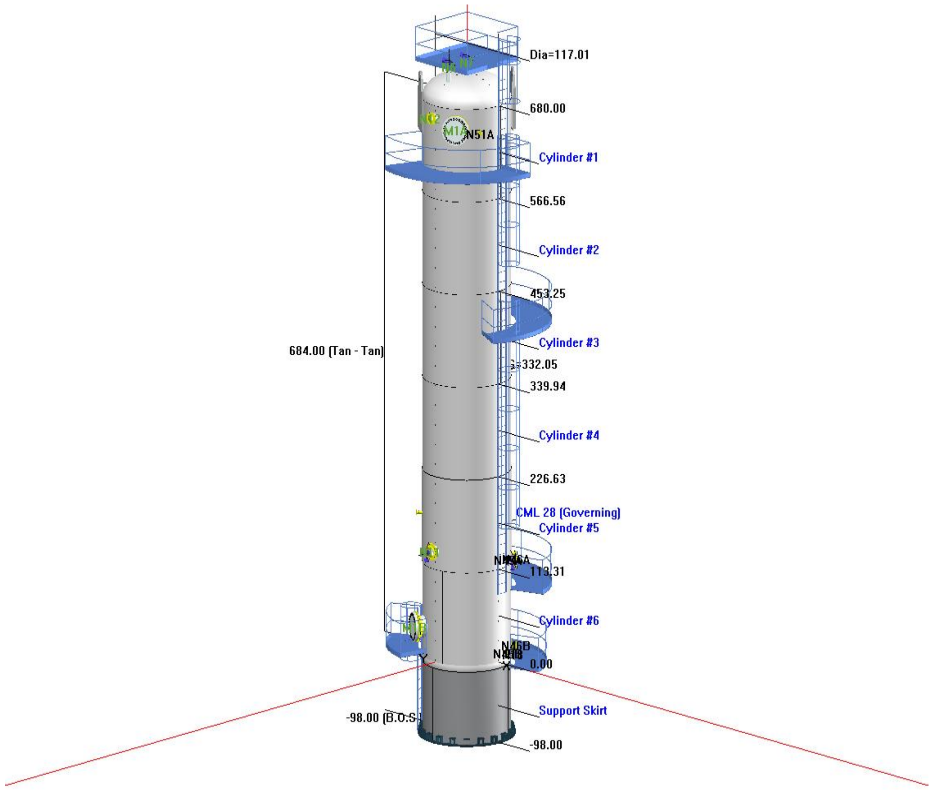
Your Company Name Here

Your Address Here



COMPRESS Pressure Vessel Calculations Rev 1

Contact: Engineer's Name Here
Item: Example Amine Absorber
Drawing No: 12345-1 Rev 3
Customer:
Size: 114"ID x 57'-0" Tan/Tan x 400 psig DP @ -20/400 F.
Date: Monday, February 5, 2007

Vessel is 114"ID x 57'-0" Tan/Tan x 400 psig DP @ -20/400 F.
LIFT LUG CALCULATION INCLUDED

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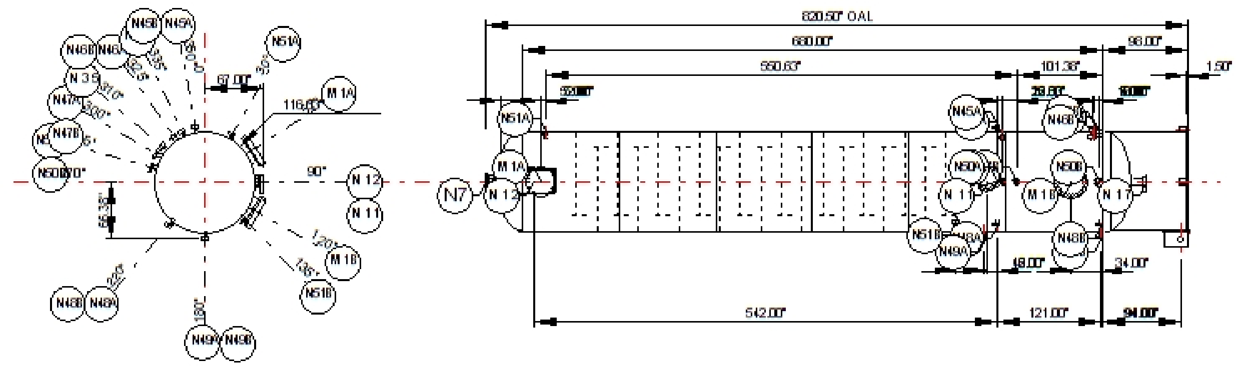


DESIGN DATA

Design Pressure	220 psi
Vacuum Pressure	0 psi
Test Pressure (Shop)	411 psi
Test Pressure (Field)	411 psi
Design Temperature	500 °F
MDMT	-20 °F
Corrosion Allowance	0"
Radiography	RT4
PWHT	PHT

Estimated Weights

Dry: 175,201 lb Wet: 175,201 lb

Materials

Cylinder(s):	SA-516 70
Head(s):	SA-516 70
Transition(s):	
Support:	SA-516 70

MARK	NOZZLE	SIZE & SCH	FLANGE	MARK	NOZZLE	SIZE & SCH	FLANGE
N49A	N49A NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3	N47B	N47B NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3
N45A	N45A NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3	N46B	N46B NPS 3 RFLWN (	4.62 OD x 0.81	NPS 3 LWN Class 3
N51B	N51B NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3	N45B	N45B NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3
N11	N11 NPS 12 RFWN S	NPS 12 XS	NPS 12 WN Class 3	N35	N35 NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3
M1A	M1A NPS 24 RFWN (	25.75 OD x 1.25	NPS 24 WN Class 3	N18	N18 NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3
N51A	N51A NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3	N47A	N47A NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3
N12	N12 NPS 8 RFWN S	8.625 OD x 0.624	NPS 8 WN Class 300	N46A	N46A NPS 3 RFLWN (	4.62 OD x 0.81	NPS 3 LWN Class 3
N7	N7 NPS 12 RFWN (0	NPS 12 XS	NPS 12 WN Class 3	N48A	N48A NPS 2 RFLWN (	3.31 OD x 0.665	NPS 2 LWN Class 3
N6	N6 NPS 6 RFWN (0.43	NPS 6 Sch 80 (XS)	NPS 6 WN Class 300	N50A	N50A NPS 3 RFLWN (	4.62 OD x 0.81	NPS 3 LWN Class 3

NOZZLE SCHEDULE

REV	DATE	DESCRIPTION
0	11/08/2006	FOR APPROV

REVISIONS

ABC Fabricators Inc.
2600 Washington Blvd.
Dallas, TX, 75204

DWN BY:
CHK BY:

General Arrangeme

DWG NO. 145685-1
DATE:
Rev 0

Amine Absorber_PC_JE.CW7

MARK	NOZZLE	SIZE & SCH	FLANGE
N17	N17 NPS 8 RFWN S	NPS 8 Sch 80 (XS)	NPS 8 WN Class 300
N48B	N48B NPS 2 RFLWN	3.31 OD x 0.665	NPS 2 LWN Class 3
M1B	M1B NPS 24 RFWN	25.75 OD x 1.25	NPS 24 WN Class 3
N50B	N50B NPS 3 RFLWN	4.62 OD x 0.81	NPS 3 LWN Class 3
N49B	N49B NPS 2 RFLWN	3.31 OD x 0.665	NPS 2 LWN Class 3

NOZZLE SCHEDULE

REV	DATE	DESCRIPTION
0	11/08/2006	FOR APPROV

REVISIONS

ABC Fabricators Inc.
2600 Washington Blvd.
Dallas, TX, 75204

DWN BY:
CHK BY:
General Arrangeme
145685-1
DWG NO.
DATE:
Rev
0

Deficiencies Summary

Deficiencies for N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)
Load case 1: UG-45: The total combined shear stress (12,636psi) is greater than the allowable ($0.7*S_n = 0.7*17,100 =$ 11,970 psi)

Deficiencies for N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)
Load case 1: UG-45: The total combined shear stress (30,360psi) is greater than the allowable ($0.7*S_n = 0.7*19,600 =$ 13,720 psi)

Deficiencies for N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)
Load case 1: UG-45: The total combined shear stress (17,942psi) is greater than the allowable ($0.7*S_n = 0.7*17,100 =$ 11,970 psi)

Deficiencies for Tailing Lug
The local stresses in the WRC 107 calculation are excessive.

Warnings Summary

Warnings for Bottom Ellipsoidal Head #2
UCS-79: The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming. (warning)

Warnings for Cylinder #4
INSPECT only supports butt joint construction in shell components. Please check the circumferential joint between Cylinder #4 and Cylinder #5. A common source of this error is specifying one component as an OD design and an adjacent component as an ID design. (warning)

Warnings for Cylinder #5
INSPECT only supports butt joint construction in shell components. Please check the circumferential joint between Cylinder #5 and Cylinder #6. A common source of this error is specifying one component as an OD design and an adjacent component as an ID design. (warning)

Warnings for First Inspection
The measured thickness of CML 77, located on Cylinder #2 has increased since the last inspection. (warning)

Warnings for M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)
UCS-79: The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming. (warning)

Warnings for M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)
UCS-79: The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming. (warning)

Warnings for N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)
The design of this nozzle does not include mill undertolerance because a minimum (as built) thickness was entered. (warning)

Warnings for N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)
The design of this nozzle does not include mill undertolerance because a minimum (as built) thickness was entered. (warning)

Warnings for N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)
Load case 1: WRC 107: Rigid insert assumption questionable ($tn < 1.2188$ in) (warning)
The design of this nozzle does not include mill undertolerance because a minimum (as built) thickness was entered.

(warning)

Warnings for N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)

Warnings for N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)
Part of the pad width is beyond the limits of reinforcement. (warning)
Load case 1: WRC 107: Rigid insert assumption questionable (tn < 1.0313 in) (warning)
The design of this nozzle does not include mill undertolerance because a minimum (as built) thickness was entered. (warning)

Warnings for N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)
ASME B16.5: External loads have not been considered in the flange pressure rating. (warning)
Load case 1: WRC 107: Rigid insert assumption questionable (tn < 1.0938 in) (warning)
The design of this nozzle does not include mill undertolerance because a minimum (as built) thickness was entered. (warning)

Warnings for Tailing Lug
Actual lug C1 / C2 < 1/4, C1 / C2 = 1/4 used as this is the minimum ratio covered by WRC 107. (warning)
The WRC 107 analysis performed does not include consideration of the additional stiffness of the skirt base ring. This analysis may be overly conservative as the tailing lug is within $0.78*(Ro*t)^{0.5}$ of the base ring. (warning)

Warnings for Top Ellipsoidal Head #1
UCS-79: The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming. (warning)

Warnings for Vessel
Inconsistent PWHT: The vessel has one or more components with PWHT, but not all components have PWHT specified. (warning)

Nozzle Schedule

Nozzle mark	Service	Size	Materials		Impact Tested	Normalized	Fine Grain	Flange	Blind
M1A	M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway	25.75 OD x 1.25	Nozzle	SA-516 70	Yes	Yes	No	NPS 24 Class 300 WN A105	NPS 24 Class 300 A105
			Pad	SA-516 70	Yes	Yes	No		
M1B	M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway	25.75 OD x 1.25	Nozzle	SA-516 70	Yes	Yes	No	NPS 24 Class 300 WN A105	NPS 24 Class 300 A105
			Pad	SA-516 70	Yes	Yes	No		
N11	N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle	NPS 12 XS	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 12 Class 300 WN A105	No
			Pad	SA-516 70	Yes	Yes	No		
N12	N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle	8.625 OD x 0.624	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 8 Class 300 WN A105	No
			Pad	SA-516 70	Yes	Yes	No		
N17	N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle	NPS 8 Sch 80 (XS)	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 8 Class 300 WN A105	No
			Pad	SA-516 70	Yes	Yes	No		
N18	N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N35	N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N45A	N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N45B	N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N46A	N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle	4.62 OD x 0.81	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 3 Class 300 LWN A350 LF2 Cl.1	No
N46B	N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle	4.62 OD x 0.81	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 3 Class 300 LWN A350 LF2 Cl.1	No
N47A	N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	NPS 2 Class 300 A350 LF2 Cl.1
N47B	N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	NPS 2 Class 300 A350 LF2 Cl.1
N48A	N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N48B	N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	Yes	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N49A	N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N49B	N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2	No

								Cl.1	
N50A	N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle	4.62 OD x 0.81	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 3 Class 300 LWN A350 LF2 Cl.1	No
N50B	N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle	4.62 OD x 0.81	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 3 Class 300 LWN A350 LF2 Cl.1	No
N51A	N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N51B	N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle	3.31 OD x 0.655	Nozzle	SA-350 LF2 Cl 1	No	No	No	NPS 2 Class 300 LWN A350 LF2 Cl.1	No
N6	N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle	NPS 6 Sch 80 (XS)	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 6 Class 300 WN A105	No
			Pad	SA-516 70	Yes	Yes	No		
N7	N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle	NPS 12 XS	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 12 Class 300 WN A105	No
			Pad	SA-516 70	Yes	Yes	No		

Nozzle Summary

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)		
M1A	25.75	1.25	0.215	Yes	Yes	1.06	1.06	1.06	8	1.25	0	106.7
M1B	25.75	1.25	0.2233	Yes	Yes	1.1	1.1	1.1	8	1.25	0	103.5
N11	12.75	0.5	0.3281	Yes	Yes	1.08	1.07	1.07	5	1.25	0	116.9
N12	8.625	0.624	0.2818	Yes	Yes	1.06	1.06	1.06	3	1.25	0	136.3
N17	8.625	0.5	0.3228	Yes	Yes	1.1875*	1.1549	1.1875	2.5	1.25	0	100.0
N18	3.31	0.655	0.189	Yes	Yes	1.1	N/A	1.1	N/A	N/A	0	Exempt
N35	3.31	0.655	0.189	Yes	Yes	1.1	N/A	1.1	N/A	N/A	0	Exempt
N45A	3.31	0.655	0.5999	Yes	Yes	1.08	N/A	1.07	N/A	N/A	0	Exempt
N45B	3.31	0.655	0.189	Yes	Yes	1.1	N/A	1.1	N/A	N/A	0	Exempt
N46A	4.62	0.81	0.2258	Yes	Yes	1.08	1.07	1.07	N/A	N/A	0	103.1
N46B	4.62	0.81	0.2258	Yes	Yes	1.1	1.1	1.1	N/A	N/A	0	100.2
N47A	3.31	0.655	0.189	Yes	Yes	1.08	N/A	1.07	N/A	N/A	0	Exempt
N47B	3.31	0.655	0.189	Yes	Yes	1.1	N/A	1.1	N/A	N/A	0	Exempt
N48A	3.31	0.655	0.189	Yes	Yes	1.08	N/A	1.07	N/A	N/A	0	Exempt
N48B	3.31	0.655	0.189	Yes	Yes	1.1	N/A	1.1	N/A	N/A	0	Exempt
N49A	3.31	0.655	0.189	Yes	Yes	1.08	N/A	1.07	N/A	N/A	0	Exempt
N49B	3.31	0.655	0.189	Yes	Yes	1.1	N/A	1.1	N/A	N/A	0	Exempt
N50A	4.62	0.81	0.2258	Yes	Yes	1.08	1.07	1.07	N/A	N/A	0	103.1
N50B	4.62	0.81	0.2258	Yes	Yes	1.1	1.1	1.1	N/A	N/A	0	100.2
N51A	3.31	0.655	0.189	Yes	Yes	1.06	N/A	1.06	N/A	N/A	0	Exempt
N51B	3.31	0.655	0.189	Yes	Yes	1.08	N/A	1.07	N/A	N/A	0	Exempt
N6	6.625	0.432	0.3878	Yes	Yes	1.1875*	1.0711	1.1875	3	0.875	0	100.0
N7	12.75	0.5	0.3281	Yes	Yes	1.1875*	1.0926	1.1875	5	1	0	100.0

t_n: Nozzle thickness
Req t_n: 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
* Head minimum thickness after forming

Pressure Summary

Pressure Summary for Chamber bounded by Bottom Ellipsoidal Head #2 and Top Ellipsoidal Head #1

Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MDMT (°F)	MDMT Exemption		Impact Tested
Top Ellipsoidal Head #1	220	500	414.89	414.89	N/A	N/A		Yes
Top Ellipsoidal Head #1 (Dished Region)	220	500	466.06	466.06	N/A	N/A		Yes
Straight Flange on Top Ellipsoidal Head #1	220	500	517.02	517.02	N/A	N/A		Yes
Cylinder #1	220	500	365.83	365.83	N/A	N/A		Yes
Cylinder #2	220	500	421.51	421.51	N/A	N/A		Yes
Cylinder #3	220	500	383.21	383.21	N/A	N/A		Yes
Cylinder #4	220	500	400.61	400.61	N/A	N/A		Yes
Cylinder #5	220	500	316.15	316.15	N/A	N/A		Yes
Cylinder #6	220	500	379.74	379.74	N/A	N/A		Yes
Straight Flange on Bottom Ellipsoidal Head #2	220	500	517.02	517.02	N/A	N/A		Yes
Bottom Ellipsoidal Head #2	220	500	414.89	414.89	N/A	N/A		Yes
Bottom Ellipsoidal Head #2 (Dished Region)	220	500	466.06	466.06	N/A	N/A		Yes
M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)	220	500	365.83	N/I	0	Nozzle	N/A	Yes
						Pad	N/A	Yes
M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)	220	500	379.73	N/I	0	Nozzle	N/A	Yes
						Pad	N/A	Yes
N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)	220	500	368.54	N/I	0	Nozzle	N/A	No
						Pad	N/A	Yes
N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)	220	500	365.83	N/I	0	Nozzle	N/A	No
						Pad	N/A	Yes
N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)	220	500	448.26	N/I	0	Nozzle	N/A	No
						Pad	N/A	Yes
N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle (N18)	220	500	379.73	N/I	0	N/A		No
N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle (N35)	220	500	379.73	N/I	0	N/A		No
N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)	220	500	368.54	N/I	0	N/A		No
N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45B)	220	500	379.73	N/I	0	N/A		No
N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46A)	220	500	368.54	N/I	0	N/A		No
N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46B)	220	500	379.73	N/I	0	N/A		No
N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47A)	220	500	368.54	N/I	0	N/A		No
N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47B)	220	500	379.73	N/I	0	N/A		No
N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48A)	220	500	368.54	N/I	0	N/A		No
N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48B)	220	500	379.73	N/I	0	N/A		No
N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49A)	220	500	368.54	N/I	0	N/A		No
N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49B)	220	500	379.73	N/I	0	N/A		No
N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50A)	220	500	368.54	N/I	0	N/A		No
N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50B)	220	500	379.73	N/I	0	N/A		No
N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51A)	220	500	365.83	N/I	0	N/A		No
N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51B)	220	500	368.54	N/I	0	N/A		No
N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)	220	500	415.78	N/I	0	Nozzle	N/A	No
						Pad	N/A	Yes

N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)	220	500	424.15	N/I	0	Nozzle	N/A	No
						Pad	N/A	Yes

Chamber MAWP hot & corroded is 316.15 psi @ 500 °F

Chamber MAP cold & new is 316.15 psi @ 71.6 °F

This pressure chamber is not designed for external pressure.

Design notes are available on the Settings Summary page.

Revision History

No.	Date	Operator	Notes
0	8/29/2004	Warren Kmicik	New vessel created ASME Division 1 [Build 6234]
1	1/31/2007	Les Bildy	Converted from ASME Section VIII Division 1, 2001 Edition, A03 Addenda to ASME Section VIII Division 1, 2004 Edition, A06 Addenda. Default Forging Material Changed to A 105. During the conversion, changes may have been made to your vessel (some may be listed above). Please check your vessel carefully.
2	8/20/2013	Matt	Converted from ASME Section VIII Division 1, 2004 Edition, A06 Addenda to ASME Section VIII Division 1, 2010 Edition, A11 Addenda. Default Forging Material Changed to A 105. During the conversion, changes may have been made to your vessel (some may be listed above). Please check your vessel carefully.

Settings Summary

INSPECT 2013 Build 7330

Vessel calculations are based on the projected corroded state of the vessel at the date of the inspection on 9/2/2015

Units: U.S. Customary

Datum Line Location: 0.00" from bottom seam

Design

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Design or Rating:	Get Pressure Rating and Calculate Required Thickness
Minimum thickness:	0.0625" per UG-16(b)
Design for cold shut down only:	No
Design for lethal service (full radiography required):	No
Rate nozzles for:	Find nozzle MAWP
Corrosion weight loss:	100% of theoretical loss
UG-23 Stress Increase:	1.20
Skirt/legs stress increase:	1.3
Minimum nozzle projection:	2"
Juncture calculations for $\alpha > 30$ only:	Yes
Preheat P-No 1 Materials > 1.25" and <= 1.50" thick:	No
UG-37(a) shell tr calculation considers longitudinal stress:	No

Pipe under-tolerance is not applied to cylindrical shell thicknesses.
Pipe under-tolerance is not applied to nozzle wall thicknesses.
Pipe under-tolerance is not applied to pipe cap thicknesses.
Butt welds are tapered per Figure UCS-66.3(a).

Hydro/Pneumatic Test

Shop Hydrotest Pressure:	1.3 times vessel MAWP
Test liquid specific gravity:	1.00
Field Hydrotest Pressure:	1.3 times vessel MAWP
Wind load present @ field:	33% of design
Maximum stress during test:	90% of yield

Required Marking - UG-116

UG-116(e) Radiography:	RT4
UG-116(f) Postweld heat treatment:	PHT

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:	Yes
Apply interpretation VIII-1-01-37:	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:	No
UG-22(f) Seismic reactions:	No
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.

Radiography Summary

Radiography for Chamber bounded by Bottom Ellipsoidal Head #2 and Top Ellipsoidal Head #1

Component	Longitudinal Seam		Top Circumferential Seam		Bottom Circumferential Seam		Mark
	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	
Top Ellipsoidal Head #1	N/A	Seamless No RT	N/A	N/A	B	Full UW-11(a) / Type 1	RT1
Cylinder #1	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	RT1
Cylinder #2	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	RT1
Cylinder #3	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	RT1
Cylinder #4	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 1	RT1
Cylinder #5	A	Spot UW-11(b) / Type 1	B	Full UW-11(a) / Type 1	B	User Defined (E = 1.00)	RT4
Cylinder #6	A	Full UW-11(a) / Type 1	B	User Defined (E = 1.00)	B	Full UW-11(a) / Type 1	RT1
Bottom Ellipsoidal Head #2	N/A	Seamless No RT	B	Full UW-11(a) / Type 1	N/A	N/A	RT1
Nozzle	**Longitudinal Seam**		**Nozzle to Vessel Circumferential Seam**		**Nozzle free end Circumferential Seam**		
N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)	N/A	Seamless No RT	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51A)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)	A	User Defined (E = 1.00)	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)	N/A	Seamless No RT	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51B)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49A)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50A)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48A)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46A)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47A)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle (N18)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle (N35)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45B)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46B)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A

N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47B)							
N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49B)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50B)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)	A	User Defined (E = 1.00)	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48B)	N/A	Seamless No RT	D	N/A / Type 7	C	N/A	N/A
N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Nozzle Flange	**Longitudinal Seam**		**Flange Face**		**Nozzle to Flange Circumferential Seam**		
ASME B16.5/16.47 flange attached to N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A
ASME B16.5/16.47 flange attached to N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
ASME B16.5/16.47 flange attached to N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A
ASME B16.5/16.47 flange attached to N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
ASME B16.5/16.47 flange attached to N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
ASME B16.5/16.47 flange attached to N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47A)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle (N18)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle (N35)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
ASME B16.5/16.47 flange attached to N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48B)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	N/A	N/A
ASME B16.5/16.47 flange attached to N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A

Chamber bounded by Bottom Ellipsoidal Head #2 and Top Ellipsoidal Head #1 - UG-116(e) Radiography: **RT4**

Thickness Summary

Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
Top Ellipsoidal Head #1	SA-516 70	114.25 ID	29.75	1.1875*	0.6291	0	1.00	Internal
Straight Flange on Top Ellipsoidal Head #1	SA-516 70	114.25 ID	2	1.5	0.6326	0	1.00	Internal
Top Ellipsoidal Head #1 (Dished Region)	SA-516 70	203.3603 ID	102.8677	1.1875*	0.5599	0	1.00	Internal
Cylinder #1	SA-516 70	114.63 ID	113.44	1.06	0.6347	0	1.00	Internal
Cylinder #2	SA-516 70	114.31 ID	113.3125	1.22	0.6329	0	1.00	Internal
Cylinder #3	SA-516 70	114.53 ID	113.3125	1.11	0.6342	0	1.00	Internal
Cylinder #4	SA-516 70	114.43 ID	113.3125	1.16	0.6336	0	1.00	Internal
Cylinder #5	SA-516 70	114.85 ID	113.3125	1.08	0.749	0	0.85	Internal
Cylinder #6	SA-516 70	114.55 ID	113.3125	1.1	0.6343	0	1.00	Internal
Straight Flange on Bottom Ellipsoidal Head #2	SA-516 70	114.25 ID	2	1.5	0.6326	0	1.00	Internal
Bottom Ellipsoidal Head #2	SA-516 70	114.25 ID	29.75	1.1875*	0.6291	0	1.00	Internal
Bottom Ellipsoidal Head #2 (Dished Region)	SA-516 70	203.3603 ID	102.8677	1.1875*	0.5599	0	1.00	Internal
Support Skirt	SA-516 70	114 ID	89.71	0.625	0.093	0	0.55	Weight

Nominal t:	Vessel wall nominal thickness
Design t:	Required vessel thickness due to governing loading + corrosion
Joint E:	Longitudinal seam joint efficiency
*	Head minimum thickness after forming

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

Weight Summary

Component	Weight (lb) Contributed by Vessel Elements									
	Metal New*	Metal Corroded*	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid	
							New	Corroded	New	Corroded
Top Ellipsoidal Head #1	5,439.7	5,439.7	273.5	150	520.1	0	0	0	7,755.4	7,755.4
Cylinder #1	12,191.8	12,191.8	734.7	150	1,479.3	0	0	0	42,165.2	42,165.2
Cylinder #2	14,199.4	14,199.4	733.9	150	1,473.5	0	0	0	41,793.3	41,793.3
Cylinder #3	12,931.4	12,931.4	733.9	150	1,476.3	0	0	0	41,954.7	41,954.7
Cylinder #4	13,508	13,508	733.9	150	1,475	0	0	0	41,881.3	41,881.3
Cylinder #5	12,551	12,551	735.5	150	1,480.5	0	0	0	42,210.6	42,210.6
Cylinder #6	12,627.4	12,627.4	733.9	150	1,476.6	0	0	0	42,060	42,060
Bottom Ellipsoidal Head #2	5,474.5	5,474.5	273.5	150	520.1	0	0	0	7,744.8	7,744.8
Support Skirt	5,618.4	5,618.4	0	0	0	0	0	0	0	0
Skirt Base Ring #1	2,325	2,325	0	0	0	0	0	0	0	0
TOTAL:	**96,866.6**	**96,866.6**	**4,952.9**	**1,200**	**9,901.4**	**0**	**0**	**0**	**267,565.4**	**267,565.4**

* Shells with attached nozzles have weight reduced by material cut out for opening.

Component	Weight (lb) Contributed by Attachments									
	Body Flanges		Nozzles & Flanges		Packed Beds	Ladders & Platforms	Trays	Tray Supports	Rings & Clips	Vertical Loads
	New	Corroded	New	Corroded						
Top Ellipsoidal Head #1	0	0	374.6	374.6	0	1,883.7	0	0	0	0
Cylinder #1	0	0	2,191.5	2,191.5	0	2,214.1	2,551.8	1,500	3,850.8	0
Cylinder #2	0	0	0	0	0	236.1	3,402.3	2,000	0	0
Cylinder #3	0	0	0	0	0	2,287.6	4,252.9	2,500	0	0
Cylinder #4	0	0	0	0	0	236.1	4,252.9	2,500	0	15,000
Cylinder #5	0	0	480.3	480.3	0	342.2	1,701.2	1,000	0	0
Cylinder #6	0	0	2,258.4	2,258.4	0	2,743	0	0	0	0
Bottom Ellipsoidal Head #2	0	0	165.5	165.5	0	204.2	0	0	0	0
Support Skirt	0	0	0	0	0	1,741	0	0	409.9	0
TOTAL:	**0**	**0**	**5,470.3**	**5,470.3**	**0**	**11,887.9**	**16,161.1**	**9,500**	**4,260.6**	**15,000**

* Nozzle weight includes lining.

Vessel operating weight, Corroded:	175,201 lb
Vessel operating weight, New:	175,201 lb
Vessel empty weight, Corroded:	175,201 lb
Vessel empty weight, New:	175,201 lb
Vessel test weight, New:	442,766 lb
Vessel test weight, Corroded:	442,766 lb

Vessel center of gravity location - from datum - lift condition

Vessel Lift Weight, New:	175,201 lb
Center of Gravity:	333.6655"

Vessel Capacity

Vessel Capacity** (New):	32,057 US gal
Vessel Capacity** (Corroded):	32,057 US gal

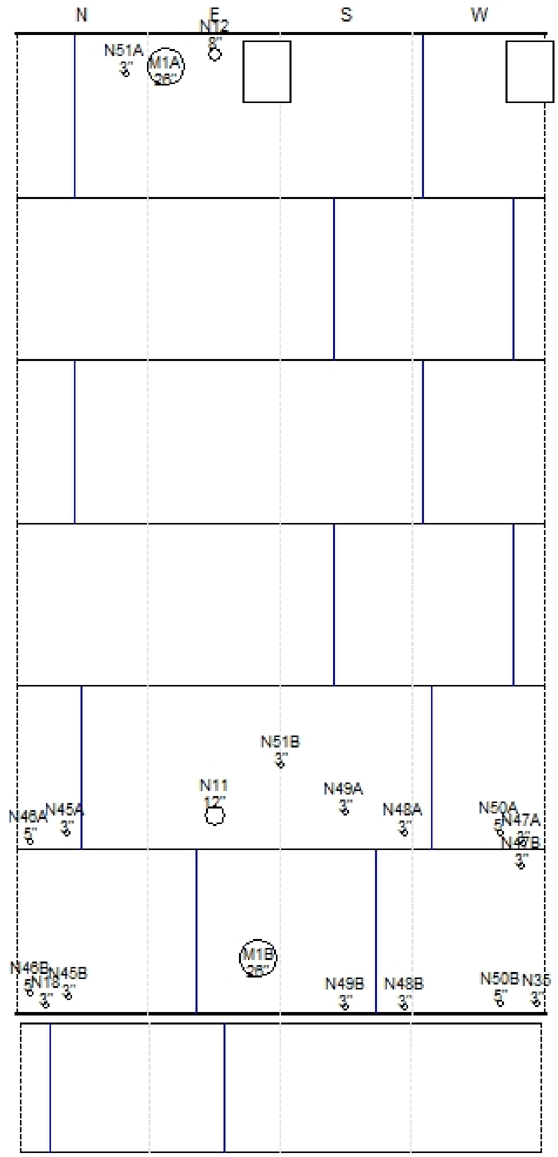
**The vessel capacity does not include volume of nozzle, piping or other attachments.

Long Seam Summary

Shell Long Seam Angles		
Component	**Seam 1**	**Seam 2**
Cylinder #1	233.1123°	355°
Cylinder #2	172.1123°	294°
Cylinder #3	233.1123°	355°
Cylinder #4	172.1123°	294°
Cylinder #5	0°	238.1122°
Cylinder #6	78.1123°	200°
Support Skirt	96°	335.93°

Shell Plate Lengths			
Component	**Starting Angle**	**Plate 1**	**Plate 2**
Cylinder #1	355°	240.3948"	123.0561"
Cylinder #2	294°	240.0623"	122.8859"
Cylinder #3	355°	240.2909"	123.0029"
Cylinder #4	294°	240.187"	122.9497"
Cylinder #5	0°	240.8934"	123.3115"
Cylinder #6	200°	240.3117"	123.0135"
Support Skirt	96°	240"	120.105"

*North is located at 0°
*Plate Lengths use the circumference of the vessel based on the mid diameter of the components



Shell Rollout

Hydrostatic Test

Shop test pressure determination for Chamber bounded by Bottom Ellipsoidal Head #2 and Top Ellipsoidal Head #1 based on MAWP per UG-99(b)

Shop hydrostatic test gauge pressure is 411 psi at 71.6 °F (the chamber MAWP = 316.154 psi)

The shop test is performed with the vessel in the horizontal position.

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 Ellipsoidal Head #1 (1)	415.428	4.428	1	1.30	17,986	34,200	No
Straight Flange on Top Ellipsoidal Head #1	415.428	4.428	1	1.30	16,028	34,200	No
Cylinder #1	415.43	4.43	1	1.30	22,670	34,200	No
Cylinder #2	415.424	4.424	1	1.30	19,669	34,200	No
Cylinder #3	415.428	4.428	1	1.30	21,639	34,200	No
Cylinder #4	415.427	4.427	1	1.30	20,697	34,200	No
Cylinder #5	415.434	4.434	1	1.30	22,296	34,200	No
Cylinder #6	415.429	4.429	1	1.30	21,838	34,200	No
Straight Flange on Bottom Ellipsoidal Head #2	415.428	4.428	1	1.30	16,028	34,200	No
Bottom Ellipsoidal Head #2	415.428	4.428	1	1.30	17,986	34,200	No
M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)	412.57	1.57	1	1.30	18,069	51,300	No
M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)	414.999	3.999	1	1.30	18,365	51,300	No
N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)	413.578	2.578	1	1.30	18,215	51,300	No
N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)	413.499	2.499	1	1.30	16,801	51,300	No
N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)	413.503	2.503	1	1.30	17,777	51,300	No
N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle (N18)	411.471	0.471	1.0204	1.30	23,406	51,300	No
N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle (N35)	412.039	1.039	1.0204	1.30	23,439	51,300	No
N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)	411.292	0.292	1.0204	1.30	24,092	51,300	No
N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45B)	411.297	0.297	1.0204	1.30	23,397	51,300	No
N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46A)	411.667	0.667	1.0204	1.30	24,541	51,300	No
N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46B)	411.671	0.671	1.0204	1.30	23,868	51,300	No
N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47A)	412.341	1.341	1.0204	1.30	24,154	51,300	No
N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47B)	412.343	1.344	1.0204	1.30	23,456	51,300	No
N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48A)	415.224	4.224	1.0204	1.30	24,323	51,300	No
	415.224	4.224	1.0204	1.30	23,620	51,300	No

N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48B)							
N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49A)	415.762	4.762	1.0204	1.30	24,354	51,300	No
N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49B)	415.762	4.762	1.0204	1.30	23,651	51,300	No
N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50A)	412.871	1.872	1.0204	1.30	24,613	51,300	No
N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50B)	412.873	1.873	1.0204	1.30	23,938	51,300	No
N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51A)	411.559	0.559	1.0204	1.30	24,280	51,300	No
N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51B)	415.085	4.086	1.0204	1.30	24,314	51,300	No
N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)	413.47	2.47	1	1.30	17,807	51,300	No
N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)	413.578	2.578	1	1.30	19,139	51,300	No

Notes:
(1) Top Ellipsoidal Head #1 limits the UG-99(b) stress ratio.
(2) P_L stresses at nozzle openings have been estimated using the method described in PVP-Vol. 399, pages 77-82.
(3) 1.5*0.9*S_y used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.
(4) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

The test temperature of 71.6 °F is warmer than the minimum recommended temperature of 30 °F so the brittle fracture provision of UG-99(h) has been met.

Field test pressure determination for Chamber bounded by Bottom Ellipsoidal Head #2 and Top Ellipsoidal Head #1 based on MAWP per UG-99(b)

Field hydrostatic test gauge pressure is 411 psi at 71.6 °F (the chamber MAWP = 316.154 psi)

The field test is performed with the vessel in the vertical position.

