11,903	8,105
Primary membrane longitudinal stress*			5,710	5,710	6,238	6,238	9,488	9,488	10,004	10,004
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-19,003	29,368	24,276	-18,633	1,659	25,868	17,330	8,378
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 220.07*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,503 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 373.14 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.2408	0.2625	weld size is adequate

Calculations for internal pressure 373.14 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = $MAX(d, R_n + (t_n - C_n) + (t - C))$
= $MAX(1.687, 0.8435 + (0.344 - 0) + (0.5 - 0))$
= 1.6875 in

Outer Normal Limit of reinforcement per UG-40

L_H = $MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$
= $MIN(2.5*(0.5 - 0), 2.5*(0.344 - 0) + 0)$
= 0.86 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= $373.1371*0.8435 / ((17{,}000 / 0.85)*1 - 0.6*373.1371)$
= 0.0159 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= $373.1371*27 / (20{,}000*1 + 0.4*373.1371)$
= 0.5 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $373.1371*27 / (20,000*0.85 + 0.4*373.1371)$
= 0.5875 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.344 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.2408 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P) + Corrosion$
= $373.1371*0.8435 / (17,000*1 - 0.6*373.1371) + 0$
= 0.0188 in

$t_{a\ UG-22}$ = 0.0563 in

t_a = $max[t_{a\ UG-27} , t_{a\ UG-22}]$
= max[0.0188 , 0.0563]
= 0.0563 in

t_{b1} = $P*R_o / (S*E + 0.4*P) + Corrosion$
= $373.1371*27 / (20,000*1 + 0.4*373.1371) + 0$
= 0.5 in

t_{b1} = $max[t_{b1} , t_{b\ UG16}]$
= max[0.5 , 0.0625]
= 0.5 in

t_b = $min[t_{b3} , t_{b1}]$
= min[0.1348 , 0.5]
= 0.1348 in

t_{UG-45} = $max[t_a , t_b]$
= max[0.0563 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 120.36 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2246	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

Calculations for external pressure 120.36 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-28 t_{rn} = 0.0285 in

From UG-37(d)(1) required thickness t_r = 0.4375 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.1535 in

$t_{a\ UG\text{-}22}$ = 0.1684 in

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.1535 , 0.1684]
= 0.1684 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 120.3613*27 / (20,000*1 + 0.4*120.3613) + 0.0625
= 0.2246 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.2246 , 0.1875]
= 0.2246 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.2246]
= 0.2246 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.1684 , 0.2246]
= 0.2246 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

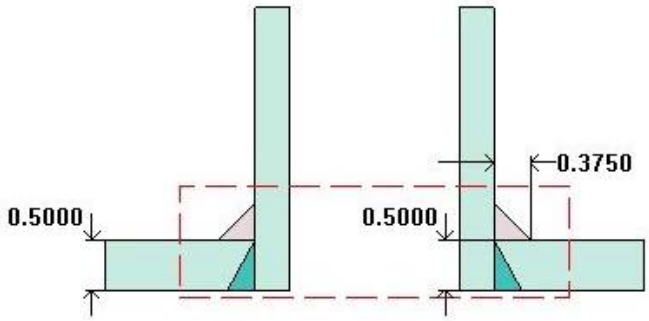
External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0261 / 2.375 = 2.5373
D_o / t = 2.375 / 0.0285 = 83.4050
From table G: A = 0.000659
From table HA-1: B = 7,529.1628 psi

P_a = $4*B / (3*(D_o / t))$
= 4*7,529.16 / (3*(2.375 / 0.0285))
= 120.36 psi

Design thickness for external pressure P_a = 120.36 psi

t_a = t + Corrosion = 0.0285 + 0.125 = 0.1535"

ASME Section VIII Division 1, 2013 Edition	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Bonnet Shell
Orientation	118°
Nozzle center line offset to datum line	-31.5"
End of nozzle to shell center	33"
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.5"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner Fillet, Leg_{41}	0.375"
Nozzle to vessel groove weld	0.5"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Local stresses at the nozzle OD per WRC 107 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 220.07 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	220.07	700	2,856	0	3,696	0	0	29,368	42,300	21,150	21,150	No

Calculations for internal pressure 220.07 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 220.0712*0.9685 / ((12,000 / 0.85)*1 - 0.6*220.0712)
= 0.0152 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 220.0712*27 / (14,100*1 + 0.4*220.0712)
= 0.4188 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 220.0712*27 / (14,100*0.85 + 0.4*220.0712)
= 0.4922 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= 220.0712*0.9685 / (12,000*1 - 0.6*220.0712) + 0.125
= 0.143 in

$t_{a\ UG-22}$ = 0.1872 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.143 , 0.1872]
= 0.1872 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 220.0712*27 / (14,100*1 + 0.4*220.0712) + 0.0625
= 0.4813 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.4813 , 0.1875]
= 0.4813 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.4813]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]

= max[0.1872 , 0.2598]

= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	220.07 psi
Mean shell radius, R_m	26.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 26.7813 / 0.4375 = 61.2143$

$\beta = 0.875*r_o / R_m = 0.875*1.1875 / 26.7813 = 0.0388$

Pressure stress intensity factor, I = 1.5612 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =20,859 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =10,429 psi

Maximum combined stress (P_L+P_b+Q) = 29,368 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 21,150 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	11.8113	0	0	0	0	-706	-706	-706	-706
4C*	N_ϕ / (P / R_m)	11.4327	-683	-683	-683	-683	0	0	0	0
1C	M_ϕ / P	0.2036	0	0	0	0	-4,468	4,468	-4,468	4,468
2C-1	M_ϕ / P	0.1604	-3,520	3,520	-3,520	3,520	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.8485	0	0	0	0	-199	-199	199	199
1A	M_ϕ / [M_c / (R_m*β)]	0.1038	0	0	0	0	-8,944	8,944	8,944	-8,944
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.2099	-974	-974	974	974	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0596	-6,646	6,646	6,646	-6,646	0	0	0	0
Pressure stress*			20,859	20,859	20,859	20,859	13,361	13,361	13,361	13,361
Total circumferential stress			9,036	29,368	24,276	18,024	-956	25,868	17,330	8,378
Primary membrane circumferential stress*			19,202	19,202	21,150	21,150	12,456	12,456	12,854	12,854
3C*	N_x / (P / R_m)	11.8113	-706	-706	-706	-706	0	0	0	0
4C*	N_x / (P / R_m)	11.4327	0	0	0	0	-683	-683	-683	-683
1C-1	M_x / P	0.2012	-4,415	4,415	-4,415	4,415	0	0	0	0
2C	M_x / P	0.1569	0	0	0	0	-3,443	3,443	-3,443	3,443
4A*	N_x / [M_c / (R_m^2*β)]	1.0987	0	0	0	0	-258	-258	258	258
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-5,342	5,342	5,342	-5,342
4B*	N_x / [M_L / (R_m^2*β)]	0.8681	-264	-264	264	264	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.101	-11,262	11,262	11,262	-11,262	0	0	0	0
Pressure stress*			6,680	6,680	6,680	6,680	10,429	10,429	10,429	10,429
Total longitudinal stress			-9,967	21,387	13,085	-609	703	18,273	11,903	8,105
Primary membrane longitudinal stress*			5,710	5,710	6,238	6,238	9,488	9,488	10,004	10,004
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-19,003	29,368	24,276	-18,633	1,659	25,868	17,330	8,378
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 220.07*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,503 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 373.14 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.2408	0.2625	weld size is adequate

Calculations for internal pressure 373.14 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.687, 0.8435 + (0.344 - 0) + (0.5 - 0))
= 1.6875 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.344 - 0) + 0)
= 0.86 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 373.1371*0.8435 / ((17,000 / 0.85)*1 - 0.6*373.1371)
= 0.0159 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 373.1371*27 / (20,000*1 + 0.4*373.1371)
= 0.5 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $373.1371*27 / (20,000*0.85 + 0.4*373.1371)$
= 0.5875 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.344 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.2408 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P) + Corrosion$
= $373.1371*0.8435 / (17,000*1 - 0.6*373.1371) + 0$
= 0.0188 in

$t_{a\ UG-22}$ = 0.0563 in

t_a = $max[t_{a\ UG-27} , t_{a\ UG-22}]$
= max[0.0188 , 0.0563]
= 0.0563 in

t_{b1} = $P*R_o / (S*E + 0.4*P) + Corrosion$
= $373.1371*27 / (20,000*1 + 0.4*373.1371) + 0$
= 0.5 in

t_{b1} = $max[t_{b1} , t_{b\ UG16}]$
= max[0.5 , 0.0625]
= 0.5 in

t_b = $min[t_{b3} , t_{b1}]$
= min[0.1348 , 0.5]
= 0.1348 in

t_{UG-45} = $max[t_a , t_b]$
= max[0.0563 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 120.36 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2246	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

Calculations for external pressure 120.36 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-28 t_{rn} = 0.0285 in

From UG-37(d)(1) required thickness t_r = 0.4375 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.1535 in

$t_{a\ UG\text{-}22}$ = 0.1684 in

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.1535 , 0.1684]
= 0.1684 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 120.3613*27 / (20,000*1 + 0.4*120.3613) + 0.0625
= 0.2246 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.2246 , 0.1875]
= 0.2246 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.2246]
= 0.2246 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.1684 , 0.2246]
= 0.2246 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

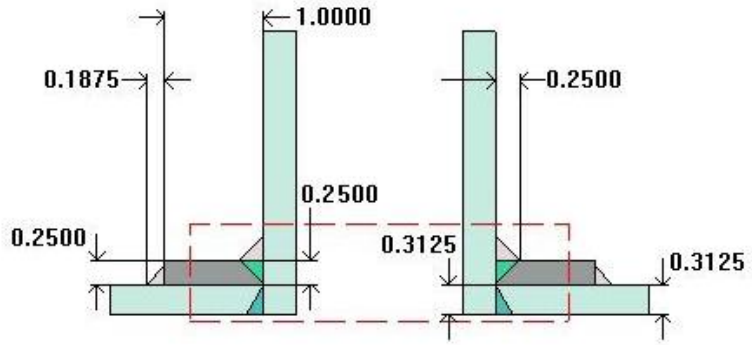
External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0261 / 2.375 = 2.5373
D_o / t = 2.375 / 0.0285 = 83.4050
From table G: A = 0.000659
From table HA-1: B = 7,529.1628 psi

P_a = $4*B / (3*(D_o / t))$
= 4*7,529.16 / (3*(2.375 / 0.0285))
= 120.36 psi

Design thickness for external pressure P_a = 120.36 psi

t_a = t + Corrosion = 0.0285 + 0.125 = 0.1535"

ASME Section VIII Division 1, 2013 Edition

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Vessel Body Upper Shell
Orientation	330°
Nozzle center line offset to datum line	106.8125"
End of nozzle to shell center	30"
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	4.375"
Thickness, t_e	0.25"

Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = t_r*E^* / (t_n - c) = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*24 / (20,000*1 + 0.4*61.16) =	0.0733"
Stress ratio = t_r*E^* / (t_n - c) = 0.0733*1 / (0.3125 - 0.0625) =	0.2932
Impact test exempt per UHA-51(g) (coincident ratio = 0.2932)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 147.49 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	147.49	700	2,856	0	3,696	0	0	31,802	42,300	15,480	21,150	No

Calculations for internal pressure 147.49 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 147.4865*0.9685 / ((12,000 / 0.85)*1 - 0.6*147.4865)
= 0.0102 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 147.4865*24 / (14,100*1 + 0.4*147.4865)
= 0.25 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 147.4865*24 / (14,100*0.85 + 0.4*147.4865)
= 0.2939 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 147.4865*0.9685 / (12,000*1 - 0.6*147.4865) + 0.125
= 0.137 in

$t_{a\ UG-22}$ = 0.1834 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.137 , 0.1834]
= 0.1834 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 147.4865*24 / (14,100*1 + 0.4*147.4865) + 0.0625
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.1875]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.3125]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]
= max[0.1834 , 0.2598]
= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	147.49 psi
Mean shell radius, R_m	23.875"
Local shell thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 23.875 / 0.25 = 95.5$

$\beta = 0.875*r_o / R_m = 0.875*2.1875 / 23.875 = 0.0802$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =14,011 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =7,006 psi

Maximum combined stress (P_L+P_b+Q) = 31,802 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 15,480 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	13.5763	0	0	0	0	-1,592	-1,592	-1,592	-1,592
4C*	N_ϕ / (P / R_m)	15.731	-1,845	-1,845	-1,845	-1,845	0	0	0	0
1C	M_ϕ / P	0.1089	0	0	0	0	-7,318	7,318	-7,318	7,318
2C-1	M_ϕ / P	0.0734	-4,932	4,932	-4,932	4,932	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	3.2512	0	0	0	0	-813	-813	813	813
1A	M_ϕ / [M_c / (R_m*β)]	0.0899	0	0	0	0	-12,878	12,878	12,878	-12,878
3B*	N_ϕ / [M_L / (R_m^2*β)]	10.2434	-3,314	-3,314	3,314	3,314	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0405	-7,508	7,508	7,508	-7,508	0	0	0	0
Pressure stress*			14,011	14,011	14,011	14,011	14,011	14,011	14,011	14,011
Total circumferential stress			-3,588	21,292	18,056	12,904	-8,590	31,802	18,792	7,672
Primary membrane circumferential stress*			8,852	8,852	15,480	15,480	11,606	11,606	13,232	13,232
3C*	N_x / (P / R_m)	13.5763	-1,592	-1,592	-1,592	-1,592	0	0	0	0
4C*	N_x / (P / R_m)	15.731	0	0	0	0	-1,845	-1,845	-1,845	-1,845
1C-1	M_x / P	0.1103	-7,412	7,412	-7,412	7,412	0	0	0	0
2C	M_x / P	0.0732	0	0	0	0	-4,919	4,919	-4,919	4,919
4A*	N_x / [M_c / (R_m^2*β)]	5.0007	0	0	0	0	-1,250	-1,250	1,250	1,250
2A	M_x / [M_c / (R_m*β)]	0.0502	0	0	0	0	-7,191	7,191	7,191	-7,191
4B*	N_x / [M_L / (R_m^2*β)]	3.247	-1,050	-1,050	1,050	1,050	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0621	-11,512	11,512	11,512	-11,512	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	7,006	7,006	7,006	7,006
Total longitudinal stress			-14,560	23,288	10,564	2,364	-8,199	16,021	8,683	4,139
Primary membrane longitudinal stress*			4,364	4,364	6,464	6,464	3,911	3,911	6,411	6,411
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-14,560	23,288	18,056	12,904	-8,590	31,802	18,792	7,672
* denotes primary stress.										

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 23.875 / 0.5 = 47.75$

$\beta = 0.875 * r_o / R_m = 0.875 * 1.1875 / 23.875 = 0.0435$

Pressure stress intensity factor, I = 0.9945 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =13,934 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =6,968 psi

Maximum combined stress (P_L+P_b+Q) = 23,660 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 14,127 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	8.9875	0	0	0	0	-527	-527	-527	-527
4C*	N_ϕ / (P / R_m)	9.1733	-538	-538	-538	-538	0	0	0	0
1C	M_ϕ / P	0.2005	0	0	0	0	-3,368	3,368	-3,368	3,368
2C-1	M_ϕ / P	0.1586	-2,664	2,664	-2,664	2,664	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.5977	0	0	0	0	-138	-138	138	138
1A	M_ϕ / [M_c / (R_m*β)]	0.1053	0	0	0	0	-6,946	6,946	6,946	-6,946
3B*	N_ϕ / [M_L / (R_m^2*β)]	2.4542	-731	-731	731	731	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0597	-5,097	5,097	5,097	-5,097	0	0	0	0
Pressure stress*			13,934	13,934	13,934	13,934	14,011	14,011	14,011	14,011
Total circumferential stress			4,904	20,426	16,560	11,694	3,032	23,660	17,200	10,044
Primary membrane circumferential stress*			12,665	12,665	14,127	14,127	13,346	13,346	13,622	13,622
3C*	N_x / (P / R_m)	8.9875	-527	-527	-527	-527	0	0	0	0
4C*	N_x / (P / R_m)	9.1733	0	0	0	0	-538	-538	-538	-538
1C-1	M_x / P	0.1998	-3,357	3,357	-3,357	3,357	0	0	0	0
2C	M_x / P	0.1559	0	0	0	0	-2,619	2,619	-2,619	2,619
4A*	N_x / [M_c / (R_m^2*β)]	0.8111	0	0	0	0	-187	-187	187	187
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-4,090	4,090	4,090	-4,090
4B*	N_x / [M_L / (R_m^2*β)]	0.6335	-189	-189	189	189	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.1022	-8,725	8,725	8,725	-8,725	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	6,968	6,968	6,968	6,968
Total longitudinal stress			-5,792	18,372	12,036	1,300	-466	12,952	8,088	5,146
Primary membrane longitudinal stress*			6,290	6,290	6,668	6,668	6,243	6,243	6,617	6,617
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-10,696	20,426	16,560	11,694	-3,498	23,660	17,200	10,044
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 147.49*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,304 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 261.78 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 261.78 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.687, 0.8435 + (0.344 - 0) + (0.3125 - 0))
= 1.687 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.344 - 0) + 0.25)
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 261.7811*0.8435 / ((17,000 / 0.85)*1 - 0.6*261.7811)
= 0.0111 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 261.7811*24 / (20,000*1 + 0.4*261.7811)
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 261.7811*24 / (20,000*0.85 + 0.4*261.7811)
= 0.3673 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= 261.7811*0.8435 / (17,000*1 - 0.6*261.7811) + 0
= 0.0131 in

$t_{a\ UG-22}$ = 0.053 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0131 , 0.053]
= 0.053 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 261.7811*24 / (20,000*1 + 0.4*261.7811) + 0
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.0625]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.1348 , 0.3125]
= 0.1348 in

t_{UG-45} = max[t_a , t_b]
= max[0.053 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 28.76 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1875	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 28.76 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-28 t_{rn} = 0.0147 in

From UG-37(d)(1) required thickness t_r = 0.2401 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-28}$ = 0.1397 in

$t_{a\ UG-22}$ = 0.1647 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1397 , 0.1647]
= 0.1647 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 28.7586*24 / (20,000*1 + 0.4*28.7586) + 0.0625
= 0.097 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.097 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.1647 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

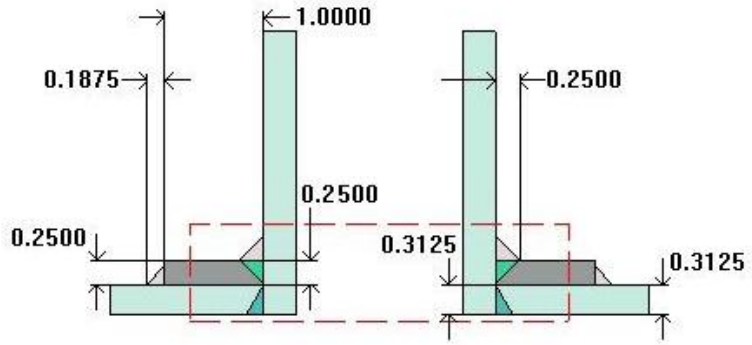
External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0294 / 2.375 = 2.5387
D_o / t = 2.375 / 0.0147 = 161.9877
From table G: A = 0.000249
From table HA-1: B = 3,493.8996 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,493.9 / (3*(2.375 / 0.0147))
= 28.76 psi

Design thickness for external pressure P_a = 28.76 psi

t_a = t + Corrosion = 0.0147 + 0.125 = 0.1397"

ASME Section VIII Division 1, 2013 Edition

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Vessel Body Upper Shell
Orientation	210°
Nozzle center line offset to datum line	106.8125"
End of nozzle to shell center	30"
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	4.375"
Thickness, t_e	0.25"

Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = t_r*E^* / (t_n - c) = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*24 / (20,000*1 + 0.4*61.16) =	0.0733"
Stress ratio = t_r*E^* / (t_n - c) = 0.0733*1 / (0.3125 - 0.0625) =	0.2932
Impact test exempt per UHA-51(g) (coincident ratio = 0.2932)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 147.49 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	147.49	700	2,856	0	3,696	0	0	31,802	42,300	15,480	21,150	No

Calculations for internal pressure 147.49 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 147.4865*0.9685 / ((12,000 / 0.85)*1 - 0.6*147.4865)
= 0.0102 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 147.4865*24 / (14,100*1 + 0.4*147.4865)
= 0.25 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 147.4865*24 / (14,100*0.85 + 0.4*147.4865)
= 0.2939 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 147.4865*0.9685 / (12,000*1 - 0.6*147.4865) + 0.125
= 0.137 in

$t_{a\ UG-22}$ = 0.1834 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.137 , 0.1834]
= 0.1834 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 147.4865*24 / (14,100*1 + 0.4*147.4865) + 0.0625
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.1875]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.3125]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]
= max[0.1834 , 0.2598]
= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	147.49 psi
Mean shell radius, R_m	23.875"
Local shell thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 23.875 / 0.25 = 95.5$

$\beta = 0.875*r_o / R_m = 0.875*2.1875 / 23.875 = 0.0802$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =14,011 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =7,006 psi

Maximum combined stress (P_L+P_b+Q) = 31,802 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 15,480 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	13.5763	0	0	0	0	-1,592	-1,592	-1,592	-1,592
4C*	N_ϕ / (P / R_m)	15.731	-1,845	-1,845	-1,845	-1,845	0	0	0	0
1C	M_ϕ / P	0.1089	0	0	0	0	-7,318	7,318	-7,318	7,318
2C-1	M_ϕ / P	0.0734	-4,932	4,932	-4,932	4,932	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	3.2512	0	0	0	0	-813	-813	813	813
1A	M_ϕ / [M_c / (R_m*β)]	0.0899	0	0	0	0	-12,878	12,878	12,878	-12,878
3B*	N_ϕ / [M_L / (R_m^2*β)]	10.2434	-3,314	-3,314	3,314	3,314	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0405	-7,508	7,508	7,508	-7,508	0	0	0	0
Pressure stress*			14,011	14,011	14,011	14,011	14,011	14,011	14,011	14,011
Total circumferential stress			-3,588	21,292	18,056	12,904	-8,590	31,802	18,792	7,672
Primary membrane circumferential stress*			8,852	8,852	15,480	15,480	11,606	11,606	13,232	13,232
3C*	N_x / (P / R_m)	13.5763	-1,592	-1,592	-1,592	-1,592	0	0	0	0
4C*	N_x / (P / R_m)	15.731	0	0	0	0	-1,845	-1,845	-1,845	-1,845
1C-1	M_x / P	0.1103	-7,412	7,412	-7,412	7,412	0	0	0	0
2C	M_x / P	0.0732	0	0	0	0	-4,919	4,919	-4,919	4,919
4A*	N_x / [M_c / (R_m^2*β)]	5.0007	0	0	0	0	-1,250	-1,250	1,250	1,250
2A	M_x / [M_c / (R_m*β)]	0.0502	0	0	0	0	-7,191	7,191	7,191	-7,191
4B*	N_x / [M_L / (R_m^2*β)]	3.247	-1,050	-1,050	1,050	1,050	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0621	-11,512	11,512	11,512	-11,512	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	7,006	7,006	7,006	7,006
Total longitudinal stress			-14,560	23,288	10,564	2,364	-8,199	16,021	8,683	4,139
Primary membrane longitudinal stress*			4,364	4,364	6,464	6,464	3,911	3,911	6,411	6,411
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-14,560	23,288	18,056	12,904	-8,590	31,802	18,792	7,672
* denotes primary stress.										