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 Ellipsoidal Head #1 (1)	412.534	1.534	1	1.30	17,861	34,200	No
Straight Flange on Top Ellipsoidal Head #1	412.534	1.534	1	1.30	15,916	34,200	No
Cylinder #1	416.629	5.629	1	1.30	22,735	34,200	No
Cylinder #2	420.719	9.719	1	1.30	19,920	34,200	No
Cylinder #3	424.809	13.81	1	1.30	22,128	34,200	No
Cylinder #4	428.9	17.9	1	1.30	21,368	34,200	No
Cylinder #5	432.99	21.99	1	1.30	23,238	34,200	No
Cylinder #6	437.08	26.08	1	1.30	22,976	34,200	No
Straight Flange on Bottom Ellipsoidal Head #2	437.152	26.152	1	1.30	16,866	34,200	No
Bottom Ellipsoidal Head #2	438.183	27.184	1	1.30	18,971	34,200	No
M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)	413.784	2.784	1	1.30	18,122	51,300	No
M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)	436.164	25.164	1	1.30	19,302	51,300	No
N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)	432.383	21.383	1	1.30	19,043	51,300	No
N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)	413.173	2.173	1	1.30	16,787	51,300	No
N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)	438.885	27.885	1	1.30	18,868	51,300	No
N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle (N18)	436.972	25.972	1.0204	1.30	24,857	51,300	No
N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle (N35)	436.936	25.936	1.0204	1.30	24,855	51,300	No
N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)	432.64	21.64	1.0204	1.30	25,343	51,300	No
N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45B)	436.755	25.755	1.0204	1.30	24,845	51,300	No
N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46A)	432.875	21.875	1.0204	1.30	25,805	51,300	No
N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46B)	436.665	25.665	1.0204	1.30	25,317	51,300	No
N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47A)	432.879	21.879	1.0204	1.30	25,357	51,300	No
N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47B)	433.457	22.457	1.0204	1.30	24,657	51,300	No
N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48A)	432.64	21.64	1.0204	1.30	25,343	51,300	No
N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48B)	437.008	26.008	1.0204	1.30	24,859	51,300	No
N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49A)	432.099	21.099	1.0204	1.30	25,311	51,300	No
N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49B)	437.008	26.008	1.0204	1.30	24,859	51,300	No

N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50A)	432.658	21.658	1.0204	1.30	25,793	51,300	No
N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50B)	436.954	25.954	1.0204	1.30	25,334	51,300	No
N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51A)	413.581	2.581	1.0204	1.30	24,399	51,300	No
N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51B)	430.908	19.908	1.0204	1.30	25,241	51,300	No
N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)	411.577	0.577	1	1.30	17,725	51,300	No
N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)	411.388	0.388	1	1.30	19,037	51,300	No

Notes:
(1) Top Ellipsoidal Head #1 limits the UG-99(b) stress ratio.
(2) P_L stresses at nozzle openings have been estimated using the method described in PVP-Vol. 399, pages 77-82.
(3) 1.5*0.9*S_y used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.

The test temperature of 71.6 °F is warmer than the minimum recommended temperature of 30 °F so the brittle fracture provision of UG-99(h) has been met.

Engineering Notes

1. ***Fireproofing material on the vessel skirt is assumed to be added after vessel erection***. The skirt fireproofing estimated density is 200#/cu. ft.

2. The vessel skirt thickness has been increased to 0.625 inches from 0.5 inches as originally submitted.

3. The baseplate ID and OD, bolt circle and chair heights have been retained from the original design.
The standard dimensions may not be met per dwg C-510-1 Rev 2

4. Grating is 20 lbs/sq ft, railing is 12 lbs/ft and ladders are 25 lbs/ft.

5. The pressure vessel software COMPRESS includes a lifting and tailing lug design option. The lift lug is included with this set of calculations.

First Inspection

Calculation Results Summary			
Projected Retirement Date:	8/30/2024	**Governing Component:**	Cylinder #5
Governing CML:	CML 28	**Projected Thickness at Retirement Date:**	0.7563"
Target MAWP:	220 psi @ 500 °F	**Target MAEP:**	N/A

Equipment Information	
Vessel Name:	Amine Absorber_PC_JE

Summary of Thickness Measurements

Component	Previous Average Thickness	Average Measured Thickness	Governing CML Thickness	Minimum Required Thickness	Short Term Corrosion Rate	Long Term Corrosion Rate	Remaining Life	Governing Component
Top Ellipsoidal Head #1	1.1875"	1.1875"	1.1875"	0.6291"	0"/yr	0"/yr	-	No
Cylinder #1	1.25"	1.211"	1.06"	0.6385"	0.038"/yr	0.038"/yr	11.092 years	No
Cylinder #2	1.25"	1.2515"	1.22"	0.6335"	0.006"/yr	0.006"/yr	97.75 years	No
Cylinder #3	1.25"	1.2337"	1.11"	0.637"	0.028"/yr	0.028"/yr	16.893 years	No
Cylinder #4	1.25"	1.236"	1.16"	0.6354"	0.018"/yr	0.018"/yr	29.144 years	No
Cylinder #5	1.2525"	1.194"	1.08"	0.7563"	0.036"/yr	0.036"/yr	8.992 years	Yes
Cylinder #6	1.25"	1.2165"	1.1"	0.7506"	0.03"/yr	0.03"/yr	11.647 years	No
Bottom Ellipsoidal Head #2	1.1875"	1.1875"	1.1875"	0.6291"	0"/yr	0"/yr	-	No

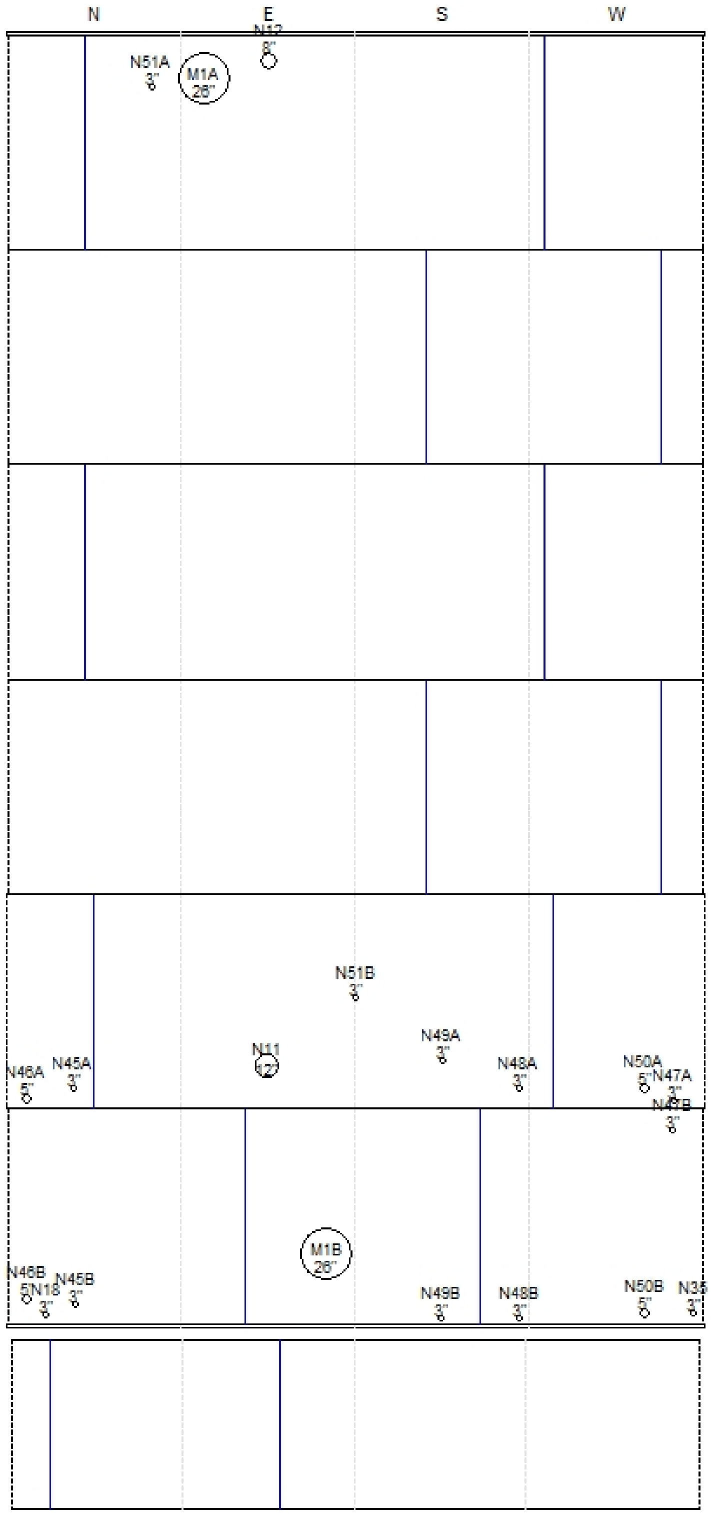
*The Previous Average Thickness is average measured thickness from the previous thickness inspection of each component.

Inspection on 9/2/2015			
Inspection Date:	9/2/2015	**Report Date:**	9/2/2015
Inspection Name:	First Inspection		
Inspections Performed			
Visual Inspection(VT): External	YES	**Visual Inspection(VT): Internal**	YES
Thickness Inspection:	YES		

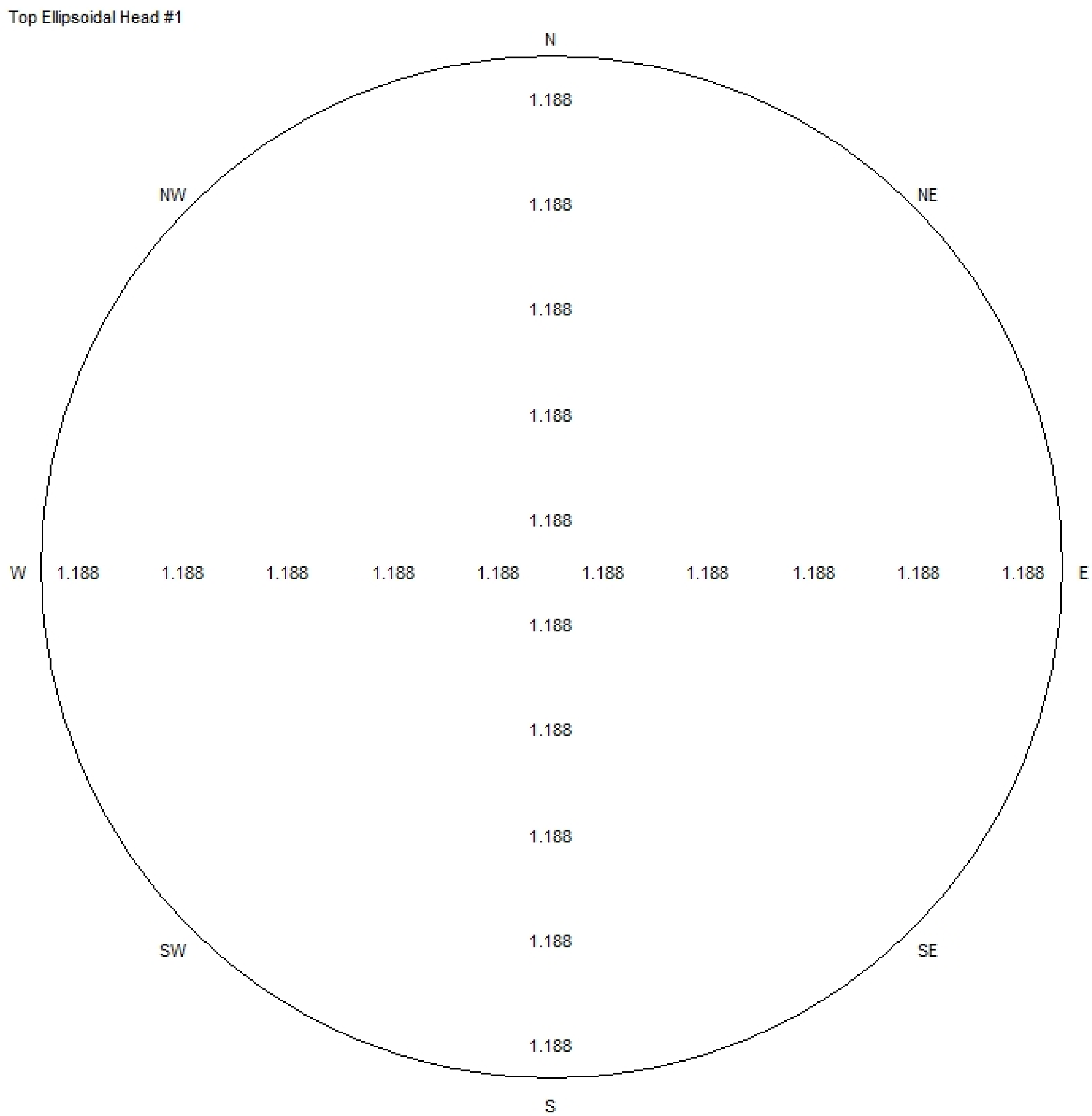
Shell Courses						
Course	**ID**	**Course Height**	**Allowable Stress**	**Joint Efficiency (circ, long)**	**Actual Thickness**	**Required Thickness**
1	Straight Flange on Top Ellipsoidal Head #1	680.0025" - 682.0025"	20,000 psi	1, 1	N/A	0.6326"
2	Cylinder #1	566.5625" - 680.0025"	20,000 psi	1, 1	1.06"	0.6385"
3	Cylinder #2	453.25" - 566.5625"	20,000 psi	1, 1	1.22"	0.6335"
4	Cylinder #3	339.9375" - 453.25"	20,000 psi	1, 1	1.11"	0.637"
5	Cylinder #4	226.625" - 339.9375"	20,000 psi	1, 1	1.16"	0.6354"
6	Cylinder #5	113.3125" - 226.625"	20,000 psi	1, 0.85	1.08"	0.7563"
7	Cylinder #6	0" - 113.3125"	20,000 psi	1, 1	1.1"	0.7506"
8	Straight Flange on Bottom Ellipsoidal Head #2	-2" - 0"	20,000 psi	1, 1	N/A	0.6326"

Shell Measured Thickness				
	0 °	**90 °**	**180 °**	**270 °**
674"	1.25"	1.25"	1.25"	1.25"
650"	1.1"	1.11"	1.12"	1.25"
626"	1.25"	1.25"	1.25"	1.06"
602"	1.25"	1.25"	1.25"	1.25"
578"	1.25"	1.25"	1.08"	1.25"
554"	1.25"	1.25"	1.25"	1.25"
530"	1.25"	1.25"	1.22"	1.25"
506"	1.25"	1.25"	1.25"	1.25"
482"	1.25"	1.25"	1.25"	1.25"
458"	1.31"	1.25"	1.25"	1.25"
434"	1.25"	1.25"	1.2"	1.25"
410"	1.25"	1.25"	1.25"	1.25"
386"	1.25"	1.11"	1.25"	1.25"
362"	1.25"	1.25"	1.18"	1.25"
338"	1.25"	1.19"	1.25"	1.25"
314"	1.25"	1.19"	1.25"	1.25"
290"	1.25"	1.16"	1.25"	1.25"
266"	1.25"	1.25"	1.21"	1.25"
242"	1.25"	1.25"	1.22"	1.25"
218"	1.25"	1.25"	1.125"	1.25"
194"	1.25"	1.25"	1.25"	1.25"
170"	1.25"	1.25"	1.25"	1.25"
146"	1.1"	1.07"	1.07"	**1.08"**
122"	1.25"	1.09"	1.094"	1.25"
98"	1.25"	1.16"	1.17"	1.25"
74"	1.25"	1.25"	1.18"	1.25"
50"	1.25"	1.13"	1.2"	1.25"
26"	1.25"	1.14"	1.25"	1.25"
2"	1.1"	1.25"	1.25"	1.25"

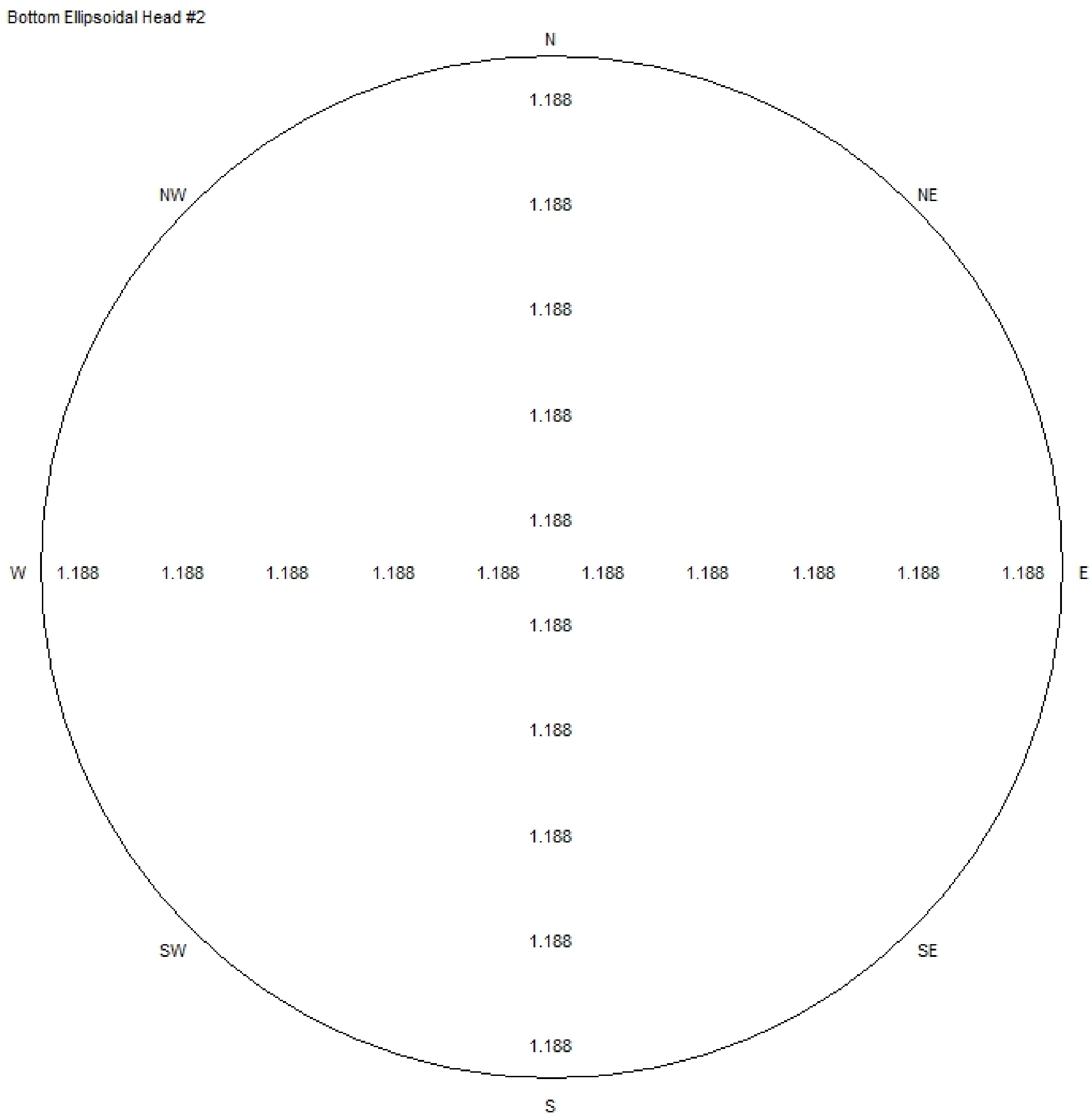
N	E	S	W
1.25	1.25	1.25	1.25
1.1	1.11	1.12	1.25
1.25	1.25	1.25	1.06
1.25	1.25	1.25	1.25
1.25	1.25	1.08	1.25
1.25	1.25	1.25	1.25
1.25	1.25	1.22	1.25
1.25	1.25	1.25	1.25
1.25	1.25	1.25	1.25
1.31	1.25	1.25	1.25
1.25	1.25	1.2	1.25
1.25	1.25	1.25	1.25
1.25	1.11	1.25	1.25
1.25	1.25	1.18	1.25
1.25	1.19	1.25	1.25
1.25	1.19	1.25	1.25
1.25	1.16	1.25	1.25
1.25	1.25	1.21	1.25
1.25	1.25	1.22	1.25
1.25	1.25	1.125	1.25
1.25	1.25	1.25	1.25
1.25	1.25	1.25	1.25
1.1	1.07	1.07	1.08
1.25	1.09	1.094	1.25
1.25	1.16	1.17	1.25
1.25	1.25	1.18	1.25
1.25	1.13	1.2	1.25
1.25	1.14	1.25	1.25
1.1	1.25	1.25	1.25


N
E
S
W
N12
8"
N51A
3"
M1A
26"
N51B
3"
N49A
3"
N11
12"
N46A
5"
N45A
3"
N48A
3"
N50A
5"
N47A
3"
N47B
3"
M1B
26"
N46B
5"
N18
3"
N45B
3"
N49B
3"
N48B
3"
N50B
5"
N35
3"

Top Ellipsoidal Head #1 Measured Thickness				
	0 °	90 °	180 °	270 °
54"	1.1875"	1.1875"	1.1875"	1.1875"
42"	1.1875"	1.1875"	1.1875"	1.1875"
30"	1.1875"	1.1875"	1.1875"	1.1875"
18"	1.1875"	1.1875"	1.1875"	1.1875"
6"	1.1875"	1.1875"	1.1875"	1.1875"



Bottom Ellipsoidal Head #2 Measured Thickness				
	0 °	90 °	180 °	270 °
54"	1.1875"	1.1875"	1.1875"	1.1875"
42"	1.1875"	1.1875"	1.1875"	1.1875"
30"	1.1875"	1.1875"	1.1875"	1.1875"
18"	1.1875"	1.1875"	1.1875"	1.1875"
6"	1.1875"	1.1875"	1.1875"	1.1875"



Nozzle Readings					
	Dist from Nozzle End	0 °	90 °	180 °	270 °
N6	**5.5071"**	0.432"	0.432"	0.432"	0.432"
N7	**2.9042"**	0.5"	0.5"	0.5"	0.5"
N12	**2.1225"**	0.624"	0.624"	0.625"	0.625"
N51A	**3.56"**	0.655"	0.655"	0.655"	0.655"
M1A	**2.69"**	1.25"	1.25"	1.25"	1.25"
N11	**1.7525"**	0.5"	0.5"	0.5"	0.5"
N51B	**3.56"**	0.655"	0.655"	0.655"	0.655"
N45A	**3.56"**	0.655"	0.655"	0.655"	0.655"
N49A	**3.56"**	0.655"	0.655"	0.655"	0.655"
N50A	**3.44"**	0.81"	0.81"	0.81"	0.81"
N48A	**3.56"**	0.655"	0.655"	0.655"	0.655"
N46A	**3.44"**	0.81"	0.81"	0.81"	0.81"
N47A	**3.56"**	0.655"	0.655"	0.655"	0.655"
N18	**2.8725"**	0.655"	0.655"	0.655"	0.655"
N35	**3.56"**	0.655"	0.655"	0.655"	0.655"
N45B	**3.56"**	0.655"	0.655"	0.655"	0.655"
N46B	**3.44"**	0.81"	0.81"	0.81"	0.81"
N47B	**3.56"**	0.655"	0.655"	0.655"	0.655"
N49B	**3.56"**	0.655"	0.655"	0.655"	0.655"
N50B	**3.44"**	0.81"	0.81"	0.81"	0.81"
M1B	**2.69"**	1.25"	1.25"	1.25"	1.25"
N48B	**3.56"**	0.655"	0.655"	0.655"	0.655"
N17	**6.9757"**	0.5"	0.5"	0.5"	0.5"

Shell Details							
Component	Measured Thickness	Min. Reqired Thickness	Length	Rem Corr.	Governs	Corr. Allow	Material
Cylinder #1	1.06"	0.6385"	113.44"	0.4215"	No	0"	SA-516 70
Cylinder #2	1.22"	0.6335"	113.3125"	0.5865"	No	0"	SA-516 70
Cylinder #3	1.11"	0.637"	113.3125"	0.473"	No	0"	SA-516 70
Cylinder #4	1.16"	0.6354"	113.3125"	0.5246"	No	0"	SA-516 70
Cylinder #5	1.08"	0.7563"	113.3125"	0.3237"	**Yes**	0"	SA-516 70
Cylinder #6	1.1"	0.7506"	113.3125"	0.3494"	No	0"	SA-516 70

Head Details						
Component	**Measured Thickness**	**Min. Reqired Thickness**	**Rem Corr.**	**Governs**	**Corr. Allow**	**Material**
Top Ellipsoidal Head #1	1.1875"	0.6291"	0.5584"	No	0"	SA-516 70
Bottom Ellipsoidal Head #2	1.1875"	0.6291"	0.5584"	No	0"	SA-516 70

Nozzle Details				
Nozzle	**Minimum Measured Thickness**	**Governs**	**Corr. Allow**	**Material**
N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)	0.432"	No	0"	SA-106 B
N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)	0.5"	No	0"	SA-106 B
N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)	0.624"	No	0"	SA-106 B
N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51A)	0.655"	No	0"	SA-350 LF2
M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)	1.25"	No	0"	SA-516 70
N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)	0.5"	No	0"	SA-106 B
N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51B)	0.655"	No	0"	SA-350 LF2
N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)	0.655"	No	0"	SA-350 LF2
N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49A)	0.655"	No	0"	SA-350 LF2
N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50A)	0.81"	No	0"	SA-350 LF2
N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48A)	0.655"	No	0"	SA-350 LF2
N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46A)	0.81"	No	0"	SA-350 LF2
N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47A)	0.655"	No	0"	SA-350 LF2
N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle (N18)	0.655"	No	0"	SA-350 LF2
N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle (N35)	0.655"	No	0"	SA-350 LF2
N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45B)	0.655"	No	0"	SA-350 LF2
N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46B)	0.81"	No	0"	SA-350 LF2
N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47B)	0.655"	No	0"	SA-350 LF2
N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49B)	0.655"	No	0"	SA-350 LF2
N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50B)	0.81"	No	0"	SA-350 LF2
M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)	1.25"	No	0"	SA-516 70
N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48B)	0.655"	No	0"	SA-350 LF2
N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)	0.5"	No	0"	SA-106 B

*The minimum required thickness may be calculated for each nozzle by activating the switch on the *Remaining Life Basis* dialog.

Remaining Life Calculation

Governing Component:	Cylinder #5
Corrosion Basis:	Short Term Corrosion Rate (ST)
Target MAWP:	220 psi @ 500 °F

Target MAEP:	N/A
Current Inspection Date:	9/2/2015

Governing CML

CML ID:	CML 28
Static Head:	0 psi
Effective Circumferential Seam Joint Efficiency:	1
Effective Longitudinal Seam Joint Efficiency:	0.85
Minimum Required Thickness, $t_{required}$:	0.7563"
Measured Thickness, t_{actual}:	1.08"
Measured On:	9/2/2015
Previous Measured Thickness, $t_{previous}$:	1.26"
Previously Measured On:	9/2/2010
Time Between Measurements:	5 years

Corrosion Rate

Corrosion Rate = $(t_{previous} - t_{actual})$ / Years Difference
= (1.26 - 1.08) / 5
= 0.036"/yr

Remaining Life

Remaining Life = $(t_{actual} - t_{required})$ / Corrosion Rate
= (1.08 - 0.7563) / 0.036
= 8.992 years

Thickness Inspection Interval, API 510 6.5

4.496 years or 10 years (whichever is less) = 4.496 years
Next Thickness Inspection required by **3/2/2020**

Internal Inspection Interval, API 510 6.5

4.496 years or 10 years (whichever is less) = 4.496 years
Next Internal Inspection required by **3/2/2020**

External Inspection Interval, API 510 6.4

4.496 years or 5 years (whichever is less) = 4.496 years
Next External Inspection required by **3/2/2020**

Projected Retirement Date

9/2/2015 + 8.992 years = **8/30/2024**

Cylinder #1

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Component:	Cylinder
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th}	=	4.43 psi	(SG = 1, H_s = 122.7303", Horizontal test head)
P_{tv}	=	5.63 psi	(SG = 1, H_s = 155.94", Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Top circumferential joint -	Full UW-11(a) Type 1
	Bottom circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 12,191.8 lb	corr = 12,191.8 lb
Capacity	New = 5,045.97 US gal	corr = 5,045.97 US gal

ID	=	114.63"					
Length L_c	=	113.44"					
t	=	1.06"					
Insulation thk:	2"		density:	15 lb/ft^3		Weight:	734.7 lb
Insulation Support Spacing:	96"		Individual Support Weight:	150 lb		Total Support Weight:	150 lb
Lining/Refractory thickness:	0.125"		density:	501.12 lb/ft^3		Weight:	1,479.3 lb

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.315 / (20,000*1.00 - 0.60*220) + 0
= 0.6347"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*1.00*1.06 / (57.315 + 0.60*1.06) - 0
= 365.83 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*1.00*1.06 / (57.315 + 0.60*1.06)
= 365.83 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 116.75 = 6.0218
D_o / t = 116.75 / 1.06 = 110.1415
From table G: A = 0.000172
From table CS-2: B = 2,472.4066 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,472.41 / (3*(116.75 / 1.06))
= 29.93 psi

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*1.06 / 57.845)*(1 - 57.845 / ∞)
= 0.9162%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.6347"

The governing condition is due to internal pressure.

The cylinder thickness of 1.06" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	11,772	500	0	Weight	747.7	0.3111	0.3082
Operating, Hot & New	20,000	11,772	500	0	Weight	747.7	0.3111	0.3082
Hot Shut Down, Corroded	20,000	11,772	500	0	Weight	0	0.0058	0.0108
Hot Shut Down, New	20,000	11,772	500	0	Weight	0	0.0058	0.0108
Empty, Corroded	20,000	15,365	70	0	Weight	0	0.0044	0.0083
Empty, New	20,000	15,365	70	0	Weight	0	0.0044	0.0083
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	11,772	500	0	Weight	0	0.0058	0.0108

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.375 / 1.06)
= 0.002270
B = 11,772 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cHC} = min(B, S) = 11,772 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

S_{cHN} = S_{cHC}
= 11,772 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.375 / 1.06)
= 0.002270
B = 15,365 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCN} = min(B, S) = 15,365 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 15,365 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.375 / 1.06)
= 0.002270
B = 15,365 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cVC} = min(B, S) = 15,365 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 220*57.315 / (2*20,000*1.00*1.00 + 0.40*|220|)
= 0.3145"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= $311,660 / (\pi*57.845^2*20,000*1.00*1.00)$
= 0.0015"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= $35,540.1 / (2*\pi*57.845*20,000*1.00*1.00)$
= 0.0049"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3145 + 0.0015 - (0.0049)
= 0.3111"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0015 + (0.0049) - (0.3145)|
= 0.3082"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.06 - 0.0015 + (0.0049)) / (57.315 - 0.40*(1.06 - 0.0015 + (0.0049)))$
$= 747.7$ psi

Operating, Hot & New, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\lvert P\rvert)$	(Pressure)
	=	$220*57.315 / (2*20{,}000*1.00*1.00 + 0.40*\lvert 220\rvert)$	
	=	0.3145"	
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c)$	(bending)
	=	$311{,}660 / (\pi*57.845^2*20{,}000*1.00*1.00)$	
	=	0.0015"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$35{,}540.1 / (2*\pi*57.845*20{,}000*1.00*1.00)$	
	=	0.0049"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.3145 + 0.0015 - (0.0049)	
	=	0.3111"	
t_c	=	$\lvert t_{mc} + t_{wc} - t_{pc}\rvert$	(total, net tensile)
	=	|0.0015 + (0.0049) - (0.3145)|	
	=	0.3082"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.06 - 0.0015 + (0.0049)) / (57.315 - 0.40*(1.06 - 0.0015 + (0.0049)))$
$= 747.7$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p	= 0"	(Pressure)
t_m	$= M / (\pi*R_m{}^2*S_c*K_s)$	(bending)
	$= 311{,}660 / (\pi*57.845^2*11{,}771.56*1.00)$	
	= 0.0025"	
t_w	$= W / (2*\pi*R_m*S_c*K_s)$	(Weight)
	$= 35{,}540.1 / (2*\pi*57.845*11{,}771.56*1.00)$	
	= 0.0083"	
t_t	$= \lvert t_p + t_m - t_w\rvert$	(total, net compressive)
	= |0 + 0.0025 - (0.0083)|	
	= 0.0058"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	= 0.0025 + (0.0083) - (0)	
	= 0.0108"	

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^{2}*S_c*K_s) (bending)
= 311,660 / (π*57.845^2*11,771.56*1.00)
= 0.0025"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 35,540.1 / (2*π*57.845*11,771.56*1.00)
= 0.0083"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0025 - (0.0083)|
= 0.0058"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0025 + (0.0083) - (0)
= 0.0108"

Empty, Corroded, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^{2}*S_c*K_s) (bending)
= 311,660 / (π*57.845^2*15,364.66*1.00)
= 0.0019"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 35,540.1 / (2*π*57.845*15,364.66*1.00)
= 0.0064"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0019 - (0.0064)|
= 0.0044"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0019 + (0.0064) - (0)
= 0.0083"

Empty, New, Bottom Seam

t_p = 0" (Pressure)

t_m = M / (π*R_m^{2}*S_c*K_s) (bending)
= 311,660 / (π*57.845^2*15,364.66*1.00)
= 0.0019"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 35,540.1 / (2*π*57.845*15,364.66*1.00)
= 0.0064"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0019 - (0.0064)|
= 0.0044"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0019 + (0.0064) - (0)
= 0.0083"

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

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $311{,}660 / (\pi * 57.845^2 * 11{,}771.56 * 1.00)$
= 0.0025"

t_w = $W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $35{,}540.1 / (2 * \pi * 57.845 * 11{,}771.56 * 1.00)$
= 0.0083"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|0 + 0.0025 - (0.0083)|$
= 0.0058"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0025 + (0.0083) - (0)
= 0.0108"

Cylinder #2

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Component:	Cylinder
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th}	=	4.42 psi	(SG = 1, H_s = 122.5703", Horizontal test head)
P_{tv}	=	9.72 psi	(SG = 1, H_s = 269.2525", Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Top circumferential joint -	Full UW-11(a) Type 1
	Bottom circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 14,199.4 lb	corr = 14,199.4 lb
Capacity	New = 5,012.13 US gal	corr = 5,012.13 US gal

ID	= 114.31"				
Length L_c	= 113.3125"				
t	= 1.22"				
Insulation thk:	2"	density:	15 lb/ft^3	Weight:	733.9 lb
Insulation Support Spacing:	96"	Individual Support Weight:	150 lb	Total Support Weight:	150 lb
Lining/Refractory thickness:	0.125"	density:	501.12 lb/ft^3	Weight:	1,473.5 lb

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.155 / (20,000*1.00 - 0.60*220) + 0
= 0.6329"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*1.00*1.22 / (57.155 + 0.60*1.22) - 0
= 421.51 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*1.00*1.22 / (57.155 + 0.60*1.22)
= 421.51 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 116.75 = 6.0218
D_o / t = 116.75 / 1.22 = 95.6967
From table G: A = 0.000210
From table CS-2: B = 3,013.1277 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,013.13 / (3*(116.75 / 1.22))
= 41.98 psi

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*1.22 / 57.765)*(1 - 57.765 / ∞)
= 1.056%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.6329"

The governing condition is due to internal pressure.

The cylinder thickness of 1.22" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	12,095	500	0	Weight	865.74	0.3072	0.3043
Operating, Hot & New	20,000	12,095	500	0	Weight	865.74	0.3072	0.3043
Hot Shut Down, Corroded	20,000	12,095	500	0	Weight	0	0.0106	0.0155
Hot Shut Down, New	20,000	12,095	500	0	Weight	0	0.0106	0.0155
Empty, Corroded	20,000	15,780	70	0	Weight	0	0.0081	0.0119
Empty, New	20,000	15,780	70	0	Weight	0	0.0081	0.0119
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	12,095	500	0	Weight	0	0.0106	0.0155

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.375 / 1.22)
= 0.002612
B = 12,095 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cHC} = min(B, S) = 12,095 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

S_{cHN} = S_{cHC}
= 12,095 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.375 / 1.22)
= 0.002612
B = 15,780 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCN} = min(B, S) = 15,780 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 15,780 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.375 / 1.22)
= 0.002612
B = 15,780 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cVC} = min(B, S) = 15,780 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 220*57.155 / (2*20,000*1.00*1.00 + 0.40*|220|)
= 0.3137"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 311,660 / (π*57.765²*20,000*1.00*1.00)
= 0.0015"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 57,349.2 / (2*π*57.765*20,000*1.00*1.00)
= 0.0079"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3137 + 0.0015 - (0.0079)
= 0.3072"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0015 + (0.0079) - (0.3137)|
= 0.3043"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.22 - 0.0015 + (0.0079)) / (57.155 - 0.40*(1.22 - 0.0015 + (0.0079)))$
$= 865.74$ psi

Operating, Hot & New, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\|P\|)$	(Pressure)
	=	$220*57.155 / (2*20{,}000*1.00*1.00 + 0.40*\|220\|)$	
	=	0.3137"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$311{,}660 / (\pi*57.765^2*20{,}000*1.00*1.00)$	
	=	0.0015"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$57{,}349.2 / (2*\pi*57.765*20{,}000*1.00*1.00)$	
	=	0.0079"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.3137 + 0.0015 - (0.0079)	
	=	0.3072"	
t_c	=	$\|t_{mc} + t_{wc} - t_{pc}\|$	(total, net tensile)
	=	|0.0015 + (0.0079) - (0.3137)|	
	=	0.3043"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.22 - 0.0015 + (0.0079)) / (57.155 - 0.40*(1.22 - 0.0015 + (0.0079)))$
$= 865.74$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p	= 0"	(Pressure)
t_m	$= M / (\pi*R_m^2*S_c*K_s)$	(bending)
	$= 311{,}660 / (\pi*57.765^2*12{,}095.31*1.00)$	
	= 0.0025"	
t_w	$= W / (2*\pi*R_m*S_c*K_s)$	(Weight)
	$= 57{,}349.2 / (2*\pi*57.765*12{,}095.31*1.00)$	
	= 0.0131"	
t_t	$= \|t_p + t_m - t_w\|$	(total, net compressive)
	= |0 + 0.0025 - (0.0131)|	
	= 0.0106"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	= 0.0025 + (0.0131) - (0)	
	= 0.0155"	

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)

$t_m = M / (\pi{*}R_m{}^2{*}S_c{*}K_s)$ (bending)

$= 311{,}660 / (\pi{*}57.765^2{*}12{,}095.31{*}1.00)$

= 0.0025"

$t_w = W / (2{*}\pi{*}R_m{*}S_c{*}K_s)$ (Weight)

$= 57{,}349.2 / (2{*}\pi{*}57.765{*}12{,}095.31{*}1.00)$

= 0.0131"

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

= |0 + 0.0025 - (0.0131)|

= 0.0106"

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

= 0.0025 + (0.0131) - (0)

= 0.0155"

Empty, Corroded, Bottom Seam

t_p = 0" (Pressure)

$t_m = M / (\pi{*}R_m{}^2{*}S_c{*}K_s)$ (bending)

$= 311{,}660 / (\pi{*}57.765^2{*}15{,}780.17{*}1.00)$

= 0.0019"

$t_w = W / (2{*}\pi{*}R_m{*}S_c{*}K_s)$ (Weight)

$= 57{,}349.2 / (2{*}\pi{*}57.765{*}15{,}780.17{*}1.00)$

= 0.01"

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

= |0 + 0.0019 - (0.01)|

= 0.0081"

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

= 0.0019 + (0.01) - (0)

= 0.0119"

Empty, New, Bottom Seam

t_p = 0" (Pressure)

$t_m = M / (\pi{*}R_m{}^2{*}S_c{*}K_s)$ (bending)

$= 311{,}660 / (\pi{*}57.765^2{*}15{,}780.17{*}1.00)$

= 0.0019"

$t_w = W / (2{*}\pi{*}R_m{*}S_c{*}K_s)$ (Weight)

$= 57{,}349.2 / (2{*}\pi{*}57.765{*}15{,}780.17{*}1.00)$

= 0.01"

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

= |0 + 0.0019 - (0.01)|

= 0.0081"

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

= 0.0019 + (0.01) - (0)

= 0.0119"

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

t_p = 0" (Pressure)

$t_m = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 311{,}660 / (\pi * 57.765^2 * 12{,}095.31 * 1.00)$
= 0.0025"

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 57{,}349.2 / (2 * \pi * 57.765 * 12{,}095.31 * 1.00)$
= 0.0131"

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0025 - (0.0131)|$
= 0.0106"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0025 + (0.0131) - (0)$
= 0.0155"

Cylinder #3

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Component:	Cylinder
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th}	=	4.43 psi	(SG = 1, H_s = 122.6803", Horizontal test head)
P_{tv}	=	13.81 psi	(SG = 1, H_s = 382.565", Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Top circumferential joint -	Full UW-11(a) Type 1
	Bottom circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 12,931.4 lb	corr = 12,931.4 lb
Capacity	New = 5,031.49 US gal	corr = 5,031.49 US gal

ID	=	114.53"
Length L_c	=	113.3125"
t	=	1.11"

Insulation thk:	2"	density:	15 lb/ft^3	Weight:	733.9 lb
Insulation Support Spacing:	96"	Individual Support Weight:	150 lb	Total Support Weight:	150 lb
Lining/Refractory thickness:	0.125"	density:	501.12 lb/ft^3	Weight:	1,476.3 lb

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.265 / (20,000*1.00 - 0.60*220) + 0
= 0.6342"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*1.00*1.11 / (57.265 + 0.60*1.11) - 0
= 383.21 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*1.00*1.11 / (57.265 + 0.60*1.11)
= 383.21 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 116.75 = 6.0218
D_o / t = 116.75 / 1.11 = 105.1802
From table G: A = 0.000183
From table CS-2: B = 2,626.1253 psi

P_a = $4*B / (3*(D_o / t))$
= 4*2,626.13 / (3*(116.75 / 1.11))
= 33.29 psi

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*1.11 / 57.82)*(1 - 57.82 / \infty)$
= 0.9599%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.6342"

The governing condition is due to internal pressure.

The cylinder thickness of 1.11" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	11,880	500	0	Weight	788.29	0.3046	0.3014
Operating, Hot & New	20,000	11,880	500	0	Weight	788.29	0.3046	0.3014
Hot Shut Down, Corroded	20,000	11,880	500	0	Weight	0	0.0163	0.0216
Hot Shut Down, New	20,000	11,880	500	0	Weight	0	0.0163	0.0216
Empty, Corroded	20,000	15,500	70	0	Weight	0	0.0125	0.0166
Empty, New	20,000	15,500	70	0	Weight	0	0.0125	0.0166
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	11,880	500	0	Weight	0	0.0163	0.0216

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.375 / 1.11)
= 0.002377
B = 11,880 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cHC} = min(B, S) = 11,880 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

S_{cHN} = S_{cHC}
= 11,880 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.375 / 1.11)
= 0.002377

B = 15,500 psi

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

S_{cCN} = min(B, S) = 15,500 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 15,500 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.375 / 1.11)
= 0.002377

B = 15,500 psi

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

S_{cVC} = min(B, S) = 15,500 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 220*57.265 / (2*20,000*1.00*1.00 + 0.40*|220|)
= 0.3143"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 330,308 / (π*57.82^2*20,000*1.00*1.00)
= 0.0016"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 81,964.1 / (2*π*57.82*20,000*1.00*1.00)
= 0.0113"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3143 + 0.0016 - (0.0113)
= 0.3046"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0016 + (0.0113) - (0.3143)|
= 0.3014"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.11 - 0.0016 + (0.0113)) / (57.265 - 0.40*(1.11 - 0.0016 + (0.0113)))$
$= 788.29$ psi

Operating, Hot & New, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\lvert P\rvert)$	(Pressure)
	=	$220*57.265 / (2*20{,}000*1.00*1.00 + 0.40*\lvert 220\rvert)$	
	=	0.3143"	
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c)$	(bending)
	=	$330{,}308 / (\pi*57.82^2*20{,}000*1.00*1.00)$	
	=	0.0016"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$81{,}964.1 / (2*\pi*57.82*20{,}000*1.00*1.00)$	
	=	0.0113"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.3143 + 0.0016 - (0.0113)	
	=	0.3046"	
t_c	=	$\lvert t_{mc} + t_{wc} - t_{pc}\rvert$	(total, net tensile)
	=	|0.0016 + (0.0113) - (0.3143)|	
	=	0.3014"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.11 - 0.0016 + (0.0113)) / (57.265 - 0.40*(1.11 - 0.0016 + (0.0113)))$
$= 788.29$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p	= 0"	(Pressure)
t_m	$= M / (\pi*R_m{}^2*S_c*K_s)$	(bending)
	$= 330{,}308 / (\pi*57.82^2*11{,}880.01*1.00)$	
	= 0.0026"	
t_w	$= W / (2*\pi*R_m*S_c*K_s)$	(Weight)
	$= 81{,}964.1 / (2*\pi*57.82*11{,}880.01*1.00)$	
	= 0.019"	
t_t	$= \lvert t_p + t_m - t_w\rvert$	(total, net compressive)
	= |0 + 0.0026 - (0.019)|	
	= 0.0163"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	= 0.0026 + (0.019) - (0)	
	= 0.0216"	

Hot Shut Down, New, Bottom Seam

t_p	$= 0"$	(Pressure)
t_m	$= M / (\pi * R_m{}^2 * S_c * K_s)$	(bending)
	$= 330{,}308 / (\pi * 57.82^2 * 11{,}880.01 * 1.00)$	
	$= 0.0026"$	
t_w	$= W / (2 * \pi * R_m * S_c * K_s)$	(Weight)
	$= 81{,}964.1 / (2 * \pi * 57.82 * 11{,}880.01 * 1.00)$	
	$= 0.019"$	
t_t	$= \lvert t_p + t_m - t_w \rvert$	(total, net compressive)
	$= \lvert 0 + 0.0026 - (0.019) \rvert$	
	$=$ 0.0163"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	$= 0.0026 + (0.019) - (0)$	
	$=$ 0.0216"	

Empty, Corroded, Bottom Seam

t_p	$= 0"$	(Pressure)
t_m	$= M / (\pi * R_m{}^2 * S_c * K_s)$	(bending)
	$= 330{,}308 / (\pi * 57.82^2 * 15{,}499.67 * 1.00)$	
	$= 0.002"$	
t_w	$= W / (2 * \pi * R_m * S_c * K_s)$	(Weight)
	$= 81{,}964.1 / (2 * \pi * 57.82 * 15{,}499.67 * 1.00)$	
	$= 0.0146"$	
t_t	$= \lvert t_p + t_m - t_w \rvert$	(total, net compressive)
	$= \lvert 0 + 0.002 - (0.0146) \rvert$	
	$=$ 0.0125"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	$= 0.002 + (0.0146) - (0)$	
	$=$ 0.0166"	

Empty, New, Bottom Seam

t_p	$= 0"$	(Pressure)
t_m	$= M / (\pi * R_m{}^2 * S_c * K_s)$	(bending)
	$= 330{,}308 / (\pi * 57.82^2 * 15{,}499.67 * 1.00)$	
	$= 0.002"$	
t_w	$= W / (2 * \pi * R_m * S_c * K_s)$	(Weight)
	$= 81{,}964.1 / (2 * \pi * 57.82 * 15{,}499.67 * 1.00)$	
	$= 0.0146"$	
t_t	$= \lvert t_p + t_m - t_w \rvert$	(total, net compressive)
	$= \lvert 0 + 0.002 - (0.0146) \rvert$	
	$=$ 0.0125"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	$= 0.002 + (0.0146) - (0)$	
	$=$ 0.0166"	

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

t_p = 0" (Pressure)

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

= $330{,}308 / (\pi * 57.82^2 * 11{,}880.01 * 1.00)$

= 0.0026"

t_w = $W / (2 * \pi * R_m * S_c * K_s)$ (Weight)

= $81{,}964.1 / (2 * \pi * 57.82 * 11{,}880.01 * 1.00)$

= 0.019"

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

= $|0 + 0.0026 - (0.019)|$

= 0.0163"

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

= $0.0026 + (0.019) - (0)$

= 0.0216"

Cylinder #4

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Component:	Cylinder
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th}	=	4.43 psi	(SG = 1, H_s = 122.6303", Horizontal test head)
P_{tv}	=	17.9 psi	(SG = 1, H_s = 495.8775", Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Top circumferential joint -	Full UW-11(a) Type 1
	Bottom circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 13,508 lb	corr = 13,508 lb
Capacity	New = 5,022.68 US gal	corr = 5,022.68 US gal

ID	= 114.43"				
Length L_c	= 113.3125"				
t	= 1.16"				
Insulation thk:	2"	density:	15 lb/ft^3	Weight:	733.9 lb
Insulation Support Spacing:	96"	Individual Support Weight:	150 lb	Total Support Weight:	150 lb
Lining/Refractory thickness:	0.125"	density:	501.12 lb/ft^3	Weight:	1,475 lb

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.215 / (20,000*1.00 - 0.60*220) + 0
= 0.6336"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*1.00*1.16 / (57.215 + 0.60*1.16) - 0
= 400.61 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*1.00*1.16 / (57.215 + 0.60*1.16)
= 400.61 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 116.75 = 6.0218
D_o / t = 116.75 / 1.16 = 100.6466
From table G: A = 0.000193
From table CS-2: B = 2,766.6252 psi

P_a = $4*B / (3*(D_o / t))$
= 4*2,766.63 / (3*(116.75 / 1.16))
= 36.65 psi

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*1.16 / 57.795)*(1 - 57.795 / \infty)$
= 1.0035%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.6336"

The governing condition is due to internal pressure.

The cylinder thickness of 1.16" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	11,985	500	0	Weight	828.18	0.2991	0.296
Operating, Hot & New	20,000	11,985	500	0	Weight	828.18	0.2991	0.296
Hot Shut Down, Corroded	20,000	11,985	500	0	Weight	0	0.0248	0.0301
Hot Shut Down, New	20,000	11,985	500	0	Weight	0	0.0248	0.0301
Empty, Corroded	20,000	15,630	70	0	Weight	0	0.019	0.0231
Empty, New	20,000	15,630	70	0	Weight	0	0.019	0.0231
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	11,985	500	0	Weight	0	0.0248	0.0301

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.375 / 1.16)
= 0.002484

B = 11,985 psi

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

S_{cHC} = min(B, S) = 11,985 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

S_{cHN} = S_{cHC}

= 11,985 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A = 0.125 / (R_o / t)

= 0.125 / (58.375 / 1.16)

= 0.002484

B = 15,630 psi

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

S_{cCN} = min(B, S) = 15,630 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}

= 15,630 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = 0.125 / (R_o / t)

= 0.125 / (58.375 / 1.16)

= 0.002484

B = 15,630 psi

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

S_{cVC} = min(B, S) = 15,630 psi

Operating, Hot & Corroded, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\|P\|)$	(Pressure)
	=	220*57.215 / (2*20,000*1.00*1.00 + 0.40*|220|)	
	=	0.314"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$330,308 / (\pi*57.795^2*20,000*1.00*1.00)$	
	=	0.0016"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$119,434 / (2*\pi*57.795*20,000*1.00*1.00)$	
	=	0.0164"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.314 + 0.0016 - (0.0164)	
	=	0.2991"	
t_c	=	$\|t_{mc} + t_{wc} - t_{pc}\|$	(total, net tensile)
	=	|0.0016 + (0.0164) - (0.314)|	
	=	0.296"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.16 - 0.0016 + (0.0164)) / (57.215 - 0.40*(1.16 - 0.0016 + (0.0164)))$
$= 828.18$ psi

Operating, Hot & New, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\lvert P\rvert)$	(Pressure)
	=	$220*57.215 / (2*20{,}000*1.00*1.00 + 0.40*\lvert 220\rvert)$	
	=	0.314"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$330{,}308 / (\pi*57.795^2*20{,}000*1.00*1.00)$	
	=	0.0016"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$119{,}434 / (2*\pi*57.795*20{,}000*1.00*1.00)$	
	=	0.0164"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.314 + 0.0016 - (0.0164)	
	=	0.2991"	
t_c	=	$\lvert t_{mc} + t_{wc} - t_{pc}\rvert$	(total, net tensile)
	=	|0.0016 + (0.0164) - (0.314)|	
	=	0.296"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.16 - 0.0016 + (0.0164)) / (57.215 - 0.40*(1.16 - 0.0016 + (0.0164)))$
$= 828.18$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p	= 0"	(Pressure)
t_m	$= M / (\pi*R_m^2*S_c*K_s)$	(bending)
	$= 330{,}308 / (\pi*57.795^2*11{,}984.62*1.00)$	
	= 0.0026"	
t_w	$= W / (2*\pi*R_m*S_c*K_s)$	(Weight)
	$= 119{,}434 / (2*\pi*57.795*11{,}984.62*1.00)$	
	= 0.0274"	
t_t	$= \lvert t_p + t_m - t_w\rvert$	(total, net compressive)
	= |0 + 0.0026 - (0.0274)|	
	= 0.0248"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	= 0.0026 + (0.0274) - (0)	
	= 0.0301"	

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)
$t_m = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 330{,}308 / (\pi * 57.795^2 * 11{,}984.62 * 1.00)$
= 0.0026"

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 119{,}434 / (2 * \pi * 57.795 * 11{,}984.62 * 1.00)$
= 0.0274"

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0026 - (0.0274)|
= 0.0248"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0026 + (0.0274) - (0)
= 0.0301"

Empty, Corroded, Bottom Seam

t_p = 0" (Pressure)
$t_m = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 330{,}308 / (\pi * 57.795^2 * 15{,}629.84 * 1.00)$
= 0.002"

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 119{,}434 / (2 * \pi * 57.795 * 15{,}629.84 * 1.00)$
= 0.021"

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.002 - (0.021)|
= 0.019"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.002 + (0.021) - (0)
= 0.0231"

Empty, New, Bottom Seam

t_p = 0" (Pressure)
$t_m = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 330{,}308 / (\pi * 57.795^2 * 15{,}629.84 * 1.00)$
= 0.002"

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 119{,}434 / (2 * \pi * 57.795 * 15{,}629.84 * 1.00)$
= 0.021"

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.002 - (0.021)|
= 0.019"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.002 + (0.021) - (0)
= 0.0231"

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

t_p	$= 0"$	(Pressure)
t_m	$= M / (\pi * R_m^2 * S_c * K_s)$	(bending)
	$= 330{,}308 / (\pi * 57.795^2 * 11{,}984.62 * 1.00)$	
	$= 0.0026"$	
t_w	$= W / (2 * \pi * R_m * S_c * K_s)$	(Weight)
	$= 119{,}434 / (2 * \pi * 57.795 * 11{,}984.62 * 1.00)$	
	$= 0.0274"$	
t_t	$= \lvert t_p + t_m - t_w \rvert$	(total, net compressive)
	$= \lvert 0 + 0.0026 - (0.0274) \rvert$	
	= 0.0248"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	$= 0.0026 + (0.0274) - (0)$	
	= 0.0301"	

Cylinder #5

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Component:	Cylinder
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th}	=	4.43 psi	(SG = 1, H_s = 122.8403", Horizontal test head)
P_{tv}	=	21.99 psi	(SG = 1, H_s = 609.19", Vertical test head)

Corrosion allowance   Inner C = 0"   Outer C = 0"

PWHT is performed

Radiography:	Longitudinal joint -	Spot UW-11(b) Type 1
	Top circumferential joint -	Full UW-11(a) Type 1
	Bottom circumferential joint -	User Defined (E = 1)

Estimated weight	New = 12,551 lb	corr = 12,551 lb
Capacity	New = 5,059.7 US gal	corr = 5,059.7 US gal

ID	=	114.85"
Length L_c	=	113.3125"
t	=	1.08"

Insulation thk:	2"	density:	15 lb/ft^3	Weight:	735.5 lb
Insulation Support Spacing:	96"	Individual Support Weight:	150 lb	Total Support Weight:	150 lb
Lining/Refractory thickness:	0.125"	density:	501.12 lb/ft^3	Weight:	1,480.5 lb

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.425 / (20,000*0.85 - 0.60*220) + 0
= 0.749"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*0.85*1.08 / (57.425 + 0.60*1.08) - 0
= 316.15 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*0.85*1.08 / (57.425 + 0.60*1.08)
= 316.15 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 117.01 = 6.0084
D_o / t = 117.01 / 1.08 = 108.3426
From table G: A = 0.000177
From table CS-2: B = 2,534.3632 psi

P_a = $4*B / (3*(D_o / t))$
= 4*2,534.36 / (3*(117.01 / 1.08))
= 31.19 psi

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*1.08 / 57.965)*(1 - 57.965 / \infty)$
= 0.9316%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.749"

The governing condition is due to internal pressure.

The cylinder thickness of 1.08" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	11,810	500	0	Weight	770.19	0.2979	0.2947
Operating, Hot & New	20,000	11,810	500	0	Weight	770.19	0.2979	0.2947
Hot Shut Down, Corroded	20,000	11,810	500	0	Weight	0	0.0292	0.0347
Hot Shut Down, New	20,000	11,810	500	0	Weight	0	0.0292	0.0347
Empty, Corroded	20,000	15,413	70	0	Weight	0	0.0224	0.0266
Empty, New	20,000	15,413	70	0	Weight	0	0.0224	0.0266
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	11,810	500	0	Weight	0	0.0292	0.0347

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.505 / 1.08)
= 0.002307
B = 11,810 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cHC} = min(B, S) = 11,810 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

S_{cHN} = S_{cHC}
= 11,810 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.505 / 1.08)
= 0.002307
B = 15,413 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCN} = min(B, S) = 15,413 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 15,413 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (58.505 / 1.08)
= 0.002307
B = 15,413 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cVC} = min(B, S) = 15,413 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 220*57.425 / (2*20,000*1.00*1.00 + 0.40*|220|)
= 0.3151"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 338,056 / (π*57.965^2*20,000*1.00*1.00)
= 0.0016"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 137,382.4 / (2*π*57.965*20,000*1.00*1.00)
= 0.0189"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3151 + 0.0016 - (0.0189)
= 0.2979"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0016 + (0.0189) - (0.3151)|
= 0.2947"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.08 - 0.0016 + (0.0189)) / (57.425 - 0.40*(1.08 - 0.0016 + (0.0189)))$
$= 770.19$ psi

Operating, Hot & New, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\lvert P\rvert)$	(Pressure)
	=	$220*57.425 / (2*20{,}000*1.00*1.00 + 0.40*\lvert 220\rvert)$	
	=	0.3151"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	$338{,}056 / (\pi*57.965^2*20{,}000*1.00*1.00)$	
	=	0.0016"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	$137{,}382.4 / (2*\pi*57.965*20{,}000*1.00*1.00)$	
	=	0.0189"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.3151 + 0.0016 - (0.0189)	
	=	0.2979"	
t_c	=	$\lvert t_{mc} + t_{wc} - t_{pc}\rvert$	(total, net tensile)
	=	|0.0016 + (0.0189) - (0.3151)|	
	=	0.2947"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.08 - 0.0016 + (0.0189)) / (57.425 - 0.40*(1.08 - 0.0016 + (0.0189)))$
$= 770.19$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p	=	0"	(Pressure)
t_m	=	$M / (\pi*R_m^2*S_c*K_s)$	(bending)
	=	$338{,}056 / (\pi*57.965^2*11{,}810.19*1.00)$	
	=	0.0027"	
t_w	=	$W / (2*\pi*R_m*S_c*K_s)$	(Weight)
	=	$137{,}382.4 / (2*\pi*57.965*11{,}810.19*1.00)$	
	=	0.0319"	
t_t	=	$\lvert t_p + t_m - t_w\rvert$	(total, net compressive)
	=	|0 + 0.0027 - (0.0319)|	
	=	0.0292"	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	0.0027 + (0.0319) - (0)	
	=	0.0347"	

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $338{,}056 / (\pi * 57.965^2 * 11{,}810.19 * 1.00)$
= 0.0027"

t_w = $W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $137{,}382.4 / (2 * \pi * 57.965 * 11{,}810.19 * 1.00)$
= 0.0319"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0027 - (0.0319)|
= 0.0292"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0027 + (0.0319) - (0)
= 0.0347"

Empty, Corroded, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $338{,}056 / (\pi * 57.965^2 * 15{,}412.76 * 1.00)$
= 0.0021"

t_w = $W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $137{,}382.4 / (2 * \pi * 57.965 * 15{,}412.76 * 1.00)$
= 0.0245"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0021 - (0.0245)|
= 0.0224"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0021 + (0.0245) - (0)
= 0.0266"

Empty, New, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi * R_m^2 * S_c * K_s)$ (bending)
= $338{,}056 / (\pi * 57.965^2 * 15{,}412.76 * 1.00)$
= 0.0021"

t_w = $W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
= $137{,}382.4 / (2 * \pi * 57.965 * 15{,}412.76 * 1.00)$
= 0.0245"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0021 - (0.0245)|
= 0.0224"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0021 + (0.0245) - (0)
= 0.0266"

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

t_p = 0" (Pressure)

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

$= 338{,}056 / (\pi * 57.965^2 * 11{,}810.19 * 1.00)$

$= 0.0027"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)

$= 137{,}382.4 / (2 * \pi * 57.965 * 11{,}810.19 * 1.00)$

$= 0.0319"$

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

$= |0 + 0.0027 - (0.0319)|$

= 0.0292"

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

$= 0.0027 + (0.0319) - (0)$

= 0.0347"

Cylinder #6

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Component:	Cylinder
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th}	=	4.43 psi	(SG = 1, H_s = 122.6903", Horizontal test head)
P_{tv}	=	26.08 psi	(SG = 1, H_s = 722.5025", Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Top circumferential joint -	User Defined (E = 1)
	Bottom circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 12,627.4 lb	corr = 12,627.4 lb
Capacity	New = 5,033.25 US gal	corr = 5,033.25 US gal

ID	=	114.55"
Length L_c	=	113.3125"
t	=	1.1"

Insulation thk:	2"	density:	15 lb/ft^3	Weight:	733.9 lb
Insulation Support Spacing:	96"	Individual Support Weight:	150 lb	Total Support Weight:	150 lb
Lining/Refractory thickness:	0.125"	density:	501.12 lb/ft^3	Weight:	1,476.6 lb

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.275 / (20,000*1.00 - 0.60*220) + 0
= 0.6343"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*1.00*1.1 / (57.275 + 0.60*1.1) - 0
= 379.74 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*1.00*1.1 / (57.275 + 0.60*1.1)
= 379.74 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 116.75 = 6.0218
D_o / t = 116.75 / 1.1 = 106.1364
From table G: A = 0.000181
From table CS-2: B = 2,596.4965 psi

P_a = $4*B / (3*(D_o / t))$
= 4*2,596.5 / (3*(116.75 / 1.1))
= 32.62 psi

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*1.1 / 57.825)*(1 - 57.825 / \infty)$
= 0.9511%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.6343"

The governing condition is due to internal pressure.

The cylinder thickness of 1.1" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	11,859	500	0	Weight	788.53	0.2941	0.2912
Operating, Hot & New	20,000	11,859	500	0	Weight	788.53	0.2941	0.2912
Hot Shut Down, Corroded	20,000	11,859	500	0	Weight	0	0.0341	0.039
Hot Shut Down, New	20,000	11,859	500	0	Weight	0	0.0341	0.039
Empty, Corroded	20,000	15,473	70	0	Weight	0	0.0262	0.0299
Empty, New	20,000	15,473	70	0	Weight	0	0.0262	0.0299
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	11,859	500	0	Weight	0	0.0341	0.039

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.375 / 1.1)
= 0.002355
B = 11,859 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cHC} = min(B, S) = 11,859 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

S_{cHN} = S_{cHC}
= 11,859 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.375 / 1.1)
= 0.002355
B = 15,473 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cCN} = min(B, S) = 15,473 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 15,473 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.375 / 1.1)
= 0.002355
B = 15,473 psi
S = 20,000 / 1.00 = 20,000 psi
S_{cVC} = min(B, S) = 15,473 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 220*57.275 / (2*20,000*1.00*1.00 + 0.40*|220|)
= 0.3143"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= $300,165 / (\pi*57.825^2*20,000*1.00*1.00)$
= 0.0014"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= $157,473 / (2*\pi*57.825*20,000*1.00*1.00)$
= 0.0217"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3143 + 0.0014 - (0.0217)
= 0.2941"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0014 + (0.0217) - (0.3143)|
= 0.2912"

Maximum allowable working pressure, Longitudinal Stress

$P = 2{*}S_t{*}K_s{*}E_c{*}(t - t_m + t_w) / (R - 0.40{*}(t - t_m + t_w))$
$= 2{*}20{,}000{*}1.00{*}1.00{*}(1.1 - 0.0014 + (0.0217)) / (57.275 - 0.40{*}(1.1 - 0.0014 + (0.0217)))$
$= 788.53$ psi

Operating, Hot & New, Bottom Seam

t_p	=	$P{*}R / (2{*}S_t{*}K_s{*}E_c + 0.40{*}\lvert P\rvert)$	(Pressure)
	=	$220{*}57.275 / (2{*}20{,}000{*}1.00{*}1.00 + 0.40{*}\lvert 220\rvert)$	
	=	0.3143"	
t_m	=	$M / (\pi{*}R_m^2{*}S_t{*}K_s{*}E_c)$	(bending)
	=	$300{,}165 / (\pi{*}57.825^2{*}20{,}000{*}1.00{*}1.00)$	
	=	0.0014"	
t_w	=	$W / (2{*}\pi{*}R_m{*}S_t{*}K_s{*}E_c)$	(Weight)
	=	$157{,}473 / (2{*}\pi{*}57.825{*}20{,}000{*}1.00{*}1.00)$	
	=	0.0217"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.3143 + 0.0014 - (0.0217)	
	=	0.2941"	
t_c	=	$\lvert t_{mc} + t_{wc} - t_{pc}\rvert$	(total, net tensile)
	=	|0.0014 + (0.0217) - (0.3143)|	
	=	0.2912"	

Maximum allowable working pressure, Longitudinal Stress

$P = 2{*}S_t{*}K_s{*}E_c{*}(t - t_m + t_w) / (R - 0.40{*}(t - t_m + t_w))$
$= 2{*}20{,}000{*}1.00{*}1.00{*}(1.1 - 0.0014 + (0.0217)) / (57.275 - 0.40{*}(1.1 - 0.0014 + (0.0217)))$
$= 788.53$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p	= 0"	(Pressure)
t_m	$= M / (\pi{*}R_m^2{*}S_c{*}K_s)$	(bending)
	$= 300{,}165 / (\pi{*}57.825^2{*}11{,}858.64{*}1.00)$	
	= 0.0024"	
t_w	$= W / (2{*}\pi{*}R_m{*}S_c{*}K_s)$	(Weight)
	$= 157{,}473 / (2{*}\pi{*}57.825{*}11{,}858.64{*}1.00)$	
	= 0.0365"	
t_t	$= \lvert t_p + t_m - t_w\rvert$	(total, net compressive)
	= |0 + 0.0024 - (0.0365)|	
	= 0.0341"	
t_c	$= t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	= 0.0024 + (0.0365) - (0)	
	= 0.039"	

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)

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

$= 300{,}165 / (\pi * 57.825^2 * 11{,}858.64 * 1.00)$

= 0.0024"

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)

$= 157{,}473 / (2 * \pi * 57.825 * 11{,}858.64 * 1.00)$

= 0.0365"

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

= |0 + 0.0024 - (0.0365)|

= 0.0341"

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

= 0.0024 + (0.0365) - (0)

= 0.039"

Empty, Corroded, Bottom Seam

t_p = 0" (Pressure)

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

$= 300{,}165 / (\pi * 57.825^2 * 15{,}473.07 * 1.00)$

= 0.0018"

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)

$= 157{,}473 / (2 * \pi * 57.825 * 15{,}473.07 * 1.00)$

= 0.028"

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

= |0 + 0.0018 - (0.028)|

= 0.0262"

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

= 0.0018 + (0.028) - (0)

= 0.0299"

Empty, New, Bottom Seam

t_p = 0" (Pressure)

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

$= 300{,}165 / (\pi * 57.825^2 * 15{,}473.07 * 1.00)$

= 0.0018"

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)

$= 157{,}473 / (2 * \pi * 57.825 * 15{,}473.07 * 1.00)$

= 0.028"

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

= |0 + 0.0018 - (0.028)|

= 0.0262"

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

= 0.0018 + (0.028) - (0)

= 0.0299"

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

t_p = 0" (Pressure)

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

$= 300{,}165 / (\pi * 57.825^2 * 11{,}858.64 * 1.00)$

$= 0.0024"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)

$= 157{,}473 / (2 * \pi * 57.825 * 11{,}858.64 * 1.00)$

$= 0.0365"$

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

$= |0 + 0.0024 - (0.0365)|$

= 0.0341"

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

$= 0.0024 + (0.0365) - (0)$

= 0.039"

Top Ellipsoidal Head #1

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Component:	Ellipsoidal Head
Material Specification:	SA-516 70 (II-D p.18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_s= 0 psi (SG=1, H_s=0" Operating head)
P_{th}= 4.43 psi (SG=1, H_s=122.6653" Horizontal test head)
P_{tv}= 1.46 psi (SG=1, H_s=40.5" Vertical test head)

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -20°F	Impact test performed
Rated MDMT = N/A	Material is normalized
	Material is not produced to fine grain practice
	PWHT is not performed
	Do not Optimize MDMT / Find MAWP

Radiography:	Category A joints -	Seamless No RT
	Head to shell seam -	Full UW-11(a) Type 1

Estimated weight*:	new = 5,439.7 lb	corr = 5,439.7 lb
Capacity*:	new = 926.1 US gal	corr = 926.1 US gal

* includes straight flange

Inner diameter	=	114.25"
Minimum head thickness	=	1.1875"
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	2 (corroded)
Straight flange length L_{sf}	=	2"
Nominal straight flange thickness t_{sf}	=	1.5"

Insulation thk*:	2"	density: 15.0001 lb/ft^3	weight: 273.5296 lb
Insulation support ring spacing:	96"	individual weight: 150 lb	total weight: 150 lb
Lining/ref thk*:	0.125"	density: 501.12 lb/ft^3	weight: 520.1457 lb

* includes straight flange if applicable

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	=	0.6291"
Maximum allowable working pressure (MAWP)	=	414.89 psi
Maximum allowable pressure (MAP)	=	414.89 psi
Maximum allowable external pressure (MAEP)	=	157.71 psi

Design thickness for internal pressure, (Corroded at 500 °F) UG-32(d)(1)

t = P*D / (2*S*E - 0.2*P) + Corrosion
= 220*114.25 / (2*20,000*1 - 0.2*220) + 0

$= \quad 0.6291"$

The head internal pressure design thickness is 0.6291".

Maximum allowable working pressure, (Corroded at 500 °F) UG-32(d)(1)

$$
\begin{aligned}
P &= 2*S*E*t / (D + 0.2*t) - P_s \\
&= 2*20{,}000*1*1.1875 / (114.25 + 0.2*1.1875) - 0 \\
&= 414.89 \text{ psi}
\end{aligned}
$$

The maximum allowable working pressure (MAWP) is 414.89 psi.

Maximum allowable pressure, (New at 71.6 °F) UG-32(d)(1)

$$
\begin{aligned}
P &= 2*S*E*t / (D + 0.2*t) - P_s \\
&= 2*20{,}000*1*1.1875 / (114.25 + 0.2*1.1875) - 0 \\
&= 414.89 \text{ psi}
\end{aligned}
$$

The maximum allowable pressure (MAP) is 414.89 psi.

Maximum Allowable External Pressure, (Corroded at 50 °F) UG-33(d)

Equivalent outside spherical radius (R_o)

$$
\begin{aligned}
R_o &= K_o*D_o \\
&= 0.882*116.625 \\
&= 102.8677 \text{ in}
\end{aligned}
$$

$$
\begin{aligned}
A &= 0.125 / (R_o / t) \\
&= 0.125 / (102.8677 / 1.1875) \\
&= 0.001443
\end{aligned}
$$

From Table CS-2: $B = 13{,}661.65$ psi

$$
\begin{aligned}
P_a &= B / (R_o / t) \\
&= 13{,}661.65 / (102.8677 / 1.1875) \\
&= 157.7096 \text{ psi}
\end{aligned}
$$

Check the Maximum External Pressure, UG-33(a)(1) UG-32(d)(1)

$$
\begin{aligned}
P &= 2*S*E*t / ((D + 0.2*t)*1.67) - P_{s2} \\
&= 2*20{,}000*1*1.1875 / ((114.25 + 0.2*1.1875)*1.67) - 0 \\
&= 248.44 \text{ psi}
\end{aligned}
$$

The maximum allowable external pressure (MAEP) is 157.71 psi.

% Extreme fiber elongation - UCS-79(d)

$$
\begin{aligned}
EFE &= (75*t / R_f)*(1 - R_f / R_o) \\
&= (75*1.5 / 20.1725)*(1 - 20.1725 / \infty) \\
&= 5.5769\%
\end{aligned}
$$

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming.