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 23.875 / 0.5 = 47.75$

$\beta = 0.875 * r_o / R_m = 0.875 * 1.1875 / 23.875 = 0.0435$

Pressure stress intensity factor, I = 0.9945 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =13,934 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =6,968 psi

Maximum combined stress (P_L+P_b+Q) = 23,660 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 14,127 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	8.9875	0	0	0	0	-527	-527	-527	-527
4C*	N_ϕ / (P / R_m)	9.1733	-538	-538	-538	-538	0	0	0	0
1C	M_ϕ / P	0.2005	0	0	0	0	-3,368	3,368	-3,368	3,368
2C-1	M_ϕ / P	0.1586	-2,664	2,664	-2,664	2,664	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.5977	0	0	0	0	-138	-138	138	138
1A	M_ϕ / [M_c / (R_m*β)]	0.1053	0	0	0	0	-6,946	6,946	6,946	-6,946
3B*	N_ϕ / [M_L / (R_m^2*β)]	2.4542	-731	-731	731	731	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0597	-5,097	5,097	5,097	-5,097	0	0	0	0
Pressure stress*			13,934	13,934	13,934	13,934	14,011	14,011	14,011	14,011
Total circumferential stress			4,904	20,426	16,560	11,694	3,032	23,660	17,200	10,044
Primary membrane circumferential stress*			12,665	12,665	14,127	14,127	13,346	13,346	13,622	13,622
3C*	N_x / (P / R_m)	8.9875	-527	-527	-527	-527	0	0	0	0
4C*	N_x / (P / R_m)	9.1733	0	0	0	0	-538	-538	-538	-538
1C-1	M_x / P	0.1998	-3,357	3,357	-3,357	3,357	0	0	0	0
2C	M_x / P	0.1559	0	0	0	0	-2,619	2,619	-2,619	2,619
4A*	N_x / [M_c / (R_m^2*β)]	0.8111	0	0	0	0	-187	-187	187	187
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-4,090	4,090	4,090	-4,090
4B*	N_x / [M_L / (R_m^2*β)]	0.6335	-189	-189	189	189	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.1022	-8,725	8,725	8,725	-8,725	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	6,968	6,968	6,968	6,968
Total longitudinal stress			-5,792	18,372	12,036	1,300	-466	12,952	8,088	5,146
Primary membrane longitudinal stress*			6,290	6,290	6,668	6,668	6,243	6,243	6,617	6,617
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-10,696	20,426	16,560	11,694	-3,498	23,660	17,200	10,044
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 147.49*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,304 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 261.78 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 261.78 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.687, 0.8435 + (0.344 - 0) + (0.3125 - 0))
= 1.687 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.344 - 0) + 0.25)
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 261.7811*0.8435 / ((17,000 / 0.85)*1 - 0.6*261.7811)
= 0.0111 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 261.7811*24 / (20,000*1 + 0.4*261.7811)
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 261.7811*24 / (20,000*0.85 + 0.4*261.7811)
= 0.3673 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= 261.7811*0.8435 / (17,000*1 - 0.6*261.7811) + 0
= 0.0131 in

$t_{a\ UG-22}$ = 0.053 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0131 , 0.053]
= 0.053 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 261.7811*24 / (20,000*1 + 0.4*261.7811) + 0
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.0625]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.1348 , 0.3125]
= 0.1348 in

t_{UG-45} = max[t_a , t_b]
= max[0.053 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 28.76 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1875	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 28.76 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-28 t_{rn} = 0.0147 in

From UG-37(d)(1) required thickness t_r = 0.2401 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nodzzle Neck Thickness Check

$t_{a\ UG-28}$ = 0.1397 in

$t_{a\ UG-22}$ = 0.1647 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1397 , 0.1647]
= 0.1647 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 28.7586*24 / (20,000*1 + 0.4*28.7586) + 0.0625
= 0.097 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.097 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.1647 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

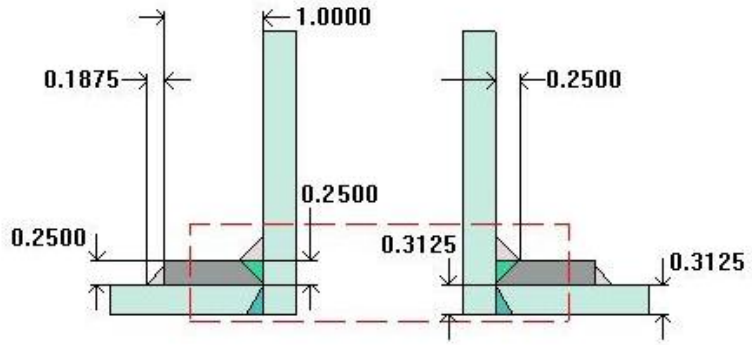
External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0294 / 2.375 = 2.5387
D_o / t = 2.375 / 0.0147 = 161.9877
From table G: A = 0.000249
From table HA-1: B = 3,493.8996 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,493.9 / (3*(2.375 / 0.0147))
= 28.76 psi

Design thickness for external pressure P_a = 28.76 psi

t_a = t + Corrosion = 0.0147 + 0.125 = 0.1397"

ASME Section VIII Division 1, 2013 Edition

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Vessel Body Upper Shell
Orientation	90°
Nozzle center line offset to datum line	106.8125"
End of nozzle to shell center	30"
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	4.375"
Thickness, t_e	0.25"

Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*24 / (20,000*1 + 0.4*61.16) =	0.0733"
Stress ratio = t_r*E^* / (t_n - c) = 0.0733*1 / (0.3125 - 0.0625) =	0.2932
Impact test exempt per UHA-51(g) (coincident ratio = 0.2932)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 147.49 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	147.49	700	2,856	0	3,696	0	0	31,802	42,300	15,480	21,150	No

Calculations for internal pressure 147.49 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 147.4865*0.9685 / ((12,000 / 0.85)*1 - 0.6*147.4865)
= 0.0102 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= $147.4865*24 / (14,100*1 + 0.4*147.4865)$
= 0.25 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $147.4865*24 / (14,100*0.85 + 0.4*147.4865)$
= 0.2939 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 147.4865*0.9685 / (12,000*1 - 0.6*147.4865) + 0.125
= 0.137 in

$t_{a\ UG-22}$ = 0.1834 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.137 , 0.1834]
= 0.1834 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 147.4865*24 / (14,100*1 + 0.4*147.4865) + 0.0625
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.1875]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.3125]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]
= max[0.1834 , 0.2598]
= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	147.49 psi
Mean shell radius, R_m	23.875"
Local shell thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 23.875 / 0.25 = 95.5$

$\beta = 0.875*r_o / R_m = 0.875*2.1875 / 23.875 = 0.0802$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =14,011 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =7,006 psi

Maximum combined stress (P_L+P_b+Q) = 31,802 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 15,480 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	13.5763	0	0	0	0	-1,592	-1,592	-1,592	-1,592
4C*	N_ϕ / (P / R_m)	15.731	-1,845	-1,845	-1,845	-1,845	0	0	0	0
1C	M_ϕ / P	0.1089	0	0	0	0	-7,318	7,318	-7,318	7,318
2C-1	M_ϕ / P	0.0734	-4,932	4,932	-4,932	4,932	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	3.2512	0	0	0	0	-813	-813	813	813
1A	M_ϕ / [M_c / (R_m*β)]	0.0899	0	0	0	0	-12,878	12,878	12,878	-12,878
3B*	N_ϕ / [M_L / (R_m^2*β)]	10.2434	-3,314	-3,314	3,314	3,314	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0405	-7,508	7,508	7,508	-7,508	0	0	0	0
Pressure stress*			14,011	14,011	14,011	14,011	14,011	14,011	14,011	14,011
Total circumferential stress			-3,588	21,292	18,056	12,904	-8,590	31,802	18,792	7,672
Primary membrane circumferential stress*			8,852	8,852	15,480	15,480	11,606	11,606	13,232	13,232
3C*	N_x / (P / R_m)	13.5763	-1,592	-1,592	-1,592	-1,592	0	0	0	0
4C*	N_x / (P / R_m)	15.731	0	0	0	0	-1,845	-1,845	-1,845	-1,845
1C-1	M_x / P	0.1103	-7,412	7,412	-7,412	7,412	0	0	0	0
2C	M_x / P	0.0732	0	0	0	0	-4,919	4,919	-4,919	4,919
4A*	N_x / [M_c / (R_m^2*β)]	5.0007	0	0	0	0	-1,250	-1,250	1,250	1,250
2A	M_x / [M_c / (R_m*β)]	0.0502	0	0	0	0	-7,191	7,191	7,191	-7,191
4B*	N_x / [M_L / (R_m^2*β)]	3.247	-1,050	-1,050	1,050	1,050	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0621	-11,512	11,512	11,512	-11,512	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	7,006	7,006	7,006	7,006
Total longitudinal stress			-14,560	23,288	10,564	2,364	-8,199	16,021	8,683	4,139
Primary membrane longitudinal stress*			4,364	4,364	6,464	6,464	3,911	3,911	6,411	6,411
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-14,560	23,288	18,056	12,904	-8,590	31,802	18,792	7,672
* denotes primary stress.										

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 23.875 / 0.5 = 47.75$

$\beta = 0.875 * r_o / R_m = 0.875 * 1.1875 / 23.875 = 0.0435$

Pressure stress intensity factor, I = 0.9945 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =13,934 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =6,968 psi

Maximum combined stress (P_L+P_b+Q) = 23,660 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 14,127 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	8.9875	0	0	0	0	-527	-527	-527	-527
4C*	N_ϕ / (P / R_m)	9.1733	-538	-538	-538	-538	0	0	0	0
1C	M_ϕ / P	0.2005	0	0	0	0	-3,368	3,368	-3,368	3,368
2C-1	M_ϕ / P	0.1586	-2,664	2,664	-2,664	2,664	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.5977	0	0	0	0	-138	-138	138	138
1A	M_ϕ / [M_c / (R_m*β)]	0.1053	0	0	0	0	-6,946	6,946	6,946	-6,946
3B*	N_ϕ / [M_L / (R_m^2*β)]	2.4542	-731	-731	731	731	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0597	-5,097	5,097	5,097	-5,097	0	0	0	0
Pressure stress*			13,934	13,934	13,934	13,934	14,011	14,011	14,011	14,011
Total circumferential stress			4,904	20,426	16,560	11,694	3,032	23,660	17,200	10,044
Primary membrane circumferential stress*			12,665	12,665	14,127	14,127	13,346	13,346	13,622	13,622
3C*	N_x / (P / R_m)	8.9875	-527	-527	-527	-527	0	0	0	0
4C*	N_x / (P / R_m)	9.1733	0	0	0	0	-538	-538	-538	-538
1C-1	M_x / P	0.1998	-3,357	3,357	-3,357	3,357	0	0	0	0
2C	M_x / P	0.1559	0	0	0	0	-2,619	2,619	-2,619	2,619
4A*	N_x / [M_c / (R_m^2*β)]	0.8111	0	0	0	0	-187	-187	187	187
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-4,090	4,090	4,090	-4,090
4B*	N_x / [M_L / (R_m^2*β)]	0.6335	-189	-189	189	189	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.1022	-8,725	8,725	8,725	-8,725	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	6,968	6,968	6,968	6,968
Total longitudinal stress			-5,792	18,372	12,036	1,300	-466	12,952	8,088	5,146
Primary membrane longitudinal stress*			6,290	6,290	6,668	6,668	6,243	6,243	6,617	6,617
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-10,696	20,426	16,560	11,694	-3,498	23,660	17,200	10,044
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 147.49*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,304 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 261.78 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 261.78 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.687, 0.8435 + (0.344 - 0) + (0.3125 - 0))
= 1.687 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.344 - 0) + 0.25)
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 261.7811*0.8435 / ((17,000 / 0.85)*1 - 0.6*261.7811)
= 0.0111 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 261.7811*24 / (20,000*1 + 0.4*261.7811)
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 261.7811*24 / (20,000*0.85 + 0.4*261.7811)
= 0.3673 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= 261.7811*0.8435 / (17,000*1 - 0.6*261.7811) + 0
= 0.0131 in

$t_{a\ UG-22}$ = 0.053 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0131 , 0.053]
= 0.053 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 261.7811*24 / (20,000*1 + 0.4*261.7811) + 0
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.0625]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.1348 , 0.3125]
= 0.1348 in

t_{UG-45} = max[t_a , t_b]
= max[0.053 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 28.76 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1875	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 28.76 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-28 t_{rn} = 0.0147 in

From UG-37(d)(1) required thickness t_r = 0.2401 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nodzzle Neck Thickness Check

$t_{a\ UG-28}$ = 0.1397 in

$t_{a\ UG-22}$ = 0.1647 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1397 , 0.1647]
= 0.1647 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 28.7586*24 / (20,000*1 + 0.4*28.7586) + 0.0625
= 0.097 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.097 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.1647 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

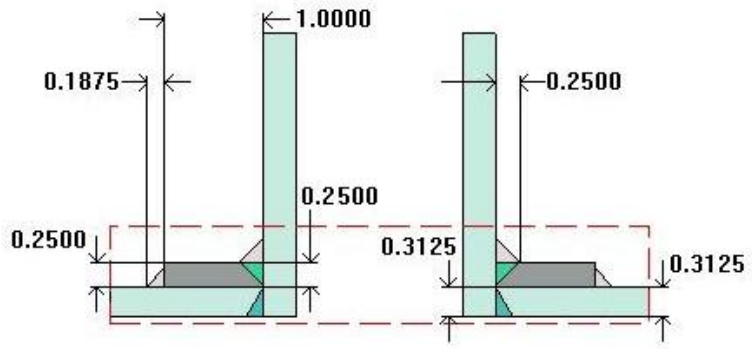
External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0294 / 2.375 = 2.5387
D_o / t = 2.375 / 0.0147 = 161.9877
From table G: A = 0.000249
From table HA-1: B = 3,493.8996 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,493.9 / (3*(2.375 / 0.0147))
= 28.76 psi

Design thickness for external pressure P_a = 28.76 psi

t_a = t + Corrosion = 0.0147 + 0.125 = 0.1397"

ASME Section VIII Division 1, 2013 Edition

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Vessel Body Upper Shell
Orientation	150°
Nozzle center/shell outer surface intersection to datum	25.9375"
End of nozzle to shell center	31.4246"
Tilted	45° from radial
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Opening chord length	2.7393"
Projection available outside vessel, Lpr	6.5625"
Projection available outside vessel to flange face, Lf	9.3125"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)

Diameter, D_p	5.3588"
Thickness, t_e	0.25"
Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = t_r*E^* / (t_n - c) = 0.0411*1 / (0.301 - 0.125) =	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*24 / (20,000*1 + 0.4*61.16) =	0.0733"
Stress ratio = t_r*E^* / (t_n - c) = 0.0733*1 / (0.3125 - 0.0625) =	0.2932
Impact test exempt per UHA-51(g) (coincident ratio = 0.2932)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 147.49 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	147.49	700	2,856	0	3,696	0	0	31,802	42,300	18,669	21,150	No

Calculations for internal pressure 147.49 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2.7393, 1.3697 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 2.7393 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 147.4865*0.9685 / ((12,000 / 0.85)*1 - 0.6*147.4865)
= 0.0102 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 147.4865*24 / (14,100*1 + 0.4*147.4865)
= 0.25 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 147.4865*24 / (14,100*0.85 + 0.4*147.4865)
= 0.2939 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 147.4865*0.9685 / (12,000*1 - 0.6*147.4865) + 0.125
= 0.137 in

$t_{a\ UG-22}$ = 0.1834 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.137 , 0.1834]
= 0.1834 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 147.4865*24 / (14,100*1 + 0.4*147.4865) + 0.0625
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.1875]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.3125]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]
= max[0.1834 , 0.2598]
= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	147.49 psi
Mean shell radius, R_m	23.875"
Local shell thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 23.875 / 0.25 = 95.5$

$\beta = 0.875*r_o / R_m = 0.875*2.1875 / 23.875 = 0.0802$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =14,011 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =7,006 psi

Maximum combined stress (P_L+P_b+Q) = 31,802 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 15,480 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	13.5763	0	0	0	0	-1,592	-1,592	-1,592	-1,592
4C*	N_ϕ / (P / R_m)	15.731	-1,845	-1,845	-1,845	-1,845	0	0	0	0
1C	M_ϕ / P	0.1089	0	0	0	0	-7,318	7,318	-7,318	7,318
2C-1	M_ϕ / P	0.0734	-4,932	4,932	-4,932	4,932	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	3.2512	0	0	0	0	-813	-813	813	813
1A	M_ϕ / [M_c / (R_m*β)]	0.0899	0	0	0	0	-12,878	12,878	12,878	-12,878
3B*	N_ϕ / [M_L / (R_m^2*β)]	10.2434	-3,314	-3,314	3,314	3,314	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0405	-7,508	7,508	7,508	-7,508	0	0	0	0
Pressure stress*			14,011	14,011	14,011	14,011	14,011	14,011	14,011	14,011
Total circumferential stress			-3,588	21,292	18,056	12,904	-8,590	31,802	18,792	7,672
Primary membrane circumferential stress*			8,852	8,852	15,480	15,480	11,606	11,606	13,232	13,232
3C*	N_x / (P / R_m)	13.5763	-1,592	-1,592	-1,592	-1,592	0	0	0	0
4C*	N_x / (P / R_m)	15.731	0	0	0	0	-1,845	-1,845	-1,845	-1,845
1C-1	M_x / P	0.1103	-7,412	7,412	-7,412	7,412	0	0	0	0
2C	M_x / P	0.0732	0	0	0	0	-4,919	4,919	-4,919	4,919
4A*	N_x / [M_c / (R_m^2*β)]	5.0007	0	0	0	0	-1,250	-1,250	1,250	1,250
2A	M_x / [M_c / (R_m*β)]	0.0502	0	0	0	0	-7,191	7,191	7,191	-7,191
4B*	N_x / [M_L / (R_m^2*β)]	3.247	-1,050	-1,050	1,050	1,050	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0621	-11,512	11,512	11,512	-11,512	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	7,006	7,006	7,006	7,006
Total longitudinal stress			-14,560	23,288	10,564	2,364	-8,199	16,021	8,683	4,139
Primary membrane longitudinal stress*			4,364	4,364	6,464	6,464	3,911	3,911	6,411	6,411
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-14,560	23,288	18,056	12,904	-8,590	31,802	18,792	7,672
* denotes primary stress.										

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 23.875 / 0.5 = 47.75$

$\beta = 0.875 * r_o / R_m = 0.875 * 1.1875 / 23.875 = 0.0435$

Pressure stress intensity factor, I = 1.3187 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =18,476 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =9,239 psi

Maximum combined stress (P_L+P_b+Q) = 24,968 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 18,669 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	8.9875	0	0	0	0	-527	-527	-527	-527
4C*	N_ϕ / (P / R_m)	9.1733	-538	-538	-538	-538	0	0	0	0
1C	M_ϕ / P	0.2005	0	0	0	0	-3,368	3,368	-3,368	3,368
2C-1	M_ϕ / P	0.1586	-2,664	2,664	-2,664	2,664	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.5977	0	0	0	0	-138	-138	138	138
1A	M_ϕ / [M_c / (R_m*β)]	0.1053	0	0	0	0	-6,946	6,946	6,946	-6,946
3B*	N_ϕ / [M_L / (R_m^2*β)]	2.4542	-731	-731	731	731	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0597	-5,097	5,097	5,097	-5,097	0	0	0	0
Pressure stress*			18,476	18,476	18,476	18,476	14,011	14,011	14,011	14,011
Total circumferential stress			9,446	24,968	21,102	16,236	3,032	23,660	17,200	10,044
Primary membrane circumferential stress*			17,207	17,207	18,669	18,669	13,346	13,346	13,622	13,622
3C*	N_x / (P / R_m)	8.9875	-527	-527	-527	-527	0	0	0	0
4C*	N_x / (P / R_m)	9.1733	0	0	0	0	-538	-538	-538	-538
1C-1	M_x / P	0.1998	-3,357	3,357	-3,357	3,357	0	0	0	0
2C	M_x / P	0.1559	0	0	0	0	-2,619	2,619	-2,619	2,619
4A*	N_x / [M_c / (R_m^2*β)]	0.8111	0	0	0	0	-187	-187	187	187
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-4,090	4,090	4,090	-4,090
4B*	N_x / [M_L / (R_m^2*β)]	0.6335	-189	-189	189	189	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.1022	-8,725	8,725	8,725	-8,725	0	0	0	0
Pressure stress*			7,006	7,006	7,006	7,006	9,239	9,239	9,239	9,239
Total longitudinal stress			-5,792	18,372	12,036	1,300	1,805	15,223	10,359	7,417
Primary membrane longitudinal stress*			6,290	6,290	6,668	6,668	8,514	8,514	8,888	8,888
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-15,238	24,968	21,102	16,236	3,032	23,660	17,200	10,044
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 147.49*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,304 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 261.78 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 261.78 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2.3858, 1.1929 + (0.344 - 0) + (0.3125 - 0))
= 2.3858 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.344 - 0) + 0.25)
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 261.7811*0.8435 / ((17,000 / 0.85)*1 - 0.6*261.7811)
= 0.0111 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 261.7811*24 / (20,000*1 + 0.4*261.7811)
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 261.7811*24 / (20,000*0.85 + 0.4*261.7811)
= 0.3673 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= 261.7811*0.8435 / (17,000*1 - 0.6*261.7811) + 0
= 0.0131 in

$t_{a\ UG-22}$ = 0.053 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0131 , 0.053]
= 0.053 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 261.7811*24 / (20,000*1 + 0.4*261.7811) + 0
= 0.3125 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3125 , 0.0625]
= 0.3125 in

t_b = min[t_{b3} , t_{b1}]
= min[0.1348 , 0.3125]
= 0.1348 in

t_{UG-45} = max[t_a , t_b]
= max[0.053 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 28.76 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1875	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1533	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 28.76 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2.7393, 1.3697 + (0.344 - 0.125) + (0.3125 - 0.0625))
= 2.7393 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.344 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-28 t_{rn} = 0.0196 in

From UG-37(d)(1) required thickness t_r = 0.25 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nodzzle Neck Thickness Check

$t_{a\ UG-28}$ = 0.1446 in

$t_{a\ UG-22}$ = 0.1647 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1446 , 0.1647]
= 0.1647 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 28.7586*24 / (20,000*1 + 0.4*28.7586) + 0.0625
= 0.097 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.097 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.1647 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

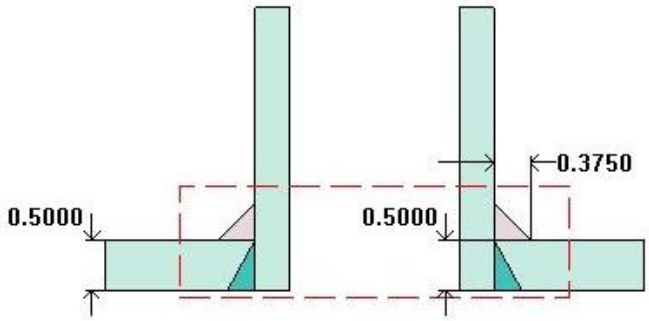
L / D_o = 11.6875 / 2.375 = 4.9211
D_o / t = 2.375 / 0.0196 = 121.0708
From table G: A = 0.000186
From table HA-1: B = 2,611.388 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,611.39 / (3*(2.375 / 0.0196))
= 28.76 psi

Design thickness for external pressure P_a = 28.76 psi

t_a = t + Corrosion = 0.0196 + 0.125 = 0.1446"

High Diff Press Xmittr Conn (P1)

ASME Section VIII Division 1, 2013 Edition	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Bonnet Shell
Orientation	150°
Nozzle center line offset to datum line	-17.625"
End of nozzle to shell center	33"
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	1.687"
Nominal wall thickness	0.344"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.25"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.5"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner Fillet, Leg_{41}	0.375"
Nozzle to vessel groove weld	0.5"

ASME B16.5-2009 Flange	
Description	NPS 2 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c) = 0.0411 * 1 / (0.301 - 0.125) =$	0.2336
Impact test exempt per UHA-51(g) (coincident ratio = 0.2336)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Local stresses at the nozzle OD per WRC 107 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 220.07 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2598	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	220.07	700	2,856	0	3,696	0	0	29,368	42,300	21,150	21,150	No

Calculations for internal pressure 220.07 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 220.0712*0.9685 / ((12,000 / 0.85)*1 - 0.6*220.0712)
= 0.0152 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o$ / (S*E + 0.4*P)
= 220.0712*27 / (14,100*1 + 0.4*220.0712)
= 0.4188 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o$ / (S*E + 0.4*P)
= 220.0712*27 / (14,100*0.85 + 0.4*220.0712)
= 0.4922 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 220.0712*0.9685 / (12,000*1 - 0.6*220.0712) + 0.125
= 0.143 in

$t_{a\ UG-22}$ = 0.1872 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.143 , 0.1872]
= 0.1872 in

t_{b1} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 220.0712*27 / (14,100*1 + 0.4*220.0712) + 0.0625
= 0.4813 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.4813 , 0.1875]
= 0.4813 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2598 , 0.4813]
= 0.2598 in

t_{UG-45} = max[t_a , t_b]

= max[0.1872 , 0.2598]
= 0.2598 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	700 lb_f
Circumferential moment, M_c	2,856 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	3,696 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	220.07 psi
Mean shell radius, R_m	26.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 26.7813 / 0.4375 = 61.2143$

$\beta = 0.875*r_o / R_m = 0.875*1.1875 / 26.7813 = 0.0388$

Pressure stress intensity factor, I = 1.5612 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =20,859 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =10,429 psi