Straight Flange on Top Ellipsoidal Head #1

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Component:	Straight Flange
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th}	=	4.43 psi	(SG = 1, H_s = 122.6653", Horizontal test head)
P_{tv}	=	1.53 psi	(SG = 1, H_s = 42.5", Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	Longitudinal joint -	Seamless No RT
	Circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 308.7 lb	corr = 308.7 lb
Capacity	New = 88.37 US gal	corr = 88.37 US gal

ID	=	114.25"				
Length L_c	=	2"				
t	=	1.5"				
Insulation thk:	2"	density:	15 lb/ft^3	Weight:	0 lb	
Lining/Refractory thickness:	0.125"	density:	501.12 lb/ft^3	Weight:	0 lb	

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.125 / (20,000*1.00 - 0.60*220) + 0
= 0.6326"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*1.00*1.5 / (57.125 + 0.60*1.5) - 0
= 517.02 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*1.00*1.5 / (57.125 + 0.60*1.5)
= 517.02 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 117.25 = 5.9961
D_o / t = 117.25 / 1.5 = 78.1667
From table G: A = 0.000281

From table CS-2: $B = 4{,}044.5325$ psi

$$
\begin{aligned}
P_a &= 4*B / (3*(D_o / t)) \\
&= 4*4{,}044.53 / (3*(117.25 / 1.5)) \\
&= 68.99 \text{ psi}
\end{aligned}
$$

% Extreme fiber elongation - UCS-79(d)

$$
\begin{aligned}
EFE &= (50*t / R_f)*(1 - R_f / R_o) \\
&= (50*1.5 / 57.875)*(1 - 57.875 / \infty) \\
&= 1.2959\%
\end{aligned}
$$

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.6326"

The governing condition is due to internal pressure.

The cylinder thickness of 1.5" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	12,510	500	0	Weight	1,062.32	0.3123	0.3123
Operating, Hot & New	20,000	12,510	500	0	Weight	1,062.32	0.3123	0.3123
Hot Shut Down, Corroded	20,000	12,510	500	0	Weight	0	0.0019	0.0019
Hot Shut Down, New	20,000	12,510	500	0	Weight	0	0.0019	0.0019
Empty, Corroded	20,000	16,332	70	0	Weight	0	0.0014	0.0015
Empty, New	20,000	16,332	70	0	Weight	0	0.0014	0.0015
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	12,510	500	0	Weight	0	0.0019	0.0019

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

$$
\begin{aligned}
A &= 0.125 / (R_o / t) \\
&= 0.125 / (58.625 / 1.5) \\
&= 0.003198 \\
B &= 12{,}510 \text{ psi} \\
S &= 20{,}000 / 1.00 = 20{,}000 \text{ psi} \\
S_{cHC} &= \min(B, S) = 12{,}510 \text{ psi}
\end{aligned}
$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$
\begin{aligned}
S_{cHN} &= S_{cHC} \\
&= 12{,}510 \text{ psi}
\end{aligned}
$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A	=	0.125 / (R_o / t)
	=	0.125 / (58.625 / 1.5)
	=	0.003198
B	=	16,332 psi
S	=	20,000 / 1.00 = 20,000 psi
S_{cCN}	=	min(B, S) = 16,332 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC}	=	S_{cCN}
	=	16,332 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A	=	0.125 / (R_o / t)
	=	0.125 / (58.625 / 1.5)
	=	0.003198
B	=	16,332 psi
S	=	20,000 / 1.00 = 20,000 psi
S_{cVC}	=	min(B, S) = 16,332 psi

Operating, Hot & Corroded, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + 0.40*\|P\|)$	(Pressure)
	=	220*57.125 / (2*20,000*1.00*1.00 + 0.40*|220|)	
	=	0.3135"	
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$	(bending)
	=	3,268 / (π*57.875²*20,000*1.00*1.00)	
	=	0"	
t_w	=	$W / (2*\pi*R_m*S_t*K_s*E_c)$	(Weight)
	=	8,647.9 / (2*π*57.875*20,000*1.00*1.00)	
	=	0.0012"	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	0.3135 + 0 - (0.0012)	
	=	0.3123"	
t_c	=	$\|t_{mc} + t_{wc} - t_{pc}\|$	(total, net tensile)
	=	|0 + (0.0012) - (0.3135)|	
	=	0.3123"	

Maximum allowable working pressure, Longitudinal Stress

$$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$$
$$= 2*20,000*1.00*1.00*(1.5 - 0 + (0.0012)) / (57.125 - 0.40*(1.5 - 0 + (0.0012)))$$
$$= 1,062.32 \text{ psi}$$

Operating, Hot & New, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= $220*57.125 / (2*20,000*1.00*1.00 + 0.40*|220|)$
= 0.3135"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= $3,268 / (\pi*57.875^2*20,000*1.00*1.00)$
= 0"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= $8,647.9 / (2*\pi*57.875*20,000*1.00*1.00)$
= 0.0012"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3135 + 0 - (0.0012)
= 0.3123"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0 + (0.0012) - (0.3135)|
= 0.3123"

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*20,000*1.00*1.00*(1.5 - 0 + (0.0012)) / (57.125 - 0.40*(1.5 - 0 + (0.0012)))
= 1,062.32 psi

Hot Shut Down, Corroded, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $3,268 / (\pi*57.875^2*12,510.17*1.00)$
= 0"

t_w = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= $8,647.9 / (2*\pi*57.875*12,510.17*1.00)$
= 0.0019"

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

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

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $3,268 / (\pi*57.875^2*12,510.17*1.00)$
= 0"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 8,647.9 / (2*π*57.875*12,510.17*1.00)
= 0.0019"

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

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

Empty, Corroded, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 3,268 / (π*57.875^2*16,331.61*1.00)
= 0"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 8,647.9 / (2*π*57.875*16,331.61*1.00)
= 0.0015"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0 - (0.0015)|
= 0.0014"

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

Empty, New, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 3,268 / (π*57.875^2*16,331.61*1.00)
= 0"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 8,647.9 / (2*π*57.875*16,331.61*1.00)
= 0.0015"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0 - (0.0015)|
= 0.0014"

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

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)
= 3,268 / (π*57.875^2*12,510.17*1.00)

$= 0"$

$t_w = W / (2*\pi*R_m*S_c*K_s)$ (Weight)
$= 8,647.9 / (2*\pi*57.875*12,510.17*1.00)$
$= 0.0019"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0 - (0.0019)|$
$=$ <u>0.0019"</u>

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0 + (0.0019) - (0)$
$=$ <u>0.0019"</u>

Top Ellipsoidal Head #1 (Dished Region)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

Component:	Hemi Head
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th} = 4.43 psi (SG = 1, H_s = 0", Horizontal test head)
P_{tv} = 1.46 psi (SG = 1, H_s = 0",Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	RT on Category A Joints - Long. Seam -	Seamless No RT
	RT on Category A Joints - Circ. Seam -	User Defined (E = 1.)

Estimated weight	New = 22,086.9 lb	corr = 22,086.9 lb
Capacity	New = 9,531.4 US gal	corr = 9,531.4 US gal

Inner diameter	=	203.3603"
Minimum head thickness	=	1.1875"

Design thickness, (at 500 °F) UG-32(f)

t = P*R / (2*S*E - 0.20*P) + Corrosion
= 220*101.6802 / (2*20,000*1.00 - 0.20*220) + 0
= 0.5599"

Maximum allowable working pressure, (at 500 °F) UG-32(f)

P = 2*S*E*t / (R + 0.20*t) - P_s
= 2*20,000*1.00*1.1875 / (101.6802 + 0.20*1.1875) - 0
= 466.06 psi

Maximum allowable pressure, (at 71.6 °F) UG-32(f)

P = 2*S*E*t / (R + 0.20*t)
= 2*20,000*1.00*1.1875 / (101.6802 + 0.20*1.1875)
= 466.06 psi

Maximum Allowable External Pressure, (Corroded @ 50 °F)

A = 0.125 / (R_o / t)
= 0.125 / (102.8677 / 1.1875)
= 0.001443
From table CS-2: B = 13,661.6538 psi

P_a = B / (R_o / t)
= 13,661.65 / (102.8677 / 1.1875)
= 157.71 psi

The maximum allowable external pressure is 157.71 psi

% Extreme fiber elongation - UCS-79(d)

$$\begin{aligned} EFE &= (75*t / R_f)*(1 - R_f / R_o) \\ &= (75*1.1875 / 102.2739)*(1 - 102.2739 / \infty) \\ &= 0.8708\% \end{aligned}$$

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.5599"

The governing condition is due to internal pressure.

The head thickness of 1.1875" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	10,757	500	0	Weight	470.88	0.5476	0.5466
Operating, Hot & New	20,000	10,757	500	0	Weight	470.88	0.5476	0.5466
Hot Shut Down, Corroded	20,000	10,757	500	0	Weight	0	0.0229	0.0246
Hot Shut Down, New	20,000	10,757	500	0	Weight	0	0.0229	0.0246
Empty, Corroded	20,000	13,662	70	0	Weight	0	0.018	0.0193
Empty, New	20,000	13,662	70	0	Weight	0	0.018	0.0193
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	10,757	500	0	Weight	0	0.0229	0.0246

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

$$\begin{aligned} A &= 0.125 / (R_o / t) \\ &= 0.125 / (102.8677 / 1.1875) \\ &= 0.001443 \\ B &= 10{,}757 \text{ psi} \\ S &= 20{,}000 / 1.00 = 20{,}000 \text{ psi} \\ S_{cHC} &= \min(B, S) = 10{,}757 \text{ psi} \end{aligned}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$\begin{aligned} S_{cHN} &= S_{cHC} \\ &= 10{,}757 \text{ psi} \end{aligned}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

$$\begin{aligned} A &= 0.125 / (R_o / t) \\ &= 0.125 / (102.8677 / 1.1875) \\ &= 0.001443 \\ B &= 13{,}662 \text{ psi} \\ S &= 20{,}000 / 1.00 = 20{,}000 \text{ psi} \\ S_{cCN} &= \min(B, S) = 13{,}662 \text{ psi} \end{aligned}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 13,662 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (102.8677 / 1.1875)
= 0.001443

B = 13,662 psi

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

S_{cVC} = min(B, S) = 13,662 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c - 0.20*|P|)$ (Pressure)
= 220*101.6802 / (2*20,000*1.00*1.00 - 0.20*|220|)
= 0.5599"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 300,165 / (π*102.2739^2*20,000*1.00*1.00)
= 0.0005"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 163,906.7 / (2*π*102.2739*20,000*1.00*1.00)
= 0.0128"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.5599 + 0.0005 - (0.0128)
= 0.5476"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0005 + (0.0128) - (0.5599)|
= 0.5466"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R + 0.20*(t - t_m + t_w))$
= 2*20,000*1.00*1.00*(1.1875 - 0.0005 + (0.0128)) / (101.6802 + 0.20*(1.1875 - 0.0005 + (0.0128)))
= 470.88 psi

Operating, Hot & New, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c - 0.20*|P|)$ (Pressure)
= 220*101.6802 / (2*20,000*1.00*1.00 - 0.20*|220|)
= 0.5599"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 300,165 / (π*102.2739^2*20,000*1.00*1.00)
= 0.0005"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= $163,906.7 / (2*\pi*102.2739*20,000*1.00*1.00)$
= 0.0128"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= $0.5599 + 0.0005 - (0.0128)$
= 0.5476"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= $|0.0005 + (0.0128) - (0.5599)|$
= 0.5466"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R + 0.20*(t - t_m + t_w))$
$= 2*20,000*1.00*1.00*(1.1875 - 0.0005 + (0.0128)) / (101.6802 + 0.20*(1.1875 - 0.0005 + (0.0128)))$
$= 470.88$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $300,165 / (\pi*102.2739^2*10,756.97*1.00)$
= 0.0008"

t_w = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= $163,906.7 / (2*\pi*102.2739*10,756.97*1.00)$
= 0.0237"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|0 + 0.0008 - (0.0237)|$
= 0.0229"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= $0.0008 + (0.0237) - (0)$
= 0.0246"

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $300,165 / (\pi*102.2739^2*10,756.97*1.00)$
= 0.0008"

t_w = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= $163,906.7 / (2*\pi*102.2739*10,756.97*1.00)$
= 0.0237"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|0 + 0.0008 - (0.0237)|$
= 0.0229"

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

$= 0.0008 + (0.0237) - (0)$
$= \underline{0.0246"}$

Empty, Corroded, Bottom Seam

$t_p = 0"$ (Pressure)
$t_m = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 300{,}165 / (\pi * 102.2739^2 * 13{,}661.65 * 1.00)$
$= 0.0007"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 163{,}906.7 / (2 * \pi * 102.2739 * 13{,}661.65 * 1.00)$
$= 0.0187"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0007 - (0.0187)|$
$= \underline{0.018"}$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0007 + (0.0187) - (0)$
$= \underline{0.0193"}$

Empty, New, Bottom Seam

$t_p = 0"$ (Pressure)
$t_m = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 300{,}165 / (\pi * 102.2739^2 * 13{,}661.65 * 1.00)$
$= 0.0007"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 163{,}906.7 / (2 * \pi * 102.2739 * 13{,}661.65 * 1.00)$
$= 0.0187"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0007 - (0.0187)|$
$= \underline{0.018"}$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0007 + (0.0187) - (0)$
$= \underline{0.0193"}$

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

$t_p = 0"$ (Pressure)
$t_m = M / (\pi * R_m^2 * S_c * K_s)$ (bending)
$= 300{,}165 / (\pi * 102.2739^2 * 10{,}756.97 * 1.00)$
$= 0.0008"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 163{,}906.7 / (2 * \pi * 102.2739 * 10{,}756.97 * 1.00)$
$= 0.0237"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0008 - (0.0237)|$
$= \underline{0.0229"}$

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

$= 0.0008 + (0.0237) - (0)$

$=$ 0.0246"

Straight Flange on Bottom Ellipsoidal Head #2

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Component:	Straight Flange
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th} = 4.43 psi (SG = 1, H_s = 122.6653", Horizontal test head)
P_{tv} = 26.15 psi (SG = 1, H_s = 724.5025", Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	Longitudinal joint -	Seamless No RT
	Circumferential joint -	Full UW-11(a) Type 1

Estimated weight	New = 308.7 lb	corr = 308.7 lb
Capacity	New = 88.37 US gal	corr = 88.37 US gal

ID = 114.25"
Length L_c = 2"
t = 1.5"

Insulation thk:	2"	density:	15 lb/ft^3	Weight:	0 lb
Lining/Refractory thickness:	0.125"	density:	501.12 lb/ft^3	Weight:	0 lb

Design thickness, (at 500 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 220*57.125 / (20,000*1.00 - 0.60*220) + 0
= 0.6326"

Maximum allowable working pressure, (at 500 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t) - P_s
= 20,000*1.00*1.5 / (57.125 + 0.60*1.5) - 0
= 517.02 psi

Maximum allowable pressure, (at 71.6 °F) UG-27(c)(1)

P = S*E*t / (R + 0.60*t)
= 20,000*1.00*1.5 / (57.125 + 0.60*1.5)
= 517.02 psi

Maximum Allowable External Pressure, (Corroded & at 50 °F) UG-28(c)

L / D_o = 703.0442 / 117.25 = 5.9961
D_o / t = 117.25 / 1.5 = 78.1667
From table G: A = 0.000281
B = 4,044.5325 psi

From table
CS-2:

P_a = $4*B / (3*(D_o / t))$
= $4*4,044.53 / (3*(117.25 / 1.5))$
= 68.99 psi

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*1.5 / 57.875)*(1 - 57.875 / \infty)$
= 1.2959%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.6326"

The governing condition is due to internal pressure.

The cylinder thickness of 1.5" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	12,510	500	0	Weight	1,075.97	0.2932	0.2904
Operating, Hot & New	20,000	12,510	500	0	Weight	1,075.97	0.2932	0.2904
Hot Shut Down, Corroded	20,000	12,510	500	0	Weight	0	0.0324	0.037
Hot Shut Down, New	20,000	12,510	500	0	Weight	0	0.0324	0.037
Empty, Corroded	20,000	16,332	70	0	Weight	0	0.0248	0.0283
Empty, New	20,000	16,332	70	0	Weight	0	0.0248	0.0283
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	12,510	500	0	Weight	0	0.0324	0.037

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

A = $0.125 / (R_o / t)$
= $0.125 / (58.625 / 1.5)$
= 0.003198

B = 12,510 psi

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

S_{cHC} = min(B, S) = 12,510 psi

Allowable Compressive Stress, Hot and New- S_{cHN}

S_{cHN} = S_{cHC}
= 12,510 psi

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.625 / 1.5)
= 0.003198

B = 16,332 psi

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

S_{cCN} = min(B, S) = 16,332 psi

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 16,332 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = $0.125 / (R_o / t)$
= 0.125 / (58.625 / 1.5)
= 0.003198

B = 16,332 psi

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

S_{cVC} = min(B, S) = 16,332 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= 220*57.125 / (2*20,000*1.00*1.00 + 0.40*|220|)
= 0.3135"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= $300{,}165 / (\pi*57.875^2*20{,}000*1.00*1.00)$
= 0.0014"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= $157{,}781.7 / (2*\pi*57.875*20{,}000*1.00*1.00)$
= 0.0217"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3135 + 0.0014 - (0.0217)
= 0.2932"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0014 + (0.0217) - (0.3135)|
= 0.2904"

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*20,000*1.00*1.00*(1.5 - 0.0014 + (0.0217)) / (57.125 - 0.40*(1.5 - 0.0014 + (0.0217)))
= 1,075.97 psi

Operating, Hot & New, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + 0.40*|P|)$ (Pressure)
= $220*57.125 / (2*20,000*1.00*1.00 + 0.40*|220|)$
= 0.3135"

t_m = $M / (\pi*R_m{}^2*S_t*K_s*E_c)$ (bending)
= $300,165 / (\pi*57.875^2*20,000*1.00*1.00)$
= 0.0014"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= $157,781.7 / (2*\pi*57.875*20,000*1.00*1.00)$
= 0.0217"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.3135 + 0.0014 - (0.0217)
= 0.2932"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0014 + (0.0217) - (0.3135)|
= 0.2904"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R - 0.40*(t - t_m + t_w))$
= $2*20,000*1.00*1.00*(1.5 - 0.0014 + (0.0217)) / (57.125 - 0.40*(1.5 - 0.0014 + (0.0217)))$
= 1,075.97 psi

Hot Shut Down, Corroded, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m{}^2*S_c*K_s)$ (bending)
= $300,165 / (\pi*57.875^2*12,510.17*1.00)$
= 0.0023"

t_w = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= $157,781.7 / (2*\pi*57.875*12,510.17*1.00)$
= 0.0347"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |0 + 0.0023 - (0.0347)|
= 0.0324"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 0.0023 + (0.0347) - (0)
= 0.037"

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m{}^2*S_c*K_s)$ (bending)
= $300,165 / (\pi*57.875^2*12,510.17*1.00)$
= 0.0023"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 157,781.7 / (2*π*57.875*12,510.17*1.00)
= 0.0347"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0023 - (0.0347)|
= 0.0324"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0023 + (0.0347) - (0)
= 0.037"

Empty, Corroded, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 300,165 / (π*57.875^2*16,331.61*1.00)
= 0.0017"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 157,781.7 / (2*π*57.875*16,331.61*1.00)
= 0.0266"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0017 - (0.0266)|
= 0.0248"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0017 + (0.0266) - (0)
= 0.0283"

Empty, New, Bottom Seam

t_p = 0" (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) (bending)
= 300,165 / (π*57.875^2*16,331.61*1.00)
= 0.0017"

t_w = W / (2*π*R_m*S_c*K_s) (Weight)
= 157,781.7 / (2*π*57.875*16,331.61*1.00)
= 0.0266"

t_t = |t_p + t_m - t_w| (total, net compressive)
= |0 + 0.0017 - (0.0266)|
= 0.0248"

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 0.0017 + (0.0266) - (0)
= 0.0283"

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)
= 300,165 / (π*57.875^2*12,510.17*1.00)

$= 0.0023"$

$t_w = W / (2*\pi*R_m*S_c*K_s)$ (Weight)

$= 157{,}781.7 / (2*\pi*57.875*12{,}510.17*1.00)$

$= 0.0347"$

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

$= |0 + 0.0023 - (0.0347)|$

= 0.0324"

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

$= 0.0023 + (0.0347) - (0)$

= 0.037"

Bottom Ellipsoidal Head #2

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Component:	Ellipsoidal Head
Material Specification:	SA-516 70 (II-D p.18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_s= 0 psi (SG=1, H_s=0" Operating head)
P_{th}= 4.43 psi (SG=1, H_s=122.6653" Horizontal test head)
P_{tv}= 27.18 psi (SG=1, H_s=753.065" Vertical test head)

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -20°F	Impact test performed
Rated MDMT = N/A	Material is normalized
	Material is not produced to fine grain practice
	PWHT is not performed
	Do not Optimize MDMT / Find MAWP

Radiography:	Category A joints -	Seamless No RT
	Head to shell seam -	Full UW-11(a) Type 1

Estimated weight*:	new = 5,474.5 lb	corr = 5,474.5 lb
Capacity*:	new = 926.1 US gal	corr = 926.1 US gal

* includes straight flange

Inner diameter	=	114.25"
Minimum head thickness	=	1.1875"
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	2 (corroded)
Straight flange length L_{sf}	=	2"
Nominal straight flange thickness t_{sf}	=	1.5"

Insulation thk*:	2"	density: 15.0001 lb/ft^3	weight: 273.5296 lb
Insulation support ring spacing:	96"	individual weight: 150 lb	total weight: 150 lb
Lining/ref thk*:	0.125"	density: 501.12 lb/ft^3	weight: 520.1457 lb

* includes straight flange if applicable

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	=	0.6291"
Maximum allowable working pressure (MAWP)	=	414.89 psi
Maximum allowable pressure (MAP)	=	414.89 psi
Maximum allowable external pressure (MAEP)	=	157.71 psi

Design thickness for internal pressure, (Corroded at 500 °F) UG-32(d)(1)

t = P*D / (2*S*E - 0.2*P) + Corrosion
= 220*114.25 / (2*20,000*1 - 0.2*220) + 0

$= \quad 0.6291"$

The head internal pressure design thickness is 0.6291".

Maximum allowable working pressure, (Corroded at 500 °F) UG-32(d)(1)

$$P = 2*S*E*t / (D + 0.2*t) - P_s$$
$$= 2*20{,}000*1*1.1875 / (114.25 + 0.2*1.1875) - 0$$
$$= 414.89 \text{ psi}$$

The maximum allowable working pressure (MAWP) is 414.89 psi.

Maximum allowable pressure, (New at 71.6 °F) UG-32(d)(1)

$$P = 2*S*E*t / (D + 0.2*t) - P_s$$
$$= 2*20{,}000*1*1.1875 / (114.25 + 0.2*1.1875) - 0$$
$$= 414.89 \text{ psi}$$

The maximum allowable pressure (MAP) is 414.89 psi.

Maximum Allowable External Pressure, (Corroded at 50 °F) UG-33(d)

Equivalent outside spherical radius (R_o)

$$R_o = K_o*D_o$$
$$= 0.882*116.625$$
$$= 102.8677 \text{ in}$$

$$A = 0.125 / (R_o / t)$$
$$= 0.125 / (102.8677 / 1.1875)$$
$$= 0.001443$$

From Table CS-2:	B	=	13,661.65 psi

$$P_a = B / (R_o / t)$$
$$= 13{,}661.65 / (102.8677 / 1.1875)$$
$$= 157.7096 \text{ psi}$$

Check the Maximum External Pressure, UG-33(a)(1) UG-32(d)(1)

$$P = 2*S*E*t / ((D + 0.2*t)*1.67) - P_{s2}$$
$$= 2*20{,}000*1*1.1875 / ((114.25 + 0.2*1.1875)*1.67) - 0$$
$$= 248.44 \text{ psi}$$

The maximum allowable external pressure (MAEP) is 157.71 psi.

% Extreme fiber elongation - UCS-79(d)

$$EFE = (75*t / R_f)*(1 - R_f / R_o)$$
$$= (75*1.5 / 20.1725)*(1 - 20.1725 / \infty)$$
$$= 5.5769\%$$

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming.

Bottom Ellipsoidal Head #2 (Dished Region)

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Component:	Hemi Head
Material specification:	SA-516 70 (II-D p. 18, ln. 19)

Internal design pressure: P = 220 psi @ 500 °F

Static liquid head:

P_{th} = 4.43 psi (SG = 1, H_s = 0", Horizontal test head)
P_{tv} = 27.18 psi (SG = 1, H_s = 0",Vertical test head)

Corrosion allowance Inner C = 0" Outer C = 0"

PWHT is not performed

Radiography:	RT on Category A Joints - Long. Seam -	Seamless No RT
	RT on Category A Joints - Circ. Seam -	User Defined (E = 1.)

Estimated weight	New = 22,086.9 lb	corr = 22,086.9 lb
Capacity	New = 9,531.4 US gal	corr = 9,531.4 US gal

Inner diameter	=	203.3603"
Minimum head thickness	=	1.1875"

Design thickness, (at 500 °F) UG-32(f)

t = P*R / (2*S*E - 0.20*P) + Corrosion
= 220*101.6802 / (2*20,000*1.00 - 0.20*220) + 0
= 0.5599"

Maximum allowable working pressure, (at 500 °F) UG-32(f)

P = 2*S*E*t / (R + 0.20*t) - P_s
= 2*20,000*1.00*1.1875 / (101.6802 + 0.20*1.1875) - 0
= 466.06 psi

Maximum allowable pressure, (at 71.6 °F) UG-32(f)

P = 2*S*E*t / (R + 0.20*t)
= 2*20,000*1.00*1.1875 / (101.6802 + 0.20*1.1875)
= 466.06 psi

Maximum Allowable External Pressure, (Corroded @ 50 °F)

A = 0.125 / (R_o / t)
= 0.125 / (102.8677 / 1.1875)
= 0.001443
From table CS-2: B = 13,661.6538 psi

P_a = B / (R_o / t)
= 13,661.65 / (102.8677 / 1.1875)
= 157.71 psi

The maximum allowable external pressure is 157.71 psi

% Extreme fiber elongation - UCS-79(d)

$$EFE = (75*t / R_f)*(1 - R_f / R_o)$$
$$= (75*1.1875 / 102.2739)*(1 - 102.2739 / \infty)$$
$$= 0.8708\%$$

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.5599"

The governing condition is due to internal pressure.

The head thickness of 1.1875" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	20,000	10,757	500	0	Weight	470.88	0.5476	0.5466
Operating, Hot & New	20,000	10,757	500	0	Weight	470.88	0.5476	0.5466
Hot Shut Down, Corroded	20,000	10,757	500	0	Weight	0	0.0229	0.0246
Hot Shut Down, New	20,000	10,757	500	0	Weight	0	0.0229	0.0246
Empty, Corroded	20,000	13,662	70	0	Weight	0	0.018	0.0193
Empty, New	20,000	13,662	70	0	Weight	0	0.018	0.0193
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	20,000	10,757	500	0	Weight	0	0.0229	0.0246

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

$$A = 0.125 / (R_o / t)$$
$$= 0.125 / (102.8677 / 1.1875)$$
$$= 0.001443$$
$$B = 10{,}757 \text{ psi}$$
$$S = 20{,}000 / 1.00 = 20{,}000 \text{ psi}$$
$$S_{cHC} = \min(B, S) = 10{,}757 \text{ psi}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_{cHN} = S_{cHC}$$
$$= 10{,}757 \text{ psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

$$A = 0.125 / (R_o / t)$$
$$= 0.125 / (102.8677 / 1.1875)$$
$$= 0.001443$$
$$B = 13{,}662 \text{ psi}$$
$$S = 20{,}000 / 1.00 = 20{,}000 \text{ psi}$$
$$S_{cCN} = \min(B, S) = 13{,}662 \text{ psi}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

S_{cCC} = S_{cCN}
= 13,662 psi

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

A = 0.125 / (R_o / t)
= 0.125 / (102.8677 / 1.1875)
= 0.001443

B = 13,662 psi

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

S_{cVC} = min(B, S) = 13,662 psi

Operating, Hot & Corroded, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c - 0.20*|P|)$ (Pressure)
= 220*101.6802 / (2*20,000*1.00*1.00 - 0.20*|220|)
= 0.5599"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 300,165 / (π*102.2739^2*20,000*1.00*1.00)
= 0.0005"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= 163,906.7 / (2*π*102.2739*20,000*1.00*1.00)
= 0.0128"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 0.5599 + 0.0005 - (0.0128)
= 0.5476"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |0.0005 + (0.0128) - (0.5599)|
= 0.5466"

Maximum allowable working pressure, Longitudinal Stress

P = $2*S_t*K_s*E_c*(t - t_m + t_w) / (R + 0.20*(t - t_m + t_w))$
= 2*20,000*1.00*1.00*(1.1875 - 0.0005 + (0.0128)) / (101.6802 + 0.20*(1.1875 - 0.0005 + (0.0128)))
= 470.88 psi

Operating, Hot & New, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c - 0.20*|P|)$ (Pressure)
= 220*101.6802 / (2*20,000*1.00*1.00 - 0.20*|220|)
= 0.5599"

t_m = $M / (\pi*R_m^2*S_t*K_s*E_c)$ (bending)
= 300,165 / (π*102.2739^2*20,000*1.00*1.00)
= 0.0005"

t_w = $W / (2*\pi*R_m*S_t*K_s*E_c)$ (Weight)
= $163{,}906.7 / (2*\pi*102.2739*20{,}000*1.00*1.00)$
= 0.0128"

t_t = $t_p + t_m - t_w$ (total required, tensile)
= $0.5599 + 0.0005 - (0.0128)$
= 0.5476"

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= $|0.0005 + (0.0128) - (0.5599)|$
= 0.5466"

Maximum allowable working pressure, Longitudinal Stress

$P = 2*S_t*K_s*E_c*(t - t_m + t_w) / (R + 0.20*(t - t_m + t_w))$
$= 2*20{,}000*1.00*1.00*(1.1875 - 0.0005 + (0.0128)) / (101.6802 + 0.20*(1.1875 - 0.0005 + (0.0128)))$
$= 470.88$ psi

Hot Shut Down, Corroded, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $300{,}165 / (\pi*102.2739^2*10{,}756.97*1.00)$
= 0.0008"

t_w = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= $163{,}906.7 / (2*\pi*102.2739*10{,}756.97*1.00)$
= 0.0237"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|0 + 0.0008 - (0.0237)|$
= 0.0229"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= $0.0008 + (0.0237) - (0)$
= 0.0246"

Hot Shut Down, New, Bottom Seam

t_p = 0" (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ (bending)
= $300{,}165 / (\pi*102.2739^2*10{,}756.97*1.00)$
= 0.0008"

t_w = $W / (2*\pi*R_m*S_c*K_s)$ (Weight)
= $163{,}906.7 / (2*\pi*102.2739*10{,}756.97*1.00)$
= 0.0237"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= $|0 + 0.0008 - (0.0237)|$
= 0.0229"

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

$= 0.0008 + (0.0237) - (0)$
$= \underline{0.0246"}$

Empty, Corroded, Bottom Seam

$t_p = 0"$ (Pressure)
$t_m = M / (\pi * R_m^{2} * S_c * K_s)$ (bending)
$= 300,165 / (\pi * 102.2739^2 * 13,661.65 * 1.00)$
$= 0.0007"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 163,906.7 / (2 * \pi * 102.2739 * 13,661.65 * 1.00)$
$= 0.0187"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0007 - (0.0187)|$
$= \underline{0.018"}$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0007 + (0.0187) - (0)$
$= \underline{0.0193"}$

Empty, New, Bottom Seam

$t_p = 0"$ (Pressure)
$t_m = M / (\pi * R_m^{2} * S_c * K_s)$ (bending)
$= 300,165 / (\pi * 102.2739^2 * 13,661.65 * 1.00)$
$= 0.0007"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 163,906.7 / (2 * \pi * 102.2739 * 13,661.65 * 1.00)$
$= 0.0187"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0007 - (0.0187)|$
$= \underline{0.018"}$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
$= 0.0007 + (0.0187) - (0)$
$= \underline{0.0193"}$

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

$t_p = 0"$ (Pressure)
$t_m = M / (\pi * R_m^{2} * S_c * K_s)$ (bending)
$= 300,165 / (\pi * 102.2739^2 * 10,756.97 * 1.00)$
$= 0.0008"$

$t_w = W / (2 * \pi * R_m * S_c * K_s)$ (Weight)
$= 163,906.7 / (2 * \pi * 102.2739 * 10,756.97 * 1.00)$
$= 0.0237"$

$t_t = |t_p + t_m - t_w|$ (total, net compressive)
$= |0 + 0.0008 - (0.0237)|$
$= \underline{0.0229"}$

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

$= 0.0008 + (0.0237) - (0)$

$= \underline{0.0246''}$

M1A NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1A)

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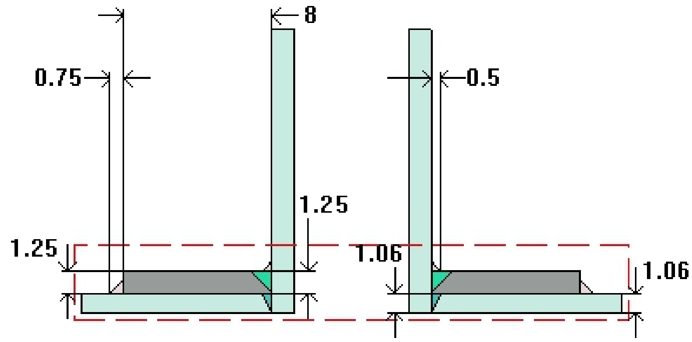

$t_{w(lower)}$ = 1.06 in
Leg_{41} = 0.5 in
$t_{w(upper)}$ = 1.25 in
Leg_{42} = 0.75 in
D_p = 41.75 in
t_e = 1.25 in

.

Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Cylinder #1
Orientation:	57°
Nozzle center line offset to datum line:	657 in
End of nozzle to shell center:	70.375 in
Passes through a Category A joint:	No

Nozzle

Access opening:	Yes
Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Inside diameter, new:	23.25 in
Nominal wall thickness:	1.25 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	5.38 in
Projection available outside vessel to flange face, Lf:	12 in
User input vessel thickness:	1.06 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Diameter:	41.75 in
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 24 Class 300 WN A105
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	Yes
Liquid static head:	0 psi

MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 365.83 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
24.645	26.298	--	5.4855	--	20	0.8125	0.215	1.25

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
492,900	525,960	1,155,497.41	167,710	1,581,031.63	578,960	1,116,566.79

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.35	weld size is adequate
Pad to shell fillet (Leg_{42})	0.375	0.525	weld size is adequate
Nozzle to pad groove (Upper)	0.525	1.25	weld size is adequate

Calculations for internal pressure 365.83 psi @ 500 °F

Nozzle rated MDMT: 0 °F

Pad rated MDMT: 0 °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 + (1.25 - 0) + (1.06 - 0))

= 23.25 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*(1.06 - 0), 2.5*(1.25 - 0) + 1.25)

= 2.65 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)

= 365.8266*11.625 / (20,000*1 - 0.6*365.8266)

= 0.215 in

Required thickness t_r from UG-37(a)

t_r = $P*R / (S*E - 0.6*P)$
= 365.8266*57.315 / (20,000*1 - 0.6*365.8266)
= 1.06 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*1.06*1 + 2*1.25*1.06*1*(1 - 1)
= 24.645 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 23.25*(1*1.06 - 1*1.06) - 2*1.25*(1*1.06 - 1*1.06)*(1 - 1)
= 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*(1.06 + 1.25)*(1*1.06 - 1*1.06) - 2*1.25*(1*1.06 - 1*1.06)*(1 - 1)
= 0 in^2

A_2 = smaller of the following= 5.4855 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= 5*(1.25 - 0.215)*1*1.06
= 5.4855 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= 2*(1.25 - 0.215)*(2.5*1.25 + 1.25)*1
= 9.0562 in^2

A_{41} = Leg^2*f_{r3}
= 0.5^2*1
= 0.25 in^2

A_{42} = Leg^2*f_{r4}
= 0.75^2*1
= 0.5625 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (41.75 - 23.25 - 2*1.25)*1.25*1
= 20 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0 + 5.4855 + 0.25 + 0.5625 + 20
= 26.298 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 = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.75 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.375 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.75 = 0.525 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 365.8266*11.625 / (20,000*1 - 0.6*365.8266) + 0
= 0.215 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.215 , 0]
= 0.215 in

Available nozzle wall thickness new, t_n = 1.25 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 = $(\pi / 2)$*25.75*0.5*9,800 = 198,195.23 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*41.75*0.75*9,800 = 482,018.49 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*24.5*1.25*14,000 = 673,478.92 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*25.75*1.06*14,800 = 634,548.31 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*25.75*1.25*14,800 = 748,288.1 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (24.645 - 0 + 2*1.25*1*(1*1.06 - 1*1.06))*20,000$
$=$ 492,900 lb_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (5.4855 + 20 + 0.25 + 0.5625)*20,000$
$=$ 525,960 lb_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (5.4855 + 0 + 0.25 + 0 + 2*1.25*1.06*1)*20,000$
$=$ 167,710 lb_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (5.4855 + 0 + 20 + 0.25 + 0.5625 + 0 + 2*1.25*1.06*1)*20,000$
$=$ 578,960 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 492,900 lb_f
Path 1-1 through (2) & (3) = 482,018.49 + 673,478.92 = 1,155,497.41 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} = 167,710 lb_f
Path 2-2 through (1), (4), (6) = 198,195.23 + 634,548.31 + 748,288.1 = 1,581,031.63 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} = 492,900 lb_f
Path 3-3 through (2), (4) = 482,018.49 + 634,548.31 = 1,116,566.79 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

$$EFE = (50*t / R_f)*(1 - R_f / R_o)$$
$$= (50*1.25 / 12.25)*(1 - 12.25 / \infty)$$
$$= 5.102\%$$

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming.

M1B NPS 24 RFWN (1.25"wt. 23.25"ID) Manway (M1B)

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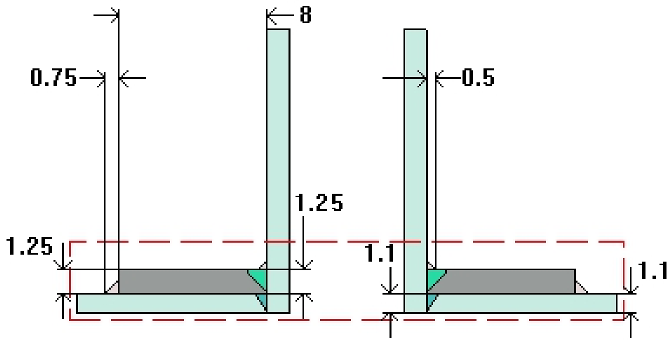

$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.5 in
$t_{w(upper)}$ = 1.25 in
Leg_{42} = 0.75 in
D_p = 41.75 in
t_e = 1.25 in

Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Cylinder #6
Orientation:	120°
Nozzle center line offset to datum line:	37 in
End of nozzle to shell center:	70.375 in
Passes through a Category A joint:	No

Nozzle

Access opening:	Yes
Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Inside diameter, new:	23.25 in
Nominal wall thickness:	1.25 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	5.38 in
Projection available outside vessel to flange face, Lf:	12 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Diameter:	41.75 in
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 24 Class 300 WN A105
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	Yes
Liquid static head:	0 psi

MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
25.5748	26.4595	0.0002	5.6468	--	20	0.8125	0.2233	1.25

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
511,491.85	529,186	1,155,497.41	172,936	1,604,976.85	584,186	1,140,512.01

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.35	weld size is adequate
Pad to shell fillet (Leg_{42})	0.375	0.525	weld size is adequate
Nozzle to pad groove (Upper)	0.525	1.25	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle rated MDMT: 0 °F

Pad rated MDMT: 0 °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 + (1.25 - 0) + (1.1 - 0))

= 23.25 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*(1.1 - 0), 2.5*(1.25 - 0) + 1.25)

= 2.75 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)

= 379.7331*11.625 / (20,000*1 - 0.6*379.7331)

= 0.2233 in

Required thickness t_r from UG-37(a)

t_r = $P*R / (S*E - 0.6*P)$
= $379.7331*57.275 / (20,000*1 - 0.6*379.7331)$
= 1.1 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 = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $23.25*1.1*1 + 2*1.25*1.1*1*(1 - 1)$
= 25.5748 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.0002 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $23.25*(1*1.1 - 1*1.1) - 2*1.25*(1*1.1 - 1*1.1)*(1 - 1)$
= 0.0002 in^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $2*(1.1 + 1.25)*(1*1.1 - 1*1.1) - 2*1.25*(1*1.1 - 1*1.1)*(1 - 1)$
= 0 in^2

A_2 = smaller of the following= 5.6468 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $5*(1.25 - 0.2233)*1*1.1$
= 5.6468 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $2*(1.25 - 0.2233)*(2.5*1.25 + 1.25)*1$
= 8.9836 in^2

A_{41} = Leg^2*f_{r3}
= 0.5^2*1
= 0.25 in^2

A_{42} = Leg^2*f_{r4}
= 0.75^2*1
= 0.5625 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $(41.75 - 23.25 - 2*1.25)*1.25*1$
= 20 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= $0.0002 + 5.6468 + 0.25 + 0.5625 + 20$
= 26.4595 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 = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.75 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.375 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.75 = 0.525 in

UG-45 Nozzle Neck Thickness Check (Access Opening)

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 379.7331*11.625 / (20,000*1 - 0.6*379.7331) + 0
= 0.2233 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.2233 , 0]
= 0.2233 in

Available nozzle wall thickness new, t_n = 1.25 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 = $(\pi / 2)$*25.75*0.5*9,800 = 198,195.23 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*41.75*0.75*9,800 = 482,018.49 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*24.5*1.25*14,000 = 673,478.92 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*25.75*1.1*14,800 = 658,493.53 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*25.75*1.25*14,800 = 748,288.1 lb_f

Loading on welds per UG-41(b)(1)

$$W = (A - A_1 + 2 t_n f_{r1} (E_1 t - F t_r)) S_v$$
$$= (25.5748 - 0.0002 + 2*1.25*1*(1*1.1 - 1*1.1))*20{,}000$$
$$= 511{,}491.85\ lb_f$$

$$W_{1\text{-}1} = (A_2 + A_5 + A_{41} + A_{42}) S_v$$
$$= (5.6468 + 20 + 0.25 + 0.5625)*20{,}000$$
$$= 529{,}186\ lb_f$$

$$W_{2\text{-}2} = (A_2 + A_3 + A_{41} + A_{43} + 2 t_n t f_{r1}) S_v$$
$$= (5.6468 + 0 + 0.25 + 0 + 2*1.25*1.1*1)*20{,}000$$
$$= 172{,}936\ lb_f$$

$$W_{3\text{-}3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 t_n t f_{r1}) S_v$$
$$= (5.6468 + 0 + 20 + 0.25 + 0.5625 + 0 + 2*1.25*1.1*1)*20{,}000$$
$$= 584{,}186\ lb_f$$

Load for path 1-1 lesser of W or W_{1-1} = 511,491.85 lb_f
Path 1-1 through (2) & (3) = 482,018.49 + 673,478.92 = 1,155,497.41 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} = 172,936 lb_f
Path 2-2 through (1), (4), (6) = 198,195.23 + 658,493.53 + 748,288.1 = 1,604,976.85 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} = 511,491.85 lb_f
Path 3-3 through (2), (4) = 482,018.49 + 658,493.53 = 1,140,512.01 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

$$EFE = (50*t / R_f)*(1 - R_f / R_o)$$
$$= (50*1.25 / 12.25)*(1 - 12.25 / \infty)$$
$$= 5.102\%$$

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming.

N11 NPS 12 RFWN S/XH(0.5"wt) Vapor Feed Nozzle (N11)

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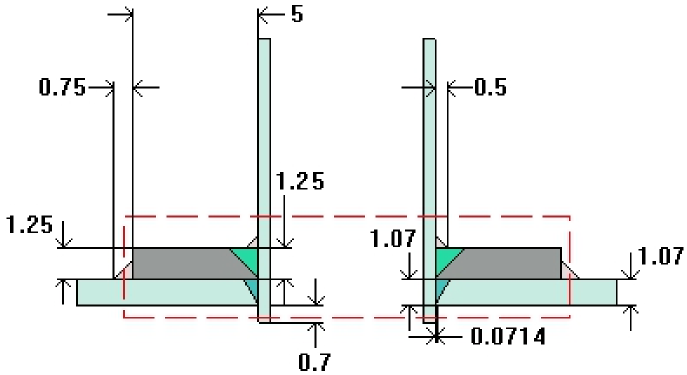

$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.5 in
$t_{w(upper)}$ = 1.25 in
Leg_{42} = 0.75 in
Leg_{43} = 0.0714 in
h_{new} = 0.7 in
D_p = 22.75 in
t_e = 1.25 in

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #5
Orientation:	90°
Nozzle center line offset to datum line:	136 in
End of nozzle to shell center:	67 in
Passes through a Category A joint:	No

Nozzle	
Access opening:	No
Material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Description:	NPS 12 XS
Inside diameter, new:	11.75 in
Nominal wall thickness:	0.5 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	3.375 in
Internal projection, h_{new}:	0.7 in
Projection available outside vessel to flange face, Lf:	8.495 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

Reinforcing Pad	
Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Diameter:	22.75 in
Is split:	No

ASME B16.5-2009 Flange	
Description:	NPS 12 Class 300 WN A105
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)

Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel
PWHT performed:	Yes
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 368.54 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
12.7277	14.8834	--	1.589	0.1543	12.5	0.6401	0.3281	0.5

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
254,553	294,494	377,821.68	57,527.55	783,561.9	315,965.55	591,801.24

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.35	weld size is adequate
Pad to shell fillet (Leg_{42})	0.375	0.525	weld size is adequate
Nozzle to pad groove (Upper)	0.35	1.25	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	368.54	7,500	306,360	8,010	306,360	8,010	919,080	**33,107**	**60,000**	**21,632**	**30,000**	No
Load case 1 (Hot Shut Down)	0	7,500	306,360	8,010	306,360	8,010	919,080	-16,838	60,000	-3,725	30,000	No

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F
Pad rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(11.75, 5.875 + (0.5 - 0) + (1.07 - 0))

= 11.75 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*(1.07 - 0), 2.5*(0.5 - 0) + 1.25)
= 2.5 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(0.7, 2.5*(1.07 - 0), 2.5*(0.5 - 0 - 0))
= 0.475 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 368.5408*5.875 / (17,100*1 - 0.6*368.5408)
= 0.1283 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 368.5408*57.425 / (20,000*1 - 0.6*368.5408)
= 1.07 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,100, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.855

f_{r2} = lesser of 1 or S_n / S_v = 0.855

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.855

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})
= 11.75*1.07*1 + 2*0.5*1.07*1*(1 - 0.855)
= 12.7277 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})
= 11.75*(1*1.07 - 1*1.07) - 2*0.5*(1*1.07 - 1*1.07)*(1 - 0.855)
= 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})

$= 2*(1.07 + 0.5)*(1*1.07 - 1*1.07) - 2*0.5*(1*1.07 - 1*1.07)*(1 - 0.855)$
$= 0\ in^2$

A_2 = smaller of the following= 1.589 in^2

$= 5*(t_n - t_{rn})*f_{r2}*t$
$= 5*(0.5 - 0.1283)*0.855*1.07$
$= 1.7002\ in^2$

$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
$= 2*(0.5 - 0.1283)*(2.5*0.5 + 1.25)*0.855$
$= 1.589\ in^2$

A_3 = smaller of the following= 0.1543 in^2

$= 5*t*t_i*f_{r2}$
$= 5*1.07*0.19*0.855$
$= 0.8691\ in^2$

$= 5*t_i*t_i*f_{r2}$
$= 5*0.19*0.19*0.855$
$= 0.1543\ in^2$

$= 2*h*t_i*f_{r2}$
$= 2*0.7*0.19*0.855$
$= 0.2274\ in^2$

$A_{41} = Leg^2*f_{r3}$
$= 0.5^2*0.855$
$= 0.2138\ in^2$

$A_{42} = Leg^2*f_{r4}$
$= 0.6495^2*1$
$= 0.4219\ in^2$

(Part of the weld is outside of the limits)

$A_{43} = Leg^2*f_{r2}$
$= 0.0714^2*0.855$
$= 0.0044\ in^2$

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= (22.75 - 11.75 - 2*0.5)*1.25*1$
$= 12.5\ in^2$

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
$= 0 + 1.589 + 0.1543 + 0.2138 + 0.4219 + 0.0044 + 12.5$
$= 14.8834\ in^2$

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 = 0.5 in

$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in

$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.75 in

$t_{w(min)}$ = 0.5*t_{min} = 0.375 in

$t_{w(actual)}$ = 0.7*Leg = 0.7*0.75 = 0.525 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion

= 368.5408*5.875 / (17,100*1 - 0.6*368.5408) + 0

= 0.1283 in

$t_{a\ UG\text{-}22}$ = 0.266 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]

= max[0.1283 , 0.266]

= 0.266 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion

= 368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0

= 1.07 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]

= max[1.07 , 0.0625]

= 1.07 in

t_b = min[t_{b3} , t_{b1}]

= min[0.3281 , 1.07]

= 0.3281 in

$t_{UG\text{-}45}$ = max[t_a , t_b]

= max[0.266 , 0.3281]

= 0.3281 in

Available nozzle wall thickness new, t_n = 0.5 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*17,100 =	11,970 psi

Inner fillet weld in shear:	0.49*17,100 =	8,379 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*17,100 =	8,379 psi

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*12.75*0.5*8,379 = 83,905.85 lb_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*22.75*0.75*9,800 = 262,656.78 lb_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*12.25*0.5*11,970 = 115,164.9 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*12.75*1.07*14,800 = 317,157.91 lb_f

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*12.75*0.0714*8,379 = 11,986.55 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*12.75*1.25*14,800 = 370,511.58 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (12.7277 - 0 + 2*0.5*0.855*(1*1.07 - 1*1.07))*20,000
= 254,553 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (1.589 + 12.5 + 0.2138 + 0.4219)*20,000
= 294,494 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (1.589 + 0.1543 + 0.2138 + 0.0044 + 2*0.5*1.07*0.855)*20,000
= 57,527.55 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (1.589 + 0.1543 + 12.5 + 0.2138 + 0.4219 + 0.0044 + 2*0.5*1.07*0.855)*20,000
= 315,965.55 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 254,553 lb_f
Path 1-1 through (2) & (3) = 262,656.78 + 115,164.9 = 377,821.68 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} = 57,527.55 lb_f
Path 2-2 through (1), (4), (5), (6) = 83,905.85 + 317,157.91 + 11,986.55 + 370,511.58 = 783,561.9 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} = 254,553 lb_f
Path 3-3 through (2), (4), (5) = 262,656.78 + 317,157.91 + 11,986.55 = 591,801.24 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 =	7,500	lb_f
Circumferential moment:	M_c =	306,360	lb_f-in
Circumferential shear:	V_c =	8,010	lb_f
Longitudinal moment:	M_L =	306,360	lb_f-in
Longitudinal shear:	V_L =	8,010	lb_f
Torsion moment:	M_t =	919,080	lb_f-in
Internal pressure:	P =	368.541	psi
Mean shell radius:	R_m =	57.96	in
Local shell thickness:	t =	1.07	in
Shell yield stress:	S_y =	31,000	psi
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / t = 57.96 / 1.07 = 54.1682$

$\beta = 0.875 * r_o / R_m = 0.875*11.375 / 57.96 = 0.1717$

Pressure stress intensity factor, I = 1 (derived from PVP-Vol. 399, pages 77-82)

Local circumferential pressure stress = $I*P*R_i / t$ =19,779 psi

Local longitudinal pressure stress = $I*P*R_i / (2*t)$ =9,890 psi

Maximum combined stress (P_L+P_b+Q) = 33,107 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) = 21,632 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**		A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	N_ϕ / (P / R_m)	5.2047	0	0	0	0	-629	-629	-629	-629
4C*	N_ϕ / (P / R_m)	7.7418	-936	-936	-936	-936	0	0	0	0
1C	M_ϕ / P	0.0715	0	0	0	0	-2,810	2,810	-2,810	2,810
2C-1	M_ϕ / P	0.0374	-1,470	1,470	-1,470	1,470	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	2.1895	0	0	0	0	-1,087	-1,087	1,087	1,087
1A	M_ϕ / [M_c / (R_m*β)]	0.0756	0	0	0	0	-12,195	12,195	12,195	-12,195
3B*	N_ϕ / [M_L / (R_m^2*β)]	5.6184	-2,789	-2,789	2,789	2,789	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0263	-4,242	4,242	4,242	-4,242	0	0	0	0
Pressure stress*			19,779	19,779	19,779	19,779	19,779	19,779	19,779	19,779
Total circumferential stress			10,342	21,766	24,404	18,860	3,058	33,068	29,622	10,852
Primary membrane circumferential stress*			16,054	16,054	21,632	21,632	18,063	18,063	20,237	20,237
3C*	N_x / (P / R_m)	5.2047	-629	-629	-629	-629	0	0	0	0
4C*	N_x / (P / R_m)	7.7418	0	0	0	0	-936	-936	-936	-936
1C-1	M_x / P	0.0699	-2,747	2,747	-2,747	2,747	0	0	0	0
2C	M_x / P	0.0408	0	0	0	0	-1,604	1,604	-1,604	1,604
4A*	N_x / [M_c / (R_m^2*β)]	4.209	0	0	0	0	-2,089	-2,089	2,089	2,089
2A	M_x / [M_c / (R_m*β)]	0.0377	0	0	0	0	-6,081	6,081	6,081	-6,081
4B*	N_x / [M_L / (R_m^2*β)]	2.1903	-1,087	-1,087	1,087	1,087	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.0383	-6,178	6,178	6,178	-6,178	0	0	0	0
Pressure stress*			9,890	9,890	9,890	9,890	9,890	9,890	9,890	9,890
Total longitudinal stress			-751	17,099	13,779	6,917	-820	14,550	15,520	6,566
Primary membrane longitudinal stress*			8,174	8,174	10,348	10,348	6,865	6,865	11,043	11,043
Shear from M_t			1,057	1,057	1,057	1,057	1,057	1,057	1,057	1,057
Circ shear from V_c			209	209	-209	-209	0	0	0	0
Long shear from V_L			0	0	0	0	-209	-209	209	209
Total Shear stress			1,266	1,266	848	848	848	848	1,266	1,266
Combined stress (P_L+P_b+Q)			11,378	22,087	24,471	18,920	4,233	33,107	29,735	11,198

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

γ = R_m / t = 57.96 / 2.32 = 24.9828

β = 0.875*r_o / R_m = 0.875*6.375 / 57.96 = 0.0962

Pressure stress intensity factor, I = 0.8206 (derived from PVP-Vol. 399, pages 77-82)

Local circumferential pressure stress = I*P*R_i / t =16,231 psi

Local longitudinal pressure stress = I*P*R_i / (2*t) =8,116 psi

Maximum combined stress (P_L+P_b+Q) = 26,914 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) = 19,794 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 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*	$N_\phi / (P / R_m)$	4.1879	0	0	0	0	-234	-234	-234	-234
4C*	$N_\phi / (P / R_m)$	4.5517	-254	-254	-254	-254	0	0	0	0
1C	M_ϕ / P	0.154	0	0	0	0	-1,288	1,288	-1,288	1,288
2C-1	M_ϕ / P	0.1142	-955	955	-955	955	0	0	0	0
3A*	$N_\phi / [M_c / (R_m{}^2 * \beta)]$	0.6106	0	0	0	0	-249	-249	249	249
1A	$M_\phi / [M_c / (R_m * \beta)]$	0.1013	0	0	0	0	-6,202	6,202	6,202	-6,202
3B*	$N_\phi / [M_L / (R_m{}^2 * \beta)]$	2.1453	-876	-876	876	876	0	0	0	0
1B-1	$M_\phi / [M_L / (R_m * \beta)]$	0.0525	-3,214	3,214	3,214	-3,214	0	0	0	0
Pressure stress*			16,231	16,231	16,231	16,231	19,779	19,779	19,779	19,779
Total circumferential stress			10,932	19,270	19,112	14,594	11,806	26,786	24,708	14,880
Primary membrane circumferential stress*			15,101	15,101	16,853	16,853	19,296	19,296	19,794	19,794
3C*	$N_x / (P / R_m)$	4.1879	-234	-234	-234	-234	0	0	0	0
4C*	$N_x / (P / R_m)$	4.5517	0	0	0	0	-254	-254	-254	-254
1C-1	M_x / P	0.1571	-1,313	1,313	-1,313	1,313	0	0	0	0
2C	M_x / P	0.114	0	0	0	0	-953	953	-953	953
4A*	$N_x / [M_c / (R_m{}^2 * \beta)]$	0.7979	0	0	0	0	-326	-326	326	326
2A	$M_x / [M_c / (R_m * \beta)]$	0.058	0	0	0	0	-3,551	3,551	3,551	-3,551
4B*	$N_x / [M_L / (R_m{}^2 * \beta)]$	0.5831	-238	-238	238	238	0	0	0	0
2B-1	$M_x / [M_L / (R_m * \beta)]$	0.0835	-5,112	5,112	5,112	-5,112	0	0	0	0
Pressure stress*			9,890	9,890	9,890	9,890	8,116	8,116	8,116	8,116
Total longitudinal stress			2,993	15,843	13,693	6,095	3,032	12,040	10,786	5,590
Primary membrane longitudinal stress*			9,418	9,418	9,894	9,894	7,536	7,536	8,188	8,188
Shear from M_t			1,551	1,551	1,551	1,551	1,551	1,551	1,551	1,551
Circ shear from V_c			172	172	-172	-172	0	0	0	0
Long shear from V_L			0	0	0	0	-172	-172	172	172
Total Shear stress			1,723	1,723	1,379	1,379	1,379	1,379	1,723	1,723
Combined stress (P_L+P_b+Q)			11,290	19,986	19,443	14,812	12,018	26,914	24,918	15,189

Note: * denotes primary stress.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o{}^2 - R_i{}^2)) + M*R_o / I$
$= 368.54*5.875 / (2*0.5) - 7{,}500 / (\pi*(6.375^2 - 5.875^2)) + 433{,}258.5*6.375 / 361.5439$
= 9,415 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 = 17,100 psi)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L{}^2 + V_c{}^2)^{0.5} / (\pi*R_i*t_n)$
$= (8{,}010^2 + 8{,}010^2)^{0.5} / (\pi*5.875*0.5)$
= 1,228 psi

$\sigma_{torsion} = M_t / (2*\pi*R_i{}^2*t_n)$
$= 919{,}080 / (2*\pi*5.875^2*0.5)$

= 8,476 psi

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 1,228 + 8,476
= 9,703 psi

UG-45: The total combined shear stress (9,703 psi) ≤ allowable ($0.7*S_n$ = 0.7*17,100 = 11,970 psi)

N12 NPS 8 RFWN S/XH(0.5"wt) Amine Feed Nozzle (N12)

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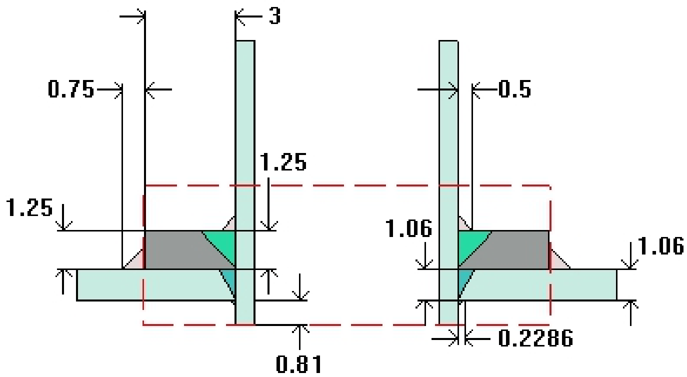

$t_{w(lower)}$ = 1.06 in
Leg_{41} = 0.5 in
$t_{w(upper)}$ = 1.25 in
Leg_{42} = 0.75 in
Leg_{43} = 0.2286 in
h_{new} = 0.81 in
D_p = 14.625 in
t_e = 1.25 in

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #1
Orientation:	90°
Nozzle center line offset to datum line:	666 in
End of nozzle to shell center:	67 in
Passes through a Category A joint:	No

Nozzle	
Access opening:	No
Material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Inside diameter, new:	7.377 in
Nominal wall thickness:	0.624 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	4.245 in
Internal projection, h_{new}:	0.81 in
Projection available outside vessel to flange face, Lf:	8.625 in
User input vessel thickness:	1.06 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

Reinforcing Pad	
Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Diameter:	14.625 in
Is split:	No

ASME B16.5-2009 Flange	
Description:	NPS 8 Class 300 WN A105
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No

Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 365.83 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
8.0114	10.9178	--	2.4656	0.6011	7.5	0.3511	0.2818	0.624

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
160,228.75	205,440	262,724.26	89,125.92	545,890.26	240,977.92	407,341.02

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.35	weld size is adequate
Pad to shell fillet (Leg_{42})	0.375	0.525	weld size is adequate
Nozzle to pad groove (Upper)	0.4368	1.25	weld size is adequate

Calculations for internal pressure 365.83 psi @ 500 °F

Nozzle UCS-66 governing thk:	0 in
Nozzle rated MDMT:	0 °F
Pad rated MDMT:	0 °F

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(7.377, 3.6885 + (0.624 - 0) + (1.06 - 0))$$
$$= 7.377 \text{ in}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(1.06 - 0), 2.5*(0.624 - 0) + 1.25)$$
$$= 2.65 \text{ in}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))$$
$$= MIN(0.81, 2.5*(1.06 - 0), 2.5*(0.624 - 0 - 0))$$
$$= 0.81 \text{ in}$$

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 365.8266*3.6885 / (17,100*1 - 0.6*365.8266)
= 0.0799 in

Required thickness t_r from UG-37(a)

t_r = $P*R / (S*E - 0.6*P)$
= 365.8266*57.315 / (20,000*1 - 0.6*365.8266)
= 1.06 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,100, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.855

f_{r2} = lesser of 1 or S_n / S_v = 0.855

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.855

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= 7.377*1.06*1 + 2*0.624*1.06*1*(1 - 0.855)
= 8.0114 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= 7.377*(1*1.06 - 1*1.06) - 2*0.624*(1*1.06 - 1*1.06)*(1 - 0.855)
= 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*(1.06 + 0.624)*(1*1.06 - 1*1.06) - 2*0.624*(1*1.06 - 1*1.06)*(1 - 0.855)
= 0 in^2

A_2 = smaller of the following= 2.4656 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= 5*(0.624 - 0.0799)*0.855*1.06
= 2.4656 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= 2*(0.624 - 0.0799)*(2.5*0.624 + 1.25)*0.855

$= \quad 2.6145\ in^2$

A_3 = smaller of the following= 0.6011 in^2

$= \quad 5*t*t_i*f_{r2}$
$= \quad 5*1.06*0.434*0.855$
$= \quad 1.9667\ in^2$

$= \quad 5*t_i*t_i*f_{r2}$
$= \quad 5*0.434*0.434*0.855$
$= \quad 0.8052\ in^2$

$= \quad 2*h*t_i*f_{r2}$
$= \quad 2*0.81*0.434*0.855$
$= \quad 0.6011\ in^2$

$A_{41} = Leg^2*f_{r3}$
$= \quad 0.5^2*0.855$
$= \quad 0.2138\ in^2$

$A_{42} = Leg^2*f_{r4}$
$= \quad 0.3043^2*1$
$= \quad 0.0926\ in^2$

(Part of the weld is outside of the limits)

$A_{43} = Leg^2*f_{r2}$
$= \quad 0.2286^2*0.855$
$= \quad 0.0447\ in^2$

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= \quad (14.625 - 7.377 - 2*0.624)*1.25*1$
$= \quad 7.5\ in^2$

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
$= \quad 0 + 2.4656 + 0.6011 + 0.2138 + 0.0926 + 0.0447 + 7.5$
$= \quad 10.9178\ in^2$

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 = 0.624 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.75 in

$t_{w(min)}$ = 0.5*t_{min} = 0.375 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.75 = 0.525 in

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$	=	P*R / (S*E - 0.6*P) + Corrosion
	=	365.8266*3.6885 / (17,100*1 - 0.6*365.8266) + 0
	=	0.0799 in

t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.0799 , 0]
	=	0.0799 in

t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	365.8266*57.315 / (20,000*1 - 0.6*365.8266) + 0
	=	1.06 in

t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.06 , 0.0625]
	=	1.06 in

t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.2818 , 1.06]
	=	0.2818 in

$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.0799 , 0.2818]
	=	0.2818 in

Available nozzle wall thickness new, t_n = 0.624 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*17,100 =	11,970 psi
Inner fillet weld in shear:	0.49*17,100 =	8,379 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*17,100 =	8,379 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*8.625*0.5*8,379 = 56,759.84 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*14.625*0.75*9,800 = 168,850.79 lb_f

(3) Nozzle wall in shear

$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*8.001*0.624*11,970 = 93,873.47 lb_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*8.625*1.06*14,800 = 212,542.88 lb_f

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*8.625*0.2286*8,379 = 25,947.36 lb_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*8.625*1.25*14,800 = 250,640.19 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (8.0114 - 0 + 2*0.624*0.855*(1*1.06 - 1*1.06))*20,000
= 160,228.75 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (2.4656 + 7.5 + 0.2138 + 0.0926)*20,000
= 205,440 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (2.4656 + 0.6011 + 0.2138 + 0.0447 + 2*0.624*1.06*0.855)*20,000
= 89,125.92 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (2.4656 + 0.6011 + 7.5 + 0.2138 + 0.0926 + 0.0447 + 2*0.624*1.06*0.855)*20,000
= 240,977.92 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 160,228.75 lb_f
Path 1-1 through (2) & (3) = 168,850.79 + 93,873.47 = 262,724.26 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} = 89,125.92 lb_f
Path 2-2 through (1), (4), (5), (6) = 56,759.84 + 212,542.88 + 25,947.36 + 250,640.19 = 545,890.26 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} = 160,228.75 lb_f
Path 3-3 through (2), (4), (5) = 168,850.79 + 212,542.88 + 25,947.36 = 407,341.02 lb_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

N17 NPS 8 RFWN S/XH(0.5"wt) Amine Outlet Nozzle (N17)

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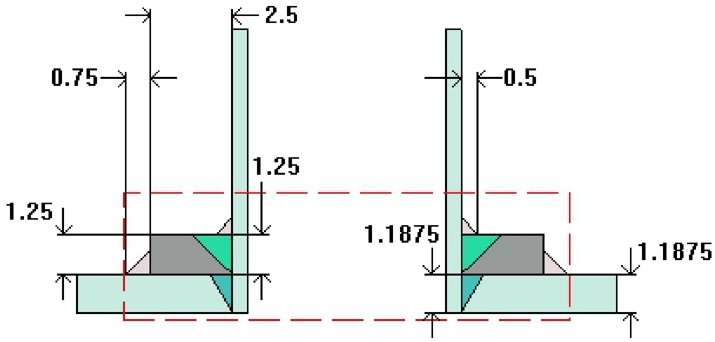


$t_{w(lower)}$ = 1.1875 in
Leg_{41} = 0.5 in
$t_{w(upper)}$ = 1.25 in
Leg_{42} = 0.75 in
D_p = 13.625 in
t_e = 1.25 in

Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Bottom Ellipsoidal Head #2
Orientation:	135°
End of nozzle to datum line:	-50 in
Calculated as hillside:	No
Distance to head center, R:	0 in
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Description:	NPS 8 Sch 80 (XS)
Inside diameter, new:	7.625 in
Nominal wall thickness:	0.5 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	13.9515 in
Projection available outside vessel to flange face, Lf:	18.3315 in
User input vessel thickness:	1.1875 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Diameter:	13.625 in
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 8 Class 300 WN A105
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)

Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 448.26 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
8.9735	8.9738	0.2439	1.7036	--	6.25	0.7763	0.3228	0.5

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
175,149.54	174,598	233,690.31	58,654.25	545,508.21	194,904.25	395,413.61

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.35	weld size is adequate
Pad to shell fillet (Leg_{42})	0.375	0.525	weld size is adequate
Nozzle to pad groove (Upper)	0.35	1.25	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_1 (lb_f-in)	V_1 (lb_f)	M_2 (lb_f-in)	V_2 (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	448.26	4,100	176,520	4,400	176,520	4,400	529,560	**31,817**	**60,000**	**20,620**	**30,000**	No
Load case 1 (Hot Shut Down)	0	4,100	176,520	4,400	176,520	4,400	529,560	-15,238	60,000	-1,774	30,000	No

Calculations for internal pressure 448.26 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F
Pad rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(7.625, 3.8125 + (0.5 - 0) + (1.1875 - 0))$$

= 7.625 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*(1.1875 - 0), 2.5*(0.5 - 0) + 1.25)
= 2.5 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 448.2581*3.8125 / (17,100*1 - 0.6*448.2581)
= 0.1015 in

Required thickness t_r from UG-37(a)(c)

t_r = P*K_1*D / (2*S*E - 0.2*P)
= 448.2581*0.9*114.25 / (2*20,000*1 - 0.2*448.2581)
= 1.1549 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,100, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.855

f_{r2} = lesser of 1 or S_n / S_v = 0.855

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.855

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})
= 7.625*1.1549*1 + 2*0.5*1.1549*1*(1 - 0.855)
= 8.9735 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.2439 in^2

= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= 7.625*(1*1.1875 - 1*1.1549) - 2*0.5*(1*1.1875 - 1*1.1549)*(1 - 0.855)
= 0.2439 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*(1.1875 + 0.5)*(1*1.1875 - 1*1.1549) - 2*0.5*(1*1.1875 - 1*1.1549)*(1 - 0.855)
= 0.1053 in^2

A_2 = smaller of the following= 1.7036 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= 5*(0.5 - 0.1015)*0.855*1.1875
= 2.023 in^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= 2*(0.5 - 0.1015)*(2.5*0.5 + 1.25)*0.855
= 1.7036 in^2

A_{41} = Leg^2*f_{r3}
= $0.5^2*0.855$
= 0.2138 in^2

A_{42} = Leg^2*f_{r4}
= 0.75^2*1
= 0.5625 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (13.625 - 7.625 - 2*0.5)*1.25*1
= 6.25 in^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0.2439 + 1.7036 + 0.2138 + 0.5625 + 6.25
= 8.9738 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 = 0.5 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.75 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.375 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.75 = 0.525 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
= 448.2581*3.8125 / (17,100*1 - 0.6*448.2581) + 0
= 0.1015 in

$t_{a\ UG-22}$ = 0.3228 in

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.1015 , 0.3228]
= 0.3228 in

t_{b1} = 1.2832 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.2832 , 0.0625]
= 1.2832 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2818 , 1.2832]
= 0.2818 in

t_{UG-45} = max[t_a , t_b]
= max[0.3228 , 0.2818]
= 0.3228 in

Available nozzle wall thickness new, t_n = 0.5 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*17,100 =	11,970 psi
Inner fillet weld in shear:	0.49*17,100 =	8,379 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)*8.625*0.5*8,379 = 56,759.84 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*13.625*0.75*9,800 = 157,305.43 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*8.125*0.5*11,970 = 76,384.88 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*8.625*1.1875*14,800 = 238,108.18 lb_f

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*8.625*1.25*14,800 = 250,640.19 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
= (8.9735 - 0.2439 + 2*0.5*0.855*(1*1.1875 - 1*1.1549))*20,000

= 175,149.54 lb_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (1.7036 + 6.25 + 0.2138 + 0.5625)*20,000
= 174,598 lb_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (1.7036 + 0 + 0.2138 + 0 + 2*0.5*1.1875*0.855)*20,000
= 58,654.25 lb_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (1.7036 + 0 + 6.25 + 0.2138 + 0.5625 + 0 + 2*0.5*1.1875*0.855)*20,000
= 194,904.25 lb_f

Load for path 1-1 lesser of W or W_{1-1} = 174,598 lb_f
Path 1-1 through (2) & (3) = 157,305.43 + 76,384.88 = 233,690.31 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} = 58,654.25 lb_f
Path 2-2 through (1), (4), (6) = 56,759.84 + 238,108.18 + 250,640.19 = 545,508.21 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} = 175,149.54 lb_f
Path 3-3 through (2), (4) = 157,305.43 + 238,108.18 = 395,413.61 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 =	4,100	lb_f
Circumferential moment:	M_1 =	176,520	lb_f-in
Circumferential shear:	V_2 =	4,400	lb_f
Longitudinal moment:	M_2 =	176,520	lb_f-in
Longitudinal shear:	V_1 =	4,400	lb_f
Torsion moment:	M_t =	529,560	lb_f-in
Internal pressure:	P =	448.258	psi
Mean dish radius:	R_m =	103.9329	in
Local head thickness:	t =	1.1875	in
Head yield stress:	S_y =	31,000	psi
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

U = r_o / Sqr(R_m*T) = 6.8125 / Sqr(103.9329*1.1875) = 0.613

Pressure stress intensity factor, I = 1 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =19,504 psi