Maximum combined stress (P_L+P_b+Q) = 29,368 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 21,150 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	11.8113	0	0	0	0	-706	-706	-706	-706
4C*	N_ϕ / (P / R_m)	11.4327	-683	-683	-683	-683	0	0	0	0
1C	M_ϕ / P	0.2036	0	0	0	0	-4,468	4,468	-4,468	4,468
2C-1	M_ϕ / P	0.1604	-3,520	3,520	-3,520	3,520	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.8485	0	0	0	0	-199	-199	199	199
1A	M_ϕ / [M_c / (R_m*β)]	0.1038	0	0	0	0	-8,944	8,944	8,944	-8,944
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.2099	-974	-974	974	974	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0596	-6,646	6,646	6,646	-6,646	0	0	0	0
Pressure stress*			20,859	20,859	20,859	20,859	13,361	13,361	13,361	13,361
Total circumferential stress			9,036	29,368	24,276	18,024	-956	25,868	17,330	8,378
Primary membrane circumferential stress*			19,202	19,202	21,150	21,150	12,456	12,456	12,854	12,854
3C*	N_x / (P / R_m)	11.8113	-706	-706	-706	-706	0	0	0	0
4C*	N_x / (P / R_m)	11.4327	0	0	0	0	-683	-683	-683	-683
1C-1	M_x / P	0.2012	-4,415	4,415	-4,415	4,415	0	0	0	0
2C	M_x / P	0.1569	0	0	0	0	-3,443	3,443	-3,443	3,443
4A*	N_x / [M_c / (R_m^2*β)]	1.0987	0	0	0	0	-258	-258	258	258
2A	M_x / [M_c / (R_m*β)]	0.062	0	0	0	0	-5,342	5,342	5,342	-5,342
4B*	N_x / [M_L / (R_m^2*β)]	0.8681	-264	-264	264	264	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.101	-11,262	11,262	11,262	-11,262	0	0	0	0
Pressure stress*			6,680	6,680	6,680	6,680	10,429	10,429	10,429	10,429
Total longitudinal stress			-9,967	21,387	13,085	-609	703	18,273	11,903	8,105
Primary membrane longitudinal stress*			5,710	5,710	6,238	6,238	9,488	9,488	10,004	10,004
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-19,003	29,368	24,276	-18,633	1,659	25,868	17,330	8,378
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 220.07*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) + 4,670.9*1.1875 / 0.8708
= 6,503 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*0.9685 / (2*0.176) - 700 / (π*(1.1875^2 - 0.9685^2)) - 4,670.9*1.1875 / 0.8708)
= 6,862 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 373.14 psi @ 70 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.1348	0.301

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.2408	0.2625	weld size is adequate

Calculations for internal pressure 373.14 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.687, 0.8435 + (0.344 - 0) + (0.5 - 0))
= 1.6875 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.344 - 0) + 0)
= 0.86 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 373.1371*0.8435 / ((17,000 / 0.85)*1 - 0.6*373.1371)
= 0.0159 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 373.1371*27 / (20,000*1 + 0.4*373.1371)
= 0.5 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o$ / (S*E + 0.4*P)
= 373.1371*27 / (20,000*0.85 + 0.4*373.1371)
= 0.5875 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.344 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.2408 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 373.1371*0.8435 / (17,000*1 - 0.6*373.1371) + 0
= 0.0188 in

$t_{a\ UG-22}$ = 0.0563 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0188 , 0.0563]
= 0.0563 in

t_{b1} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 373.1371*27 / (20,000*1 + 0.4*373.1371) + 0
= 0.5 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.5 , 0.0625]
= 0.5 in

t_b = min[t_{b3} , t_{b1}]
= min[0.1348 , 0.5]
= 0.1348 in

t_{UG-45} = max[t_a , t_b]
= max[0.0563 , 0.1348]
= 0.1348 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 120.36 psi @ 0 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2246	0.301

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.2625	weld size is adequate

Calculations for external pressure 120.36 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(1.937, 0.9685 + (0.344 - 0.125) + (0.5 - 0.0625))
= 1.937 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.344 - 0.125) + 0)
= 0.5475 in

Nozzle required thickness per UG-28 t_{rn} = 0.0285 in

From UG-37(d)(1) required thickness t_r = 0.4375 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.219 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.1533 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.1535 in

$t_{a\ UG\text{-}22}$ = 0.1684 in

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.1535 , 0.1684]
= 0.1684 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 120.3613*27 / (20,000*1 + 0.4*120.3613) + 0.0625
= 0.2246 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.2246 , 0.1875]
= 0.2246 in

t_b = min[t_{b3} , t_{b2}]
= min[0.2598 , 0.2246]
= 0.2246 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.1684 , 0.2246]
= 0.2246 in

Available nozzle wall thickness new, t_n = 0.875*0.344 = 0.301 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 6.0261 / 2.375 = 2.5373
D_o / t = 2.375 / 0.0285 = 83.4050
From table G: A = 0.000659
From table HA-1: B = 7,529.1628 psi

P_a = $4*B / (3*(D_o / t))$
= 4*7,529.16 / (3*(2.375 / 0.0285))
= 120.36 psi

Design thickness for external pressure P_a = 120.36 psi

t_a = t + Corrosion = 0.0285 + 0.125 = 0.1535"

Level Indicator Conn (L)

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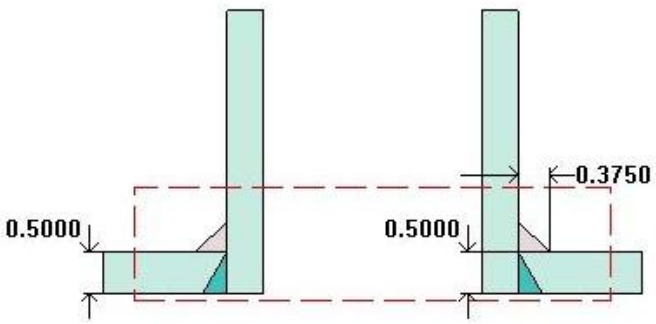

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Vessel Body Mid Shell
Orientation	180°
Nozzle center line offset to datum line	132.375"
End of nozzle to shell center	30"
Passes through a Category A joint	No

Nozzle	
Description	NPS 3 Sch 160
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	2.624"
Nominal wall thickness	0.438"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	2.88"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	0.5"
Liquid static head included	0.02 psi
Longitudinal joint efficiency	1

Welds	
Inner Fillet, Leg_{41}	0.375"
Nozzle to vessel groove weld	0.5"

ASME B16.5-2009 Flange	
Description	NPS 3 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0431*1 / (0.3833 - 0.125) =	0.1668
Impact test exempt per UHA-51(g) (coincident ratio = 0.1668)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 188.44 psi @ 980 ° F							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.314	0.3833

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.2191	0.2625	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	188.44	1,050	6,432	0	8,316	0	0	27,091	42,300	17,112	21,150	No

Calculations for internal pressure 188.44 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2.874, 1.437 + (0.438 - 0.125) + (0.5 - 0.0625))
= 2.874 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.438 - 0.125) + 0)
= 0.7825 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 188.4373*1.437 / ((12,000 / 0.85)*1 - 0.6*188.4373)
= 0.0193 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 188.4373*24 / (14,100*1 + 0.4*188.4373)
= 0.319 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 188.4373*24 / (14,100*0.85 + 0.4*188.4373)
= 0.375 in

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.313 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.2191 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = $P*R / (S*E - 0.6*P)$ + Corrosion
= 188.4373*1.437 / (12,000*1 - 0.6*188.4373) + 0.125
= 0.1478 in

$t_{a\ UG-22}$ = 0.1903 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1478 , 0.1903]
= 0.1903 in

t_{b1} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 188.4373*24 / (14,100*1 + 0.4*188.4373) + 0.0625
= 0.3815 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.3815 , 0.1875]
= 0.3815 in

t_b = min[t_{b3} , t_{b1}]
= min[0.314 , 0.3815]
= 0.314 in

t_{UG-45} = max[t_a , t_b]

= max[0.1903 , 0.314]
= 0.314 in

Available nozzle wall thickness new, t_n = 0.875*0.438 = 0.3833 in

The nozzle neck thickness is adequate.

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	1,050 lb_f
Circumferential moment, M_c	6,432 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	8,316 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	188.44 psi
Mean shell radius, R_m	23.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 23.7813 / 0.4375 = 54.3571$

$\beta = 0.875*r_o / R_m = 0.875*1.75 / 23.7813 = 0.0644$

Pressure stress intensity factor, I = 1.5472 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =15,702 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =7,850 psi

Maximum combined stress (P_L+P_b+Q) = 27,091 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 17,112 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	9.2987	0	0	0	0	-938	-938	-938	-938
4C*	N_ϕ / (P / R_m)	9.8895	-998	-998	-998	-998	0	0	0	0
1C	M_ϕ / P	0.1528	0	0	0	0	-5,029	5,029	-5,029	5,029
2C-1	M_ϕ / P	0.1158	-3,811	3,811	-3,811	3,811	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	1.2419	0	0	0	0	-501	-501	501	501
1A	M_ϕ / [M_c / (R_m*β)]	0.1014	0	0	0	0	-13,352	13,352	13,352	-13,352
3B*	N_ϕ / [M_L / (R_m^2*β)]	4.613	-2,408	-2,408	2,408	2,408	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.053	-9,023	9,023	9,023	-9,023	0	0	0	0
Pressure stress*			15,702	15,702	15,702	15,702	10,149	10,149	10,149	10,149
Total circumferential stress			-538	25,130	22,324	11,900	-9,671	27,091	18,035	1,389
Primary membrane circumferential stress*			12,296	12,296	17,112	17,112	8,710	8,710	9,712	9,712
3C*	N_x / (P / R_m)	9.2987	-938	-938	-938	-938	0	0	0	0
4C*	N_x / (P / R_m)	9.8895	0	0	0	0	-998	-998	-998	-998
1C-1	M_x / P	0.1536	-5,056	5,056	-5,056	5,056	0	0	0	0
2C	M_x / P	0.1132	0	0	0	0	-3,726	3,726	-3,726	3,726
4A*	N_x / [M_c / (R_m^2*β)]	1.6925	0	0	0	0	-683	-683	683	683
2A	M_x / [M_c / (R_m*β)]	0.0585	0	0	0	0	-7,703	7,703	7,703	-7,703
4B*	N_x / [M_L / (R_m^2*β)]	1.2391	-647	-647	647	647	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0871	-14,828	14,828	14,828	-14,828	0	0	0	0
Pressure stress*			5,074	5,074	5,074	5,074	7,850	7,850	7,850	7,850
Total longitudinal stress			-16,395	23,373	14,555	-4,989	-5,260	17,598	11,512	3,558
Primary membrane longitudinal stress*			3,489	3,489	4,783	4,783	6,169	6,169	7,535	7,535
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-16,395	25,130	22,324	-16,889	-9,671	27,091	18,035	3,558
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 188.44*1.437 / (2*0.2583) - 1,050 / (π*(1.75^2 - 1.437^2)) + 10,513.2*1.75 / 4.0172
= 4,769 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*1.437 / (2*0.2583) - 1,050 / (π*(1.75^2 - 1.437^2)) - 10,513.2*1.75 / 4.0172)
= 4,936 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 341.96 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.123	1.123	0.2304	0.7731	--	--	0.1195	0.189	0.3833

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 341.96 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2.624, 1.312 + (0.438 - 0) + (0.5 - 0))
= 2.624 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.438 - 0) + 0)
= 1.095 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 341.9589*1.312 / ((17,000 / 0.85)*1 - 0.6*341.9589)
= 0.0227 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 341.9589*24 / (20,000*1 + 0.4*341.9589)
= 0.4076 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $341.9589*24 / (20,000*0.85 + 0.4*341.9589)$
= 0.4789 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $2.624*0.4076*1 + 2*0.438*0.4076*1*(1 - 0.85)$
= 1.123 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.2304 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2.624*(1*0.5 - 1*0.4076) - 2*0.438*(1*0.5 - 1*0.4076)*(1 - 0.85)$
= 0.2304 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.5 + 0.438)*(1*0.5 - 1*0.4076) - 2*0.438*(1*0.5 - 1*0.4076)*(1 - 0.85)$
= 0.1613 in^2

A_2 = smaller of the following= 0.7731 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.438 - 0.0227)*0.85*0.5$
= 0.8825 in^2

= $5*(t_n - t_{rn})*f_{r2}*t_n$
= $5*(0.438 - 0.0227)*0.85*0.438$
= 0.7731 in^2

A_{41} = Leg^2*f_{r2}
= $0.375^2*0.85$
= 0.1195 in^2

Area = $A_1 + A_2 + A_{41}$
= $0.2304 + 0.7731 + 0.1195$

= 1.123 in^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.438 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 341.9589*1.312 / (17,000*1 - 0.6*341.9589) + 0
= 0.0267 in

$t_{a\ UG\text{-}22}$ = 0.0609 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0267 , 0.0609]
= 0.0609 in

t_{b1} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 341.9589*24 / (20,000*1 + 0.4*341.9589) + 0
= 0.4076 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.4076 , 0.0625]
= 0.4076 in

t_b = min[t_{b3} , t_{b1}]
= min[0.189 , 0.4076]
= 0.189 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0609 , 0.189]
= 0.189 in

Available nozzle wall thickness new, t_n = 0.875*0.438 = 0.3833 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 84.84 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.5957	0.5957	0.1003	0.3759	--	--	0.1195	0.1875	0.3833

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.2191	0.2625	weld size is adequate

Calculations for external pressure 84.84 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2.874, 1.437 + (0.438 - 0.125) + (0.5 - 0.0625))
= 2.874 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.438 - 0.125) + 0)
= 0.7825 in

Nozzle required thickness per UG-28 t_{rn} = 0.0304 in

From UG-37(d)(1) required thickness t_r = 0.4014 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

A = 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))

= 0.5*(2.874*0.4014*1 + 2*0.313*0.4014*1*(1 - 0.85))
= 0.5957 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.1003 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2.874*(1*0.4375 - 1*0.4014) - 2*0.313*(1*0.4375 - 1*0.4014)*(1 - 0.85)
= 0.1003 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2*(0.4375 + 0.313)*(1*0.4375 - 1*0.4014) - 2*0.313*(1*0.4375 - 1*0.4014)*(1 - 0.85)
= 0.0508 in^2

A_2 = smaller of the following= 0.3759 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= 5*(0.313 - 0.0304)*0.85*0.4375
= 0.5255 in^2

= $5*(t_n - t_{rn})*f_{r2}*t_n$
= 5*(0.313 - 0.0304)*0.85*0.313
= 0.3759 in^2

A_{41} = Leg^2*f_{r2}
= $0.375^2*0.85$
= 0.1195 in^2

Area = $A_1 + A_2 + A_{41}$
= 0.1003 + 0.3759 + 0.1195
= 0.5957 in^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.313 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.2191 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-28}$ = 0.1554 in

$t_{a\ UG-22}$ = 0.1692 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1554 , 0.1692]
= 0.1692 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 84.8409*24 / (20,000*1 + 0.4*84.8409) + 0.0625
= 0.1641 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.1641 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.314 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.1692 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.438 = 0.3833 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

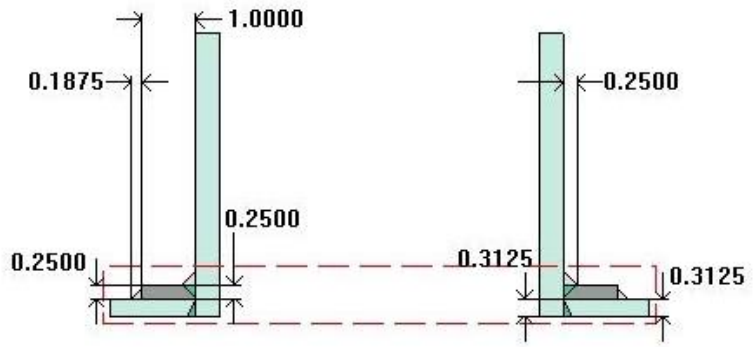
L / D_o = 6.0639 / 3.5 = 1.7325
D_o / t = 3.5 / 0.0304 = 115.1736
From table G: A = 0.000618
From table HA-1: B = 7,328.5328 psi

P_a = $4*B / (3*(D_o / t))$
= 4*7,328.53 / (3*(3.5 / 0.0304))
= 84.84 psi

Design thickness for external pressure P_a = 84.84 psi

t_a = t + Corrosion = 0.0304 + 0.125 = 0.1554"

Cleanout Handhole (H1)

ASME Section VIII Division 1, 2013 Edition	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Vessel Body Lower Shell
Orientation	0°
Nozzle center/shell outer surface intersection to datum	148.125"
End of nozzle to shell center	34.8276"
Tilted	45° from radial
Passes through a Category A joint	No
Nozzle	
Description	NPS 6 Sch 80S (XS)
Access opening	Yes
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	5.761"
Nominal wall thickness	0.432"
Corrosion allowance	0.125"
Opening chord length	8.5008"
Projection available outside vessel, Lpr	8.12"
Projection available outside vessel to flange face, Lf	12"
Local vessel minimum thickness	0.3125"
Liquid static head included	0.22 psi
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)

Diameter, D_p	11.3692"
Thickness, t_e	0.25"
Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 6 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0.07 psi
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
t_r = 61.38*24 / (20,000*1 + 0.4*61.38) =	0.0736"
Stress ratio = t_r*E^* / (t_n - c) = 0.0736*1 / (0.3125 - 0.0625) =	0.2942
Impact test exempt per UHA-51(g) (coincident ratio = 0.2942)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.38*24 / (20,000*1 + 0.4*61.38) =	0.0736"
Stress ratio = t_r*E^* / (t_n - c) = 0.0736*1 / (0.3125 - 0.0625) =	0.2942
Impact test exempt per UHA-51(g) (coincident ratio = 0.2942)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 103.52 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.5161	1.5165	0.625	0.3031	--	0.5	0.0884	0.1511	0.378

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
13,112.71	12,570.15	48,727.52	6,865.91	69,588.44	14,412.23	50,280.18

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 103.52 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(8.5008, 4.2504 + (0.432 - 0.125) + (0.3125 - 0.0625))
= 8.5008 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.432 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 103.515*3.0055 / ((12,000 / 0.85)*1 - 0.6*103.515)
= 0.0221 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o$ / (S*E + 0.4*P)
= 103.515*24 / (14,100*1 + 0.4*103.515)

= 0.1757 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= 103.515*24 / (14,100*0.85 + 0.4*103.515)
= 0.2066 in

Area required per UG-37(c)

Allowable stresses: S_n = 12,000, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.8511

f_{r2} = lesser of 1 or S_n / S_v = 0.8511

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8511

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + (2*t_n/Cos(45))*t_r*F*(1 - f_{r1})$
= 8.5008*0.1757*1 + (2*0.307/Cos(45))*0.1757*1*(1 - 0.8511)
= 1.5161 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.625 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 8.5008*(1*0.25 - 1*0.1757) - 2*0.307*(1*0.25 - 1*0.1757)*(1 - 0.8511)
= 0.625 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2*(0.25 + 0.307)*(1*0.25 - 1*0.1757) - 2*0.307*(1*0.25 - 1*0.1757)*(1 - 0.8511)
= 0.076 in^2

A_2 = smaller of the following= 0.3031 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= 5*(0.307 - 0.0221)*0.8511*0.25
= 0.3031 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= 2*(0.307 - 0.0221)*(2.5*0.307 + 0.25)*0.8511
= 0.4934 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.8511$
= 0.0532 in^2

A_{42} = $Leg^2 * f_{r4}$
= $0.1875^2 * 1$
= 0.0352 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (11.3692 - 9.3692)*0.25*1
= 0.5 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0.625 + 0.3031 + 0.0532 + 0.0352 + 0.5
= 1.5165 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 103.515*3.0055 / (12,000*1 - 0.6*103.515) + 0.125
= 0.1511 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1511 , 0]
= 0.1511 in

Available nozzle wall thickness new, t_n = 0.875*0.432 = 0.378 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 =	10,434 psi
Nozzle wall in shear:	0.7*12,000 =	8,400 psi
Inner fillet weld in shear:	0.49*12,000 =	5,880 psi
Outer fillet weld in shear:	0.49*14,100 =	6,909 psi
Upper groove weld in tension:	0.74*14,100 =	10,434 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*6.625*0.25*5,880 = 15,297.59 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*11.3692*0.1875*6,909 = 23,134.76 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*6.318*0.307*8,400 = 25,592.76 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*6.625*0.25*10,434 = 27,145.42 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*6.625*0.25*10,434 = 27,145.42 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (1.5161 - 0.625 + 2*0.307*0.8511*(1*0.25 - 1*0.1757))*14,100$
$= 13,112.71$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.3031 + 0.5 + 0.0532 + 0.0352)*14,100$
$= 12,570.15$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.3031 + 0 + 0.0532 + 0 + 2*0.307*0.25*0.8511)*14,100$
$= 6,865.91$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.3031 + 0 + 0.5 + 0.0532 + 0.0352 + 0 + 2*0.307*0.25*0.8511)*14,100$
$= 14,412.23$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = 12,570.15 lb_f
Path 1-1 through (2) & (3) = 23,134.76 + 25,592.76 = 48,727.52 lb_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 6,865.91 lb_f
Path 2-2 through (1), (4), (6) = 15,297.59 + 27,145.42 + 27,145.42 = 69,588.44 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 13,112.71 lb_f
Path 3-3 through (2), (4) = 23,134.76 + 27,145.42 = 50,280.18 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 185.81 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.8506	1.8507	0.7244	0.538	--	0.5	0.0883	0.0317	0.378

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
23,851.77	22,526	82,824.66	16,412	108,305.92	27,116	80,945.44

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 185.81 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(8.1473, 4.0736 + (0.432 - 0) + (0.3125 - 0))
= 8.1473 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.432 - 0) + 0.25)
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 185.8122*2.8805 / ((17,000 / 0.85)*1 - 0.6*185.8122)
= 0.0269 in

Required thickness t_r from UG-37(a)

t_r = P*R_o / (S*E + 0.4*P)
= 185.8122*24 / (20,000*1 + 0.4*185.8122)

= 0.2221 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $185.8122*24 / (20,000*0.85 + 0.4*185.8122)$
= 0.2612 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + (2*t_n/Cos(45))*t_r*F*(1 - f_{r1})$
= $8.1473*0.2222*1 + (2*0.432/Cos(45))*0.2222*1*(1 - 0.85)$
= 1.8506 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.7244 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $8.1473*(1*0.3125 - 1*0.2222) - 2*0.432*(1*0.3125 - 1*0.2222)*(1 - 0.85)$
= 0.7244 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.3125 + 0.432)*(1*0.3125 - 1*0.2222) - 2*0.432*(1*0.3125 - 1*0.2222)*(1 - 0.85)$
= 0.1228 in^2

A_2 = smaller of the following= 0.538 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.432 - 0.0269)*0.85*0.3125$
= 0.538 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.432 - 0.0269)*(2.5*0.432 + 0.25)*0.85$
= 0.9159 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = $Leg^2 * f_{r4}$
= $0.1875^2 * 1$
= 0.0352 in^2

A_5 = $(D_p - d - 2*t_n) * t_e * f_{r4}$
= (11.3692 - 9.3692)*0.25*1
= 0.5 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0.7244 + 0.538 + 0.0531 + 0.0352 + 0.5
= 1.8507 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 185.8122*2.8805 / (17,000*1 - 0.6*185.8122) + 0
= 0.0317 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0317 , 0]
= 0.0317 in

Available nozzle wall thickness new, t_n = 0.875*0.432 = 0.378 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*17,000 =	11,900 psi
Inner fillet weld in shear:	0.49*17,000 =	8,330 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*6.625*0.25*8,330 = 21,671.59 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*11.3692*0.1875*9,800 = 32,815.26 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*6.193*0.432*11,900 = 50,009.4 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*6.625*0.3125*14,800 = 48,130.18 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*6.625*0.25*14,800 = 38,504.14 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (1.8506 - 0.7244 + 2*0.432*0.85*(1*0.3125 - 1*0.2222))*20,000$
$=$ 23,851.77 lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.538 + 0.5 + 0.0531 + 0.0352)*20,000$
$=$ 22,526 lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.538 + 0 + 0.0531 + 0 + 2*0.432*0.3125*0.85)*20,000$
$=$ 16,412 lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.538 + 0 + 0.5 + 0.0531 + 0.0352 + 0 + 2*0.432*0.3125*0.85)*20,000$
$=$ 27,116 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 22,526 lb_f
Path 1-1 through (2) & (3) = 32,815.26 + 50,009.4 = 82,824.66 lb_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 16,412 lb_f
Path 2-2 through (1), (4), (6) = 21,671.59 + 48,130.18 + 38,504.14 = 108,305.92 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 23,851.77 lb_f
Path 3-3 through (2), (4) = 32,815.26 + 48,130.18 = 80,945.44 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 27.09 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.0081	1.0081	0.138	0.2818	--	0.5	0.0883	0.1668	0.378

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 27.09 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(8.5008, 4.2504 + (0.432 - 0.125) + (0.3125 - 0.0625))
= 8.5008 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.432 - 0.125) + 0.25)
= 0.625 in

Nozzle required thickness per UG-28 t_{rn} = 0.0418 in

From UG-37(d)(1) required thickness t_r = 0.2336 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + (2*t_n/Cos(45))*t_r*F*(1 - f_{r1}))$
= $0.5*(8.5008*0.2336*1 + (2*0.307/Cos(45))*0.2336*1*(1 - 0.85))$
= 1.0081 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.138 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $8.5008*(1*0.25 - 1*0.2336) - 2*0.307*(1*0.25 - 1*0.2336)*(1 - 0.85)$
= 0.138 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.25 + 0.307)*(1*0.25 - 1*0.2336) - 2*0.307*(1*0.25 - 1*0.2336)*(1 - 0.85)$
= 0.0168 in^2

A_2 = smaller of the following= 0.2818 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.307 - 0.0418)*0.85*0.25$
= 0.2818 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.307 - 0.0418)*(2.5*0.307 + 0.25)*0.85$
= 0.4587 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0.1875^2*1
= 0.0352 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(11.3692 - 9.3692)*0.25*1$
= 0.5 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= $0.138 + 0.2818 + 0.0531 + 0.0352 + 0.5$
= 1.0081 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG-28}$ = 0.1668 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1668 , 0]
= 0.1668 in

Available nozzle wall thickness new, t_n = 0.875*0.432 = 0.378 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

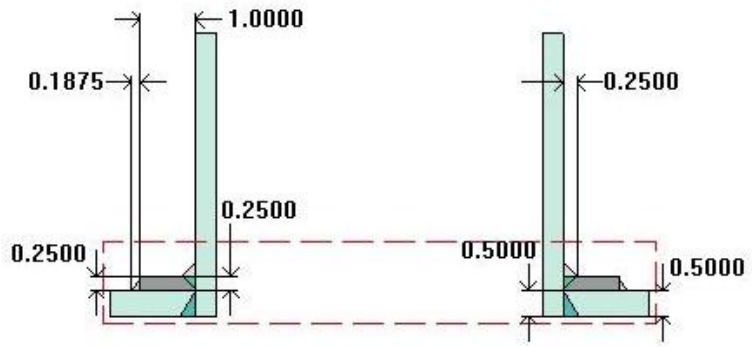
L / D_o = 18.625 / 6.625 = 2.8113
D_o / t = 6.625 / 0.0418 = 158.5255
From table G: A = 0.000229
From table HA-1: B = 3,220.6268 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,220.63 / (3*(6.625 / 0.0418))
= 27.09 psi

Design thickness for external pressure P_a = 27.09 psi

t_a = t + Corrosion = 0.0418 + 0.125 = 0.1668"

Manway (MW1)

ASME Section VIII Division 1, 2013 Edition

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Vessel Body Mid Shell
Orientation	270°
Nozzle center line offset to datum line	125.125"
End of nozzle to shell center	34"
Passes through a Category A joint	No

Nozzle	
Access opening	Yes
Material specification	SA-240 304 (II-D p. 94, ln. 8)
Inside diameter, new	23.25"
Nominal wall thickness	0.375"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.38"
Projection available outside vessel to flange face, Lf	10"
Local vessel minimum thickness	0.5"
User input radial limit of reinforcement	15"
Liquid static head included	0.06 psi
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	26"
Thickness, t_e	0.25"

Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Nozzle to vessel groove weld	0.5"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 24 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	Yes
Rated MDMT	-320° F
Liquid static head	0 psi
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
t_r = 61.22*11.75 / (20,000*1 - 0.6*61.22) =	0.036"
Stress ratio = t_r*E^* / (t_n - c) = 0.036*1 / (0.375 - 0.125) =	0.1441
Impact test exempt per UHA-51(g) (coincident ratio = 0.1441)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.22*24 / (20,000*1 + 0.4*61.22) =	0.0734"
Stress ratio = t_r*E^* / (t_n - c) = 0.0734*1 / (0.5 - 0.0625) =	0.1677
Impact test exempt per UHA-51(g) (coincident ratio = 0.1677)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 73.99 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
2.9532	2.954	2.0269	0.3294	--	0.5	0.0977	0.1868	0.375

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
15,259.87	13,072.11	144,960.15	8,610.17	335,545.66	16,156.49	224,998.31

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 73.99 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(23.5, 11.75 + (0.375 - 0.125) + (0.5 - 0.0625))
= 23.5 in

L_R = 15 in (User Defined)

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.375 - 0.125) + 0.25)
= 0.875 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 73.9862*11.75 / (14,100*1 - 0.6*73.9862)
= 0.0618 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= $73.9862*24 / (14{,}100*1 + 0.4*73.9862)$
= 0.1257 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $73.9862*24 / (14{,}100*0.85 + 0.4*73.9862)$
= 0.1478 in

Area required per UG-37(c)

Allowable stresses: S_n = 14,100, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $23.5*0.1257*1 + 2*0.25*0.1257*1*(1 - 1)$
= 2.9532 in^2

Area available from FIG. UG-37.1

A_1: (specified limit governs) = 2.0269 in^2

= $(2*limits - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*15 - 23.5)*(1*0.4375 - 1*0.1257) - 2*0.25*(1*0.4375 - 1*0.1257)*(1 - 1)$
= 2.0269 in^2

A_2 = smaller of the following= 0.3294 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.25 - 0.0618)*1*0.4375$
= 0.4117 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.25 - 0.0618)*(2.5*0.25 + 0.25)*1$
= 0.3294 in^2

A_{41} = Leg^2*f_{r3}
= 0.25^2*1
= 0.0625 in^2

A_{42} = $Leg^2 * f_{r4}$
= $0.1875^2 * 1$
= 0.0352 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(26 - 23.5 - 2*0.25)*0.25*1$
= 0.5 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 2.0269 + 0.3294 + 0.0625 + 0.0352 + 0.5
= 2.954 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 73.9862*11.75 / (14,100*1 - 0.6*73.9862) + 0.125
= 0.1868 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1868 , 0]
= 0.1868 in

Available nozzle wall thickness new, t_n = 0.375 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 =	10,434 psi
Nozzle wall in shear:	0.7*14,100 =	9,870 psi
Inner fillet weld in shear:	0.49*14,100 =	6,909 psi
Outer fillet weld in shear:	0.49*14,100 =	6,909 psi
Upper groove weld in tension:	0.74*14,100 =	10,434 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*24*0.25*6,909 = 65,115.79 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*26*0.1875*6,909 = 52,906.58 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*23.75*0.25*9,870 = 92,053.57 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*24*0.4375*10,434 = 172,091.73 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*24*0.25*10,434 = 98,338.13 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (2.9532 - 2.0269 + 2*0.25*1*(1*0.4375 - 1*0.1257))*14,100$
$= 15,259.87$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.3294 + 0.5 + 0.0625 + 0.0352)*14,100$
$= 13,072.11$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.3294 + 0 + 0.0625 + 0 + 2*0.25*0.4375*1)*14,100$
$= 8,610.17$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.3294 + 0 + 0.5 + 0.0625 + 0.0352 + 0 + 2*0.25*0.4375*1)*14,100$
$= 16,156.49$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = 13,072.11 lb_f
Path 1-1 through (2) & (3) = 52,906.58 + 92,053.57 = 144,960.15 lb_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 8,610.17 lb_f
Path 2-2 through (1), (4), (6) = 65,115.79 + 172,091.73 + 98,338.13 = 335,545.66 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 15,259.87 lb_f
Path 3-3 through (2), (4) = 52,906.58 + 172,091.73 = 224,998.31 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Check Large Opening per Appendix 1-7(a)

Area required within 75 percent of the limits of reinforcement
= 2 / 3*A = (2 / 3)*2.9532 = 1.9688 in^2

L_R = MAX(0.75*d, R_n + (t_n - C_n) + (t - C))
= MAX(0.75*23.5, 11.75 + (0.375 - 0.125) + (0.5 - 0.0625))
= 17.625 in

L_R = 15 in (User Defined)

A_1 = (2*L_R - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (2*15 - 23.5)*(1*0.4375 - 1*0.1257) - 2*0.25*(1*0.4375 - 1*0.1257)*(1 - 1)
= 2.0269 in^2

A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}
= (26 - 23.5 - 2*0.25)*0.25*1
= 0.5 in^2

Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5
= 2.0269 + 0.3294 + 0 + 0.0625 + 0.0352 + 0 + 0.5
= 2.954 in^2

The area replacement requirements of Appendix 1-7(a) are satisfied.

Check Large Opening per Appendix 1-7(b)

1-7(b)(1)(a)	D_i = 47.125 in > 60 in	False
1-7(b)(1)(b)	d = 23.5 in > 40 in	False
1-7(b)(1)(b)	d = 23.5 in > 3.4*(23.5625*0.4375)$^{0.5}$ = 10.9164 in	True
1-7(b)(1)(c)	R_n / R = 11.75 / 23.5625 = 0.4987 ≤ 0.7	True

The opening is not within the size range defined by 1-7(b)(1)(a) and (b) so it is exempt from the requirements of 1-7(b)(2),(3) and (4).

R_n / R = 0.4987 does not exceed 0.7 so a U-2(g) analysis is not required per 1-7(b)(1)(c).

% Forming strain - UHA-44(a)(2)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.375 / 11.8125)*(1 - 11.8125 / ∞)
= 1.5873%

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 130.4 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
3.6289	3.6291	2.3215	0.7099	--	0.5	0.0977	0.0761	0.375

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
31,306	26,152	269,872.63	22,948	510,822.96	33,652	354,018.22

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 130.4 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(23.25, 11.625 + (0.375 - 0) + (0.5 - 0))
= 23.25 in

L_R = 15 in (User Defined)

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.375 - 0) + 0.25)
= 1.1875 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 130.4044*11.625 / (20,000*1 - 0.6*130.4044)
= 0.0761 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= $130.4044*24 / (20{,}000*1 + 0.4*130.4044)$
= 0.1561 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $130.4044*24 / (20{,}000*0.85 + 0.4*130.4044)$
= 0.1835 in

Area required per UG-37(c)

Allowable stresses: S_n = 20,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $23.25*0.1561*1 + 2*0.375*0.1561*1*(1 - 1)$
= 3.6289 in^2

Area available from FIG. UG-37.1

A_1: (specified limit governs) = 2.3215 in^2

= $(2*limits - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*15 - 23.25)*(1*0.5 - 1*0.1561) - 2*0.375*(1*0.5 - 1*0.1561)*(1 - 1)$
= 2.3215 in^2

A_2 = smaller of the following= 0.7099 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.375 - 0.0761)*1*0.5$
= 0.7472 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.375 - 0.0761)*(2.5*0.375 + 0.25)*1$
= 0.7099 in^2

A_{41} = Leg^2*f_{r3}
= 0.25^2*1
= 0.0625 in^2

A_{42} = $Leg^2 * f_{r4}$
= $0.1875^2 * 1$
= 0.0352 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (26 - 23.25 - 2*0.375)*0.25*1
= 0.5 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 2.3215 + 0.7099 + 0.0625 + 0.0352 + 0.5
= 3.6291 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 130.4044*11.625 / (20,000*1 - 0.6*130.4044) + 0
= 0.0761 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0761 , 0]
= 0.0761 in

Available nozzle wall thickness new, t_n = 0.375 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*20,000 =	14,000 psi
Inner fillet weld in shear:	0.49*20,000 =	9,800 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*24*0.25*9,800 = 92,362.82 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*26*0.1875*9,800 = 75,044.79 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*23.625*0.375*14,000 = 194,827.83 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*24*0.5*14,800 = 278,973.43 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*24*0.25*14,800 = 139,486.71 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (3.6289 - 2.3215 + 2*0.375*1*(1*0.5 - 1*0.1561))*20{,}000$
$= 31{,}306$ lb_f

$W_{1\text{-}1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.7099 + 0.5 + 0.0625 + 0.0352)*20{,}000$
$= 26{,}152$ lb_f

$W_{2\text{-}2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.7099 + 0 + 0.0625 + 0 + 2*0.375*0.5*1)*20{,}000$
$= 22{,}948$ lb_f

$W_{3\text{-}3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.7099 + 0 + 0.5 + 0.0625 + 0.0352 + 0 + 2*0.375*0.5*1)*20{,}000$
$= 33{,}652$ lb_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 26,152 lb_f
Path 1-1 through (2) & (3) = 75,044.79 + 194,827.83 = 269,872.63 lb_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 22,948 lb_f
Path 2-2 through (1), (4), (6) = 92,362.82 + 278,973.43 + 139,486.71 = 510,822.96 lb_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or $W_{3\text{-}3}$ = 31,306 lb_f
Path 3-3 through (2), (4) = 75,044.79 + 278,973.43 = 354,018.22 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Check Large Opening per Appendix 1-7(a)

Area required within 75 percent of the limits of reinforcement
= 2 / 3*A = (2 / 3)*3.6289 = 2.4192 in^2

L_R = MAX(0.75*d, R_n + (t_n - C_n) + (t - C))
= MAX(0.75*23.25, 11.625 + (0.375 - 0) + (0.5 - 0))
= 17.4375 in

L_R = 15 in (User Defined)

A_1 = (2*L_R - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (2*15 - 23.25)*(1*0.5 - 1*0.1561) - 2*0.375*(1*0.5 - 1*0.1561)*(1 - 1)
= 2.3215 in^2

A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}
= (26 - 23.25 - 2*0.375)*0.25*1
= 0.5 in^2

Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5
= 2.3215 + 0.7099 + 0 + 0.0625 + 0.0352 + 0 + 0.5
= 3.6291 in^2

The area replacement requirements of Appendix 1-7(a) are satisfied.

Check Large Opening per Appendix 1-7(b)

1-7(b)(1)(a)	D_i = 47 in > 60 in	False
1-7(b)(1)(b)	d = 23.25 in > 40 in	False
1-7(b)(1)(b)	d = 23.25 in > 3.4*(23.5*0.5)$^{0.5}$ = 11.6546 in	True
1-7(b)(1)(c)	R_n / R = 11.625 / 23.5 = 0.4947 ≤ 0.7	True

The opening is not within the size range defined by 1-7(b)(1)(a) and (b) so it is exempt from the requirements of 1-7(b)(2),(3) and (4).

R_n / R = 0.4947 does not exceed 0.7 so a U-2(g) analysis is not required per 1-7(b)(1)(c).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 20.06 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
2.4213	2.4214	1.5043	0.3194	--	0.5	0.0977	0.1925	0.375

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 20.06 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(23.5, 11.75 + (0.375 - 0.125) + (0.5 - 0.0625))
= 23.5 in

L_R = 15 in (User Defined)

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.375 - 0.125) + 0.25)
= 0.875 in

Nozzle required thickness per UG-28 t_{rn} = 0.0675 in

From UG-37(d)(1) required thickness t_r = 0.2061 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 20,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= $0.5*(23.5*0.2061*1 + 2*0.25*0.2061*1*(1 - 1))$
= 2.4213 in^2

Area available from FIG. UG-37.1

A_1: (specified limit governs) = 1.5043 in^2

= $(2*\text{limits} - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*15 - 23.5)*(1*0.4375 - 1*0.2061) - 2*0.25*(1*0.4375 - 1*0.2061)*(1 - 1)$
= 1.5043 in^2

A_2 = smaller of the following= 0.3194 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.25 - 0.0675)*1*0.4375$
= 0.3992 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.25 - 0.0675)*(2.5*0.25 + 0.25)*1$
= 0.3194 in^2

A_{41} = Leg^2*f_{r3}
= 0.25^2*1
= 0.0625 in^2

A_{42} = Leg^2*f_{r4}
= 0.1875^2*1
= 0.0352 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(26 - 23.5 - 2*0.25)*0.25*1$
= 0.5 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= $1.5043 + 0.3194 + 0.0625 + 0.0352 + 0.5$
= 2.4214 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG-28}$ = 0.1925 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1925 , 0]
= 0.1925 in

Available nozzle wall thickness new, t_n = 0.375 in

The nozzle neck thickness is adequate.

Check Large Opening per Appendix 1-7(a)

Area required within 75 percent of the limits of reinforcement
= 2 / 3*A = (2 / 3)*2.4213 = 1.6142 in^2

L_R = MAX(0.75*d, R_n + (t_n - C_n) + (t - C))
= MAX(0.75*23.5, 11.75 + (0.375 - 0.125) + (0.5 - 0.0625))
= 17.625 in

L_R = 15 in (User Defined)

A_1 = (2*L_R - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (2*15 - 23.5)*(1*0.4375 - 1*0.2061) - 2*0.25*(1*0.4375 - 1*0.2061)*(1 - 1)
= 1.5043 in^2

A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}
= (26 - 23.5 - 2*0.25)*0.25*1
= 0.5 in^2

Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5
= 1.5043 + 0.3194 + 0 + 0.0625 + 0.0352 + 0 + 0.5
= 2.4214 in^2

The area replacement requirements of Appendix 1-7(a) are satisfied.

Check Large Opening per Appendix 1-7(b)

1-7(b)(1)(a)	D_i = 47.125 in > 60 in	False
1-7(b)(1)(b)	d = 23.5 in > 40 in	False
1-7(b)(1)(b)	d = 23.5 in > $3.4*(23.5625*0.4375)^{0.5}$ = 10.9164 in	True
1-7(b)(1)(c)	R_n / R = 11.75 / 23.5625 = 0.4987 ≤ 0.7	True

The opening is not within the size range defined by 1-7(b)(1)(a) and (b) so it is exempt from the requirements of 1-7(b)(2),(3) and (4).

R_n / R = 0.4987 does not exceed 0.7 so a U-2(g) analysis is not required per 1-7(b)(1)(c).

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 13.2154 / 24 = 0.5506
D_o / t = 24 / 0.0675 = 355.5776
From table G: A = 0.000381
From table HA-1: B = 5,350.2961 psi

P_a = 4*B / (3*(D_o / t))
= 4*5,350.3 / (3*(24 / 0.0675))
= 20.06 psi

Design thickness for external pressure P_a = 20.06 psi

t_a = t + Corrosion = 0.0675 + 0.125 = 0.1925"

Process Gas Outlet (B1)

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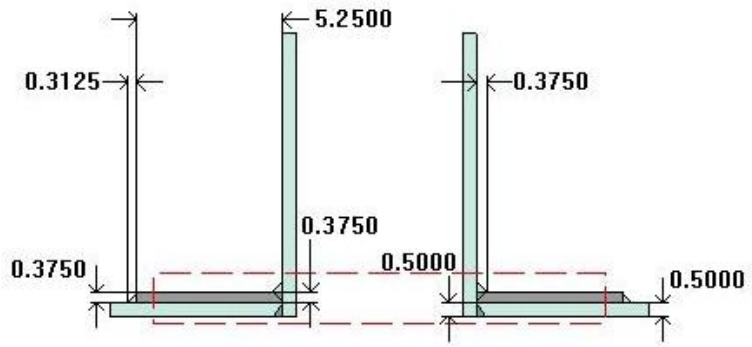

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bonnet Shell
Orientation	270°
Nozzle center line offset to datum line	-25.625"
End of nozzle to shell center	35"
Passes through a Category A joint	No

Nozzle	
Description	NPS 10 Sch 80S (XS)
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	9.75"
Nominal wall thickness	0.5"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.38"
Projection available outside vessel to flange face, Lf	8"
Local vessel minimum thickness	0.5"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	21.25"
Thickness, t_e	0.375"

Is split	No
Welds	
Inner Fillet, Leg_{41}	0.375"
Outer Fillet, Leg_{42}	0.3125"
Nozzle to vessel groove weld	0.5"
Pad groove weld	0.375"

ASME B16.5-2009 Flange	
Description	NPS 10 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320° F
Material is exempt from impact testing at the Design MDMT of -20° F.

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*27 / (20,000*1 + 0.4*61.16) =	0.0825"
Stress ratio = t_r*E* / (t_n - c) = 0.0825*1 / (0.5 - 0.0625) =	0.1885
Impact test exempt per UHA-51(g) (coincident ratio = 0.1885)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Local stresses at the nozzle OD per WRC 107 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 61.16 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.1822	7.4164	3.1701	0.6578	--	3.4688	0.1197	0.2769	0.4375

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-25,144.58	59,872.13	123,403.85	14,900.42	180,387.45	63,809.79	149,151.01

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.1875	0.2188	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	61.16	7,000	142,800	0	184,800	0	0	42,300	42,300	10,491	21,150	No

Calculations for internal pressure 61.16 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(10, 5 + (0.5 - 0.125) + (0.5 - 0.0625))
= 10 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.5 - 0.125) + 0.375)
= 1.0938 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= $61.1565*5 / ((12,000 / 0.85)*1 - 0.6*61.1565)$
= 0.0217 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= $61.1565*27 / (14,100*1 + 0.4*61.1565)$
= 0.1169 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $61.1565*27 / (14,100*0.85 + 0.4*61.1565)$
= 0.1375 in

Area required per UG-37(c)

Allowable stresses: S_n = 12,000, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.8511

f_{r2} = lesser of 1 or S_n / S_v = 0.8511

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8511

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $10*0.1169*1 + 2*0.375*0.1169*1*(1 - 0.8511)$
= 1.1822 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 3.1701 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $10*(1*0.4375 - 1*0.1169) - 2*0.375*(1*0.4375 - 1*0.1169)*(1 - 0.8511)$
= 3.1701 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.4375 + 0.375)*(1*0.4375 - 1*0.1169) - 2*0.375*(1*0.4375 - 1*0.1169)*(1 - 0.8511)$
= 0.4852 in^2

A_2 = smaller of the following= 0.6578 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$

= 5*(0.375 - 0.0217)*0.8511*0.4375
= 0.6578 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= 2*(0.375 - 0.0217)*(2.5*0.375 + 0.375)*0.8511
= 0.7893 in^2

A_{41} = Leg^2*f_{r3}
= $0.375^2*0.8511$
= 0.1197 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (20 - 10 - 2*0.375)*0.375*1
= 3.4688 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 3.1701 + 0.6578 + 0.1197 + 0 + 3.4688
= 7.4164 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.375 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.375 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.1875 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.3125 = 0.2188 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 61.1565*5 / (12,000*1 - 0.6*61.1565) + 0.125
= 0.1506 in

$t_{a\ UG-22}$ = 0.2769 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1506 , 0.2769]
= 0.2769 in

t_{b1} = $P*R_o$ / ($S*E$ + 0.4*P) + Corrosion
= 61.1565*27 / (14,100*1 + 0.4*61.1565) + 0.0625
= 0.1794 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.1794 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b1}]
= min[0.4444 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.2769 , 0.1875]
= 0.2769 in

Available nozzle wall thickness new, t_n = 0.875*0.5 = 0.4375 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 = 10,434 psi
Nozzle wall in shear:	0.7*12,000 = 8,400 psi
Inner fillet weld in shear:	0.49*12,000 = 5,880 psi
Outer fillet weld in shear:	0.49*14,100 = 6,909 psi
Upper groove weld in tension:	0.74*14,100 = 10,434 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*10.75*0.375*5,880 = 37,233.76 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*21.25*0.3125*6,909 = 72,068.26 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*10.375*0.375*8,400 = 51,335.59 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*10.75*0.4375*10,434 = 77,082.76 lb_f

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*10.75*0.375*10,434 = 66,070.93 lb_f

Loading on welds per UG-41(b)(1)

W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v
= (1.1822 - 3.1701 + 2*0.375*0.8511*(1*0.4375 - 1*0.1169))*14,100

= -25,144.58 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (0.6578 + 3.4688 + 0.1197 + 0)*14,100
= 59,872.13 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.6578 + 0 + 0.1197 + 0 + 2*0.375*0.4375*0.8511)*14,100
= 14,900.42 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.6578 + 0 + 3.4688 + 0.1197 + 0 + 0 + 2*0.375*0.4375*0.8511)*14,100
= 63,809.79 lb_f

Load for path 1-1 lesser of W or W_{1-1} = -25,144.58 lb_f
Path 1-1 through (2) & (3) = 72,068.26 + 51,335.59 = 123,403.85 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -25,144.58 lb_f
Path 2-2 through (1), (4), (6) = 37,233.76 + 77,082.76 + 66,070.93 = 180,387.45 lb_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -25,144.58 lb_f
Path 3-3 through (2), (4) = 72,068.26 + 77,082.76 = 149,151.01 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	7,000 lb_f
Circumferential moment, M_c	142,800 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	184,800 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	61.16 psi
Mean shell radius, R_m	26.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 26.7813 / 0.4375 = 61.2143$

$\beta = 0.875*r_o / R_m = 0.875*10.625 / 26.7813 = 0.3471$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =3,713 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =1,856 psi

Maximum combined stress (P_L+P_b+Q) = 42,300 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = -8,840 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	1.9642	0	0	0	0	-1,173	-1,173	-1,173	-1,173
4C*	N_ϕ / (P / R_m)	5.1126	-3,054	-3,054	-3,054	-3,054	0	0	0	0
1C	M_ϕ / P	0.0647	0	0	0	0	-14,197	14,197	-14,197	14,197
2C-1	M_ϕ / P	0.0087	-1,909	1,909	-1,909	1,909	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	1.5818	0	0	0	0	-2,074	-2,074	2,074	2,074
1A	M_ϕ / [M_c / (R_m*β)]	0.0574	0	0	0	0	-27,637	27,637	27,637	-27,637
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.0624	-5,195	-5,195	5,195	5,195	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0095	-5,919	5,919	5,919	-5,919	0	0	0	0
Pressure stress*			3,713	3,713	3,713	3,713	3,713	3,713	3,713	3,713
Total circumferential stress			-12,364	3,292	9,864	1,844	-41,368	42,300	18,054	-8,826
Primary membrane circumferential stress*			-4,536	-4,536	5,854	5,854	466	466	4,614	4,614
3C*	N_x / (P / R_m)	1.9642	-1,173	-1,173	-1,173	-1,173	0	0	0	0
4C*	N_x / (P / R_m)	5.1126	0	0	0	0	-3,054	-3,054	-3,054	-3,054
1C-1	M_x / P	0.0217	-4,762	4,762	-4,762	4,762	0	0	0	0
2C	M_x / P	0.03	0	0	0	0	-6,583	6,583	-6,583	6,583
4A*	N_x / [M_c / (R_m^2*β)]	5.8293	0	0	0	0	-7,642	-7,642	7,642	7,642
2A	M_x / [M_c / (R_m*β)]	0.0228	0	0	0	0	-10,978	10,978	10,978	-10,978
4B*	N_x / [M_L / (R_m^2*β)]	1.7268	-2,930	-2,930	2,930	2,930	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0181	-11,278	11,278	11,278	-11,278	0	0	0	0
Pressure stress*			1,856	1,856	1,856	1,856	1,856	1,856	1,856	1,856
Total longitudinal stress			-18,287	13,793	10,129	-2,903	-26,401	8,721	10,839	2,049
Primary membrane longitudinal stress*			-2,247	-2,247	3,613	3,613	-8,840	-8,840	6,444	6,444
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-18,287	13,793	10,129	-4,747	-41,368	42,300	18,054	10,875
* denotes primary stress.										