Maximum combined stress (P_L+P_b+Q) = 31,817 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) = 20,620 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		A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
SR-2*	N_x*T / P	0.1132	-329	-329	-329	-329	-329	-329	-329	-329
SR-2	M_x / P	0.0668	-1,165	1,165	-1,165	1,165	-1,165	1,165	-1,165	1,165
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1282	0	0	0	0	-1,445	-1,445	1,445	1,445
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.1779	0	0	0	0	-12,027	12,027	12,027	-12,027
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1282	-1,445	-1,445	1,445	1,445	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.1779	-12,027	12,027	12,027	-12,027	0	0	0	0
Pressure stress*			19,504	19,504	19,504	19,504	19,504	19,504	19,504	19,504
Total O_x stress			4,538	30,922	31,482	9,758	4,538	30,922	31,482	9,758
Membrane O_x stress*			17,730	17,730	20,620	20,620	17,730	17,730	20,620	20,620
SR-2*	N_y*T / P	0.0335	-97	-97	-97	-97	-97	-97	-97	-97
SR-2	M_y / P	0.0206	-359	359	-359	359	-359	359	-359	359
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0385	0	0	0	0	-434	-434	434	434
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0547	0	0	0	0	-3,698	3,698	3,698	-3,698
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0385	-434	-434	434	434	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0547	-3,698	3,698	3,698	-3,698	0	0	0	0
Pressure stress*			19,504	19,504	19,504	19,504	19,504	19,504	19,504	19,504
Total O_y stress			14,916	23,030	23,180	16,502	14,916	23,030	23,180	16,502
Membrane O_y stress*			18,973	18,973	19,841	19,841	18,973	18,973	19,841	19,841
Shear from M_t			1,529	1,529	1,529	1,529	1,529	1,529	1,529	1,529
Shear from V_1			0	0	0	0	-173	-173	173	173
Shear from V_2			173	173	-173	-173	0	0	0	0
Total Shear stress			1,702	1,702	1,356	1,356	1,356	1,356	1,702	1,702
Combined stress (P_L+P_b+Q)			15,188	31,273	31,698	16,764	15,090	31,148	31,817	16,907

Notes: (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) = 4.3125 / Sqr(103.9329*2.4375) = 0.271

Pressure stress intensity factor, I = 0.4965 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =9,684 psi

Maximum combined stress (P_L+P_b+Q) = 16,661 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) = 9,855 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 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	0.1987	-137	-137	-137	-137	-137	-137	-137	-137
SR-2	M_x / P	0.1516	-628	628	-628	628	-628	628	-628	628
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1648	0	0	0	0	-308	-308	308	308
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.538	0	0	0	0	-6,025	6,025	6,025	-6,025
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1648	-308	-308	308	308	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.538	-6,025	6,025	6,025	-6,025	0	0	0	0
Pressure stress*			9,684	9,684	9,684	9,684	9,684	9,684	9,684	9,684
Total O_x stress			2,586	15,892	15,252	4,458	2,586	15,892	15,252	4,458
Membrane O_x stress*			9,239	9,239	9,855	9,855	9,239	9,239	9,855	9,855
SR-2*	N_y*T / P	0.0603	-42	-42	-42	-42	-42	-42	-42	-42
SR-2	M_y / P	0.0455	-188	188	-188	188	-188	188	-188	188
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0502	0	0	0	0	-94	-94	94	94
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.1574	0	0	0	0	-1,763	1,763	1,763	-1,763
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0502	-94	-94	94	94	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.1574	-1,763	1,763	1,763	-1,763	0	0	0	0
Pressure stress*			9,684	9,684	9,684	9,684	9,684	9,684	9,684	9,684
Total O_y stress			7,597	11,499	11,311	8,161	7,597	11,499	11,311	8,161
Membrane O_y stress*			9,548	9,548	9,736	9,736	9,548	9,548	9,736	9,736
Shear from M_t			1,859	1,859	1,859	1,859	1,859	1,859	1,859	1,859
Shear from V_1			0	0	0	0	-133	-133	133	133
Shear from V_2			133	133	-133	-133	0	0	0	0
Total Shear stress			1,992	1,992	1,726	1,726	1,726	1,726	1,992	1,992
Combined stress (P_L+P_b+Q)			8,292	16,661	15,901	8,841	8,134	16,489	16,083	9,029

Notes: (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

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 448.26*3.8125 / (2*0.5) - 4{,}100 / (\pi*(4.3125^2 - 3.8125^2)) + 249{,}637*4.3125 / 105.7162$
$= 11{,}571$ 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 = 17,100 psi)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (4{,}400^2 + 4{,}400^2)^{0.5} / (\pi*3.8125*0.5)$
$= 1{,}039$ psi

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 529{,}560 / (2*\pi*3.8125^2*0.5)$
$= 11{,}597$ psi

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$

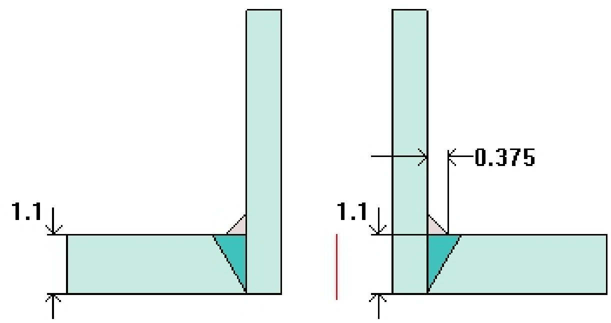
= 1,039 + 11,597
= 12,636 psi

UG-45: The total combined shear stress (12,636psi) is greater than the allowable ($0.7*S_n$ = 0.7*17,100 = 11,970 psi)

N18 NPS 2 RFLWN(0.655"wt) HC liquid Outlet Nozzle (N18)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda

$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.375 in



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Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Cylinder #6
Orientation:	335°
Nozzle center line offset to datum line:	4 in
End of nozzle to shell center:	65 in
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	5.745 in
Projection available outside vessel to flange face, Lf:	6.625 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange

Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.1 - 0))
= 2.755 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*(1.1 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1 / (19,600*1 - 0.6*379.7331)
= 0.0196 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

= 379.7331*57.275 / (20,000*1 - 0.6*379.7331)
= 1.1 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 = 0.655 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
= 379.7331*1 / (19,600*1 - 0.6*379.7331) + 0
= 0.0196 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0196 , 0]
= 0.0196 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 379.7331*57.275 / (20,000*1 - 0.6*379.7331) + 0
= 1.1 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.1 , 0.0625]
= 1.1 in

t_b = min[t_{b3} , t_{b1}]
= min[0.189 , 1.1]
= 0.189 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0196 , 0.189]
= 0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N35 NPS 2 RFLWN(0.655"wt) Steam Out Nozzle (N35)

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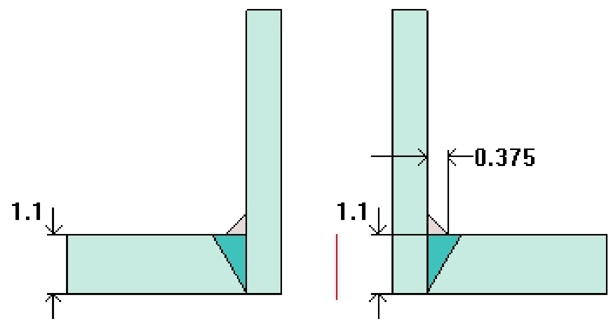

$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.375 in

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #6
Orientation:	310°
Nozzle center line offset to datum line:	5 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	7.12 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in

Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.1 - 0))
= 2.755 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*(1.1 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1 / (19,600*1 - 0.6*379.7331)
= 0.0196 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

=	379.7331*57.275 / (20,000*1 - 0.6*379.7331)
=	1.1 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 = 0.655 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
	=	379.7331*1 / (19,600*1 - 0.6*379.7331) + 0
	=	0.0196 in
t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.0196 , 0]
	=	0.0196 in
t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	379.7331*57.275 / (20,000*1 - 0.6*379.7331) + 0
	=	1.1 in
t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.1 , 0.0625]
	=	1.1 in
t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.189 , 1.1]
	=	0.189 in
$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.0196 , 0.189]
	=	0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N45A NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45A)

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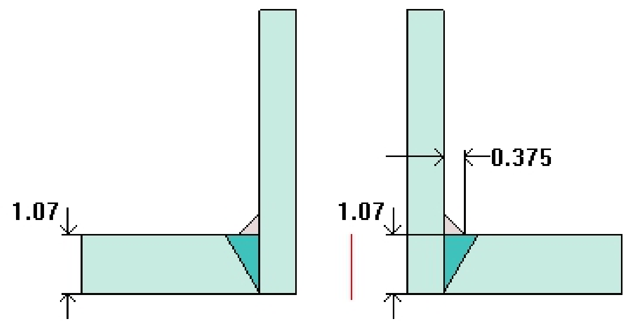
$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #5
Orientation:	350°
Nozzle center line offset to datum line:	124 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No
Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.99 in
Projection available outside vessel to flange face, Lf:	7.87 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	Yes

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 368.54 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.5999	0.655

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})	0.25	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	368.54	700	40,800	900	40,800	900	122,400	**38,256**	**60,000**	**22,167**	**30,000**	No
Load case 1 (Hot Shut Down)	0	700	40,800	900	40,800	900	122,400	-21,408	60,000	-817	30,000	No

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in

Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))

= MAX(2, 1 + (0.655 - 0) + (1.07 - 0))

= 2.725 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*(1.07 - 0), 2.5*(0.655 - 0) + 0)

= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 368.5408*1 / (19,600*1 - 0.6*368.5408)
= 0.019 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 368.5408*57.425 / (20,000*1 - 0.6*368.5408)
= 1.07 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 = 0.655 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
= 368.5408*1 / (19,600*1 - 0.6*368.5408) + 0
= 0.019 in

$t_{a\ UG\text{-}22}$ = 0.5999 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.019 , 0.5999]
= 0.5999 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0
= 1.07 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.07 , 0.0625]
= 1.07 in

t_b = min[t_{b3} , t_{b1}]
= min[0.189 , 1.07]
= 0.189 in

t_{UG-45} = max[t_a , t_b]
= max[0.5999 , 0.189]
= 0.5999 in

Available nozzle wall thickness new, t_n = 0.655 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 =	40,800	lb_f-in
Circumferential shear:	V_c =	900	lb_f
Longitudinal moment:	M_L =	40,800	lb_f-in
Longitudinal shear:	V_L =	900	lb_f
Torsion moment:	M_t =	122,400	lb_f-in
Internal pressure:	P =	368.541	psi
Mean shell radius:	R_m =	57.96	in
Local shell thickness:	t =	1.07	in
Shell yield stress:	S_y =	31,000	psi
Design factor:		3	

Maximum stresses due to the applied loads at the nozzle OD (includes pressure)

$\gamma = R_m / t = 57.96 / 1.07 = 54.1682$

$\beta = 0.875*r_o / R_m = 0.875*1.655 / 57.96 = 0.025$

Pressure stress intensity factor, I = 1.0915 (derived from PVP-Vol. 399, pages 77-82)

Local circumferential pressure stress = $I*P*R_i / t$ =21,588 psi

Local longitudinal pressure stress = $I*P*R_i / (2*t)$ =10,795 psi

Maximum combined stress (P_L+P_b+Q) = 38,256 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) = 22,167 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 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)	10.9353	0	0	0	0	-123	-123	-123	-123
4C*	N_ϕ / (P / R_m)	10.5212	-119	-119	-119	-119	0	0	0	0
1C	M_ϕ / P	0.2538	0	0	0	0	-931	931	-931	931
2C-1	M_ϕ / P	0.2119	-777	777	-777	777	0	0	0	0
3A*	N_ϕ / [M_c / (R_m^2*β)]	0.387	0	0	0	0	-176	-176	176	176
1A	M_ϕ / [M_c / (R_m*β)]	0.1047	0	0	0	0	-15,459	15,459	15,459	-15,459
3B*	N_ϕ / [M_L / (R_m^2*β)]	1.5365	-698	-698	698	698	0	0	0	0
1B-1	M_ϕ / [M_L / (R_m*β)]	0.0632	-9,332	9,332	9,332	-9,332	0	0	0	0
Pressure stress*			21,588	21,588	21,588	21,588	19,779	19,779	19,779	19,779
Total circumferential stress			10,662	30,880	30,722	13,612	3,090	35,870	34,360	5,304
Primary membrane circumferential stress*			20,771	20,771	22,167	22,167	19,480	19,480	19,832	19,832
3C*	N_x / (P / R_m)	10.9353	-123	-123	-123	-123	0	0	0	0
4C*	N_x / (P / R_m)	10.5212	0	0	0	0	-119	-119	-119	-119
1C-1	M_x / P	0.2551	-936	936	-936	936	0	0	0	0
2C	M_x / P	0.2032	0	0	0	0	-745	745	-745	745
4A*	N_x / [M_c / (R_m^2*β)]	0.4676	0	0	0	0	-212	-212	212	212
2A	M_x / [M_c / (R_m*β)]	0.0638	0	0	0	0	-9,420	9,420	9,420	-9,420
4B*	N_x / [M_L / (R_m^2*β)]	0.4085	-186	-186	186	186	0	0	0	0
2B-1	M_x / [M_L / (R_m*β)]	0.1066	-15,740	15,740	15,740	-15,740	0	0	0	0
Pressure stress*			9,890	9,890	9,890	9,890	10,795	10,795	10,795	10,795
Total longitudinal stress			-7,095	26,257	24,757	-4,851	299	20,629	19,563	2,213
Primary membrane longitudinal stress*			9,581	9,581	9,953	9,953	10,464	10,464	10,888	10,888
Shear from M_t			6,647	6,647	6,647	6,647	6,647	6,647	6,647	6,647
Circ shear from V_c			162	162	-162	-162	0	0	0	0
Long shear from V_L			0	0	0	0	-162	-162	162	162
Total Shear stress			6,809	6,809	6,485	6,485	6,485	6,485	6,809	6,809
Combined stress (P_L+P_b+Q)			22,378	35,759	34,877	22,563	13,267	38,256	37,016	13,964

Note: * denotes primary stress.

Longitudinal stress in the nozzle wall due to internal pressure + external loads

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 368.54*1 / (2*0.655) - 700 / (\pi*(1.655^2 - 1^2)) + 57{,}699.9*1.655 / 5.1069$
= 18,852 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 = 19,600 psi)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (900^2 + 900^2)^{0.5} / (\pi*1*0.655)$
= 619 psi

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 122{,}400 / (2*\pi*1^2*0.655)$

= 29,741 psi

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 619 + 29,741
= 30,360 psi

UG-45: The total combined shear stress (30,360psi) is greater than the allowable (0.7*S_n = 0.7*19,600 = 13,720 psi)

N45B NPS 2 RFLWN(0.655"wt) LG-1012 Nozzle (N45B)

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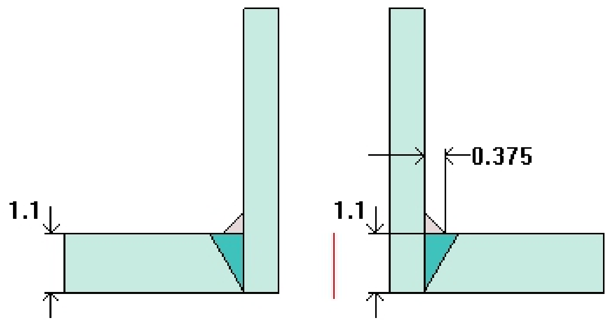

$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.375 in

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #6
Orientation:	350°
Nozzle center line offset to datum line:	10 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	7.12 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.1 - 0))
= 2.755 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*(1.1 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1 / (19,600*1 - 0.6*379.7331)
= 0.0196 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

$= \quad 379.7331*57.275 / (20{,}000*1 - 0.6*379.7331)$

$= \quad 1.1$ 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 = 0.655 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

$$t_{a\ UG\text{-}27} = P*R / (S*E - 0.6*P) + \text{Corrosion}$$
$$= 379.7331*1 / (19{,}600*1 - 0.6*379.7331) + 0$$
$$= 0.0196 \text{ in}$$

$$t_a = \max[\, t_{a\ UG\text{-}27} , t_{a\ UG\text{-}22} \,]$$
$$= \max[\, 0.0196 , 0 \,]$$
$$= 0.0196 \text{ in}$$

$$t_{b1} = P*R / (S*E - 0.6*P) + \text{Corrosion}$$
$$= 379.7331*57.275 / (20{,}000*1 - 0.6*379.7331) + 0$$
$$= 1.1 \text{ in}$$

$$t_{b1} = \max[\, t_{b1} , t_{b\ UG16} \,]$$
$$= \max[\, 1.1 , 0.0625 \,]$$
$$= 1.1 \text{ in}$$

$$t_b = \min[\, t_{b3} , t_{b1} \,]$$
$$= \min[\, 0.189 , 1.1 \,]$$
$$= 0.189 \text{ in}$$

$$t_{UG\text{-}45} = \max[\, t_a , t_b \,]$$
$$= \max[\, 0.0196 , 0.189 \,]$$
$$= 0.189 \text{ in}$$

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N46A NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46A)

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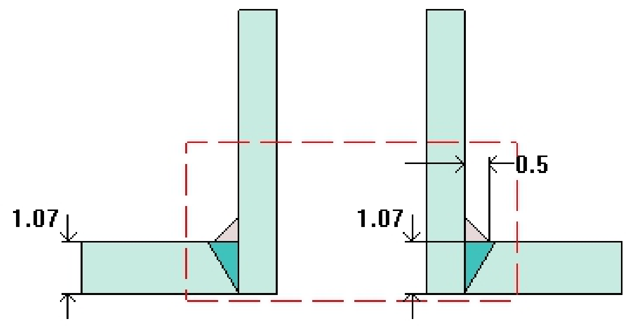

$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.5 in

.

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #5
Orientation:	325°
Nozzle center line offset to datum line:	118 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	3 in
Nominal wall thickness:	0.81 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.75 in
Projection available outside vessel to flange face, Lf:	7.87 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange	
Description:	NPS 3 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	Yes

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 368.54 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
3.2447	3.3468	--	3.1018	--	--	0.245	0.2258	0.81

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	0.35	weld size is adequate

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3, 1.5 + (0.81 - 0) + (1.07 - 0))
= 3.38 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*(1.07 - 0), 2.5*(0.81 - 0) + 0)
= 2.025 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 368.5408*1.5 / (19,600*1 - 0.6*368.5408)
= 0.0285 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 368.5408*57.425 / (20,000*1 - 0.6*368.5408)

$= \quad 1.07$ in

Area required per UG-37(c)

Allowable stresses: S_n = 19,600, S_v = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.98

f_{r2} = lesser of 1 or S_n / S_v = 0.98

$$\begin{aligned} A &= d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}) \\ &= 3*1.07*1 + 2*0.81*1.07*1*(1 - 0.98) \\ &= \underline{3.2447} \text{ in}^2 \end{aligned}$$

Area available from FIG. UG-37.1

A_1 = larger of the following= $\underline{0}$ in^2

$$\begin{aligned} &= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\ &= 3*(1*1.07 - 1*1.07) - 2*0.81*(1*1.07 - 1*1.07)*(1 - 0.98) \\ &= 0 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} &= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\ &= 2*(1.07 + 0.81)*(1*1.07 - 1*1.07) - 2*0.81*(1*1.07 - 1*1.07)*(1 - 0.98) \\ &= 0 \text{ in}^2 \end{aligned}$$

A_2 = smaller of the following= $\underline{3.1018}$ in^2

$$\begin{aligned} &= 5*(t_n - t_{rn})*f_{r2}*t \\ &= 5*(0.81 - 0.0285)*0.98*1.07 \\ &= 4.0974 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} &= 5*(t_n - t_{rn})*f_{r2}*t_n \\ &= 5*(0.81 - 0.0285)*0.98*0.81 \\ &= 3.1018 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} A_{41} &= Leg^2*f_{r2} \\ &= 0.5^2*0.98 \\ &= \underline{0.245} \text{ in}^2 \end{aligned}$$

$$\begin{aligned} \text{Area} &= A_1 + A_2 + A_{41} \\ &= 0 + 3.1018 + 0.245 \\ &= \underline{3.3468} \text{ in}^2 \end{aligned}$$

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 = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 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
	=	368.5408*1.5 / (19,600*1 - 0.6*368.5408) + 0
	=	0.0285 in
t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.0285 , 0]
	=	0.0285 in
t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0
	=	1.07 in
t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.07 , 0.0625]
	=	1.07 in
t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.2258 , 1.07]
	=	0.2258 in
$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.0285 , 0.2258]
	=	0.2258 in

Available nozzle wall thickness new, t_n = 0.81 in

The nozzle neck thickness is adequate.

N46B NPS 3 RFLWN(0.810"wt) LT-17 Nozzle (N46B)

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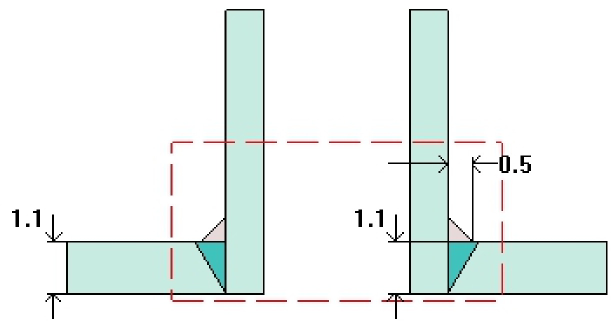
$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.5 in



Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Cylinder #6
Orientation:	325°
Nozzle center line offset to datum line:	13 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	3 in
Nominal wall thickness:	0.81 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.88 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange

Description:	NPS 3 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
3.3356	3.3432	--	3.0982	--	--	0.245	0.2258	0.81

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	0.35	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3, 1.5 + (0.81 - 0) + (1.1 - 0))
= 3.41 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*(1.1 - 0), 2.5*(0.81 - 0) + 0)
= 2.025 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1.5 / (19,600*1 - 0.6*379.7331)
= 0.0294 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 379.7331*57.275 / (20,000*1 - 0.6*379.7331)

$= \quad 1.1$ in

Area required per UG-37(c)

Allowable stresses: S_n = 19,600, S_v = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.98

f_{r2} = lesser of 1 or S_n / S_v = 0.98

$$
\begin{aligned}
A &= d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}) \\
&= 3*1.1*1 + 2*0.81*1.1*1*(1 - 0.98) \\
&= 3.3356 \text{ in}^2
\end{aligned}
$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

$$
\begin{aligned}
&= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\
&= 3*(1*1.1 - 1*1.1) - 2*0.81*(1*1.1 - 1*1.1)*(1 - 0.98) \\
&= 0 \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
&= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\
&= 2*(1.1 + 0.81)*(1*1.1 - 1*1.1) - 2*0.81*(1*1.1 - 1*1.1)*(1 - 0.98) \\
&= 0 \text{ in}^2
\end{aligned}
$$

A_2 = smaller of the following= 3.0982 in^2

$$
\begin{aligned}
&= 5*(t_n - t_{rn})*f_{r2}*t \\
&= 5*(0.81 - 0.0294)*0.98*1.1 \\
&= 4.2074 \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
&= 5*(t_n - t_{rn})*f_{r2}*t_n \\
&= 5*(0.81 - 0.0294)*0.98*0.81 \\
&= 3.0982 \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
A_{41} &= Leg^2*f_{r2} \\
&= 0.5^2*0.98 \\
&= 0.245 \text{ in}^2
\end{aligned}
$$

$$
\begin{aligned}
\text{Area} &= A_1 + A_2 + A_{41} \\
&= 0 + 3.0982 + 0.245 \\
&= 3.3432 \text{ in}^2
\end{aligned}
$$

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 = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 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
	=	379.7331*1.5 / (19,600*1 - 0.6*379.7331) + 0
	=	0.0294 in
t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.0294 , 0]
	=	0.0294 in
t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	379.7331*57.275 / (20,000*1 - 0.6*379.7331) + 0
	=	1.1 in
t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.1 , 0.0625]
	=	1.1 in
t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.2258 , 1.1]
	=	0.2258 in
$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.0294 , 0.2258]
	=	0.2258 in

Available nozzle wall thickness new, t_n = 0.81 in

The nozzle neck thickness is adequate.

N47A NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47A)

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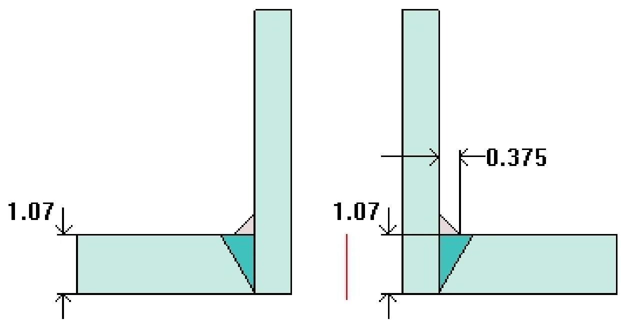

$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.375 in

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #5
Orientation:	300°
Nozzle center line offset to datum line:	117.375 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.99 in
Projection available outside vessel to flange face, Lf:	7.87 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	Yes
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	Yes

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

<table>
<tr><td colspan="7">UG-37 Area Calculation Summary (in^2)
For P = 368.54 psi @ 500 °F</td><td colspan="2">UG-45 Nozzle Wall Thickness Summary (in)
The nozzle passes UG-45</td></tr>
<tr><td>A required</td><td>A available</td><td>A_1</td><td>A_2</td><td>A_3</td><td>A_5</td><td>A welds</td><td>t_{req}</td><td>t_{min}</td></tr>
<tr><td colspan="7">This nozzle is exempt from area calculations per UG-36(c)(3)(a)</td><td>0.189</td><td>0.655</td></tr>
</table>

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

<table>
<tr><td colspan="4">UW-16 Weld Sizing Summary</td></tr>
<tr><td>Weld description</td><td>Required weld throat size (in)</td><td>Actual weld throat size (in)</td><td>Status</td></tr>
<tr><td>Nozzle to shell fillet (Leg_{41})</td><td>0.25</td><td>0.2625</td><td>weld size is adequate</td></tr>
</table>

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.07 - 0))
= 2.725 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*(1.07 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 368.5408*1 / (19,600*1 - 0.6*368.5408)
= 0.019 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

= 368.5408*57.425 / (20,000*1 - 0.6*368.5408)
= 1.07 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 = 0.655 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
	=	368.5408*1 / (19,600*1 - 0.6*368.5408) + 0
	=	0.019 in
t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.019 , 0]
	=	0.019 in
t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0
	=	1.07 in
t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.07 , 0.0625]
	=	1.07 in
t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.189 , 1.07]
	=	0.189 in
$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.019 , 0.189]
	=	0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N47B NPS 2 RFLWN(0.655"wt) LSH-48 Nozzle (N47B)

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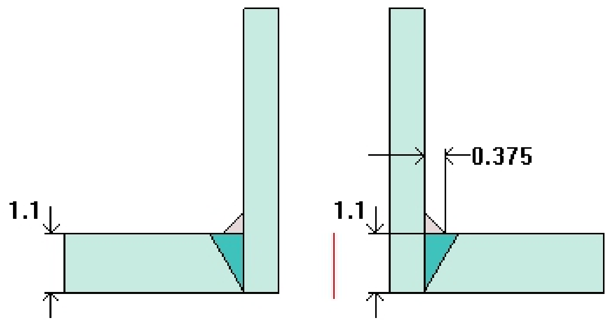
$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #6
Orientation:	300°
Nozzle center line offset to datum line:	101.375 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No
Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	7.12 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Blind included:	Yes
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.1 - 0))
= 2.755 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*(1.1 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1 / (19,600*1 - 0.6*379.7331)
= 0.0196 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

$= 379.7331*57.275 / (20,000*1 - 0.6*379.7331)$
$= 1.1$ 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 = 0.655 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
= 379.7331*1 / (19,600*1 - 0.6*379.7331) + 0
= 0.0196 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0196 , 0]
= 0.0196 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 379.7331*57.275 / (20,000*1 - 0.6*379.7331) + 0
= 1.1 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.1 , 0.0625]
= 1.1 in

t_b = min[t_{b3} , t_{b1}]
= min[0.189 , 1.1]
= 0.189 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0196 , 0.189]
= 0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N48A NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48A)

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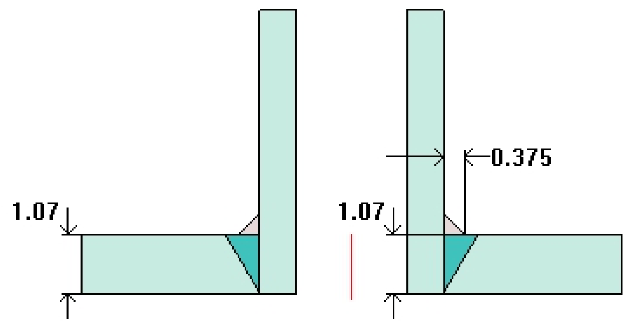
$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #5
Orientation:	220°
Nozzle center line offset to datum line:	124 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No
Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.99 in
Projection available outside vessel to flange face, Lf:	7.87 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	Yes

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 368.54 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in

Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))

= MAX(2, 1 + (0.655 - 0) + (1.07 - 0))

= 2.725 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*(1.07 - 0), 2.5*(0.655 - 0) + 0)

= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)

= 368.5408*1 / (19,600*1 - 0.6*368.5408)

= 0.019 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

$= 368.5408*57.425 / (20,000*1 - 0.6*368.5408)$
$= 1.07$ 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 = 0.655 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
= 368.5408*1 / (19,600*1 - 0.6*368.5408) + 0
= 0.019 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.019 , 0]
= 0.019 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0
= 1.07 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.07 , 0.0625]
= 1.07 in

t_b = min[t_{b3} , t_{b1}]
= min[0.189 , 1.07]
= 0.189 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.019 , 0.189]
= 0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N48B NPS 2 RFLWN(0.655"wt) LG-105 Nozzle (N48B)

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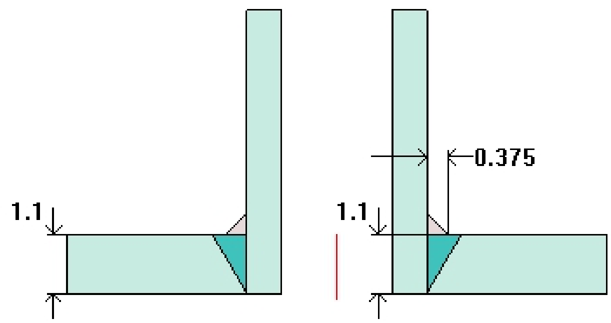
$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Cylinder #6
Orientation:	220°
Nozzle center line offset to datum line:	3 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10) (normalized)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	7.12 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange

Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.1 - 0))
= 2.755 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*(1.1 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1 / (19,600*1 - 0.6*379.7331)
= 0.0196 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

$= 379.7331*57.275 / (20{,}000*1 - 0.6*379.7331)$

$= 1.1$ 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 = 0.655 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
= 379.7331*1 / (19,600*1 - 0.6*379.7331) + 0
= 0.0196 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0196 , 0]
= 0.0196 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 379.7331*57.275 / (20,000*1 - 0.6*379.7331) + 0
= 1.1 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.1 , 0.0625]
= 1.1 in

t_b = min[t_{b3} , t_{b1}]
= min[0.189 , 1.1]
= 0.189 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0196 , 0.189]
= 0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N49A NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49A)

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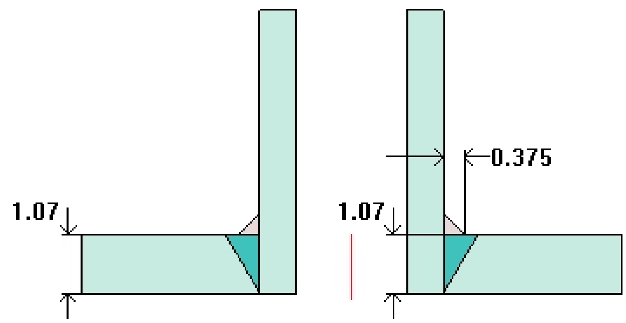
$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #5
Orientation:	180°
Nozzle center line offset to datum line:	139 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.99 in
Projection available outside vessel to flange face, Lf:	7.87 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	Yes

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 368.54 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in

Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.07 - 0))
= 2.725 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*(1.07 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 368.5408*1 / (19,600*1 - 0.6*368.5408)
= 0.019 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

$=$ 368.5408*57.425 / (20,000*1 - 0.6*368.5408)
$=$ 1.07 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 = 0.655 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
	=	368.5408*1 / (19,600*1 - 0.6*368.5408) + 0
	=	0.019 in
t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.019 , 0]
	=	0.019 in
t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0
	=	1.07 in
t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.07 , 0.0625]
	=	1.07 in
t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.189 , 1.07]
	=	0.189 in
$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.019 , 0.189]
	=	0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N49B NPS 2 RFLWN(0.655"wt) LI-1011 Nozzle (N49B)

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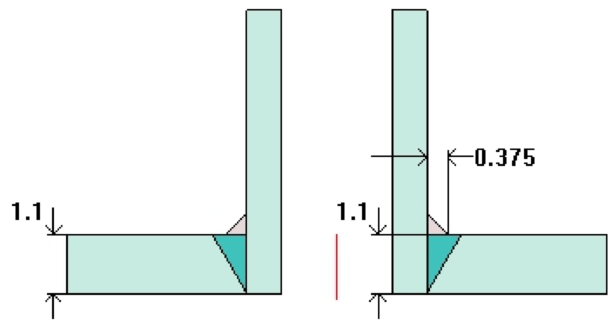
$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #6
Orientation:	180°
Nozzle center line offset to datum line:	3 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No
Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	7.12 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in

Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.1 - 0))
= 2.755 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*(1.1 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1 / (19,600*1 - 0.6*379.7331)
= 0.0196 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

$= 379.7331*57.275 / (20,000*1 - 0.6*379.7331)$
$= 1.1$ 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 = 0.655 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

$$t_{a\ UG\text{-}27} = P*R / (S*E - 0.6*P) + Corrosion$$
$$= 379.7331*1 / (19,600*1 - 0.6*379.7331) + 0$$
$$= 0.0196 \text{ in}$$

$$t_a = \max[\ t_{a\ UG\text{-}27}\ ,\ t_{a\ UG\text{-}22}\ ]$$
$$= \max[\ 0.0196\ ,\ 0\ ]$$
$$= 0.0196 \text{ in}$$

$$t_{b1} = P*R / (S*E - 0.6*P) + Corrosion$$
$$= 379.7331*57.275 / (20,000*1 - 0.6*379.7331) + 0$$
$$= 1.1 \text{ in}$$

$$t_{b1} = \max[\ t_{b1}\ ,\ t_{b\ UG16}\ ]$$
$$= \max[\ 1.1\ ,\ 0.0625\ ]$$
$$= 1.1 \text{ in}$$

$$t_b = \min[\ t_{b3}\ ,\ t_{b1}\ ]$$
$$= \min[\ 0.189\ ,\ 1.1\ ]$$
$$= 0.189 \text{ in}$$

$$t_{UG\text{-}45} = \max[\ t_a\ ,\ t_b\ ]$$
$$= \max[\ 0.0196\ ,\ 0.189\ ]$$
$$= 0.189 \text{ in}$$

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N50A NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50A)

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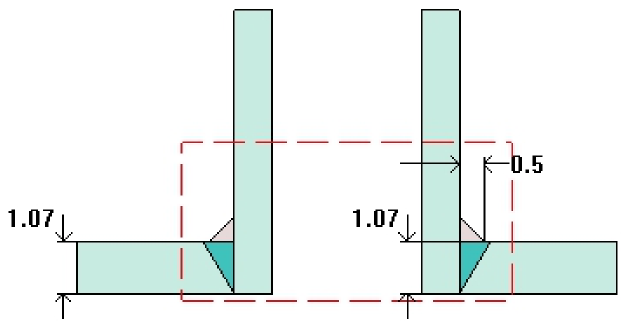

$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.5 in

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #5
Orientation:	285°
Nozzle center line offset to datum line:	124 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No
Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	3 in
Nominal wall thickness:	0.81 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.75 in
Projection available outside vessel to flange face, Lf:	7.87 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 3 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	Yes

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 368.54 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
3.2447	3.3468	--	3.1018	--	--	0.245	0.2258	0.81

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	0.35	weld size is adequate

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in

Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3, 1.5 + (0.81 - 0) + (1.07 - 0))
= 3.38 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*(1.07 - 0), 2.5*(0.81 - 0) + 0)
= 2.025 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 368.5408*1.5 / (19,600*1 - 0.6*368.5408)
= 0.0285 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 368.5408*57.425 / (20,000*1 - 0.6*368.5408)

= 1.07 in

Area required per UG-37(c)

Allowable stresses: S_n = 19,600, S_v = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.98

f_{r2} = lesser of 1 or S_n / S_v = 0.98

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= 3*1.07*1 + 2*0.81*1.07*1*(1 - 0.98)
= 3.2447 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*(1*1.07 - 1*1.07) - 2*0.81*(1*1.07 - 1*1.07)*(1 - 0.98)
= 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*(1.07 + 0.81)*(1*1.07 - 1*1.07) - 2*0.81*(1*1.07 - 1*1.07)*(1 - 0.98)
= 0 in^2

A_2 = smaller of the following= 3.1018 in^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= 5*(0.81 - 0.0285)*0.98*1.07
= 4.0974 in^2

= $5*(t_n - t_{rn})*f_{r2}*t_n$
= 5*(0.81 - 0.0285)*0.98*0.81
= 3.1018 in^2

A_{41} = Leg^2*f_{r2}
= $0.5^2*0.98$
= 0.245 in^2

Area = $A_1 + A_2 + A_{41}$
= 0 + 3.1018 + 0.245
= 3.3468 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 = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 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
	=	368.5408*1.5 / (19,600*1 - 0.6*368.5408) + 0
	=	0.0285 in
t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.0285 , 0]
	=	0.0285 in
t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0
	=	1.07 in
t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.07 , 0.0625]
	=	1.07 in
t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.2258 , 1.07]
	=	0.2258 in
$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.0285 , 0.2258]
	=	0.2258 in

Available nozzle wall thickness new, t_n = 0.81 in

The nozzle neck thickness is adequate.

N50B NPS 3 RFLWN(0.81"wt) LT-16 Nozzle (N50B)

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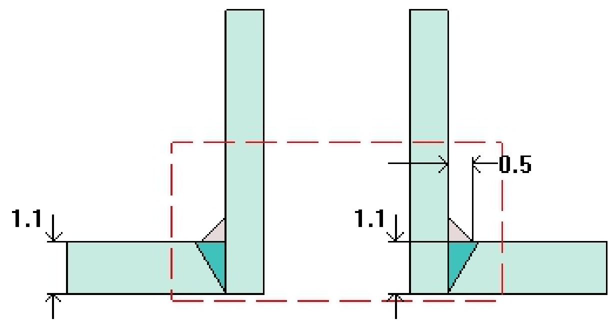

$t_{w(lower)}$ = 1.1 in
Leg_{41} = 0.5 in

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #6
Orientation:	285°
Nozzle center line offset to datum line:	5 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No
Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	3 in
Nominal wall thickness:	0.81 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.88 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.1 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 3 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 379.73 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
3.3356	3.3432	--	3.0982	--	--	0.245	0.2258	0.81

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	0.35	weld size is adequate

Calculations for internal pressure 379.73 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(3, 1.5 + (0.81 - 0) + (1.1 - 0))
= 3.41 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*(1.1 - 0), 2.5*(0.81 - 0) + 0)
= 2.025 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 379.7331*1.5 / (19,600*1 - 0.6*379.7331)
= 0.0294 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 379.7331*57.275 / (20,000*1 - 0.6*379.7331)

= 1.1 in

Area required per UG-37(c)

Allowable stresses: S_n = 19,600, S_v = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.98

f_{r2} = lesser of 1 or S_n / S_v = 0.98

$A = d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
$= 3*1.1*1 + 2*0.81*1.1*1*(1 - 0.98)$
$=$ 3.3356 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 in^2

$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= 3*(1*1.1 - 1*1.1) - 2*0.81*(1*1.1 - 1*1.1)*(1 - 0.98)$
$= 0\ in^2$

$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= 2*(1.1 + 0.81)*(1*1.1 - 1*1.1) - 2*0.81*(1*1.1 - 1*1.1)*(1 - 0.98)$
$= 0\ in^2$

A_2 = smaller of the following= 3.0982 in^2

$= 5*(t_n - t_{rn})*f_{r2}*t$
$= 5*(0.81 - 0.0294)*0.98*1.1$
$= 4.2074\ in^2$

$= 5*(t_n - t_{rn})*f_{r2}*t_n$
$= 5*(0.81 - 0.0294)*0.98*0.81$
$= 3.0982\ in^2$

$A_{41} = Leg^2*f_{r2}$
$= 0.5^2*0.98$
$=$ 0.245 in^2

$Area = A_1 + A_2 + A_{41}$
$= 0 + 3.0982 + 0.245$
$=$ 3.3432 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 = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 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
= 379.7331*1.5 / (19,600*1 - 0.6*379.7331) + 0
= 0.0294 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0294 , 0]
= 0.0294 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 379.7331*57.275 / (20,000*1 - 0.6*379.7331) + 0
= 1.1 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.1 , 0.0625]
= 1.1 in

t_b = min[t_{b3} , t_{b1}]
= min[0.2258 , 1.1]
= 0.2258 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0294 , 0.2258]
= 0.2258 in

Available nozzle wall thickness new, t_n = 0.81 in

The nozzle neck thickness is adequate.

N51A NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51A)

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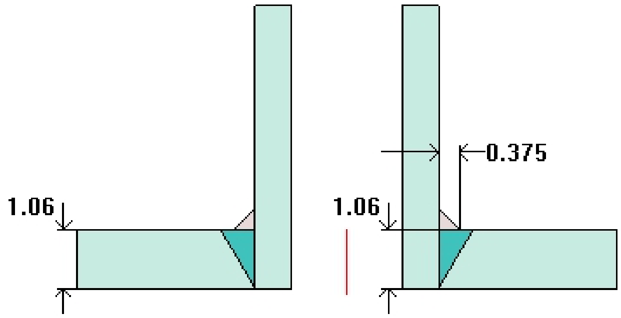
$t_{w(lower)}$ = 1.06 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on:	Cylinder #1
Orientation:	30°
Nozzle center line offset to datum line:	652 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No
Nozzle	
Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	7.12 in
Projection available outside vessel to flange face, Lf:	8 in
User input vessel thickness:	1.06 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	No

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 365.83 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 365.83 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.06 - 0))
= 2.715 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*(1.06 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 365.8266*1 / (19,600*1 - 0.6*365.8266)
= 0.0189 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

= 365.8266*57.315 / (20,000*1 - 0.6*365.8266)
= 1.06 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 = 0.655 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
= 365.8266*1 / (19,600*1 - 0.6*365.8266) + 0
= 0.0189 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0189 , 0]
= 0.0189 in

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 365.8266*57.315 / (20,000*1 - 0.6*365.8266) + 0
= 1.06 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.06 , 0.0625]
= 1.06 in

t_b = min[t_{b3} , t_{b1}]
= min[0.189 , 1.06]
= 0.189 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0189 , 0.189]
= 0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N51B NPS 2 RFLWN(0.655"wt) PDT-118 Nozzle (N51B)

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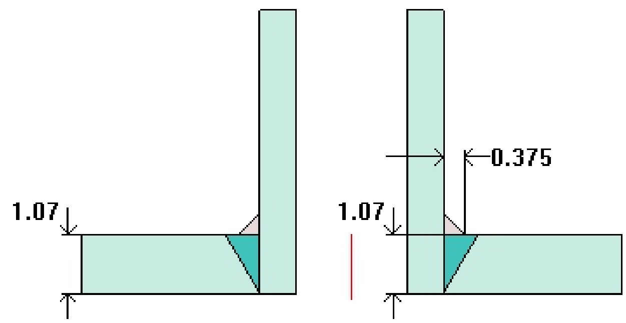
$t_{w(lower)}$ = 1.07 in
Leg_{41} = 0.375 in



Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Cylinder #5
Orientation:	135°
Nozzle center line offset to datum line:	172 in
End of nozzle to shell center:	66.375 in
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-350 LF2 Cl 1 (II-D p. 18, ln. 10)
Inside diameter, new:	2 in
Nominal wall thickness:	0.655 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	6.99 in
Projection available outside vessel to flange face, Lf:	7.87 in
User input vessel thickness:	1.07 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange

Description:	NPS 2 Class 300 LWN A350 LF2 Cl.1
Bolt Material:	SA-193 B7M Bolt <= 2 1/2 (II-D p. 334, ln. 29)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel

PWHT performed:	Yes

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 368.54 psi @ 500 °F							UG-45 Nozzle Wall Thickness Summary (in) 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)							0.189	0.655

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})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 368.54 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(2, 1 + (0.655 - 0) + (1.07 - 0))
= 2.725 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*(1.07 - 0), 2.5*(0.655 - 0) + 0)
= 1.6375 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 368.5408*1 / (19,600*1 - 0.6*368.5408)
= 0.019 in

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)

= 368.5408*57.425 / (20,000*1 - 0.6*368.5408)
= 1.07 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 = 0.655 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
	=	368.5408*1 / (19,600*1 - 0.6*368.5408) + 0
	=	0.019 in
t_a	=	max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
	=	max[0.019 , 0]
	=	0.019 in
t_{b1}	=	P*R / (S*E - 0.6*P) + Corrosion
	=	368.5408*57.425 / (20,000*1 - 0.6*368.5408) + 0
	=	1.07 in
t_{b1}	=	max[t_{b1} , $t_{b\ UG16}$]
	=	max[1.07 , 0.0625]
	=	1.07 in
t_b	=	min[t_{b3} , t_{b1}]
	=	min[0.189 , 1.07]
	=	0.189 in
$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[0.019 , 0.189]
	=	0.189 in

Available nozzle wall thickness new, t_n = 0.655 in

The nozzle neck thickness is adequate.

N6 NPS 6 RFWN(0.432"wt) S/80 Purge Nozzle (N6)

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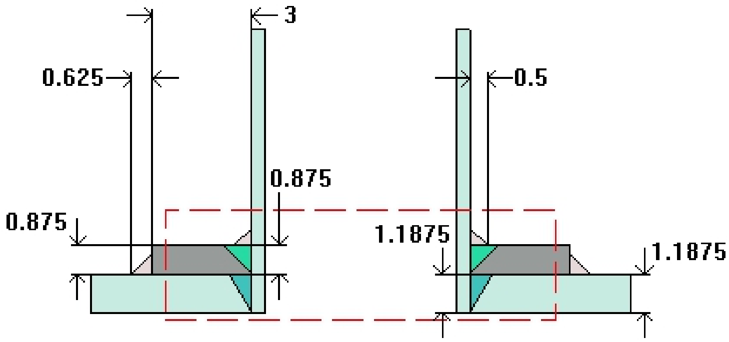


$t_{w(lower)}$ =	1.1875 in
Leg_{41} =	0.5 in
$t_{w(upper)}$ =	0.875 in
Leg_{42} =	0.625 in
D_p =	13.0069 in
t_e =	0.875 in

Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Top Ellipsoidal Head #1
Orientation:	90°
End of nozzle to datum line:	722.5025 in
Calculated as hillside:	Yes
Distance to head center, R:	33 in
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Description:	NPS 6 Sch 80 (XS)
Inside diameter, new:	5.761 in
Nominal wall thickness:	0.432 in
Corrosion allowance:	0 in
Opening chord length:	6.1096 in
Projection available outside vessel, Lpr:	11.0141 in
Projection available outside vessel to flange face, Lf:	14.8941 in
User input vessel thickness:	1.1875 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Diameter:	13.0069 in
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 6 Class 300 WN A105

Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 415.78 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
6.6779	6.678	0.6969	1.2065	--	4.5608	0.2138	0.3878	0.432

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
121,339.84	119,621.25	175,444.62	45,950.6	361,257.33	137,165.85	308,035.73

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.35	weld size is adequate
Pad to shell fillet (Leg_{42})	0.375	0.4375	weld size is adequate
Nozzle to pad groove (Upper)	0.3024	0.875	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_1 (lb_f-in)	V_1 (lb_f)	M_2 (lb_f-in)	V_2 (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	415.78	2,900	126,000	3,200	126,000	3,200	378,000	**28,141**	**60,000**	**18,925**	**30,000**	No
Load case 1 (Hot Shut Down)	0	2,900	126,000	3,200	126,000	3,200	378,000	-12,296	60,000	-1,334	30,000	No

Calculations for internal pressure 415.78 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F
Pad rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(6.1096, 3.0548 + (0.432 - 0) + (1.1875 - 0))
= 6.1096 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*(1.1875 - 0), 2.5*(0.432 - 0) + 0.875)
= 1.955 in

Nozzle required thickness per UG-27(c)(1)

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 415.7817*2.8805 / (17,100*1 - 0.6*415.7817)
= 0.0711 in

Required thickness t_r from UG-37(a)(c)

t_r = P*K_1*D / (2*S*E - 0.2*P)
= 415.7817*0.9*114.25 / (2*20,000*1 - 0.2*415.7817)
= 1.0711 in

Area required per UG-37(c)

Allowable stresses: S_n = 17,100, S_v = 20,000, S_p = 20,000 psi

f_{r1} = lesser of 1 or S_n / S_v = 0.855

f_{r2} = lesser of 1 or S_n / S_v = 0.855

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.855

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})
= 6.1096*1.0711*1 + 2*0.432*1.0711*1*(1 - 0.855)
= 6.6779 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.6969 in^2

= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= 6.1096*(1*1.1875 - 1*1.0711) - 2*0.432*(1*1.1875 - 1*1.0711)*(1 - 0.855)
= 0.6969 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*(1.1875 + 0.432)*(1*1.1875 - 1*1.0711) - 2*0.432*(1*1.1875 - 1*1.0711)*(1 - 0.855)
= 0.3626 in^2

A_2 = smaller of the following= 1.2065 in^2

= 5*(t_n - t_{rn})*f_{r2}*t

$= 5*(0.432 - 0.0711)*0.855*1.1875$
$= 1.8321\ in^2$

$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
$= 2*(0.432 - 0.0711)*(2.5*0.432 + 0.875)*0.855$
$= 1.2065\ in^2$

$A_{41} = Leg^2*f_{r3}$
$= 0.5^2*0.855$
$= 0.2138\ in^2$

$A_{42} = Leg^2*f_{r4}$
$= 0^2*1$
$= 0\ in^2$

(Part of the weld is outside of the limits)

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= (12.2192 - 7.0069)*0.875*1$
$= 4.5608\ in^2$

$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$
$= 0.6969 + 1.2065 + 0.2138 + 0 + 4.5608$
$= 6.678\ in^2$

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 = 0.432 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.5 = 0.35 in

Outer fillet: t_{min} = lesser of 0.75 or t_e or t = 0.75 in
$t_{w(min)}$ = $0.5*t_{min}$ = 0.375 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.625 = 0.4375 in

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27} = P*R / (S*E - 0.6*P) + Corrosion$
$= 415.7817*2.8805 / (17{,}100*1 - 0.6*415.7817) + 0$
$= 0.0711\ in$

$t_{a\ UG\text{-}22}$ = 0.3878 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0711 , 0.3878]
= 0.3878 in

t_{b1} = 1.1901 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.1901 , 0.0625]
= 1.1901 in

t_b = min[t_{b3} , t_{b1}]
= min[0.245 , 1.1901]
= 0.245 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.3878 , 0.245]
= 0.3878 in

Available nozzle wall thickness new, t_n = 0.432 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*17,100 =	11,970 psi
Inner fillet weld in shear:	0.49*17,100 =	8,379 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)*6.625*0.5*8,379 = 43,598.14 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*13.0069*0.625*9,800 = 125,141.04 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*6.193*0.432*11,970 = 50,303.58 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*6.625*1.1875*14,800 = 182,894.69 lb_f

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*6.625*0.875*14,800 = 134,764.51 lb_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 * t_n * f_{r1} * (E_1 * t - F * t_r)) * S_v$
= (6.6779 - 0.6969 + 2*0.432*0.855*(1*1.1875 - 1*1.0711))*20,000

$= \underline{121,339.84}\ lb_f$

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (1.2065 + 4.5608 + 0.2138 + 0)*20,000$
$= \underline{119,621.25}\ lb_f$

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (1.2065 + 0 + 0.2138 + 0 + 2*0.432*1.1875*0.855)*20,000$
$= \underline{45,950.6}\ lb_f$

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (1.2065 + 0 + 4.5608 + 0.2138 + 0 + 0 + 2*0.432*1.1875*0.855)*20,000$
$= \underline{137,165.85}\ lb_f$

Load for path 1-1 lesser of W or W_{1-1} = 119,621.25 lb_f
Path 1-1 through (2) & (3) = 125,141.04 + 50,303.58 = 175,444.62 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} = 45,950.6 lb_f
Path 2-2 through (1), (4), (6) = 43,598.14 + 182,894.69 + 134,764.51 = 361,257.33 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} = 121,339.84 lb_f
Path 3-3 through (2), (4) = 125,141.04 + 182,894.69 = 308,035.73 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 =	2,900	lb_f
Circumferential moment:	M_1 =	126,000	lb_f-in
Circumferential shear:	V_2 =	3,200	lb_f
Longitudinal moment:	M_2 =	126,000	lb_f-in
Longitudinal shear:	V_1 =	3,200	lb_f
Torsion moment:	M_t =	378,000	lb_f-in
Internal pressure:	P =	415.782	psi
Mean dish radius:	R_m =	103.9329	in
Local head thickness:	t =	1.1875	in
Head yield stress:	S_y =	31,000	psi
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$U = r_o / Sqr(R_m*T)$ = 6.3125 / Sqr(103.9329*1.1875) = 0.568

Pressure stress intensity factor, I = 1 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = $I*P*R_i / (2*t)$ =18,091 psi

Maximum combined stress (P_L+P_b+Q) = 28,141 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) = 18,925 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**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.1214	-250	-250	-250	-250	-250	-250	-250	-250
SR-2	M_x / P	0.0728	-898	898	-898	898	-898	898	-898	898
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1348	0	0	0	0	-1,084	-1,084	1,084	1,084
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.2038	0	0	0	0	-9,835	9,835	9,835	-9,835
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1348	-1,084	-1,084	1,084	1,084	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.2038	-9,835	9,835	9,835	-9,835	0	0	0	0
Pressure stress*			18,091	18,091	18,091	18,091	18,091	18,091	18,091	18,091
Total O_x stress			6,024	27,490	27,862	9,988	6,024	27,490	27,862	9,988
Membrane O_x stress*			16,757	16,757	18,925	18,925	16,757	16,757	18,925	18,925
SR-2*	N_y*T / P	0.0359	-74	-74	-74	-74	-74	-74	-74	-74
SR-2	M_y / P	0.0223	-275	275	-275	275	-275	275	-275	275
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0406	0	0	0	0	-327	-327	327	327
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0618	0	0	0	0	-2,982	2,982	2,982	-2,982
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0406	-327	-327	327	327	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0618	-2,982	2,982	2,982	-2,982	0	0	0	0
Pressure stress*			18,091	18,091	18,091	18,091	18,091	18,091	18,091	18,091
Total O_y stress			14,433	20,947	21,051	15,637	14,433	20,947	21,051	15,637
Membrane O_y stress*			17,690	17,690	18,344	18,344	17,690	17,690	18,344	18,344
Shear from M_t			1,271	1,271	1,271	1,271	1,271	1,271	1,271	1,271
Shear from V_1			0	0	0	0	-136	-136	136	136
Shear from V_2			136	136	-136	-136	0	0	0	0
Total Shear stress			1,407	1,407	1,135	1,135	1,135	1,135	1,407	1,407
Combined stress (P_L+P_b+Q)			14,662	27,780	28,046	15,857	14,584	27,681	28,141	15,968

Notes: (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) = 3.3125 / Sqr(103.9329*2.0625) = 0.226

Pressure stress intensity factor, I = 0.4974 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =8,998 psi

Maximum combined stress (P_L+P_b+Q) = 18,457 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) = 9,180 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 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	0.2146	-146	-146	-146	-146	-146	-146	-146	-146
SR-2	M_x / P	0.1768	-723	723	-723	723	-723	723	-723	723
SR-3*	$N_x*T*(R_m*T)^{0.5} / M_1$	0.1621	0	0	0	0	-328	-328	328	328
SR-3	$M_x*(R_m*T)^{0.5} / M_1$	0.6664	0	0	0	0	-8,089	8,089	8,089	-8,089
SR-3*	$N_x*T*(R_m*T)^{0.5} / M_2$	0.1621	-328	-328	328	328	0	0	0	0
SR-3	$M_x*(R_m*T)^{0.5} / M_2$	0.6664	-8,089	8,089	8,089	-8,089	0	0	0	0
Pressure stress*			8,998	8,998	8,998	8,998	8,998	8,998	8,998	8,998
Total O_x stress			-288	17,336	16,546	1,814	-288	17,336	16,546	1,814
Membrane O_x stress*			8,524	8,524	9,180	9,180	8,524	8,524	9,180	9,180
SR-2*	N_y*T / P	0.0664	-45	-45	-45	-45	-45	-45	-45	-45
SR-2	M_y / P	0.0528	-216	216	-216	216	-216	216	-216	216
SR-3*	$N_y*T*(R_m*T)^{0.5} / M_1$	0.049	0	0	0	0	-99	-99	99	99
SR-3	$M_y*(R_m*T)^{0.5} / M_1$	0.194	0	0	0	0	-2,355	2,355	2,355	-2,355
SR-3*	$N_y*T*(R_m*T)^{0.5} / M_2$	0.049	-99	-99	99	99	0	0	0	0
SR-3	$M_y*(R_m*T)^{0.5} / M_2$	0.194	-2,355	2,355	2,355	-2,355	0	0	0	0
Pressure stress*			8,998	8,998	8,998	8,998	8,998	8,998	8,998	8,998
Total O_y stress			6,283	11,425	11,191	6,913	6,283	11,425	11,191	6,913
Membrane O_y stress*			8,854	8,854	9,052	9,052	8,854	8,854	9,052	9,052
Shear from M_t			2,658	2,658	2,658	2,658	2,658	2,658	2,658	2,658
Shear from V_1			0	0	0	0	-149	-149	149	149
Shear from V_2			149	149	-149	-149	0	0	0	0
Total Shear stress			2,807	2,807	2,509	2,509	2,509	2,509	2,807	2,807
Combined stress (P_L+P_b+Q)			8,643	18,457	17,538	7,941	8,268	18,257	17,748	8,155

Notes: (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

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 415.78*2.8805 / (2*0.432) - 2{,}900 / (\pi*(3.3125^2 - 2.8805^2)) + 178{,}190.9*3.3125 / 40.4907$
= 15,619 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 = 17,100 psi)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (3{,}200^2 + 3{,}200^2)^{0.5} / (\pi*2.8805*0.432)$
= 1,158 psi

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 378{,}000 / (2*\pi*2.8805^2*0.432)$
= 16,784 psi

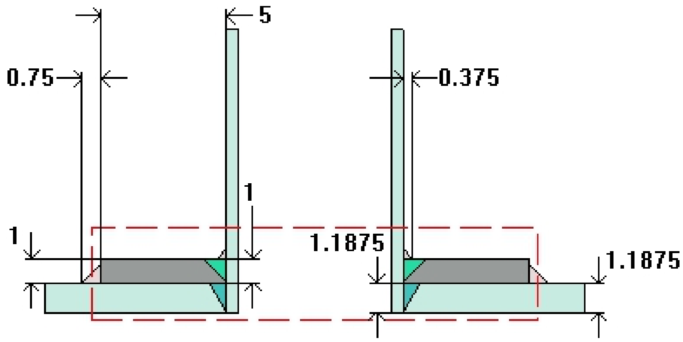
$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$

= 1,158 + 16,784
= 17,942 psi

UG-45: The total combined shear stress (17,942psi) is greater than the allowable ($0.7*S_n$ = 0.7*17,100 = 11,970 psi)

N7 NPS 12 RFWN(0.500"wt) S/XH Vapor Outlet Nozzle (N7)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda



$t_{w(lower)}$ = 1.1875 in
Leg_{41} = 0.375 in
$t_{w(upper)}$ = 1 in
Leg_{42} = 0.75 in
D_p = 22.75 in
t_e = 1 in

.

Note: round inside edges per UG-76(c)

Location and Orientation

Located on:	Top Ellipsoidal Head #1
Orientation:	0°
End of nozzle to datum line:	722.5025 in
Calculated as hillside:	No
Distance to head center, R:	0 in
Passes through a Category A joint:	No

Nozzle

Access opening:	No
Material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Description:	NPS 12 XS
Inside diameter, new:	11.75 in
Nominal wall thickness:	0.5 in
Corrosion allowance:	0 in
Projection available outside vessel, Lpr:	5.8083 in
Projection available outside vessel to flange face, Lf:	10.9283 in
User input vessel thickness:	1.1875 in
Liquid static head included:	0 psi
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D p. 18, ln. 19) (normalized)
Diameter:	22.75 in
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 12 Class 300 WN A105
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)

Blind included:	No
Liquid static head:	0 psi
MAWP rating:	605 psi @ 500°F
MAP rating:	740 psi @ 71.6°F
Hydrotest rating:	1,125 psi @ 71.6°F
Gasket Description:	Flexitallic Solid Metal Core Flexpro Facing; 304 S.S. : Metal; Monel
PWHT performed:	No
Circumferential joint radiography:	Full UW-11(a) Type 1

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (in^2) For P = 424.15 psi @ 500 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
12.997	12.9977	1.1009	1.3547	--	10	0.5421	0.3281	0.5

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
239,543.16	237,936	377,821.68	49,804.25	711,324.66	258,242.25	614,642.78

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})	0.375	0.525	weld size is adequate
Nozzle to pad groove (Upper)	0.35	1	weld size is adequate

WRC 107												
Load Case	P (psi)	P_r (lb_f)	M_1 (lb_f-in)	V_1 (lb_f)	M_2 (lb_f-in)	V_2 (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	424.15	7,500	306,360	8,010	306,360	8,010	919,080	**27,138**	**60,000**	**19,588**	**30,000**	No
Load case 1 (Hot Shut Down)	0	7,500	306,360	8,010	306,360	8,010	919,080	-11,518	60,000	-1,823	30,000	No

Calculations for internal pressure 424.15 psi @ 500 °F

Nozzle UCS-66 governing thk: 0 in
Nozzle rated MDMT: 0 °F
Pad rated MDMT: 0 °F

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(11.75, 5.875 + (0.5 - 0) + (1.1875 - 0))

$= \quad 11.75$ in

Outer Normal Limit of reinforcement per UG-40

$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$
$= MIN(2.5*(1.1875 - 0), 2.5*(0.5 - 0) + 1)$
$= 2.25$ in

Nozzle required thickness per UG-27(c)(1)

$t_{rn} = P*R_n / (S_n*E - 0.6*P)$
$= 424.1479*5.875 / (17{,}100*1 - 0.6*424.1479)$
$= 0.1479$ in

Required thickness t_r from UG-37(a)(c)

$t_r = P*K_1*D / (2*S*E - 0.2*P)$
$= 424.1479*0.9*114.25 / (2*20{,}000*1 - 0.2*424.1479)$
$= 1.0926$ in

Area required per UG-37(c)

Allowable stresses: $S_n = 17{,}100$, $S_v = 20{,}000$, $S_p = 20{,}000$ psi

f_{r1} = lesser of 1 or $S_n / S_v = 0.855$

f_{r2} = lesser of 1 or $S_n / S_v = 0.855$

f_{r3} = lesser of f_{r2} or $S_p / S_v = 0.855$

f_{r4} = lesser of 1 or $S_p / S_v = 1$

$A = d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
$= 11.75*1.0926*1 + 2*0.5*1.0926*1*(1 - 0.855)$
$=$ 12.997 in^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.1009 in^2

$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= 11.75*(1*1.1875 - 1*1.0926) - 2*0.5*(1*1.1875 - 1*1.0926)*(1 - 0.855)$
$= 1.1009$ in^2

$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= 2*(1.1875 + 0.5)*(1*1.1875 - 1*1.0926) - 2*0.5*(1*1.1875 - 1*1.0926)*(1 - 0.855)$
$= 0.3064$ in^2

A_2 = smaller of the following= 1.3547 in^2

$= 5*(t_n - t_{rn})*f_{r2}*t$
$= 5*(0.5 - 0.1479)*0.855*1.1875$
$= 1.7875\ in^2$

$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
$= 2*(0.5 - 0.1479)*(2.5*0.5 + 1)*0.855$
$= 1.3547\ in^2$

$A_{41} = Leg^2*f_{r3}$
$= 0.375^2*0.855$
$=$ 0.1202 in^2

$A_{42} = Leg^2*f_{r4}$
$= 0.6495^2*1$
$=$ 0.4219 in^2

(Part of the weld is outside of the limits)

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= (22.75 - 11.75 - 2*0.5)*1*1$
$=$ 10 in^2

Area $= A_1 + A_2 + A_{41} + A_{42} + A_5$
$= 1.1009 + 1.3547 + 0.1202 + 0.4219 + 10$
$=$ 12.9977 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 = 0.5 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 = 0.75 in
$t_{w(min)}$ = 0.5*t_{min} = 0.375 in
$t_{w(actual)}$ = 0.7*Leg = 0.7*0.75 = 0.525 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
= 424.1479*5.875 / (17,100*1 - 0.6*424.1479) + 0
= 0.1479 in

$t_{a\ UG\text{-}22}$ = 0.2763 in

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.1479 , 0.2763]
= 0.2763 in

t_{b1} = 1.214 in

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[1.214 , 0.0625]
= 1.214 in

t_b = min[t_{b3} , t_{b1}]
= min[0.3281 , 1.214]
= 0.3281 in

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.2763 , 0.3281]
= 0.3281 in

Available nozzle wall thickness new, t_n = 0.5 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*17,100 =	11,970 psi
Inner fillet weld in shear:	0.49*17,100 =	8,379 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)*12.75*0.375*8,379 = 62,929.39 lb_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*22.75*0.75*9,800 = 262,656.78 lb_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*12.25*0.5*11,970 = 115,164.9 lb_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*12.75*1.1875*14,800 = 351,986 lb_f

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*12.75*1*14,800 = 296,409.27 lb_f

Loading on welds per UG-41(b)(1)

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$

$= (12.997 - 1.1009 + 2*0.5*0.855*(1*1.1875 - 1*1.0926))*20{,}000$

$=$ 239,543.16 lb_f

$W_{1\text{-}1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$

$= (1.3547 + 10 + 0.1202 + 0.4219)*20{,}000$

$=$ 237,936 lb_f

$W_{2\text{-}2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$

$= (1.3547 + 0 + 0.1202 + 0 + 2*0.5*1.1875*0.855)*20{,}000$

$=$ 49,804.25 lb_f

$W_{3\text{-}3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$

$= (1.3547 + 0 + 10 + 0.1202 + 0.4219 + 0 + 2*0.5*1.1875*0.855)*20{,}000$

$=$ 258,242.25 lb_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 237,936 lb_f
Path 1-1 through (2) & (3) = 262,656.78 + 115,164.9 = 377,821.68 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 $W_{2\text{-}2}$ = 49,804.25 lb_f
Path 2-2 through (1), (4), (6) = 62,929.39 + 351,986 + 296,409.27 = 711,324.66 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 $W_{3\text{-}3}$ = 239,543.16 lb_f
Path 3-3 through (2), (4) = 262,656.78 + 351,986 = 614,642.78 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 =	7,500	lb_f
Circumferential moment:	M_1 =	306,360	lb_f-in
Circumferential shear:	V_2 =	8,010	lb_f
Longitudinal moment:	M_2 =	306,360	lb_f-in
Longitudinal shear:	V_1 =	8,010	lb_f
Torsion moment:	M_t =	919,080	lb_f-in
Internal pressure:	P =	424.148	psi
Mean dish radius:	R_m =	103.9329	in
Local head thickness:	t =	1.1875	in
Head yield stress:	S_y =	31,000	psi
Design factor:		3	

Maximum stresses due to the applied loads at the pad edge (includes pressure)

U = r_o / Sqr(R_m*T) = 11.375 / Sqr(103.9329*1.1875) = 1.024

Pressure stress intensity factor, I = 1 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =18,455 psi

Maximum combined stress (P_L+P_b+Q) = 27,138 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) = 19,588 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**		**A_u**	**A_l**	**B_u**	**B_l**	**C_u**	**C_l**	**D_u**	**D_l**
SR-2*	N_x*T / P	0.0649	-345	-345	-345	-345	-345	-345	-345	-345
SR-2	M_x / P	0.0344	-1,098	1,098	-1,098	1,098	-1,098	1,098	-1,098	1,098
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.0756	0	0	0	0	-1,478	-1,478	1,478	1,478
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.0719	0	0	0	0	-8,436	8,436	8,436	-8,436
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.0756	-1,478	-1,478	1,478	1,478	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.0719	-8,436	8,436	8,436	-8,436	0	0	0	0
Pressure stress*			18,455	18,455	18,455	18,455	18,455	18,455	18,455	18,455
Total O_x stress			7,098	26,166	26,926	12,250	7,098	26,166	26,926	12,250
Membrane O_x stress*			16,632	16,632	19,588	19,588	16,632	16,632	19,588	19,588
SR-2*	N_y*T / P	0.0201	-107	-107	-107	-107	-107	-107	-107	-107
SR-2	M_y / P	0.0103	-329	329	-329	329	-329	329	-329	329
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0228	0	0	0	0	-446	-446	446	446
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0217	0	0	0	0	-2,546	2,546	2,546	-2,546
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0228	-446	-446	446	446	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0217	-2,546	2,546	2,546	-2,546	0	0	0	0
Pressure stress*			18,455	18,455	18,455	18,455	18,455	18,455	18,455	18,455
Total O_y stress			15,027	20,777	21,011	16,577	15,027	20,777	21,011	16,577
Membrane O_y stress*			17,902	17,902	18,794	18,794	17,902	17,902	18,794	18,794
Shear from M_t			952	952	952	952	952	952	952	952
Shear from V_1			0	0	0	0	-189	-189	189	189
Shear from V_2			189	189	-189	-189	0	0	0	0
Total Shear stress			1,141	1,141	763	763	763	763	1,141	1,141
Combined stress (P_L+P_b+Q)			15,188	26,398	27,023	16,708	15,100	26,272	27,138	16,859

Notes: (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) = 6.375 / Sqr(103.9329*2.1875) = 0.423

Pressure stress intensity factor, **I** = 0.5344 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = **I***P*R_i / (2*t) =9,863 psi

Maximum combined stress (P_L+P_b+Q) = 18,269 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) = 10,282 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 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	0.1531	-240	-240	-240	-240	-240	-240	-240	-240
SR-2	M_x / P	0.099	-931	931	-931	931	-931	931	-931	931
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_1	0.1553	0	0	0	0	-659	-659	659	659
SR-3	M_x*(R_m*T)$^{0.5}$ / M_1	0.307	0	0	0	0	-7,821	7,821	7,821	-7,821
SR-3*	N_x*T*(R_m*T)$^{0.5}$ / M_2	0.1553	-659	-659	659	659	0	0	0	0
SR-3	M_x*(R_m*T)$^{0.5}$ / M_2	0.307	-7,821	7,821	7,821	-7,821	0	0	0	0
Pressure stress*			9,863	9,863	9,863	9,863	9,863	9,863	9,863	9,863
Total O_x stress			212	17,716	17,172	3,392	212	17,716	17,172	3,392
Membrane O_x stress*			8,964	8,964	10,282	10,282	8,964	8,964	10,282	10,282
SR-2*	N_y*T / P	0.0459	-72	-72	-72	-72	-72	-72	-72	-72
SR-2	M_y / P	0.0302	-284	284	-284	284	-284	284	-284	284
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_1	0.0476	0	0	0	0	-202	-202	202	202
SR-3	M_y*(R_m*T)$^{0.5}$ / M_1	0.0925	0	0	0	0	-2,357	2,357	2,357	-2,357
SR-3*	N_y*T*(R_m*T)$^{0.5}$ / M_2	0.0476	-202	-202	202	202	0	0	0	0
SR-3	M_y*(R_m*T)$^{0.5}$ / M_2	0.0925	-2,357	2,357	2,357	-2,357	0	0	0	0
Pressure stress*			9,863	9,863	9,863	9,863	9,863	9,863	9,863	9,863
Total O_y stress			6,948	12,230	12,066	7,920	6,948	12,230	12,066	7,920
Membrane O_y stress*			9,589	9,589	9,993	9,993	9,589	9,589	9,993	9,993
Shear from M_t			1,645	1,645	1,645	1,645	1,645	1,645	1,645	1,645
Shear from V_1			0	0	0	0	-183	-183	183	183
Shear from V_2			183	183	-183	-183	0	0	0	0
Total Shear stress			1,828	1,828	1,462	1,462	1,462	1,462	1,828	1,828
Combined stress (P_L+P_b+Q)			7,664	18,269	17,561	8,351	7,343	18,081	17,759	8,566

Notes: (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
= 424.15*5.875 / (2*0.5) - 7,500 / (π*(6.375^2 - 5.875^2)) + 433,258.5*6.375 / 361.5439
= 9,742 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 = 17,100 psi)