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 26.7813 / 0.8125 = 32.9615$

$\beta = 0.875*r_o / R_m = 0.875*5.375 / 26.7813 = 0.1756$

Pressure stress intensity factor, I = 1.4891 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =5,529 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =2,764 psi

Maximum combined stress (P_L+P_b+Q) = 29,799 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 10,491 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	3.6393	0	0	0	0	-1,171	-1,171	-1,171	-1,171
4C*	N_ϕ / (P / R_m)	4.982	-1,603	-1,603	-1,603	-1,603	0	0	0	0
1C	M_ϕ / P	0.0864	0	0	0	0	-5,497	5,497	-5,497	5,497
2C-1	M_ϕ / P	0.0526	-3,346	3,346	-3,346	3,346	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	1.2952	0	0	0	0	-1,807	-1,807	1,807	1,807
1A	M_ϕ / [M_c / (R_m*β)]	0.0854	0	0	0	0	-23,567	23,567	23,567	-23,567
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.6354	-6,565	-6,565	6,565	6,565	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0339	-12,107	12,107	12,107	-12,107	0	0	0	0
Pressure stress*			5,529	5,529	5,529	5,529	3,713	3,713	3,713	3,713
Total circumferential stress			-18,092	12,814	19,252	1,730	-28,329	29,799	22,419	-13,721
Primary membrane circumferential stress*			-2,639	-2,639	10,491	10,491	735	735	4,349	4,349
3C*	N_x / (P / R_m)	3.6393	-1,171	-1,171	-1,171	-1,171	0	0	0	0
4C*	N_x / (P / R_m)	4.982	0	0	0	0	-1,603	-1,603	-1,603	-1,603
1C-1	M_x / P	0.0902	-5,739	5,739	-5,739	5,739	0	0	0	0
2C	M_x / P	0.0535	0	0	0	0	-3,404	3,404	-3,404	3,404
4A*	N_x / [M_c / (R_m^2*β)]	2.2335	0	0	0	0	-3,117	-3,117	3,117	3,117
2A	M_x / [M_c / (R_m*β)]	0.0455	0	0	0	0	-12,556	12,556	12,556	-12,556
4B*	N_x / [M_L / (R_m^2*β)]	1.2746	-2,302	-2,302	2,302	2,302	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0528	-18,856	18,856	18,856	-18,856	0	0	0	0
Pressure stress*			1,856	1,856	1,856	1,856	2,764	2,764	2,764	2,764
Total longitudinal stress			-26,212	22,978	16,104	-10,130	-17,916	14,004	13,430	-4,874
Primary membrane longitudinal stress*			-1,617	-1,617	2,987	2,987	-1,956	-1,956	4,278	4,278
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-26,212	22,978	19,252	-11,860	-28,329	29,799	22,419	-13,721
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 61.16*5 / (2*0.3125) - 7,000 / (π*(5.375^2 - 5^2)) + 233,544.2*5.375 / 164.673
= 7,540 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*5 / (2*0.3125) - 7,000 / (π*(5.375^2 - 5^2)) - 233,544.2*5.375 / 164.673)
= 8,255 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 347.36 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
4.6104	4.6107	0.3293	0.8806	--	3.2813	0.1195	0.3194	0.4375

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
86,205.7	85,627	198,023.42	28,502	271,422.31	94,127	227,181.33

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.1875	0.2188	weld size is adequate

Calculations for internal pressure 347.36 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(9.75, 4.875 + (0.5 - 0) + (0.5 - 0))
= 9.75 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.5 - 0) + 0.375)
= 1.25 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 347.3623*4.875 / ((17,000 / 0.85)*1 - 0.6*347.3623)
= 0.0856 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o$ / (S*E + 0.4*P)
= 347.3623*27 / (20,000*1 + 0.4*347.3623)

= 0.4657 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $347.3623*27 / (20,000*0.85 + 0.4*347.3623)$
= 0.5472 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $9.75*0.4657*1 + 2*0.5*0.4657*1*(1 - 0.85)$
= 4.6104 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.3293 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $9.75*(1*0.5 - 1*0.4657) - 2*0.5*(1*0.5 - 1*0.4657)*(1 - 0.85)$
= 0.3293 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.5 + 0.5)*(1*0.5 - 1*0.4657) - 2*0.5*(1*0.5 - 1*0.4657)*(1 - 0.85)$
= 0.0635 in^2

A_2 = smaller of the following= 0.8806 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.5 - 0.0856)*0.85*0.5$
= 0.8806 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.5 - 0.0856)*(2.5*0.5 + 0.375)*0.85$
= 1.1448 in^2

A_{41} = Leg^2*f_{r3}
= $0.375^2*0.85$
= 0.1195 in^2

A_{42} = $Leg^2 * f_{r4}$
= $0^2 * 1$
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (19.5 - 9.75 - 2*0.5)*0.375*1
= 3.2813 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0.3293 + 0.8806 + 0.1195 + 0 + 3.2813
= 4.6107 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.375 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.375 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.1875 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.3125 = 0.2188 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 347.3623*4.875 / (17,000*1 - 0.6*347.3623) + 0
= 0.1008 in

$t_{a\ UG-22}$ = 0.1542 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1008 , 0.1542]
= 0.1542 in

t_{b1} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 347.3623*27 / (20,000*1 + 0.4*347.3623) + 0
= 0.4657 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.4657 , 0.0625]
= 0.4657 in

t_b = min[t_{b3} , t_{b1}]
= min[0.3194 , 0.4657]
= 0.3194 in

t_{UG-45} = max[t_a , t_b]
= max[0.1542 , 0.3194]
= 0.3194 in

Available nozzle wall thickness new, t_n = 0.875*0.5 = 0.4375 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*17,000 =	11,900 psi
Inner fillet weld in shear:	0.49*17,000 =	8,330 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*10.75*0.375*8,330 = 52,747.83 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*21.25*0.3125*9,800 = 102,224.48 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*10.25*0.5*11,900 = 95,798.94 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*10.75*0.5*14,800 = 124,956.85 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*10.75*0.375*14,800 = 93,717.64 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (4.6104 - 0.3293 + 2*0.5*0.85*(1*0.5 - 1*0.4657))*20,000
= 86,205.7 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (0.8806 + 3.2813 + 0.1195 + 0)*20,000
= 85,627 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.8806 + 0 + 0.1195 + 0 + 2*0.5*0.5*0.85)*20,000
= 28,502 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.8806 + 0 + 3.2813 + 0.1195 + 0 + 0 + 2*0.5*0.5*0.85)*20,000
= 94,127 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 85,627 lb_f
Path 1-1 through (2) & (3) = 102,224.48 + 95,798.94 = 198,023.42 lb_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 28,502 lb_f
Path 2-2 through (1), (4), (6) = 52,747.83 + 124,956.85 + 93,717.64 = 271,422.31 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 86,205.7 lb_f
Path 3-3 through (2), (4) = 102,224.48 + 124,956.85 = 227,181.33 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 120.36 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
2.2121	4.1114	--	0.5231	--	3.4688	0.1195	0.2541	0.4375

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.1875	0.2188	weld size is adequate

Calculations for external pressure 120.36 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(10, 5 + (0.5 - 0.125) + (0.5 - 0.0625))
= 10 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.5 - 0.125) + 0.375)
= 1.0938 in

Nozzle required thickness per UG-28 t_{rn} = 0.0936 in

From UG-37(d)(1) required thickness t_r = 0.4375 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= $0.5*(10*0.4375*1 + 2*0.375*0.4375*1*(1 - 0.85))$
= 2.2121 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $10*(1*0.4375 - 1*0.4375) - 2*0.375*(1*0.4375 - 1*0.4375)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.4375 + 0.375)*(1*0.4375 - 1*0.4375) - 2*0.375*(1*0.4375 - 1*0.4375)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.5231 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.375 - 0.0936)*0.85*0.4375$
= 0.5231 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.375 - 0.0936)*(2.5*0.375 + 0.375)*0.85$
= 0.6278 in^2

A_{41} = Leg^2*f_{r3}
= $0.375^2*0.85$
= 0.1195 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(20 - 10 - 2*0.375)*0.375*1$
= 3.4688 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= $0 + 0.5231 + 0.1195 + 0 + 3.4688$
= 4.1114 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.375 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.375 in
$t_{w(min)}$ = 0.5*t_{min} = 0.1875 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.3125 = 0.2188 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-28}$ = 0.2186 in

$t_{a\ UG-22}$ = 0.2541 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.2186 , 0.2541]
= 0.2541 in

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 120.3613*27 / (20,000*1 + 0.4*120.3613) + 0.0625
= 0.2246 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.2246 , 0.1875]
= 0.2246 in

t_b = min[t_{b3} , t_{b2}]
= min[0.4444 , 0.2246]
= 0.2246 in

t_{UG-45} = max[t_a , t_b]
= max[0.2541 , 0.2246]
= 0.2541 in

Available nozzle wall thickness new, t_n = 0.875*0.5 = 0.4375 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 8.5404 / 10.75 = 0.7945
D_o / t = 10.75 / 0.0936 = 114.7976
From table G: A = 0.001421
From table B = 10,362.8652 psi

HA-1:

P_a = 4*B / (3*(D_o / t))
= 4*10,362.87 / (3*(10.75 / 0.0936))
= 120.36 psi

Design thickness for external pressure P_a = 120.36 psi

t_a = t + Corrosion = 0.0936 + 0.125 = 0.2186"

Backpulse Gas Inlet (A5)

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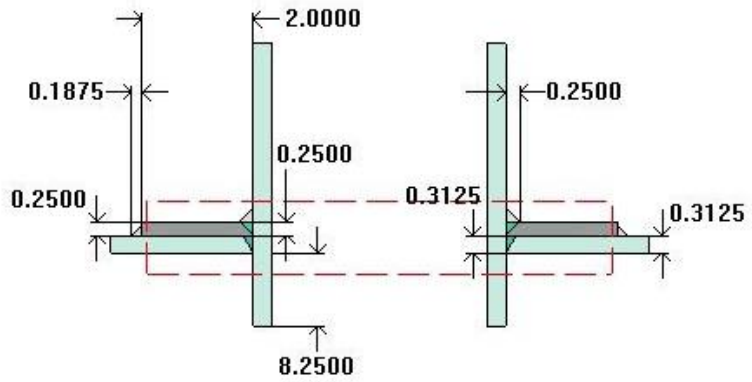

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Top Head
Orientation	225°
End of nozzle to datum line	-60"
Calculated as hillside	Yes
Distance to head center, R	14.1421"
Passes through a Category A joint	No
Nozzle	
Description	NPS 4 Sch 80S (XS)
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	3.826"
Nominal wall thickness	0.337"
Corrosion allowance	0.125"
Opening chord length	4.223"
Projection available outside vessel, Lpr	6.3069"
Internal projection, h_{new}	8.25"
Projection available outside vessel to flange face, Lf	9.6869"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Reinforcing Pad	

Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	8.6611"
Thickness, t_e	0.25"
Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Lower Fillet, Leg_{43}	0"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 4 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0479*1 / (0.2949 - 0.125) =	0.2817
Impact test exempt per UHA-51(g) (coincident ratio = 0.2817)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*54.3125*1 / (2*20,000*1 + 61.16*(1 - 0.2)) =	0.0829"
Stress ratio = t_r*E^* / (t_n - c) = 0.0829*1 / (0.3125 - 0.0625) =	0.3318
Impact test exempt per UHA-51(g) (coincident ratio = 0.3318)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The thickness requirements of UG-45 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 72.85 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.6002	1.7664	0.4575	0.2144	0.0951	0.9462	0.0532	0.2948	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
2,571.44	17,114.98	29,618.88	6,386.29	47,267.62	19,728.11	36,062.57

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_1 (lb_f-in)	V_2 (lb_f)	M_2 (lb_f-in)	V_1 (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	72.85	1,400	14,784	0	11,424	0	0	27,956	42,300	10,655	21,150	No

Calculations for internal pressure 72.85 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.223, 2.1115 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.223 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_l = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 72.8542*2.038 / ((12,000 / 0.85)*1 - 0.6*72.8542)
= 0.0105 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.8542*54.3125*1 / (2*14,100*1 + 72.8542*(1 - 0.2))
= 0.14 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.85*54.3125*1.662 / (2*14,100*0.85 + 72.85*(1.662 - 0.2))
= 0.2731"

Area required per UG-37(c)

Allowable stresses: S_n = 12,000, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.8511

f_{r2} = lesser of 1 or S_n / S_v = 0.8511

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8511

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= 4.223*0.14*1 + 2*0.212*0.14*1*(1 - 0.8511)
= 0.6002 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.4575 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 4.223*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.4575 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2*(0.25 + 0.212)*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.0947 in^2

A_2 = smaller of the following= 0.2144 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0105)*0.8511*0.25$
= 0.2144 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0105)*(2.5*0.212 + 0.25)*0.8511$
= 0.2675 in^2

A_3 = smaller of the following= 0.0951 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.8511$
= 0.159 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.8511$
= 0.0951 in^2

= $2*h*t_i*f_{r2}$
= $2*8.1875*0.1495*0.8511$
= 2.0835 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.8511$
= 0.0532 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(8.446 - 4.6611)*0.25*1$
= 0.9462 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= $0.4575 + 0.2144 + 0.0951 + 0.0532 + 0 + 0.9462$
= 1.7664 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in

$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 72.8542*2.038 / (12,000*1 - 0.6*72.8542) + 0.125
= 0.1374 in

$t_{a\ UG-22}$ = 0.1874 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1374 , 0.1874]
= 0.1874 in

t_{b1} = 0.2948 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.2948 , 0.1875]
= 0.2948 in

t_b = min[t_{b3} , t_{b1}]
= min[0.3324 , 0.2948]
= 0.2948 in

t_{UG-45} = max[t_a , t_b]
= max[0.1874 , 0.2948]
= 0.2948 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 =	10,434 psi
Nozzle wall in shear:	0.7*12,000 =	8,400 psi
Inner fillet weld in shear:	0.49*12,000 =	5,880 psi
Outer fillet weld in shear:	0.49*14,100 =	6,909 psi
Upper groove weld in tension:	0.74*14,100 =	10,434 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*4.5*0.25*5,880 = 10,390.82 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*8.6611*0.1875*6,909 = 17,624.17 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*4.288*0.212*8,400 = 11,994.71 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (0.6002 - 0.4575 + 2*0.212*0.8511*(1*0.25 - 1*0.14))*14,100$
$= 2,571.44$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.2144 + 0.9462 + 0.0532 + 0)*14,100$
$= 17,114.98$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.0532 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 6,386.29$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.9462 + 0.0532 + 0 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 19,728.11$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = 2,571.44 lb_f
Path 1-1 through (2) & (3) = 17,624.17 + 11,994.71 = 29,618.88 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 2,571.44 lb_f
Path 2-2 through (1), (4), (6) = 10,390.82 + 18,438.4 + 18,438.4 = 47,267.62 lb_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = 2,571.44 lb_f
Path 3-3 through (2), (4) = 17,624.17 + 18,438.4 = 36,062.57 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	1,400 lb_f
Circumferential moment, M_1	14,784 lb_f-in
Circumferential shear, V_2	0 lb_f
Longitudinal moment, M_2	11,424 lb_f-in
Longitudinal shear, V_1	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	72.85 psi
Mean dish radius, R_m	54.1875"
Local head thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

U = r_o / Sqr(R_m*T) = 4.25 / Sqr(54.1875*0.25) = 1.155

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local pressure stress = I*P*R_i / (2*T) =7,877 psi

Maximum combined stress (P_L+P_b+Q) = 27,956 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 10,655 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.0553	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239
SR-2	M_x / P	0.0285	-3,830	3,830	-3,830	3,830	-3,830	3,830	-3,830	3,830
SR-3*	$N_x*T*(R_m*T)^{0.5} / M_1$	0.0625	0	0	0	0	-4,017	-4,017	4,017	4,017
SR-3	$M_x*(R_m*T)^{0.5} / M_1$	0.0548	0	0	0	0	-21,131	21,131	21,131	-21,131
SR-3*	$N_x*T*(R_m*T)^{0.5} / M_2$	0.0625	-3,104	-3,104	3,104	3,104	0	0	0	0
SR-3	$M_x*(R_m*T)^{0.5} / M_2$	0.0548	-16,329	16,329	16,329	-16,329	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_x stress			-16,625	23,693	22,241	-2,757	-22,340	27,582	27,956	-6,646
Membrane O_x stress*			3,534	3,534	9,742	9,742	2,621	2,621	10,655	10,655
SR-2*	N_y*T / P	0.017	-381	-381	-381	-381	-381	-381	-381	-381
SR-2	M_y / P	0.0086	-1,156	1,156	-1,156	1,156	-1,156	1,156	-1,156	1,156
SR-3*	$N_y*T*(R_m*T)^{0.5} / M_1$	0.0188	0	0	0	0	-1,208	-1,208	1,208	1,208
SR-3	$M_y*(R_m*T)^{0.5} / M_1$	0.0166	0	0	0	0	-6,401	6,401	6,401	-6,401
SR-3*	$N_y*T*(R_m*T)^{0.5} / M_2$	0.0188	-934	-934	934	934	0	0	0	0
SR-3	$M_y*(R_m*T)^{0.5} / M_2$	0.0166	-4,946	4,946	4,946	-4,946	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_y stress			460	12,664	12,220	4,640	-1,269	13,845	13,949	3,459
Membrane O_y stress*			6,562	6,562	8,430	8,430	6,288	6,288	8,704	8,704
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-17,085	23,693	22,241	-7,397	-22,340	27,582	27,956	-10,105

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

U = r_o / Sqr(R_m*T) = 2.25 / Sqr(54.1875*0.5) = 0.432

Pressure stress intensity factor, I = 0.5451 (derived from Division 2 Part 4.5)

Local pressure stress = I*P*R_i / (2*T) =4,294 psi

Maximum combined stress (P_L+P_b+Q) = 25,267 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 5,200 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.1504	-842	-842	-842	-842	-842	-842	-842	-842
SR-2	M_x / P	0.0967	-3,249	3,249	-3,249	3,249	-3,249	3,249	-3,249	3,249
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1539	0	0	0	0	-1,748	-1,748	1,748	1,748
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.298	0	0	0	0	-20,314	20,314	20,314	-20,314
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1539	-1,351	-1,351	1,351	1,351	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.298	-15,697	15,697	15,697	-15,697	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_x stress			-16,845	21,047	17,251	-7,645	-21,859	25,267	22,265	-11,865
Membrane O_x stress*			2,101	2,101	4,803	4,803	1,704	1,704	5,200	5,200
SR-2*	N_y*T / P	0.0451	-253	-253	-253	-253	-253	-253	-253	-253
SR-2	M_y / P	0.0294	-988	988	-988	988	-988	988	-988	988
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0471	0	0	0	0	-535	-535	535	535
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0903	0	0	0	0	-6,155	6,155	6,155	-6,155
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0471	-413	-413	413	413	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0903	-4,756	4,756	4,756	-4,756	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_y stress			-2,116	9,372	8,222	686	-3,637	10,649	9,743	-591
Membrane O_y stress*			3,628	3,628	4,454	4,454	3,506	3,506	4,576	4,576
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-16,845	21,047	17,251	-8,331	-21,859	25,267	22,265	-11,865

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 72.85*2.038 / (2*0.1699) - 1,400 / (π*(2.25^2 - 2.038^2)) + 18,683.5*2.25 / 6.5799
= 6,336 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*2.038 / (2*0.1699) - 1,400 / (π*(2.25^2 - 2.038^2)) - 18,683.5*2.25 / 6.5799)
= 6,923 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 231.21 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.2704	1.7356	--	0.418	0.4476	0.8169	0.0531	0.2074	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
25,408.05	25,759.57	51,223.08	21,954.19	73,566.28	38,291.76	57,691.02

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 231.21 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3.9643, 1.9822 + (0.337 - 0) + (0.3125 - 0))
= 3.9643 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.337 - 0) + 0.25)
= 0.7813 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.25, 2.5*(0.3125 - 0), 2.5*(0.337 - 0 - 0))
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 231.2097*1.913 / ((17,000 / 0.85)*1 - 0.6*231.2097)
= 0.0223 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.2097*54.3125*1 / (2*20,000*1 + 231.2097*(1 - 0.2))$
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.21*54.3125*1.6686 / (2*20,000*0.85 + 231.21*(1.6686 - 0.2))$
= 0.6102"

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $3.9643*0.3125*1 + 2*0.337*0.3125*1*(1 - 0.85)$
= 1.2704 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $3.9643*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.3125 + 0.337)*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.418 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.337 - 0.0223)*0.85*0.3125$
= 0.418 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.337 - 0.0223)*(2.5*0.337 + 0.25)*0.85$
= 0.5845 in^2

A_3 = smaller of the following= 0.4476 in^2

= $5*t*t_i*f_{r2}$
= 5*0.3125*0.337*0.85
= 0.4476 in^2

= $5*t_i*t_i*f_{r2}$
= 5*0.337*0.337*0.85
= 0.4827 in^2

= $2*h*t_i*f_{r2}$
= 2*8.25*0.337*0.85
= 4.7264 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (7.9286 - 4.6611)*0.25*1
= 0.8169 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.418 + 0.4476 + 0.0531 + 0 + 0.8169
= 1.7356 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 231.2097*1.913 / (17,000*1 - 0.6*231.2097) + 0
= 0.0262 in

$t_{a\ UG\text{-}22}$ = 0.0621 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0262 , 0.0621]
= 0.0621 in

t_{b1} = 0.5194 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.5194 , 0.0625]
= 0.5194 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2074 , 0.5194]
= 0.2074 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0621 , 0.2074]
= 0.2074 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*17,000 =	11,900 psi
Inner fillet weld in shear:	0.49*17,000 =	8,330 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*4.5*0.25*8,330 = 14,720.33 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*8.6611*0.1875*9,800 = 24,998.82 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*4.163*0.337*11,900 = 26,224.25 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*4.5*0.3125*14,800 = 32,692.2 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*14,800 = 26,153.76 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (1.2704 - 0 + 2*0.337*0.85*(1*0.3125 - 1*0.3125))*20,000
= 25,408.05 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (0.418 + 0.8169 + 0.0531 + 0)*20,000
= 25,759.57 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.0531 + 0 + 2*0.337*0.3125*0.85)*20,000
= 21,954.19 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.8169 + 0.0531 + 0 + 0 + 2*0.337*0.3125*0.85)*20,000
= 38,291.76 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 25,408.05 lb_f
Path 1-1 through (2) & (3) = 24,998.82 + 26,224.25 = 51,223.08 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 21,954.19 lb_f
Path 2-2 through (1), (4), (6) = 14,720.33 + 32,692.2 + 26,153.76 = 73,566.28 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 25,408.05 lb_f
Path 3-3 through (2), (4) = 24,998.82 + 32,692.2 = 57,691.02 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 32.75 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.5358	1.2887	--	0.1946	0.095	0.946	0.0531	0.1875	0.2949

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 32.75 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.2226, 2.1113 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.2226 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-28 t_{rn} = 0.0288 in

From UG-37(d)(1) required thickness t_r = 0.25 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= $0.5*(4.2226*0.25*1 + 2*0.212*0.25*1*(1 - 0.85))$
= 0.5358 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $4.2226*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.25 + 0.212)*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.1946 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0288)*0.85*0.25$
= 0.1946 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0288)*(2.5*0.212 + 0.25)*0.85$
= 0.2429 in^2

A_3 = smaller of the following= 0.095 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.85$
= 0.1588 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.85$
= 0.095 in^2

= $2*h*t_i*f_{r2}$

= 2*8.1875*0.1495*0.85
= 2.0809 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (8.4452 - 4.6611)*0.25*1
= 0.946 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.1946 + 0.095 + 0.0531 + 0 + 0.946
= 1.2887 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-28}$ = 0.1538 in

$t_{a\ UG-22}$ = 0.17 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1538 , 0.17]
= 0.17 in

t_{b2} = 0.1363 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.1363 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.3324 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.17 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 10.9017 / 4.5 = 2.4226
D_o / t = 4.5 / 0.0288 = 156.1035
From table G: A = 0.000273
From table HA-1: B = 3,834.325 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,834.33 / (3*(4.5 / 0.0288))
= 32.75 psi

Design thickness for external pressure P_a = 32.75 psi

t_a = t + Corrosion = 0.0288 + 0.125 = 0.1538"

Backpulse Gas Inlet (A4)

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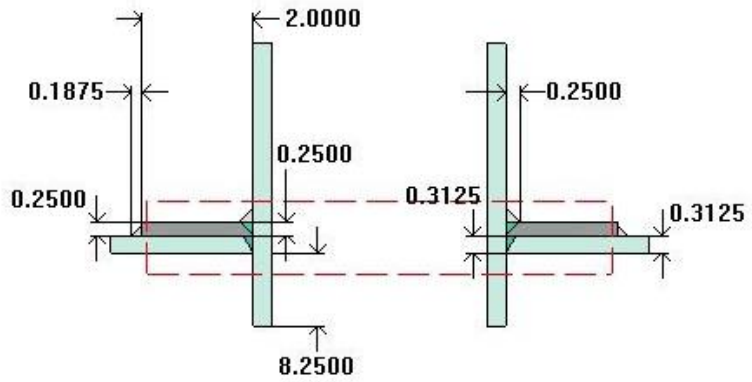
Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Top Head
Orientation	315°
End of nozzle to datum line	-60"
Calculated as hillside	Yes
Distance to head center, R	14.1421"
Passes through a Category A joint	No

Nozzle	
Description	NPS 4 Sch 80S (XS)
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	3.826"
Nominal wall thickness	0.337"
Corrosion allowance	0.125"
Opening chord length	4.223"
Projection available outside vessel, Lpr	6.3069"
Internal projection, h_{new}	8.25"
Projection available outside vessel to flange face, Lf	9.6869"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Reinforcing Pad

Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	8.6611"
Thickness, t_e	0.25"
Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Lower Fillet, Leg_{43}	0"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 4 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0479*1 / (0.2949 - 0.125) =	0.2817
Impact test exempt per UHA-51(g) (coincident ratio = 0.2817)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*54.3125*1 / (2*20,000*1 + 61.16*(1 - 0.2)) =	0.0829"
Stress ratio = t_r*E^* / (t_n - c) = 0.0829*1 / (0.3125 - 0.0625) =	0.3318
Impact test exempt per UHA-51(g) (coincident ratio = 0.3318)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The thickness requirements of UG-45 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 72.85 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.6002	1.7664	0.4575	0.2144	0.0951	0.9462	0.0532	0.2948	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
2,571.44	17,114.98	29,618.88	6,386.29	47,267.62	19,728.11	36,062.57

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_1 (lb_f-in)	V_2 (lb_f)	M_2 (lb_f-in)	V_1 (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	72.85	1,400	14,784	0	11,424	0	0	27,956	42,300	10,655	21,150	No

Calculations for internal pressure 72.85 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.223, 2.1115 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.223 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_l = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 72.8542*2.038 / ((12,000 / 0.85)*1 - 0.6*72.8542)
= 0.0105 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.8542*54.3125*1 / (2*14,100*1 + 72.8542*(1 - 0.2))
= 0.14 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.85*54.3125*1.662 / (2*14,100*0.85 + 72.85*(1.662 - 0.2))
= 0.2731"

Area required per UG-37(c)

Allowable stresses: S_n = 12,000, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.8511

f_{r2} = lesser of 1 or S_n / S_v = 0.8511

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8511

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= 4.223*0.14*1 + 2*0.212*0.14*1*(1 - 0.8511)
= 0.6002 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.4575 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 4.223*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.4575 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2*(0.25 + 0.212)*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.0947 in^2

A_2 = smaller of the following= 0.2144 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0105)*0.8511*0.25$
= 0.2144 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0105)*(2.5*0.212 + 0.25)*0.8511$
= 0.2675 in^2

A_3 = smaller of the following= 0.0951 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.8511$
= 0.159 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.8511$
= 0.0951 in^2

= $2*h*t_i*f_{r2}$
= $2*8.1875*0.1495*0.8511$
= 2.0835 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.8511$
= 0.0532 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(8.446 - 4.6611)*0.25*1$
= 0.9462 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= $0.4575 + 0.2144 + 0.0951 + 0.0532 + 0 + 0.9462$
= 1.7664 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in

$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 72.8542*2.038 / (12,000*1 - 0.6*72.8542) + 0.125
= 0.1374 in

$t_{a\ UG\text{-}22}$ = 0.1874 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.1374 , 0.1874]
= 0.1874 in

t_{b1} = 0.2948 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.2948 , 0.1875]
= 0.2948 in

t_b = min[t_{b3} , t_{b1}]
= min[0.3324 , 0.2948]
= 0.2948 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.1874 , 0.2948]
= 0.2948 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 =	10,434 psi
Nozzle wall in shear:	0.7*12,000 =	8,400 psi
Inner fillet weld in shear:	0.49*12,000 =	5,880 psi
Outer fillet weld in shear:	0.49*14,100 =	6,909 psi
Upper groove weld in tension:	0.74*14,100 =	10,434 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*4.5*0.25*5,880 = 10,390.82 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*8.6611*0.1875*6,909 = 17,624.17 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*4.288*0.212*8,400 = 11,994.71 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (0.6002 - 0.4575 + 2*0.212*0.8511*(1*0.25 - 1*0.14))*14,100$
$= 2,571.44$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.2144 + 0.9462 + 0.0532 + 0)*14,100$
$= 17,114.98$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.0532 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 6,386.29$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.9462 + 0.0532 + 0 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 19,728.11$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = 2,571.44 lb_f
Path 1-1 through (2) & (3) = 17,624.17 + 11,994.71 = 29,618.88 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 2,571.44 lb_f
Path 2-2 through (1), (4), (6) = 10,390.82 + 18,438.4 + 18,438.4 = 47,267.62 lb_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = 2,571.44 lb_f
Path 3-3 through (2), (4) = 17,624.17 + 18,438.4 = 36,062.57 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	1,400 lb_f
Circumferential moment, M_1	14,784 lb_f-in
Circumferential shear, V_2	0 lb_f
Longitudinal moment, M_2	11,424 lb_f-in
Longitudinal shear, V_1	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	72.85 psi
Mean dish radius, R_m	54.1875"
Local head thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$U = r_o / Sqr(R_m*T) = 4.25 / Sqr(54.1875*0.25) = 1.155$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local pressure stress = $I*P*R_i / (2*T)$ =7,877 psi

Maximum combined stress (P_L+P_b+Q) = 27,956 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 10,655 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.0553	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239
SR-2	M_x / P	0.0285	-3,830	3,830	-3,830	3,830	-3,830	3,830	-3,830	3,830
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.0625	0	0	0	0	-4,017	-4,017	4,017	4,017
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.0548	0	0	0	0	-21,131	21,131	21,131	-21,131
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.0625	-3,104	-3,104	3,104	3,104	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.0548	-16,329	16,329	16,329	-16,329	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_x stress			-16,625	23,693	22,241	-2,757	-22,340	27,582	27,956	-6,646
Membrane O_x stress*			3,534	3,534	9,742	9,742	2,621	2,621	10,655	10,655
SR-2*	N_y*T / P	0.017	-381	-381	-381	-381	-381	-381	-381	-381
SR-2	M_y / P	0.0086	-1,156	1,156	-1,156	1,156	-1,156	1,156	-1,156	1,156
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0188	0	0	0	0	-1,208	-1,208	1,208	1,208
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0166	0	0	0	0	-6,401	6,401	6,401	-6,401
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0188	-934	-934	934	934	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0166	-4,946	4,946	4,946	-4,946	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_y stress			460	12,664	12,220	4,640	-1,269	13,845	13,949	3,459
Membrane O_y stress*			6,562	6,562	8,430	8,430	6,288	6,288	8,704	8,704
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-17,085	23,693	22,241	-7,397	-22,340	27,582	27,956	-10,105

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

U = r_o / Sqr(R_m*T) = 2.25 / Sqr(54.1875*0.5) = 0.432

Pressure stress intensity factor, I = 0.5451 (derived from Division 2 Part 4.5)

Local pressure stress = I*P*R_i / (2*T) =4,294 psi

Maximum combined stress (P_L+P_b+Q) = 25,267 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 5,200 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.1504	-842	-842	-842	-842	-842	-842	-842	-842
SR-2	M_x / P	0.0967	-3,249	3,249	-3,249	3,249	-3,249	3,249	-3,249	3,249
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1539	0	0	0	0	-1,748	-1,748	1,748	1,748
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.298	0	0	0	0	-20,314	20,314	20,314	-20,314
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1539	-1,351	-1,351	1,351	1,351	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.298	-15,697	15,697	15,697	-15,697	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_x stress			-16,845	21,047	17,251	-7,645	-21,859	25,267	22,265	-11,865
Membrane O_x stress*			2,101	2,101	4,803	4,803	1,704	1,704	5,200	5,200
SR-2*	N_y*T / P	0.0451	-253	-253	-253	-253	-253	-253	-253	-253
SR-2	M_y / P	0.0294	-988	988	-988	988	-988	988	-988	988
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0471	0	0	0	0	-535	-535	535	535
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0903	0	0	0	0	-6,155	6,155	6,155	-6,155
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0471	-413	-413	413	413	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0903	-4,756	4,756	4,756	-4,756	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_y stress			-2,116	9,372	8,222	686	-3,637	10,649	9,743	-591
Membrane O_y stress*			3,628	3,628	4,454	4,454	3,506	3,506	4,576	4,576
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-16,845	21,047	17,251	-8,331	-21,859	25,267	22,265	-11,865

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 72.85*2.038 / (2*0.1699) - 1,400 / (\pi*(2.25^2 - 2.038^2)) + 18,683.5*2.25 / 6.5799$
= 6,336 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)} = ABS(P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) - M*R_o / I)$
$= ABS(-7.4*2.038 / (2*0.1699) - 1,400 / (\pi*(2.25^2 - 2.038^2)) - 18,683.5*2.25 / 6.5799)$
= 6,923 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 231.21 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.2704	1.7356	--	0.418	0.4476	0.8169	0.0531	0.2074	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
25,408.05	25,759.57	51,223.08	21,954.19	73,566.28	38,291.76	57,691.02

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 231.21 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3.9643, 1.9822 + (0.337 - 0) + (0.3125 - 0))
= 3.9643 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.337 - 0) + 0.25)
= 0.7813 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.25, 2.5*(0.3125 - 0), 2.5*(0.337 - 0 - 0))
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 231.2097*1.913 / ((17,000 / 0.85)*1 - 0.6*231.2097)
= 0.0223 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.2097*54.3125*1 / (2*20,000*1 + 231.2097*(1 - 0.2))$
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.21*54.3125*1.6686 / (2*20,000*0.85 + 231.21*(1.6686 - 0.2))$
= 0.6102"

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $3.9643*0.3125*1 + 2*0.337*0.3125*1*(1 - 0.85)$
= 1.2704 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $3.9643*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.3125 + 0.337)*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.418 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.337 - 0.0223)*0.85*0.3125$
= 0.418 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.337 - 0.0223)*(2.5*0.337 + 0.25)*0.85$
= 0.5845 in^2

A_3 = smaller of the following= 0.4476 in^2

= $5*t*t_i*f_{r2}$
= 5*0.3125*0.337*0.85
= 0.4476 in^2

= $5*t_i*t_i*f_{r2}$
= 5*0.337*0.337*0.85
= 0.4827 in^2

= $2*h*t_i*f_{r2}$
= 2*8.25*0.337*0.85
= 4.7264 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (7.9286 - 4.6611)*0.25*1
= 0.8169 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.418 + 0.4476 + 0.0531 + 0 + 0.8169
= 1.7356 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 231.2097*1.913 / (17,000*1 - 0.6*231.2097) + 0
= 0.0262 in

$t_{a\ UG\text{-}22}$ = 0.0621 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0262 , 0.0621]
= 0.0621 in

t_{b1} = 0.5194 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.5194 , 0.0625]
= 0.5194 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2074 , 0.5194]
= 0.2074 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0621 , 0.2074]
= 0.2074 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*17,000 =	11,900 psi
Inner fillet weld in shear:	0.49*17,000 =	8,330 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*4.5*0.25*8,330 = 14,720.33 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*8.6611*0.1875*9,800 = 24,998.82 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*4.163*0.337*11,900 = 26,224.25 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*4.5*0.3125*14,800 = 32,692.2 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*14,800 = 26,153.76 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (1.2704 - 0 + 2*0.337*0.85*(1*0.3125 - 1*0.3125))*20,000
= 25,408.05 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (0.418 + 0.8169 + 0.0531 + 0)*20,000
= 25,759.57 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.0531 + 0 + 2*0.337*0.3125*0.85)*20,000
= 21,954.19 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.8169 + 0.0531 + 0 + 0 + 2*0.337*0.3125*0.85)*20,000
= 38,291.76 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 25,408.05 lb_f
Path 1-1 through (2) & (3) = 24,998.82 + 26,224.25 = 51,223.08 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 21,954.19 lb_f
Path 2-2 through (1), (4), (6) = 14,720.33 + 32,692.2 + 26,153.76 = 73,566.28 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 25,408.05 lb_f
Path 3-3 through (2), (4) = 24,998.82 + 32,692.2 = 57,691.02 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 32.75 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.5358	1.2887	--	0.1946	0.095	0.946	0.0531	0.1875	0.2949

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 32.75 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.2226, 2.1113 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.2226 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-28 t_{rn} = 0.0288 in

From UG-37(d)(1) required thickness t_r = 0.25 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= $0.5*(4.2226*0.25*1 + 2*0.212*0.25*1*(1 - 0.85))$
= 0.5358 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $4.2226*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.25 + 0.212)*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.1946 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0288)*0.85*0.25$
= 0.1946 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0288)*(2.5*0.212 + 0.25)*0.85$
= 0.2429 in^2

A_3 = smaller of the following= 0.095 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.85$
= 0.1588 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.85$
= 0.095 in^2

= $2*h*t_i*f_{r2}$

= 2*8.1875*0.1495*0.85
= 2.0809 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (8.4452 - 4.6611)*0.25*1
= 0.946 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.1946 + 0.095 + 0.0531 + 0 + 0.946
= 1.2887 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-28}$ = 0.1538 in

$t_{a\ UG-22}$ = 0.17 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1538 , 0.17]
= 0.17 in

t_{b2} = 0.1363 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.1363 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.3324 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.17 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 10.9017 / 4.5 = 2.4226
D_o / t = 4.5 / 0.0288 = 156.1035
From table G: A = 0.000273
From table HA-1: B = 3,834.325 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,834.33 / (3*(4.5 / 0.0288))
= 32.75 psi

Design thickness for external pressure P_a = 32.75 psi

t_a = t + Corrosion = 0.0288 + 0.125 = 0.1538"

Backpulse Gas Inlet (A3)

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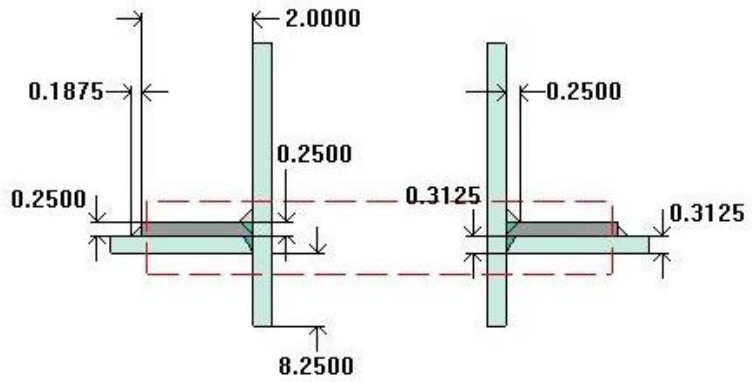

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Top Head
Orientation	45°
End of nozzle to datum line	-60"
Calculated as hillside	Yes
Distance to head center, R	14.1421"
Passes through a Category A joint	No
Nozzle	
Description	NPS 4 Sch 80S (XS)
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	3.826"
Nominal wall thickness	0.337"
Corrosion allowance	0.125"
Opening chord length	4.223"
Projection available outside vessel, Lpr	6.3069"
Internal projection, h_{new}	8.25"
Projection available outside vessel to flange face, Lf	9.6869"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Reinforcing Pad	

Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	8.6611"
Thickness, t_e	0.25"
Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Lower Fillet, Leg_{43}	0"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 4 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0479*1 / (0.2949 - 0.125) =	0.2817
Impact test exempt per UHA-51(g) (coincident ratio = 0.2817)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*54.3125*1 / (2*20,000*1 + 61.16*(1 - 0.2)) =	0.0829"
Stress ratio = t_r*E^* / (t_n - c) = 0.0829*1 / (0.3125 - 0.0625) =	0.3318
Impact test exempt per UHA-51(g) (coincident ratio = 0.3318)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The thickness requirements of UG-45 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 72.85 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.6002	1.7664	0.4575	0.2144	0.0951	0.9462	0.0532	0.2948	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
2,571.44	17,114.98	29,618.88	6,386.29	47,267.62	19,728.11	36,062.57

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_1 (lb_f-in)	V_2 (lb_f)	M_2 (lb_f-in)	V_1 (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	72.85	1,400	14,784	0	11,424	0	0	27,956	42,300	10,655	21,150	No

Calculations for internal pressure 72.85 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.223, 2.1115 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.223 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_l = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 72.8542*2.038 / ((12,000 / 0.85)*1 - 0.6*72.8542)
= 0.0105 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.8542*54.3125*1 / (2*14,100*1 + 72.8542*(1 - 0.2))
= 0.14 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.85*54.3125*1.662 / (2*14,100*0.85 + 72.85*(1.662 - 0.2))
= 0.2731"

Area required per UG-37(c)

Allowable stresses: S_n = 12,000, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.8511

f_{r2} = lesser of 1 or S_n / S_v = 0.8511

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8511

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= 4.223*0.14*1 + 2*0.212*0.14*1*(1 - 0.8511)
= 0.6002 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.4575 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 4.223*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.4575 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2*(0.25 + 0.212)*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.0947 in^2

A_2 = smaller of the following= 0.2144 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0105)*0.8511*0.25$
= 0.2144 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0105)*(2.5*0.212 + 0.25)*0.8511$
= 0.2675 in^2

A_3 = smaller of the following= 0.0951 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.8511$
= 0.159 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.8511$
= 0.0951 in^2

= $2*h*t_i*f_{r2}$
= $2*8.1875*0.1495*0.8511$
= 2.0835 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.8511$
= 0.0532 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(8.446 - 4.6611)*0.25*1$
= 0.9462 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= $0.4575 + 0.2144 + 0.0951 + 0.0532 + 0 + 0.9462$
= 1.7664 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in

$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 72.8542*2.038 / (12,000*1 - 0.6*72.8542) + 0.125
= 0.1374 in

$t_{a\ UG-22}$ = 0.1874 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1374 , 0.1874]
= 0.1874 in

t_{b1} = 0.2948 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.2948 , 0.1875]
= 0.2948 in

t_b = min[t_{b3} , t_{b1}]
= min[0.3324 , 0.2948]
= 0.2948 in

t_{UG-45} = max[t_a , t_b]
= max[0.1874 , 0.2948]
= 0.2948 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 =	10,434 psi
Nozzle wall in shear:	0.7*12,000 =	8,400 psi
Inner fillet weld in shear:	0.49*12,000 =	5,880 psi
Outer fillet weld in shear:	0.49*14,100 =	6,909 psi
Upper groove weld in tension:	0.74*14,100 =	10,434 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*4.5*0.25*5,880 = 10,390.82 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*8.6611*0.1875*6,909 = 17,624.17 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*4.288*0.212*8,400 = 11,994.71 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (0.6002 - 0.4575 + 2*0.212*0.8511*(1*0.25 - 1*0.14))*14,100$
$= 2,571.44$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.2144 + 0.9462 + 0.0532 + 0)*14,100$
$= 17,114.98$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.0532 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 6,386.29$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.9462 + 0.0532 + 0 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 19,728.11$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = 2,571.44 lb_f
Path 1-1 through (2) & (3) = 17,624.17 + 11,994.71 = 29,618.88 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 2,571.44 lb_f
Path 2-2 through (1), (4), (6) = 10,390.82 + 18,438.4 + 18,438.4 = 47,267.62 lb_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = 2,571.44 lb_f
Path 3-3 through (2), (4) = 17,624.17 + 18,438.4 = 36,062.57 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	1,400 lb_f
Circumferential moment, M_1	14,784 lb_f-in
Circumferential shear, V_2	0 lb_f
Longitudinal moment, M_2	11,424 lb_f-in
Longitudinal shear, V_1	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	72.85 psi
Mean dish radius, R_m	54.1875"
Local head thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

U = r_o / Sqr(R_m*T) = 4.25 / Sqr(54.1875*0.25) = 1.155

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local pressure stress = I*P*R_i / (2*T) =7,877 psi

Maximum combined stress (P_L+P_b+Q) = 27,956 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 10,655 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.0553	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239
SR-2	M_x / P	0.0285	-3,830	3,830	-3,830	3,830	-3,830	3,830	-3,830	3,830
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.0625	0	0	0	0	-4,017	-4,017	4,017	4,017
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.0548	0	0	0	0	-21,131	21,131	21,131	-21,131
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.0625	-3,104	-3,104	3,104	3,104	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.0548	-16,329	16,329	16,329	-16,329	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_x stress			-16,625	23,693	22,241	-2,757	-22,340	27,582	27,956	-6,646
Membrane O_x stress*			3,534	3,534	9,742	9,742	2,621	2,621	10,655	10,655
SR-2*	N_y*T / P	0.017	-381	-381	-381	-381	-381	-381	-381	-381
SR-2	M_y / P	0.0086	-1,156	1,156	-1,156	1,156	-1,156	1,156	-1,156	1,156
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0188	0	0	0	0	-1,208	-1,208	1,208	1,208
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0166	0	0	0	0	-6,401	6,401	6,401	-6,401
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0188	-934	-934	934	934	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0166	-4,946	4,946	4,946	-4,946	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_y stress			460	12,664	12,220	4,640	-1,269	13,845	13,949	3,459
Membrane O_y stress*			6,562	6,562	8,430	8,430	6,288	6,288	8,704	8,704
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-17,085	23,693	22,241	-7,397	-22,340	27,582	27,956	-10,105

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

U = r_o / Sqr(R_m*T) = 2.25 / Sqr(54.1875*0.5) = 0.432

Pressure stress intensity factor, I = 0.5451 (derived from Division 2 Part 4.5)

Local pressure stress = I*P*R_i / (2*T) =4,294 psi

Maximum combined stress (P_L+P_b+Q) = 25,267 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 5,200 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.1504	-842	-842	-842	-842	-842	-842	-842	-842
SR-2	M_x / P	0.0967	-3,249	3,249	-3,249	3,249	-3,249	3,249	-3,249	3,249
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1539	0	0	0	0	-1,748	-1,748	1,748	1,748
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.298	0	0	0	0	-20,314	20,314	20,314	-20,314
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1539	-1,351	-1,351	1,351	1,351	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.298	-15,697	15,697	15,697	-15,697	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_x stress			-16,845	21,047	17,251	-7,645	-21,859	25,267	22,265	-11,865
Membrane O_x stress*			2,101	2,101	4,803	4,803	1,704	1,704	5,200	5,200
SR-2*	N_y*T / P	0.0451	-253	-253	-253	-253	-253	-253	-253	-253
SR-2	M_y / P	0.0294	-988	988	-988	988	-988	988	-988	988
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0471	0	0	0	0	-535	-535	535	535
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0903	0	0	0	0	-6,155	6,155	6,155	-6,155
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0471	-413	-413	413	413	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0903	-4,756	4,756	4,756	-4,756	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_y stress			-2,116	9,372	8,222	686	-3,637	10,649	9,743	-591
Membrane O_y stress*			3,628	3,628	4,454	4,454	3,506	3,506	4,576	4,576
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-16,845	21,047	17,251	-8,331	-21,859	25,267	22,265	-11,865

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 72.85*2.038 / (2*0.1699) - 1,400 / (\pi*(2.25^2 - 2.038^2)) + 18,683.5*2.25 / 6.5799$
$= 6,336$ psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)} = ABS(P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) - M*R_o / I)$
$= ABS(-7.4*2.038 / (2*0.1699) - 1,400 / (\pi*(2.25^2 - 2.038^2)) - 18,683.5*2.25 / 6.5799)$
$= 6,923$ psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 231.21 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.2704	1.7356	--	0.418	0.4476	0.8169	0.0531	0.2074	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
25,408.05	25,759.57	51,223.08	21,954.19	73,566.28	38,291.76	57,691.02

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 231.21 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3.9643, 1.9822 + (0.337 - 0) + (0.3125 - 0))
= 3.9643 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.337 - 0) + 0.25)
= 0.7813 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.25, 2.5*(0.3125 - 0), 2.5*(0.337 - 0 - 0))
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 231.2097*1.913 / ((17,000 / 0.85)*1 - 0.6*231.2097)
= 0.0223 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.2097*54.3125*1 / (2*20,000*1 + 231.2097*(1 - 0.2))$
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.21*54.3125*1.6686 / (2*20,000*0.85 + 231.21*(1.6686 - 0.2))$
= 0.6102"

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $3.9643*0.3125*1 + 2*0.337*0.3125*1*(1 - 0.85)$
= 1.2704 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $3.9643*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.3125 + 0.337)*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.418 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.337 - 0.0223)*0.85*0.3125$
= 0.418 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.337 - 0.0223)*(2.5*0.337 + 0.25)*0.85$
= 0.5845 in^2

A_3 = smaller of the following= 0.4476 in^2

= $5*t*t_i*f_{r2}$
= 5*0.3125*0.337*0.85
= 0.4476 in^2

= $5*t_i*t_i*f_{r2}$
= 5*0.337*0.337*0.85
= 0.4827 in^2

= $2*h*t_i*f_{r2}$
= 2*8.25*0.337*0.85
= 4.7264 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (7.9286 - 4.6611)*0.25*1
= 0.8169 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.418 + 0.4476 + 0.0531 + 0 + 0.8169
= 1.7356 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 231.2097*1.913 / (17,000*1 - 0.6*231.2097) + 0
= 0.0262 in

$t_{a\ UG\text{-}22}$ = 0.0621 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0262 , 0.0621]
= 0.0621 in

t_{b1} = 0.5194 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.5194 , 0.0625]
= 0.5194 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2074 , 0.5194]
= 0.2074 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0621 , 0.2074]
= 0.2074 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*17,000 =	11,900 psi
Inner fillet weld in shear:	0.49*17,000 =	8,330 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*4.5*0.25*8,330 = 14,720.33 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*8.6611*0.1875*9,800 = 24,998.82 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*4.163*0.337*11,900 = 26,224.25 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*4.5*0.3125*14,800 = 32,692.2 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*14,800 = 26,153.76 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (1.2704 - 0 + 2*0.337*0.85*(1*0.3125 - 1*0.3125))*20,000
= 25,408.05 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (0.418 + 0.8169 + 0.0531 + 0)*20,000
= 25,759.57 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.0531 + 0 + 2*0.337*0.3125*0.85)*20,000
= 21,954.19 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.8169 + 0.0531 + 0 + 0 + 2*0.337*0.3125*0.85)*20,000
= 38,291.76 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 25,408.05 lb_f
Path 1-1 through (2) & (3) = 24,998.82 + 26,224.25 = 51,223.08 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 21,954.19 lb_f
Path 2-2 through (1), (4), (6) = 14,720.33 + 32,692.2 + 26,153.76 = 73,566.28 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 25,408.05 lb_f
Path 3-3 through (2), (4) = 24,998.82 + 32,692.2 = 57,691.02 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 32.75 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.5358	1.2887	--	0.1946	0.095	0.946	0.0531	0.1875	0.2949

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 32.75 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.2226, 2.1113 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.2226 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-28 t_{rn} = 0.0288 in

From UG-37(d)(1) required thickness t_r = 0.25 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= $0.5*(4.2226*0.25*1 + 2*0.212*0.25*1*(1 - 0.85))$
= 0.5358 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $4.2226*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.25 + 0.212)*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.1946 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0288)*0.85*0.25$
= 0.1946 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0288)*(2.5*0.212 + 0.25)*0.85$
= 0.2429 in^2

A_3 = smaller of the following= 0.095 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.85$
= 0.1588 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.85$
= 0.095 in^2

= $2*h*t_i*f_{r2}$

= 2*8.1875*0.1495*0.85
= 2.0809 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (8.4452 - 4.6611)*0.25*1
= 0.946 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.1946 + 0.095 + 0.0531 + 0 + 0.946
= 1.2887 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-28}$ = 0.1538 in

$t_{a\ UG-22}$ = 0.17 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1538 , 0.17]
= 0.17 in

t_{b2} = 0.1363 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.1363 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.3324 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.17 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 10.9017 / 4.5 = 2.4226
D_o / t = 4.5 / 0.0288 = 156.1035
From table G: A = 0.000273
From table HA-1: B = 3,834.325 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,834.33 / (3*(4.5 / 0.0288))
= 32.75 psi

Design thickness for external pressure P_a = 32.75 psi

t_a = t + Corrosion = 0.0288 + 0.125 = 0.1538"

Backpulse Gas Inlet (A2)

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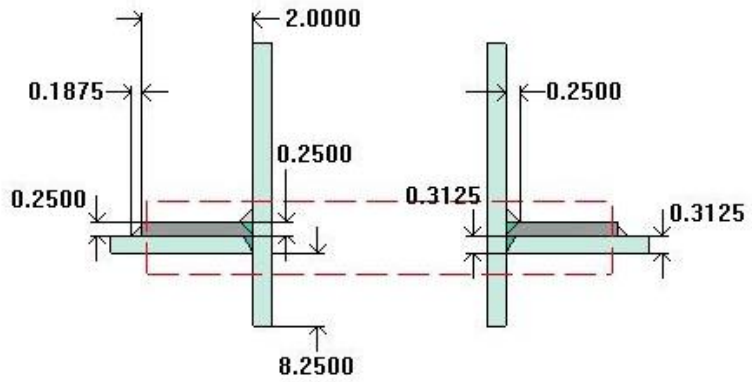
Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Top Head
Orientation	135°
End of nozzle to datum line	-60"
Calculated as hillside	Yes
Distance to head center, R	14.1421"
Passes through a Category A joint	No
Nozzle	
Description	NPS 4 Sch 80S (XS)
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	3.826"
Nominal wall thickness	0.337"
Corrosion allowance	0.125"
Opening chord length	4.223"
Projection available outside vessel, Lpr	6.3069"
Internal projection, h_{new}	8.25"
Projection available outside vessel to flange face, Lf	9.6869"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Reinforcing Pad	

Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	8.6611"
Thickness, t_e	0.25"
Is split	No
Welds	
Inner Fillet, Leg_{41}	0.25"
Outer Fillet, Leg_{42}	0.1875"
Lower Fillet, Leg_{43}	0"
Nozzle to vessel groove weld	0.3125"
Pad groove weld	0.25"

ASME B16.5-2009 Flange	
Description	NPS 4 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle	
External nozzle loadings per UG-22 govern the coincident ratio used.	
Stress ratio = $t_r * E^* / (t_n - c)$ = 0.0479*1 / (0.2949 - 0.125) =	0.2817
Impact test exempt per UHA-51(g) (coincident ratio = 0.2817)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*54.3125*1 / (2*20,000*1 + 61.16*(1 - 0.2)) =	0.0829"
Stress ratio = t_r*E^* / (t_n - c) = 0.0829*1 / (0.3125 - 0.0625) =	0.3318
Impact test exempt per UHA-51(g) (coincident ratio = 0.3318)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

The thickness requirements of UG-45 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 72.85 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.6002	1.7664	0.4575	0.2144	0.0951	0.9462	0.0532	0.2948	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
2,571.44	17,114.98	29,618.88	6,386.29	47,267.62	19,728.11	36,062.57

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_1 (lb_f-in)	V_2 (lb_f)	M_2 (lb_f-in)	V_1 (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	72.85	1,400	14,784	0	11,424	0	0	27,956	42,300	10,655	21,150	No

Calculations for internal pressure 72.85 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.223, 2.1115 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.223 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_l = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 72.8542*2.038 / ((12,000 / 0.85)*1 - 0.6*72.8542)
= 0.0105 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.8542*54.3125*1 / (2*14,100*1 + 72.8542*(1 - 0.2))
= 0.14 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M$ / (2*S*E + P*(M - 0.2))
= 72.85*54.3125*1.662 / (2*14,100*0.85 + 72.85*(1.662 - 0.2))
= 0.2731"

Area required per UG-37(c)

Allowable stresses: S_n = 12,000, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.8511

f_{r2} = lesser of 1 or S_n / S_v = 0.8511

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8511

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= 4.223*0.14*1 + 2*0.212*0.14*1*(1 - 0.8511)
= 0.6002 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.4575 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 4.223*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.4575 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2*(0.25 + 0.212)*(1*0.25 - 1*0.14) - 2*0.212*(1*0.25 - 1*0.14)*(1 - 0.8511)
= 0.0947 in^2

A_2 = smaller of the following= 0.2144 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0105)*0.8511*0.25$
= 0.2144 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0105)*(2.5*0.212 + 0.25)*0.8511$
= 0.2675 in^2

A_3 = smaller of the following= 0.0951 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.8511$
= 0.159 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.8511$
= 0.0951 in^2

= $2*h*t_i*f_{r2}$
= $2*8.1875*0.1495*0.8511$
= 2.0835 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.8511$
= 0.0532 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(8.446 - 4.6611)*0.25*1$
= 0.9462 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= $0.4575 + 0.2144 + 0.0951 + 0.0532 + 0 + 0.9462$
= 1.7664 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in

$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = 0.5*t_{min} = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 72.8542*2.038 / (12,000*1 - 0.6*72.8542) + 0.125
= 0.1374 in

$t_{a\ UG\text{-}22}$ = 0.1874 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.1374 , 0.1874]
= 0.1874 in

t_{b1} = 0.2948 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.2948 , 0.1875]
= 0.2948 in

t_b = min[t_{b3} , t_{b1}]
= min[0.3324 , 0.2948]
= 0.2948 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.1874 , 0.2948]
= 0.2948 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 =	10,434 psi
Nozzle wall in shear:	0.7*12,000 =	8,400 psi
Inner fillet weld in shear:	0.49*12,000 =	5,880 psi
Outer fillet weld in shear:	0.49*14,100 =	6,909 psi
Upper groove weld in tension:	0.74*14,100 =	10,434 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*4.5*0.25*5,880 = 10,390.82 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*8.6611*0.1875*6,909 = 17,624.17 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*4.288*0.212*8,400 = 11,994.71 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*10,434 = 18,438.4 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (0.6002 - 0.4575 + 2*0.212*0.8511*(1*0.25 - 1*0.14))*14,100$
$= 2,571.44$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.2144 + 0.9462 + 0.0532 + 0)*14,100$
$= 17,114.98$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.0532 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 6,386.29$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.2144 + 0.0951 + 0.9462 + 0.0532 + 0 + 0 + 2*0.212*0.25*0.8511)*14,100$
$= 19,728.11$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = 2,571.44 lb_f
Path 1-1 through (2) & (3) = 17,624.17 + 11,994.71 = 29,618.88 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 2,571.44 lb_f
Path 2-2 through (1), (4), (6) = 10,390.82 + 18,438.4 + 18,438.4 = 47,267.62 lb_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = 2,571.44 lb_f
Path 3-3 through (2), (4) = 17,624.17 + 18,438.4 = 36,062.57 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	1,400 lb_f
Circumferential moment, M_1	14,784 lb_f-in
Circumferential shear, V_2	0 lb_f
Longitudinal moment, M_2	11,424 lb_f-in
Longitudinal shear, V_1	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	72.85 psi
Mean dish radius, R_m	54.1875"
Local head thickness, T	0.25"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

U = r_o / Sqr(R_m*T) = 4.25 / Sqr(54.1875*0.25) = 1.155

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local pressure stress = I*P*R_i / (2*T) =7,877 psi

Maximum combined stress (P_L+P_b+Q) = 27,956 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 10,655 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.0553	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239	-1,239
SR-2	M_x / P	0.0285	-3,830	3,830	-3,830	3,830	-3,830	3,830	-3,830	3,830
SR-3*	$N_x*T*(R_m*T)^{0.5} / M_1$	0.0625	0	0	0	0	-4,017	-4,017	4,017	4,017
SR-3	$M_x*(R_m*T)^{0.5} / M_1$	0.0548	0	0	0	0	-21,131	21,131	21,131	-21,131
SR-3*	$N_x*T*(R_m*T)^{0.5} / M_2$	0.0625	-3,104	-3,104	3,104	3,104	0	0	0	0
SR-3	$M_x*(R_m*T)^{0.5} / M_2$	0.0548	-16,329	16,329	16,329	-16,329	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_x stress			-16,625	23,693	22,241	-2,757	-22,340	27,582	27,956	-6,646
Membrane O_x stress*			3,534	3,534	9,742	9,742	2,621	2,621	10,655	10,655
SR-2*	N_y*T / P	0.017	-381	-381	-381	-381	-381	-381	-381	-381
SR-2	M_y / P	0.0086	-1,156	1,156	-1,156	1,156	-1,156	1,156	-1,156	1,156
SR-3*	$N_y*T*(R_m*T)^{0.5} / M_1$	0.0188	0	0	0	0	-1,208	-1,208	1,208	1,208
SR-3	$M_y*(R_m*T)^{0.5} / M_1$	0.0166	0	0	0	0	-6,401	6,401	6,401	-6,401
SR-3*	$N_y*T*(R_m*T)^{0.5} / M_2$	0.0188	-934	-934	934	934	0	0	0	0
SR-3	$M_y*(R_m*T)^{0.5} / M_2$	0.0166	-4,946	4,946	4,946	-4,946	0	0	0	0
Pressure stress*			7,877	7,877	7,877	7,877	7,877	7,877	7,877	7,877
Total O_y stress			460	12,664	12,220	4,640	-1,269	13,845	13,949	3,459
Membrane O_y stress*			6,562	6,562	8,430	8,430	6,288	6,288	8,704	8,704
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-17,085	23,693	22,241	-7,397	-22,340	27,582	27,956	-10,105

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$U = r_o / Sqr(R_m*T) = 2.25 / Sqr(54.1875*0.5) = 0.432$

Pressure stress intensity factor, I = 0.5451 (derived from Division 2 Part 4.5)

Local pressure stress = $I*P*R_i / (2*T)$ =4,294 psi

Maximum combined stress (P_L+P_b+Q) = 25,267 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 5,200 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.1504	-842	-842	-842	-842	-842	-842	-842	-842
SR-2	M_x / P	0.0967	-3,249	3,249	-3,249	3,249	-3,249	3,249	-3,249	3,249
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1539	0	0	0	0	-1,748	-1,748	1,748	1,748
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.298	0	0	0	0	-20,314	20,314	20,314	-20,314
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1539	-1,351	-1,351	1,351	1,351	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.298	-15,697	15,697	15,697	-15,697	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_x stress			-16,845	21,047	17,251	-7,645	-21,859	25,267	22,265	-11,865
Membrane O_x stress*			2,101	2,101	4,803	4,803	1,704	1,704	5,200	5,200
SR-2*	N_y*T / P	0.0451	-253	-253	-253	-253	-253	-253	-253	-253
SR-2	M_y / P	0.0294	-988	988	-988	988	-988	988	-988	988
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0471	0	0	0	0	-535	-535	535	535
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0903	0	0	0	0	-6,155	6,155	6,155	-6,155
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0471	-413	-413	413	413	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0903	-4,756	4,756	4,756	-4,756	0	0	0	0
Pressure stress*			4,294	4,294	4,294	4,294	4,294	4,294	4,294	4,294
Total O_y stress			-2,116	9,372	8,222	686	-3,637	10,649	9,743	-591
Membrane O_y stress*			3,628	3,628	4,454	4,454	3,506	3,506	4,576	4,576
Shear from M_t			0	0	0	0	0	0	0	0
Shear from V_1			0	0	0	0	0	0	0	0
Shear from V_2			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-16,845	21,047	17,251	-8,331	-21,859	25,267	22,265	-11,865

(1) * denotes primary stress.
(2) The nozzle is assumed to be a rigid (solid) attachment.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 72.85*2.038 / (2*0.1699) - 1,400 / (\pi*(2.25^2 - 2.038^2)) + 18,683.5*2.25 / 6.5799$
= 6,336 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)} = ABS(P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) - M*R_o / I)$
$= ABS(-7.4*2.038 / (2*0.1699) - 1,400 / (\pi*(2.25^2 - 2.038^2)) - 18,683.5*2.25 / 6.5799)$
= 6,923 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 231.21 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.2704	1.7356	--	0.418	0.4476	0.8169	0.0531	0.2074	0.2949

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
25,408.05	25,759.57	51,223.08	21,954.19	73,566.28	38,291.76	57,691.02

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.175	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for internal pressure 231.21 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3.9643, 1.9822 + (0.337 - 0) + (0.3125 - 0))
= 3.9643 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0), 2.5*(0.337 - 0) + 0.25)
= 0.7813 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.25, 2.5*(0.3125 - 0), 2.5*(0.337 - 0 - 0))
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 231.2097*1.913 / ((17,000 / 0.85)*1 - 0.6*231.2097)
= 0.0223 in

Required thickness t_r from UG-37(a)(a)

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.2097*54.3125*1 / (2*20,000*1 + 231.2097*(1 - 0.2))$
= 0.3125 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*L_o*M / (2*S*E + P*(M - 0.2))$
= $231.21*54.3125*1.6686 / (2*20,000*0.85 + 231.21*(1.6686 - 0.2))$
= 0.6102"

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $3.9643*0.3125*1 + 2*0.337*0.3125*1*(1 - 0.85)$
= 1.2704 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $3.9643*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.3125 + 0.337)*(1*0.3125 - 1*0.3125) - 2*0.337*(1*0.3125 - 1*0.3125)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.418 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.337 - 0.0223)*0.85*0.3125$
= 0.418 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.337 - 0.0223)*(2.5*0.337 + 0.25)*0.85$
= 0.5845 in^2

A_3 = smaller of the following= 0.4476 in^2

= $5*t*t_i*f_{r2}$
= 5*0.3125*0.337*0.85
= 0.4476 in^2

= $5*t_i*t_i*f_{r2}$
= 5*0.337*0.337*0.85
= 0.4827 in^2

= $2*h*t_i*f_{r2}$
= 2*8.25*0.337*0.85
= 4.7264 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (7.9286 - 4.6611)*0.25*1
= 0.8169 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.418 + 0.4476 + 0.0531 + 0 + 0.8169
= 1.7356 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.25 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.175 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 231.2097*1.913 / (17,000*1 - 0.6*231.2097) + 0
= 0.0262 in

$t_{a\ UG\text{-}22}$ = 0.0621 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0262 , 0.0621]
= 0.0621 in

t_{b1} = 0.5194 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.5194 , 0.0625]
= 0.5194 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2074 , 0.5194]
= 0.2074 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0621 , 0.2074]
= 0.2074 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*17,000 =	11,900 psi
Inner fillet weld in shear:	0.49*17,000 =	8,330 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*4.5*0.25*8,330 = 14,720.33 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*8.6611*0.1875*9,800 = 24,998.82 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*4.163*0.337*11,900 = 26,224.25 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*4.5*0.3125*14,800 = 32,692.2 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*4.5*0.25*14,800 = 26,153.76 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (1.2704 - 0 + 2*0.337*0.85*(1*0.3125 - 1*0.3125))*20,000
= 25,408.05 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (0.418 + 0.8169 + 0.0531 + 0)*20,000
= 25,759.57 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.0531 + 0 + 2*0.337*0.3125*0.85)*20,000
= 21,954.19 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (0.418 + 0.4476 + 0.8169 + 0.0531 + 0 + 0 + 2*0.337*0.3125*0.85)*20,000
= 38,291.76 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 25,408.05 lb_f
Path 1-1 through (2) & (3) = 24,998.82 + 26,224.25 = 51,223.08 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = 21,954.19 lb_f
Path 2-2 through (1), (4), (6) = 14,720.33 + 32,692.2 + 26,153.76 = 73,566.28 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 25,408.05 lb_f
Path 3-3 through (2), (4) = 24,998.82 + 32,692.2 = 57,691.02 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 32.75 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
0.5358	1.2887	--	0.1946	0.095	0.946	0.0531	0.1875	0.2949

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.1484	0.175	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.1312	weld size is adequate

Calculations for external pressure 32.75 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(4.2226, 2.1113 + (0.337 - 0.125) + (0.3125 - 0.0625))
= 4.2226 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125) + 0.25)
= 0.625 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.1875, 2.5*(0.3125 - 0.0625), 2.5*(0.337 - 0.125 - 0.0625))
= 0.3738 in

Nozzle required thickness per UG-28 t_{rn} = 0.0288 in

From UG-37(d)(1) required thickness t_r = 0.25 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= $0.5*(4.2226*0.25*1 + 2*0.212*0.25*1*(1 - 0.85))$
= 0.5358 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $4.2226*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.25 + 0.212)*(1*0.25 - 1*0.25) - 2*0.212*(1*0.25 - 1*0.25)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.1946 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.212 - 0.0288)*0.85*0.25$
= 0.1946 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.212 - 0.0288)*(2.5*0.212 + 0.25)*0.85$
= 0.2429 in^2

A_3 = smaller of the following= 0.095 in^2

= $5*t*t_i*f_{r2}$
= $5*0.25*0.1495*0.85$
= 0.1588 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.1495*0.1495*0.85$
= 0.095 in^2

= $2*h*t_i*f_{r2}$

= 2*8.1875*0.1495*0.85
= 2.0809 in^2

A_{41} = Leg^2*f_{r3}
= $0.25^2*0.85$
= 0.0531 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (8.4452 - 4.6611)*0.25*1
= 0.946 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_5$
= 0 + 0.1946 + 0.095 + 0.0531 + 0 + 0.946
= 1.2887 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.212 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.1484 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.25 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.125 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.1875 = 0.1313 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-28}$ = 0.1538 in

$t_{a\ UG-22}$ = 0.17 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.1538 , 0.17]
= 0.17 in

t_{b2} = 0.1363 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.1363 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.3324 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.17 , 0.1875]
= 0.1875 in

Available nozzle wall thickness new, t_n = 0.875*0.337 = 0.2949 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 10.9017 / 4.5 = 2.4226
D_o / t = 4.5 / 0.0288 = 156.1035
From table G: A = 0.000273
From table HA-1: B = 3,834.325 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,834.33 / (3*(4.5 / 0.0288))
= 32.75 psi

Design thickness for external pressure P_a = 32.75 psi

t_a = t + Corrosion = 0.0288 + 0.125 = 0.1538"

Process Gas Inlet (A1)

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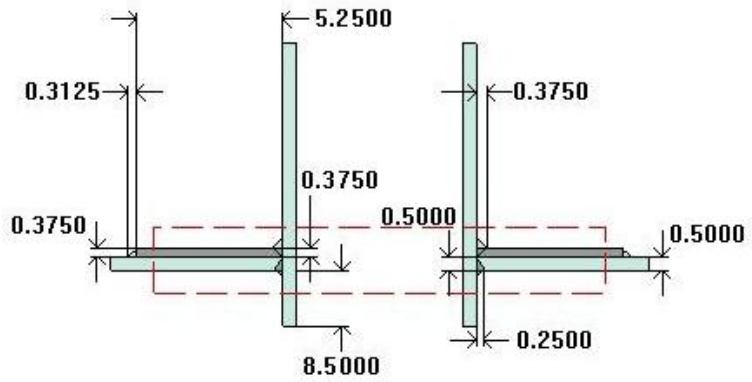

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Vessel Body Mid Shell
Orientation	90°
Nozzle center line offset to datum line	125.125"
End of nozzle to shell center	32"
Passes through a Category A joint	No

Nozzle	
Description	NPS 10 Sch 80S (XS)
Access opening	No
Material specification	SA-312 TP304 Wld pipe (II-D p. 94, ln. 21)
Inside diameter, new	9.75"
Nominal wall thickness	0.5"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.38"
Internal projection, h_{new}	8.5"
Projection available outside vessel to flange face, Lf	8"
Local vessel minimum thickness	0.5"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-240 304 (II-D p. 94, ln. 8)
Diameter, D_p	21.25"

Thickness, t_e	0.375"
Is split	No
Welds	
Inner Fillet, Leg_{41}	0.375"
Outer Fillet, Leg_{42}	0.3125"
Lower Fillet, Leg_{43}	0.25"
Nozzle to vessel groove weld	0.5"
Pad groove weld	0.375"

ASME B16.5-2009 Flange	
Description	NPS 10 Class 300 WN A182 F304
Bolt Material	SA-193 B8 1 Bolt (II-D p. 360, ln. 20)
Blind included	No
Rated MDMT	-320° F
Liquid static head	0 psi
Consider External Loads on Flange MAWP Rating	No
MAWP rating	365 psi @ 980° F
MAP rating	720 psi @ 70° F
Hydrotest rating	1,100 psi @ 70° F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UHA-51(d)(1)(a) = -320° F Bolts rated MDMT = -320° F	

UHA-51 Material Toughness Requirements Nozzle
Rated MDMT per UHA-51(d)(1)(a), (carbon content does not exceed 0.10%) = -320° F
Material is exempt from impact testing at the Design MDMT of -20° F.

UHA-51 Material Toughness Requirements Pad	
t_r = 61.16*24 / (20,000*1 + 0.4*61.16) =	0.0733"
Stress ratio = t_r*E^* / (t_n - c) = 0.0733*1 / (0.5 - 0.0625) =	0.1675
Impact test exempt per UHA-51(g) (coincident ratio = 0.1675)	
Rated MDMT =	-320° F
Material is exempt from impact testing at the Design MDMT of -20° F.	

Reinforcement Calculations for MAWP

Local stresses at the nozzle OD per WRC 107 govern the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 63.58 psi @ 980 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.0924	7.94	3.2579	0.6561	0.4156	3.4688	0.1417	0.2775	0.4375

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-27,568.7	59,848.16	123,403.85	21,046.27	196,344.78	69,955.65	165,108.34

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.1875	0.2188	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_c (lb_f-in)	V_c (lb_f)	M_L (lb_f-in)	V_L (lb_f)	M_t (lb_f-in)	Max Comb Stress (psi)	Allow Comb Stress (psi)	Max Local Primary Stress (psi)	Allow Local Primary Stress (psi)	Over stressed
Load case 1	63.58	7,000	142,800	0	184,800	0	0	42,300	42,300	9,858	21,150	No

Calculations for internal pressure 63.58 psi @ 980 ° F

Parallel Limit of reinforcement per UG-40

L_R = $MAX(d, R_n + (t_n - C_n) + (t - C))$
= $MAX(10, 5 + (0.5 - 0.125) + (0.5 - 0.0625))$
= 10 in

Outer Normal Limit of reinforcement per UG-40

L_H = $MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$
= $MIN(2.5*(0.5 - 0.0625), 2.5*(0.5 - 0.125) + 0.375)$
= 1.0938 in

Inner Normal Limit of reinforcement per UG-40

L_l = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.4375, 2.5*(0.5 - 0.0625), 2.5*(0.5 - 0.125 - 0.0625))
= 0.7813 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n$ / (S_n*E - 0.6*P)
= 63.5833*5 / ((12,000 / 0.85)*1 - 0.6*63.5833)
= 0.0226 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o$ / (S*E + 0.4*P)
= 63.5833*24 / (14,100*1 + 0.4*63.5833)
= 0.108 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o$ / (S*E + 0.4*P)
= 63.5833*24 / (14,100*0.85 + 0.4*63.5833)
= 0.1271 in

Area required per UG-37(c)

Allowable stresses: S_n = 12,000, S_v = 14,100, S_p = 14,100 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.8511

f_{r2} = lesser of 1 or S_n / S_v = 0.8511

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8511

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= 10*0.108*1 + 2*0.375*0.108*1*(1 - 0.8511)
= 1.0924 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 3.2579 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 10*(1*0.4375 - 1*0.108) - 2*0.375*(1*0.4375 - 1*0.108)*(1 - 0.8511)
= 3.2579 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 2*(0.4375 + 0.375)*(1*0.4375 - 1*0.108) - 2*0.375*(1*0.4375 - 1*0.108)*(1 - 0.8511)
= 0.4986 in^2

A_2 = smaller of the following= 0.6561 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.375 - 0.0226)*0.8511*0.4375$
= $0.6561\ in^2$

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.375 - 0.0226)*(2.5*0.375 + 0.375)*0.8511$
= $0.7873\ in^2$

A_3 = smaller of the following= 0.4156 in^2

= $5*t*t_i*f_{r2}$
= $5*0.4375*0.3125*0.8511$
= $0.5818\ in^2$

= $5*t_i*t_i*f_{r2}$
= $5*0.3125*0.3125*0.8511$
= $0.4156\ in^2$

= $2*h*t_i*f_{r2}$
= $2*8.4375*0.3125*0.8511$
= $4.4882\ in^2$

A_{41} = Leg^2*f_{r3}
= $0.375^2*0.8511$
= $0.1197\ in^2$

A_{42} = Leg^2*f_{r4}
= 0^2*1
= $0\ in^2$

(Part of the weld is outside of the limits)

A_{43} = Leg^2*f_{r2}
= $0.1607^2*0.8511$
= $0.022\ in^2$

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(20 - 10 - 2*0.375)*0.375*1$
= $3.4688\ in^2$

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= $3.2579 + 0.6561 + 0.4156 + 0.1197 + 0 + 0.022 + 3.4688$
= $7.94\ in^2$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.375 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.375 in
$t_{w(min)}$ = 0.5*t_{min} = 0.1875 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.3125 = 0.2188 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 63.5833*5 / (12,000*1 - 0.6*63.5833) + 0.125
= 0.1516 in

$t_{a\ UG\text{-}22}$ = 0.2775 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.1516 , 0.2775]
= 0.2775 in

t_{b1} = P*R_o / (S*E + 0.4*P) + Corrosion
= 63.5833*24 / (14,100*1 + 0.4*63.5833) + 0.0625
= 0.1705 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.1705 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b1}]
= min[0.4444 , 0.1875]
= 0.1875 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.2775 , 0.1875]
= 0.2775 in

Available nozzle wall thickness new, t_n = 0.875*0.5 = 0.4375 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*14,100 =	10,434 psi
Nozzle wall in shear:	0.7*12,000 =	8,400 psi
Inner fillet weld in shear:	0.49*12,000 =	5,880 psi

Outer fillet weld in shear:	0.49*14,100 =	6,909 psi
Upper groove weld in tension:	0.74*14,100 =	10,434 psi
Lower fillet weld in shear:	0.49*12,000 =	5,880 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*10.75*0.375*5,880 = 37,233.76 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*21.25*0.3125*6,909 = 72,068.26 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*10.375*0.375*8,400 = 51,335.59 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*10.75*0.4375*10,434 = 77,082.76 lb_f

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*10.75*0.1607*5,880 = 15,957.33 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*10.75*0.375*10,434 = 66,070.93 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (1.0924 - 3.2579 + 2*0.375*0.8511*(1*0.4375 - 1*0.108))*14,100$
$= -27,568.7$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.6561 + 3.4688 + 0.1197 + 0)*14,100$
$= 59,848.16$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.6561 + 0.4156 + 0.1197 + 0.022 + 2*0.375*0.4375*0.8511)*14,100$
$= 21,046.27$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.6561 + 0.4156 + 3.4688 + 0.1197 + 0 + 0.022 + 2*0.375*0.4375*0.8511)*14,100$
$= 69,955.65$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = -27,568.7 lb_f
Path 1-1 through (2) & (3) = 72,068.26 + 51,335.59 = 123,403.85 lb_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -27,568.7 lb_f
Path 2-2 through (1), (4), (5), (6) = 37,233.76 + 77,082.76 + 15,957.33 + 66,070.93 = 196,344.78 lb_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -27,568.7 lb_f
Path 3-3 through (2), (4), (5) = 72,068.26 + 77,082.76 + 15,957.33 = 165,108.34 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

WRC 107 Load case 1

Applied Loads	
Radial load, P_r	7,000 lb_f
Circumferential moment, M_c	142,800 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	184,800 lb_f-in
Longitudinal shear, V_L	0 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	63.58 psi
Mean shell radius, R_m	23.7813"
Local shell thickness, T	0.4375"
Design factor	3

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / T = 23.7813 / 0.4375 = 54.3571$

$\beta = 0.875*r_o / R_m = 0.875*10.625 / 23.7813 = 0.3909$

Pressure stress intensity factor, I = 1 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =3,424 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =1,712 psi

Maximum combined stress (P_L+P_b+Q) = 42,300 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = -8,843 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	1.5984	0	0	0	0	-1,075	-1,075	-1,075	-1,075
4C*	N_ϕ / (P / R_m)	4.2502	-2,860	-2,860	-2,860	-2,860	0	0	0	0
1C	M_ϕ / P	0.063	0	0	0	0	-13,824	13,824	-13,824	13,824
2C-1	M_ϕ / P	0.0074	-1,624	1,624	-1,624	1,624	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	1.3492	0	0	0	0	-1,992	-1,992	1,992	1,992
1A	M_ϕ / [M_c / (R_m*β)]	0.0584	0	0	0	0	-28,119	28,119	28,119	-28,119
3B*	N_ϕ / [M_L / (R_m^2*β)]	2.4635	-4,707	-4,707	4,707	4,707	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0087	-5,421	5,421	5,421	-5,421	0	0	0	0
Pressure stress*			3,424	3,424	3,424	3,424	3,424	3,424	3,424	3,424
Total circumferential stress			-11,188	2,902	9,068	1,474	-41,586	42,300	18,636	-9,954
Primary membrane circumferential stress*			-4,143	-4,143	5,271	5,271	357	357	4,341	4,341
3C*	N_x / (P / R_m)	1.5984	-1,075	-1,075	-1,075	-1,075	0	0	0	0
4C*	N_x / (P / R_m)	4.2502	0	0	0	0	-2,860	-2,860	-2,860	-2,860
1C-1	M_x / P	0.0183	-4,016	4,016	-4,016	4,016	0	0	0	0
2C	M_x / P	0.03	0	0	0	0	-6,583	6,583	-6,583	6,583
4A*	N_x / [M_c / (R_m^2*β)]	5.212	0	0	0	0	-7,695	-7,695	7,695	7,695
2A	M_x / [M_c / (R_m*β)]	0.0232	0	0	0	0	-11,171	11,171	11,171	-11,171
4B*	N_x / [M_L / (R_m^2*β)]	1.4463	-2,763	-2,763	2,763	2,763	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0171	-10,655	10,655	10,655	-10,655	0	0	0	0
Pressure stress*			1,712	1,712	1,712	1,712	1,712	1,712	1,712	1,712
Total longitudinal stress			-16,797	12,545	10,039	-3,239	-26,597	8,911	11,135	1,959
Primary membrane longitudinal stress*			-2,126	-2,126	3,400	3,400	-8,843	-8,843	6,547	6,547
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-16,797	12,545	10,039	-4,713	-41,586	42,300	18,636	11,913
* denotes primary stress.										

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / T = 23.7813 / 0.8125 = 29.2692$

$\beta = 0.875 * r_o / R_m = 0.875 * 5.375 / 23.7813 = 0.1978$

Pressure stress intensity factor, I = 1.3957 (derived from Division 2 Part 4.5)

Local circumferential pressure stress = $I*P*R_i / T$ =4,779 psi

Local longitudinal pressure stress = $I*P*R_i / (2*T)$ =2,389 psi

Maximum combined stress (P_L+P_b+Q) = 28,552 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±42,300 psi

Note: The allowable combined stress (P_L+P_b+Q) is based on the strain hardening characteristics of this material.

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 9,858 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±21,150 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the nozzle OD per WRC Bulletin 107										
Figure	**value**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
3C*	N_ϕ / (P / R_m)	2.9926	0	0	0	0	-1,084	-1,084	-1,084	-1,084
4C*	N_ϕ / (P / R_m)	4.2804	-1,551	-1,551	-1,551	-1,551	0	0	0	0
1C	M_ϕ / P	0.0781	0	0	0	0	-4,969	4,969	-4,969	4,969
2C-1	M_ϕ / P	0.0458	-2,914	2,914	-2,914	2,914	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	1.1977	0	0	0	0	-1,882	-1,882	1,882	1,882
1A	M_ϕ / [M_c / (R_m*β)]	0.0838	0	0	0	0	-23,125	23,125	23,125	-23,125
3B*	N_ϕ / [M_L / (R_m^2*β)]	3.2602	-6,630	-6,630	6,630	6,630	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0315	-11,249	11,249	11,249	-11,249	0	0	0	0
Pressure stress*			4,779	4,779	4,779	4,779	3,424	3,424	3,424	3,424
Total circumferential stress			-17,565	10,761	18,193	1,523	-27,636	28,552	22,378	-13,934
Primary membrane circumferential stress*			-3,402	-3,402	9,858	9,858	458	458	4,222	4,222
3C*	N_x / (P / R_m)	2.9926	-1,084	-1,084	-1,084	-1,084	0	0	0	0
4C*	N_x / (P / R_m)	4.2804	0	0	0	0	-1,551	-1,551	-1,551	-1,551
1C-1	M_x / P	0.0836	-5,319	5,319	-5,319	5,319	0	0	0	0
2C	M_x / P	0.0466	0	0	0	0	-2,965	2,965	-2,965	2,965
4A*	N_x / [M_c / (R_m^2*β)]	2.0592	0	0	0	0	-3,236	-3,236	3,236	3,236
2A	M_x / [M_c / (R_m*β)]	0.0443	0	0	0	0	-12,225	12,225	12,225	-12,225
4B*	N_x / [M_L / (R_m^2*β)]	1.1653	-2,370	-2,370	2,370	2,370	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0502	-17,928	17,928	17,928	-17,928	0	0	0	0
Pressure stress*			1,712	1,712	1,712	1,712	2,389	2,389	2,389	2,389
Total longitudinal stress			-24,989	21,505	15,607	-9,611	-17,588	12,792	13,334	-5,186
Primary membrane longitudinal stress*			-1,742	-1,742	2,998	2,998	-2,398	-2,398	4,074	4,074
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	0	0	0	0
Total Shear stress			0	0	0	0	0	0	0	0
Combined stress (P_L+P_b+Q)			-24,989	21,505	18,193	-11,134	-27,636	28,552	22,378	-13,934
* denotes primary stress.										

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)}$ = P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) + M*R_o / I
= 63.58*5 / (2*0.3125) - 7,000 / (π*(5.375^2 - 5^2)) + 233,544.2*5.375 / 164.673
= 7,559 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to internal pressure + external loads is acceptable (≤ S = 12,000 psi)

Longitudinal stress in the nozzle wall due to external pressure + external loads

$\sigma_{n\ (Pm)}$ = ABS(P*R_i / (2*t_n) - P_r / (π*(R_o^2 - R_i^2)) - M*R_o / I)
= ABS(-7.4*5 / (2*0.3125) - 7,000 / (π*(5.375^2 - 5^2)) - 233,544.2*5.375 / 164.673)
= 8,255 psi

The average primary stress P_m (see Division 2 5.6.a.1) across the nozzle wall due to external pressure + external loads is acceptable (≤ S = 12,000 psi)

Reinforcement Calculations for MAP

The vessel wall thickness governs the MAP of this nozzle.

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 420.17 psi @ 70 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
4.95	5.3585	--	0.8421	1.0625	3.2813	0.1726	0.3194	0.4375

UG-41 Weld Failure Path Analysis Summary (lb_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
99,000	84,857	198,023.42	50,044	306,587.53	115,669	262,346.55

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.1875	0.2188	weld size is adequate

Calculations for internal pressure 420.17 psi @ 70 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(9.75, 4.875 + (0.5 - 0) + (0.5 - 0))
= 9.75 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0), 2.5*(0.5 - 0) + 0.375)
= 1.25 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.5, 2.5*(0.5 - 0), 2.5*(0.5 - 0 - 0))
= 1.25 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 420.165*4.875 / ((17,000 / 0.85)*1 - 0.6*420.165)
= 0.1037 in

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= $420.165*24 / (20{,}000*1 + 0.4*420.165)$
= 0.5 in

Required thickness t_r per Interpretation VIII-1-07-50

t_r = $P*R_o / (S*E + 0.4*P)$
= $420.165*24 / (20{,}000*0.85 + 0.4*420.165)$
= 0.5874 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $9.75*0.5*1 + 2*0.5*0.5*1*(1 - 0.85)$
= 4.95 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $9.75*(1*0.5 - 1*0.5) - 2*0.5*(1*0.5 - 1*0.5)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.5 + 0.5)*(1*0.5 - 1*0.5) - 2*0.5*(1*0.5 - 1*0.5)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.8421 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.5 - 0.1037)*0.85*0.5$
= 0.8421 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.5 - 0.1037)*(2.5*0.5 + 0.375)*0.85$

= 1.0948 in^2

A_3 = smaller of the following= 1.0625 in^2

= $5*t*t_i*f_{r2}$
= 5*0.5*0.5*0.85
= 1.0625 in^2

= $5*t_i*t_i*f_{r2}$
= 5*0.5*0.5*0.85
= 1.0625 in^2

= $2*h*t_i*f_{r2}$
= 2*8.5*0.5*0.85
= 7.225 in^2

A_{41} = Leg^2*f_{r3}
= $0.375^2*0.85$
= 0.1195 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_{43} = Leg^2*f_{r2}
= $0.25^2*0.85$
= 0.0531 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (19.5 - 9.75 - 2*0.5)*0.375*1
= 3.2813 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 0 + 0.8421 + 1.0625 + 0.1195 + 0 + 0.0531 + 3.2813
= 5.3585 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.375 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.375 in

$t_{w(min)}$ = 0.5*t_{min} = 0.1875 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.3125 = 0.2188 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 420.165*4.875 / (17,000*1 - 0.6*420.165) + 0
= 0.1223 in

$t_{a\ UG-22}$ = 0.1639 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1223 , 0.1639]
= 0.1639 in

t_{b1} = P*R_o / (S*E + 0.4*P) + Corrosion
= 420.165*24 / (20,000*1 + 0.4*420.165) + 0
= 0.5 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[0.5 , 0.0625]
= 0.5 in

t_b = min[t_{b3} , t_{b1}]
= min[0.3194 , 0.5]
= 0.3194 in

t_{UG-45} = max[t_a , t_b]
= max[0.1639 , 0.3194]
= 0.3194 in

Available nozzle wall thickness new, t_n = 0.875*0.5 = 0.4375 in

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*20,000 =	14,800 psi
Nozzle wall in shear:	0.7*17,000 =	11,900 psi
Inner fillet weld in shear:	0.49*17,000 =	8,330 psi
Outer fillet weld in shear:	0.49*20,000 =	9,800 psi
Upper groove weld in tension:	0.74*20,000 =	14,800 psi
Lower fillet weld in shear:	0.49*17,000 =	8,330 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*10.75*0.375*8,330 = 52,747.83 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*21.25*0.3125*9,800 = 102,224.48 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*10.25*0.5*11,900 = 95,798.94 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*10.75*0.5*14,800 = 124,956.85 lb_f

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*10.75*0.25*8,330 = 35,165.22 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*10.75*0.375*14,800 = 93,717.64 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (4.95 - 0 + 2*0.5*0.85*(1*0.5 - 1*0.5))*20,000$
$= 99,000$ lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (0.8421 + 3.2813 + 0.1195 + 0)*20,000$
$= 84,857$ lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.8421 + 1.0625 + 0.1195 + 0.0531 + 2*0.5*0.5*0.85)*20,000$
$= 50,044$ lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (0.8421 + 1.0625 + 3.2813 + 0.1195 + 0 + 0.0531 + 2*0.5*0.5*0.85)*20,000$
$= 115,669$ lb_f

Load for path 1-1 lesser of W or W_{1-1} = 84,857 lb_f
Path 1-1 through (2) & (3) = 102,224.48 + 95,798.94 = 198,023.42 lb_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 50,044 lb_f
Path 2-2 through (1), (4), (5), (6) = 52,747.83 + 124,956.85 + 35,165.22 + 93,717.64 = 306,587.53 lb_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 99,000 lb_f
Path 3-3 through (2), (4), (5) = 102,224.48 + 124,956.85 + 35,165.22 = 262,346.55 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 97.82 psi @ 0 ° F The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
2.2121	4.5683	--	0.543	0.415	3.4688	0.1415	0.2507	0.4375

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.1875	0.2188	weld size is adequate

Calculations for external pressure 97.82 psi @ 0 ° F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(10, 5 + (0.5 - 0.125) + (0.5 - 0.0625))
= 10 in

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(0.5 - 0.0625), 2.5*(0.5 - 0.125) + 0.375)
= 1.0938 in

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(8.4375, 2.5*(0.5 - 0.0625), 2.5*(0.5 - 0.125 - 0.0625))
= 0.7813 in

Nozzle required thickness per UG-28 t_{rn} = 0.0829 in

From UG-37(d)(1) required thickness t_r = 0.4375 in

Area required per UG-37(d)(1)

Allowable stresses: S_n = 17,000, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.85

f_{r2} = lesser of 1 or S_n / S_v = 0.85

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.85

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= $0.5*(10*0.4375*1 + 2*0.375*0.4375*1*(1 - 0.85))$
= 2.2121 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $10*(1*0.4375 - 1*0.4375) - 2*0.375*(1*0.4375 - 1*0.4375)*(1 - 0.85)$
= 0 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(0.4375 + 0.375)*(1*0.4375 - 1*0.4375) - 2*0.375*(1*0.4375 - 1*0.4375)*(1 - 0.85)$
= 0 in^2

A_2 = smaller of the following= 0.543 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(0.375 - 0.0829)*0.85*0.4375$
= 0.543 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(0.375 - 0.0829)*(2.5*0.375 + 0.375)*0.85$
= 0.6517 in^2

A_3 = smaller of the following= 0.415 in^2

= $5*t*t_i*f_{r2}$
= $5*0.4375*0.3125*0.85$
= 0.5811 in^2

= $5*t_i*t_i*f_{r2}$
= $5*0.3125*0.3125*0.85$
= 0.415 in^2

= $2*h*t_i*f_{r2}$

= 2*8.4375*0.3125*0.85
= 4.4824 in^2

A_{41} = Leg^2*f_{r3}
= $0.375^2*0.85$
= 0.1195 in^2

A_{42} = Leg^2*f_{r4}
= 0^2*1
= 0 in^2

(Part of the weld is outside of the limits)

A_{43} = Leg^2*f_{r2}
= $0.1607^2*0.85$
= 0.022 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (20 - 10 - 2*0.375)*0.375*1
= 3.4688 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 0 + 0.543 + 0.415 + 0.1195 + 0 + 0.022 + 3.4688
= 4.5683 in^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 0.75 or t_n or t_e = 0.375 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.375 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.1875 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.3125 = 0.2188 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-28}$ = 0.2079 in

$t_{a\ UG-22}$ = 0.2507 in

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[0.2079 , 0.2507]

= 0.2507 in

t_{b2} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 97.8206*24 / (20,000*1 + 0.4*97.8206) + 0.0625
= 0.1797 in

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[0.1797 , 0.1875]
= 0.1875 in

t_b = min[t_{b3} , t_{b2}]
= min[0.4444 , 0.1875]
= 0.1875 in

t_{UG-45} = max[t_a , t_b]
= max[0.2507 , 0.1875]
= 0.2507 in

Available nozzle wall thickness new, t_n = 0.875*0.5 = 0.4375 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 0 ° F) UG-28(c)

L / D_o = 8.6096 / 10.75 = 0.8009
D_o / t = 10.75 / 0.0829 = 129.6080
From table G: A = 0.001155
From table HA-1: B = 9,508.7343 psi

P_a = $4*B / (3*(D_o / t))$
= 4*9,508.73 / (3*(10.75 / 0.0829))
= 97.82 psi

Design thickness for external pressure P_a = 97.82 psi

t_a = t + Corrosion = 0.0829 + 0.125 = 0.2079"