Shear stress in the nozzle wall due to external loads

σ_{shear} = (V_L^2 + V_c^2)$^{0.5}$ / (π*R_i*t_n)
= (8,010^2 + 8,010^2)$^{0.5}$ / (π*5.875*0.5)
= 1,228 psi

$\sigma_{torsion}$ = M_t / (2*π*R_i^2*t_n)
= 919,080 / (2*π*5.875^2*0.5)
= 8,476 psi

σ_{total} = σ_{shear} + $\sigma_{torsion}$

= 1,228 + 8,476
= 9,703 psi

UG-45: The total combined shear stress (9,703 psi) ≤ allowable ($0.7*S_n$ = 0.7*17,100 = 11,970 psi)

Platform #2 /Ladder

Distance from platform base to datum:	604"
Platform attached to:	Cylinder #1
Platform start angle:	0.00 degrees
Platform end angle:	110.00 degrees
Platform shell clearance:	L_c = 6"
Platform width:	W = 54" (4.50 ft)
Platform projected length:	L = 60" (5.00 ft)
Platform wind force coefficient:	C_f = 1.30
Floor grating unit weight:	25.00 psf
Floor grating area:	9473.08 in² (65.79 ft²)
Railing height:	h = 42.008" (3.50 ft)
Railing length:	335.26" (27.94 ft)
Railing unit weight:	12.00 lb/ft
Distance from ladder start to datum:	406"
Ladder angle:	0.00 degrees
Ladder unit weight:	25.00 lb/ft
Ladder length:	198" (16.50 ft)
Platform & railing weight:	1979.90 lb
Ladder weight:	412.50 lb
Total weight:	2392.40 lb
Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes

Platform Wind Shear Calculation

Local wind pressure:	P_w	=	0 psf	
Wind shear:	V_p	=	P_w * C_f * A_e	= 0.00 lbf

Platform #3 / Ladder

Distance from platform base to datum:	406"
Platform attached to:	Cylinder #3
Platform start angle:	255.00 degrees
Platform end angle:	27.00 degrees
Platform shell clearance:	L_c = 6"
Platform width:	W = 48" (4.00 ft)
Platform projected length:	L = 108" (9.00 ft)
Platform wind force coefficient:	C_f = 1.30
Floor grating unit weight:	25.00 psf
Floor grating area:	9772.87 in² (67.87 ft²)
Railing height:	h = 42.008" (3.50 ft)
Railing length:	354.89" (29.57 ft)
Railing unit weight:	12.00 lb/ft
Distance from ladder start to datum:	85"
Ladder angle:	0.00 degrees
Ladder unit weight:	25.00 lb/ft
Ladder length:	321" (26.75 ft)
Platform & railing weight:	2051.57 lb
Ladder weight:	668.75 lb
Total weight:	2720.32 lb
Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes

Platform Wind Shear Calculation

Local wind pressure:	P_w	=	0 psf	
Wind shear:	V_p	=	$P_w * C_f * A_e$	= 0.00 lbf

Platform #4 / Ladder

Distance from platform base to datum:	85"
Platform attached to:	Cylinder #6
Platform start angle:	225.00 degrees
Platform end angle:	342.00 degrees
Platform shell clearance:	L_c = 6"
Platform width:	W = 48" (4.00 ft)
Platform projected length:	L = 54" (4.50 ft)
Platform wind force coefficient:	C_f = 1.30

Floor grating unit weight:	25.00 psf
Floor grating area:	8662.31 in² (60.15 ft²)
Railing height:	h = 42.008" (3.50 ft)
Railing length:	325.47" (27.12 ft)
Railing unit weight:	12.00 lb/ft

Distance from ladder start to datum:	10"
Ladder angle:	225.00 degrees
Ladder unit weight:	25.00 lb/ft
Ladder length:	75" (6.25 ft)

Platform & railing weight:	1829.35 lb
Ladder weight:	156.25 lb
Total weight:	1985.60 lb

Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes

Platform Wind Shear Calculation

Local wind pressure:	P_w	=	0 psf	
Wind shear:	V_p	=	P_w * C_f * A_e	= 0.00 lbf

Platform #5 / Ladder

Distance from platform base to datum:	10"
Platform attached to:	Cylinder #6
Platform start angle:	100.00 degrees
Platform end angle:	155.00 degrees
Platform shell clearance:	L_c = 6"
Platform width:	W = 42" (3.50 ft)
Platform projected length:	L = 48" (4.00 ft)
Platform wind force coefficient:	C_f = 1.30
Floor grating unit weight:	25.00 psf
Floor grating area:	3442.07 in² (23.90 ft²)
Railing height:	h = 42.008" (3.50 ft)
Railing length:	186.11" (15.51 ft)
Railing unit weight:	12.00 lb/ft
Distance from ladder start to datum:	-98"
Ladder angle:	155.00 degrees
Ladder unit weight:	25.00 lb/ft
Ladder length:	108" (9.00 ft)
Platform & railing weight:	783.69 lb
Ladder weight:	225.00 lb
Total weight:	1008.69 lb
Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes

Platform Wind Shear Calculation

Local wind pressure:	P_w	=	0 psf	
Wind shear:	V_p	=	P_w * C_f * A_e	= 0.00 lbf

Platform #6 / Ladder

Distance from platform base to datum:	-11"
Platform attached to:	Support Skirt
Platform start angle:	225.00 degrees
Platform end angle:	342.00 degrees
Platform shell clearance:	L_c = 6"
Platform width:	W = 42" (3.50 ft)
Platform projected length:	L = 48" (4.00 ft)
Platform wind force coefficient:	C_f = 1.30
Floor grating unit weight:	25.00 psf
Floor grating area:	7257.90 in² (50.40 ft²)
Railing height:	h = 42.008" (3.50 ft)
Railing length:	299.69" (24.97 ft)
Railing unit weight:	12.00 lb/ft
Distance from ladder start to datum:	-98"
Ladder angle:	225.00 degrees
Ladder unit weight:	25.00 lb/ft
Ladder length:	87" (7.25 ft)
Platform & railing weight:	1559.74 lb
Ladder weight:	181.25 lb
Total weight:	1740.99 lb
Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes

Platform Wind Shear Calculation

Local wind pressure:	P_w	=	0 psf	
Wind shear:	V_p	=	P_w * C_f * A_e	= 0.00 lbf

Top Platform #1 /Ladder

Distance from platform base to datum:	724"
Platform attached to:	Top Ellipsoidal Head #1
Platform orientation:	0.00 degrees
Platform offset:	48"
Platform width:	W = 96" (8.00 ft)
Platform length:	L = 96" (8.00 ft)
Platform wind force coefficient:	C_f = 1.30
Floor grating unit weight:	22.00 psf
Floor grating area:	9216.00 in² (64.00 ft²)
Railing height:	h = 42" (3.50 ft)
Railing length:	384.00" (32.00 ft)
Railing unit weight:	12.00 lb/ft
Distance from ladder start to datum:	605"
Ladder angle:	0.00 degrees
Ladder unit weight:	25.00 lb/ft
Ladder length:	119" (9.92 ft)
Platform & railing weight:	1792.00 lb
Ladder weight:	247.92 lb
Total weight:	2039.92 lb
Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes

Platform Wind Shear Calculation

Local wind pressure:	P_w	=	0 psf	
Wind shear:	V_p	=	P_w * C_f * A_e	= 0.00 lbf

Skirt Base Ring #1

Inputs	
Base configuration	external bolt chairs
Foundation compressive strength	750 psi
Concrete ultimate 28-day strength	3,000 psi
Anchor bolt material	SA-320
Anchor bolt allowable stress, S_b	20,000 psi
Bolt circle, BC	121.375"
Anchor bolt corrosion allowance (applied to root radius)	0.125"
Anchor bolt clearance	0.5"
Base plate material	SA-516-70
Base plate allowable stress, S_p	20,000 psi
Base plate inner diameter, D_i	104.875"
Base plate outer diameter, D_o	127.875"
Base plate thickness, t_b	1.5"
Gusset separation, w	6"
Gusset height, h	6.75"
Gusset thickness, t_g	0.5"
Compression plate width	6.0625"
Compression plate length	8"
Compression plate thickness, t_c	1.25"
Initial bolt preload	10% (2,000 psi)
Number of bolts, N	20
Bolt size and type	1.5 inch series 8 threaded
Bolt root area (corroded), A_b	0.93 in^2
Diameter of anchor bolt holes, d_b	2"

Results Summary									
Load	Vessel condition	Base M (lb_f-ft)	W (lb)	Required bolt area (in^2)	t_r Base (in)	Foundation bearing stress (psi)	t_r comp plate (in)	t_r gusset (in)
Weight	operating, corroded	21,619.5	175,201	0	0.4615	58.18	0.3899	0.1318
Weight	operating, new	21,619.5	175,201	0	0.4615	58.18	0.3899	0.1318
Weight	empty, corroded	21,619.5	175,201	0	0.4615	58.18	0.3899	0.1318
Weight	empty, new	21,619.5	175,201	0	0.4615	58.18	0.3899	0.1318
Weight	test, new	21,619.5	442,789.2	0	0.6704	122.79	0.3899	0.1318

Anchor bolt load (operating, corroded + Weight)

P = -W / N + 48 * M / (N*BC)
= -175,200.99 / 20 + 48 * 21,619.5 / (20*121.375)
= -8,332.56 lb_f

The anchor bolts are satisfactory (no net uplift on anchor bolt)

Foundation bearing stress (operating, corroded + Weight)

A_c = pi*(D_o^2 - D_i^2) / 4 - N*pi*d_b^2 / 4
= π*(127.875^2 - 104.875^2) / 4 - 20*π*2^2 / 4
= 4,141.6009 in^2

I_c = π*(D_o^4 - D_i^4) / 64
= π*(127.875^4 - 104.875^4) / 64
= 7,187,157 in^4

f_c = N*A_b*Preload / A_c + W / A_c + 6*M*D_o / I_c
= 20*1.405*2,000 / 4,141.6009 + 175,200.99 / 4,141.6009 + 6*21,619.5*127.875 / 7,187,157
= 58 psi

As f_c <= 750 psi the base plate width is satisfactory.

Base plate required thickness (operating, corroded + Weight)

From Brownell & Young, Table 10.3:, l / b = 0.5232

M_x = 0.033*58*12.0655^2 = 279.4 lb_f

M_y = -0.3062*58*6.3125^2 = -709.9 lb_f

t_r = (6*M_{max} / S_p)$^{0.5}$
= (6*709.88 / 20,000)$^{0.5}$
= 0.4615 in

The base plate thickness is satisfactory.

Check the compression plate for bolt load (Jawad & Farr equation 12.13)

t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))$^{0.5}$
= (3.91*2,810 / (36,000*(2*6.0625 / 6+6 / (2*3.062)-2*(2 / 6+1 / (2*3.062)))))$^{0.5}$

= 0.3899 in

The compression plate thickness is satisfactory.

Check gusset plate thickness (Bednar chapter 4.3)

Radius of gyration of gusset

$r = 0.289*t_g$
$= 0.289*0.5$
$= 0.1445$ in

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25)$
$= 0.5*(6.3125 - 0.25)$
$= 3.0313$ in^2

Gusset allowable stress

$S_a = 17000 - 0.485*(h / r)^2$
$= 17000 - 0.485*(6.75 / 0.1445)^2$
$= 15,942$ psi

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
$= 2,810 / (2 * 3.0313)$
$= 464$ psi

The gusset plate thickness is satisfactory.

Check skirt thickness for bolt load reaction (Brownell & Young eq. 10.59)

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(0*3.0625 / (18.1034*9.5*30,000))^{2/3}*(115.25 / 2)^{1/3}$
$= 0$ in

The skirt thickness is satisfactory.

Note: No local skirt reaction is present because the foundation resists the initial bolt preload.

Anchor bolt load (operating, new + Weight)

$P = -W / N + 48 * M / (N*BC)$
$= -175,200.99 / 20 + 48 * 21,619.5 / (20*121.375)$
$= -8,332.56$ lb_f

The anchor bolts are satisfactory (no net uplift on anchor bolt)

Foundation bearing stress (operating, new + Weight)

$A_c = pi*(D_o^2 - D_i^2) / 4 - N*pi*d_b^2 / 4$
$= \pi*(127.875^2 - 104.875^2) / 4 - 20*\pi*2^2 / 4$
$= 4,141.6009$ in^2

$I_c = \pi*(D_o^4 - D_i^4) / 64$

$= \pi*(127.875^4 - 104.875^4) / 64$
$= 7,187,157\ in^4$

$f_c = N*A_b*Preload / A_c + W / A_c + 6*M*D_o / I_c$
$= 20*1.405*2,000 / 4,141.6009 + 175,200.99 / 4,141.6009 + 6*21,619.5*127.875 / 7,187,157$
= 58 psi

As f_c <= 750 psi the base plate width is satisfactory.

Base plate required thickness (operating, new + Weight)

From Brownell & Young, Table 10.3:, l / b = 0.5232

$M_x = 0.033*58*12.0655^2 = 279.4\ lb_f$

$M_y = -0.3062*58*6.3125^2 = -709.9\ lb_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (6*709.88 / 20,000)^{0.5}$
= 0.4615 in

The base plate thickness is satisfactory.

Check the compression plate for bolt load (Jawad & Farr equation 12.13)

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (3.91*2,810 / (36,000*(2*6.0625 / 6+6 / (2*3.062)-2*(2 / 6+1 / (2*3.062)))))^{0.5}$
= 0.3899 in

The compression plate thickness is satisfactory.

Check gusset plate thickness (Bednar chapter 4.3)

Radius of gyration of gusset

$r = 0.289*t_g$
= 0.289*0.5
= 0.1445 in

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25)$
= 0.5*(6.3125 - 0.25)
$= 3.0313\ in^2$

Gusset allowable stress

$S_a = 17000 - 0.485*(h / r)^2$
$= 17000 - 0.485*(6.75 / 0.1445)^2$
= 15,942 psi

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
= 2,810 / (2 * 3.0313)
= 464 psi

The gusset plate thickness is satisfactory.

Check skirt thickness for bolt load reaction (Brownell & Young eq. 10.59)

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(0*3.0625 / (18.1034*9.5*30{,}000))^{2/3}*(115.25 / 2)^{1/3}$
= 0 in

The skirt thickness is satisfactory.

Note: No local skirt reaction is present because the foundation resists the initial bolt preload.

Anchor bolt load (empty, corroded + Weight)

P = -W / N + 48 * M / (N*BC)
= -175,200.99 / 20 + 48 * 21,619.5 / (20*121.375)
= -8,332.56 lb_f

The anchor bolts are satisfactory (no net uplift on anchor bolt)

Foundation bearing stress (empty, corroded + Weight)

$A_c = pi*(D_o^2 - D_i^2) / 4 - N*pi*d_b^2 / 4$
$= \pi*(127.875^2 - 104.875^2) / 4 - 20*\pi*2^2 / 4$
= 4,141.6009 in^2

$I_c = \pi*(D_o^4 - D_i^4) / 64$
$= \pi*(127.875^4 - 104.875^4) / 64$
= 7,187,157 in^4

$f_c = N*A_b*Preload / A_c + W / A_c + 6*M*D_o / I_c$
= 20*1.405*2,000 / 4,141.6009 + 175,200.99 / 4,141.6009 + 6*21,619.5*127.875 / 7,187,157
= 58 psi

As f_c <= 750 psi the base plate width is satisfactory.

Base plate required thickness (empty, corroded + Weight)

From Brownell & Young, Table 10.3:, l / b = 0.5232

$M_x = 0.033*58*12.0655^2 = 279.4$ lb_f

$M_y = -0.3062*58*6.3125^2 = -709.9$ lb_f

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (6*709.88 / 20{,}000)^{0.5}$
= 0.4615 in

The base plate thickness is satisfactory.

Check the compression plate for bolt load (Jawad & Farr equation 12.13)

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (3.91*2{,}810 / (36{,}000*(2*6.0625 / 6+6 / (2*3.062)-2*(2 / 6+1 / (2*3.062)))))^{0.5}$
= 0.3899 in

The compression plate thickness is satisfactory.

Check gusset plate thickness (Bednar chapter 4.3)

Radius of gyration of gusset

$r = 0.289*t_g$
$= 0.289*0.5$
$= 0.1445$ in

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25)$
$= 0.5*(6.3125 - 0.25)$
$= 3.0313\ in^2$

Gusset allowable stress

$S_a = 17000 - 0.485*(h / r)^2$
$= 17000 - 0.485*(6.75 / 0.1445)^2$
$= 15{,}942$ psi

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
$= 2{,}810 / (2 * 3.0313)$
$= 464$ psi

The gusset plate thickness is satisfactory.

Check skirt thickness for bolt load reaction (Brownell & Young eq. 10.59)

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(0*3.0625 / (18.1034*9.5*30{,}000))^{2/3}*(115.25 / 2)^{1/3}$
$= 0$ in

The skirt thickness is satisfactory.

Note: No local skirt reaction is present because the foundation resists the initial bolt preload.

Anchor bolt load (empty, new + Weight)

$P = -W / N + 48 * M / (N*BC)$
$= -175{,}200.99 / 20 + 48 * 21{,}619.5 / (20*121.375)$
$= -8{,}332.56\ lb_f$

The anchor bolts are satisfactory (no net uplift on anchor bolt)

Foundation bearing stress (empty, new + Weight)

$A_c = pi*(D_o^2 - D_i^2) / 4 - N*pi*d_b^2 / 4$
$= \pi*(127.875^2 - 104.875^2) / 4 - 20*\pi*2^2 / 4$
$= 4{,}141.6009\ in^2$

$I_c = \pi*(D_o^4 - D_i^4) / 64$
$= \pi*(127.875^4 - 104.875^4) / 64$
$= 7{,}187{,}157\ in^4$

$f_c = N*A_b*Preload / A_c + W / A_c + 6*M*D_o / I_c$
= 20*1.405*2,000 / 4,141.6009 + 175,200.99 / 4,141.6009 + 6*21,619.5*127.875 / 7,187,157
= 58 psi

As f_c <= 750 psi the base plate width is satisfactory.

Base plate required thickness (empty, new + Weight)

From Brownell & Young, Table 10.3:, l / b = 0.5232

$M_x = 0.033*58*12.0655^2 = 279.4\ lb_f$

$M_y = -0.3062*58*6.3125^2 = -709.9\ lb_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (6*709.88 / 20,000)^{0.5}$
= 0.4615 in

The base plate thickness is satisfactory.

Check the compression plate for bolt load (Jawad & Farr equation 12.13)

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (3.91*2,810 / (36,000*(2*6.0625 / 6+6 / (2*3.062)-2*(2 / 6+1 / (2*3.062)))))^{0.5}$
= 0.3899 in

The compression plate thickness is satisfactory.

Check gusset plate thickness (Bednar chapter 4.3)

Radius of gyration of gusset

$r = 0.289*t_g$
= 0.289*0.5
= 0.1445 in

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25)$
= 0.5*(6.3125 - 0.25)
= 3.0313 in^2

Gusset allowable stress

$S_a = 17000 - 0.485*(h / r)^2$
$= 17000 - 0.485*(6.75 / 0.1445)^2$
= 15,942 psi

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
= 2,810 / (2 * 3.0313)
= 464 psi

The gusset plate thickness is satisfactory.

Check skirt thickness for bolt load reaction (Brownell & Young eq. 10.59)

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(0*3.0625 / (18.1034*9.5*30{,}000))^{2/3}*(115.25 / 2)^{1/3}$
$= 0$ in

The skirt thickness is satisfactory.

Note: No local skirt reaction is present because the foundation resists the initial bolt preload.

Anchor bolt load (test, new + Weight)

$P = -W / N + 48 * M / (N*BC)$
$= -442{,}789.23 / 20 + 48 * 21{,}619.5 / (20*121.375)$
$= -21{,}711.97\ lb_f$

The anchor bolts are satisfactory (no net uplift on anchor bolt)

Foundation bearing stress (test, new + Weight)

$A_c = pi*(D_o^2 - D_i^2) / 4 - N*pi*d_b^2 / 4$
$= \pi*(127.875^2 - 104.875^2) / 4 - 20*\pi*2^2 / 4$
$= 4{,}141.6009\ in^2$

$I_c = \pi*(D_o^4 - D_i^4) / 64$
$= \pi*(127.875^4 - 104.875^4) / 64$
$= 7{,}187{,}157\ in^4$

$f_c = N*A_b*Preload / A_c + W / A_c + 6*M*D_o / I_c$
$= 20*1.405*2{,}000 / 4{,}141.6009 + 442{,}789.23 / 4{,}141.6009 + 6*21{,}619.5*127.875 / 7{,}187{,}157$
$=$ 123 psi

As $f_c <= 750$ psi the base plate width is satisfactory.

Base plate required thickness (test, new + Weight)

From Brownell & Young, Table 10.3:, l / b = 0.5232

$M_x = 0.033*123*12.0655^2 = 589.7\ lb_f$

$M_y = -0.3062*123*6.3125^2 = -1{,}498.2\ lb_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (6*1{,}498.21 / 20{,}000)^{0.5}$
$=$ 0.6704 in

The base plate thickness is satisfactory.

Check the compression plate for bolt load (Jawad & Farr equation 12.13)

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (3.91*2{,}810 / (36{,}000*(2*6.0625 / 6+6 / (2*3.062)-2*(2 / 6+1 / (2*3.062)))))^{0.5}$
$=$ 0.3899 in

The compression plate thickness is satisfactory.

Check gusset plate thickness (Bednar chapter 4.3)

Radius of gyration of gusset

$r = 0.289*t_g$
$= 0.289*0.5$
$= 0.1445$ in

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25)$
$= 0.5*(6.3125 - 0.25)$
$= 3.0313\ in^2$

Gusset allowable stress

$S_a = 17000 - 0.485*(h / r)^2$
$= 17000 - 0.485*(6.75 / 0.1445)^2$
= 15,942 psi

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
$= 2{,}810 / (2 * 3.0313)$
= 464 psi

The gusset plate thickness is satisfactory.

Check skirt thickness for bolt load reaction (Brownell & Young eq. 10.59)

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(0*3.0625 / (18.1034*9.5*30{,}000))^{2/3}*(115.25 / 2)^{1/3}$
= 0 in

The skirt thickness is satisfactory.

Note: No local skirt reaction is present because the foundation resists the initial bolt preload.

Support Skirt

Material:		SA-516 70 (II-D p. 18, ln. 19)
Design temperature, operating:	401	°F
Inner diameter at top, new:	114	in
Inner diameter at bottom, new:	114	in
Overall length (includes base ring thickness):	89.71	in
Corrosion allowance inside:	0	in
Corrosion allowance outside:	0	in
Weld joint efficiency top:	0.55	
Weld joint efficiency bottom:	0.8	
Nominal thickness, new:	0.625	in
Skirt is attached to:		Bottom Ellipsoidal Head #2
Skirt attachment offset:	8.2864	in down from the top seam

Skirt design thickness, largest of the following + corrosion = 0.093 in

The governing condition is due to weight, compressive stress at the base, test & new.

The skirt thickness of 0.625 in is adequate.

Loading	Vessel Condition (Stress)	Governing Skirt Location	Temperature (°F)	Allowable Stress (psi)	Calculated Stress/E (psi)	Required thickness (in)
Weight	operating, corroded (+)	bottom	401	11,926.62	-727.89	0.0381
Weight	operating, corroded (-)	bottom	401	11,926.62	808.34	0.0424
Weight	empty, corroded (+)	bottom	71.6	13,419.88	-727.89	0.0339
Weight	empty, corroded (-)	bottom	71.6	13,419.88	808.34	0.0376
Weight	test, new (+)	bottom	71.6	13,419.88	-1,916.82	0.0893
Weight	test, new (-)	bottom	71.6	13,419.88	1,997.27	0.093

Loading due to weight, operating & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -W / (\pi*D*S_t*E) + 48*M / (\pi*D^2*S_t*E)$
$= -172{,}875.99 / (\pi*114.625*11{,}927*1) + 48*21{,}619.5 / (\pi*114.625^2*11{,}927*1)$
$=$ 0.0381 in

Required thickness, tensile stress at the top:

$t = -W_t / (\pi*D_t*S_t*E) + 48*M_t / (\pi*D_t^2*S_t*E)$
$= -165{,}516.58 / (\pi*114.625*11{,}927*1) + 48*21{,}619.5 / (\pi*114.625^2*11{,}927*1)$
$=$ 0.0364 in

Leeward side (compressive)

Required thickness, compressive stress at base:

$$\begin{aligned}t &= W / (\pi*D*S_c*E_c) + 48*M / (\pi*D^2*S_c*E_c)\\ &= 172{,}875.99 / (\pi*114.625*11{,}927*1) + 48*21{,}619.5 / (\pi*114.625^2*11{,}927*1)\\ &= \underline{0.0424}\text{ in}\end{aligned}$$

Required thickness, compressive stress at the top:

$$\begin{aligned}t &= W_t / (\pi*D_t*S_c*E_c) + 48*M_t / (\pi*D_t^2*S_c*E_c)\\ &= 165{,}516.58 / (\pi*114.625*11{,}927*1) + 48*21{,}619.5 / (\pi*114.625^2*11{,}927*1)\\ &= \underline{0.0406}\text{ in}\end{aligned}$$

Loading due to weight, empty & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$$\begin{aligned}t &= -W / (\pi*D*S_t*E) + 48*M / (\pi*D^2*S_t*E)\\ &= -172{,}875.99 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)\\ &= \underline{0.0339}\text{ in}\end{aligned}$$

Required thickness, tensile stress at the top:

$$\begin{aligned}t &= -W_t / (\pi*D_t*S_t*E) + 48*M_t / (\pi*D_t^2*S_t*E)\\ &= -165{,}516.58 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)\\ &= \underline{0.0324}\text{ in}\end{aligned}$$

Leeward side (compressive)

Required thickness, compressive stress at base:

$$\begin{aligned}t &= W / (\pi*D*S_c*E_c) + 48*M / (\pi*D^2*S_c*E_c)\\ &= 172{,}875.99 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)\\ &= \underline{0.0376}\text{ in}\end{aligned}$$

Required thickness, compressive stress at the top:

$$\begin{aligned}t &= W_t / (\pi*D_t*S_c*E_c) + 48*M_t / (\pi*D_t^2*S_c*E_c)\\ &= 165{,}516.58 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)\\ &= \underline{0.0361}\text{ in}\end{aligned}$$

Loading due to weight, test & new

Windward side (tensile)

Required thickness, tensile stress at base:

$$t = -W / (\pi*D*S_t*E) + 48*M / (\pi*D^2*S_t*E)$$
$$= -440{,}464.23 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)$$
$$= 0.0893 \text{ in}$$

Required thickness, tensile stress at the top:

$$t = -W_t / (\pi*D_t*S_t*E) + 48*M_t / (\pi*D_t^2*S_t*E)$$
$$= -433{,}104.82 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)$$
$$= 0.0877 \text{ in}$$

Leeward side (compressive)

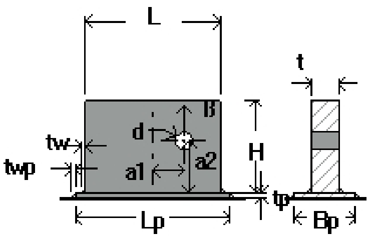
Required thickness, compressive stress at base:

$$t = W / (\pi*D*S_c*E_c) + 48*M / (\pi*D^2*S_c*E_c)$$
$$= 440{,}464.23 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)$$
$$= 0.093 \text{ in}$$

Required thickness, compressive stress at the top:

$$t = W_t / (\pi*D_t*S_c*E_c) + 48*M_t / (\pi*D_t^2*S_c*E_c)$$
$$= 433{,}104.82 / (\pi*114.625*13{,}420*1) + 48*21{,}619.5 / (\pi*114.625^2*13{,}420*1)$$
$$= 0.0915 \text{ in}$$

Tailing Lug



Geometry Inputs

Attached To	Support Skirt
Material	A36
Orientation	Longitudinal
Distance of Lift Point From Datum	-90.9964"
Angular Position	216.00°
Length of Lug, L	26"
Height of Lug, H	18"
Thickness of Lug, t	2.6405"
Hole Diameter, d	3.375"
Pin Diameter, Dp	3.25"
Load Eccentricity, a_1	-6"
Distance from Load to Shell or Pad, a_2	10"
Weld Size, t_w	1"
Width of Pad, B_p	6"
Length of Pad, L_p	30"
Pad Thickness, t_p	1"
Pad Weld Size, t_{wp}	0.875"
Load Angle Normal to Vessel, β	0.0000 °
Load Angle from Vertical, ϕ	-90.0000 °
Base ring strut area	0.0000 in²

Intermediate Values

Load Factor	2.0000
Vessel Weight (new, incl. Load Factor), W	350402 lb
Lug Weight (new), W_{lug}	410 lb
Distance from Center of Gravity to Top Lug, l_1	370.337"
Distance from Center of Gravity to Tail Lug, l_2	424.6619"
Distance from Vessel Center Line to Tail Lug, l_3	68.625"
Allowable Stress, Tensile, σ_t	20000 psi
Allowable Stress, Shear, σ_s	14000 psi
Allowable Stress, Bearing, σ_p	20000 psi
Allowable Stress, Bending, σ_b	22000 psi
Allowable Stress, Weld Shear, $\tau_{allowable}$	14000 psi
Allowable Stress set to 1/3 Sy per ASME B30.20	No

Summary Values

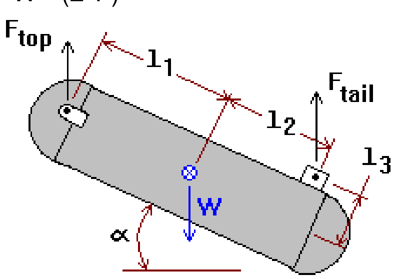
Required Lift Pin Diameter, d_{reqd}	2.7244"
Required Lug Thickness, t_{reqd}	2.5112"
Lug Stress Ratio, σ_{ratio}	0.34
Weld Shear Stress Ratio, τ_{ratio}	0.8
Lug Design	Acceptable
Local Stresses	**Unacceptable**
Base ring loading	Acceptable

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	93,587	163,229
15	95,431	159,539
30	97,461	155,480
45	100,072	150,258
60	104,201	141,999
75	113,473	123,455
90	175,201	0
36[1]	98,403	153,596
38[2]	98,743	152,915
38[3]	98,743	152,915
[1]Lift angle at maximum lug stress.		
[2]Lift angle at maximum weld stress.		
[3]Lift angle at maximum pad weld stress.		

Lug Pin Diameter - Shear stress

d_{reqd} = $(2*F_r / (\pi*\sigma_s))^{0.5}$
= $(2*163{,}229 / (\pi*14{,}000))^{0.5}$ = 2.7244"

d_{reqd} / D_p = 2.7244 / 3.25 = 0.84 Acceptable

σ = F_r / A
= $F_r / (2*(0.25*\pi*D_p^2))$
= $163{,}229 / (2*(0.25*\pi*3.25^2))$ = 9,838 psi

σ / σ_s = 9,838 / 14,000 = 0.7 Acceptable

Lug Thickness - Tensile stress

t_{reqd} = $F_r / ((L - d)*\sigma_t)$
= 163,229 / ((26 - 3.375)*20,000) = 0.3607"

t_{reqd} / t = 0.3607 / 2.6405 = 0.14 Acceptable

σ = F_r / A
= $F_r / ((L - d)*t)$
= 163,229 / ((26 - 3.375)*2.6405) = 2,732 psi

σ / σ_t = 2,732 / 20,000 = 0.14 Acceptable

Lug Thickness - Bearing stress

$t_{reqd} = F_v / (D_p*\sigma_p)$
$= 163{,}229 / (3.25*20{,}000) = $ 2.5112"

$t_{reqd} / t = 2.5112 / 2.6405 = 0.95$ Acceptable

$\sigma = F_v / A_{bearing}$
$= F_v / (D_p*(t))$
$= 163{,}229 / (3.25*(2.6405)) = 19{,}021$ psi

$\sigma / \sigma_p = 19{,}021 / 20{,}000 = 0.95$ Acceptable

Lug Thickness - Shear stress

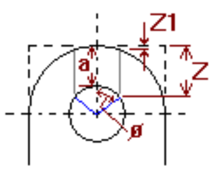
$t_{reqd} = [F_v / \sigma_s] / (2*L_{shear})$
$= (163{,}229 / 14{,}000) / (2*6.9587) = $ 0.8377"

$t_{reqd} / t = 0.8377 / 2.6405 = 0.32$ Acceptable

$\tau = F_v / A_{shear}$
$= F_v / (2*t*L_{shear})$
$= 163{,}229 / (2*2.6405*6.9587) = 4{,}442$ psi

$\tau / \sigma_s = 4{,}442 / 14{,}000 = 0.32$ Acceptable

Shear stress length (per Pressure Vessel and Stacks, A. Keith Escoe)



$\phi = 55*D_p / d$
$= 55*3.25 / 3.375$
$= 52.963°$
$L_{shear} = (H - a2 - 0.5*d) + 0.5*D_p*(1 - \cos(\phi))$
$= (18 - 10 - 0.5*3.375) + 0.5*3.25*(1 - \cos(52.963))$
$= 6.9587"$

Lug Plate Stress

Lug stress tensile + bending during lift:

$\sigma_{ratio} = [F_{ten} / (A_{ten}*\sigma_t)] + [M_{bend} / (Z_{bend}*\sigma_b)] \leq 1$
$= [(F_{tail}(\alpha)*\cos(\alpha)) / (t*L*\sigma_t)] + [(6*abs(F_{tail}(\alpha)*\sin(\alpha)*Hght - F_{tail}(\alpha)*\cos(\alpha)*a_1)) / (t*L^2*\sigma_b)] \leq 1$
$= 153{,}596*\cos(36.0) / (2.6405*26*20{,}000) + 6*abs(153{,}596*\sin(36.0)*10 - 153{,}596*\cos(36.0)*-6) / (2.6405*26^2*22{,}000)$
$=$ 0.34 Acceptable

Weld Stress

Weld stress, tensile, bending and shear during lift:

Direct shear:

Maximum shear stress occurs at lift angle 38.00°; lift force = 152,915 lbf

A_{weld} = $2*(0.707)*t_w*(L + t)$
= $2*(0.707)*1*(26 + 2.6405)$ = 40.4976 in^2

τ_t = $F_{tail}*\cos(\alpha) / A_{weld}$
= 152,915*cos(38.0) / 40.4976 = 2,975 psi

τ_s = $F_{tail}*\sin(\alpha) / A_{weld}$
= 152,915*sin(38.0) / 40.4976 = 2,325 psi

Torsional shear:

Weld areas

A_i = $0.707*t_w*L_i$
A_1 = 0.707*1*5 = 3.535 in^2
A_4 = 0.707*1*18 = 12.726 in^2
A_7 = 0.707*1*5 = 3.535 in^2
$A_{weld\ torsion}$ = ΣA_i = 19.796 in^2

Weld centroid locations

x_1 = 0"
y_1 = 2.5"
x_4 = 0"
y_4 = 0"
x_7 = 0"
y_7 = 0"
X_{bar} = $\Sigma (A_i*x_i) / \Sigma A_i$
Y_{bar} = $\Sigma (A_i*y_i) / \Sigma A_i$
X_{bar} = (3.535*0 + 12.726*0 + 3.535*0) / 19.796 = 0"
Y_{bar} = (3.535*2.5 + 12.726*0 + 3.535*0) / 19.796 = 0.4464"

Radius to centroid locations

r_i = $sqr((X_{bar} - x_i)^2 + (Y_{bar} - y_i)^2)$
r_1 = $sqr((0 - 0)^2 + (0.4464 - 2.5)^2)$ = 2.0536"
r_4 = $sqr((0 - 0)^2 + (0.4464 - 0)^2)$ = 0.4464"
r_7 = $sqr((0 - 0)^2 + (0.4464 - 0)^2)$ = 0.4464"

Radial distance from centroid to weld:

= 13"

θ_r = 0.00°

Polar Moment of Area

J_i = $0.707*t_w*(L_i^3) / 12$
J_1 = $0.707*1*(5^3) / 12$ = $7.3646\ in^4$
J_4 = $0.707*1*(18^3) / 12$ = $343.602\ in^4$
J_7 = $0.707*1*(5^3) / 12$ = $7.3646\ in^4$

J = $2*\Sigma (J_i + A_i*r_i^2)$ Parallel axis theorem (weld on both sides of lug)

J = $2*[7.3646 + 3.535*(2.0536)^2 + (343.6020 + 12.726*(0.4464)^2) + (7.3646 + 3.535*(0.4464)^2)]$ = $752.96\ in^4$

Secondary shear

τ_2 = M * r / J
= $[F(\alpha)*\cos(\alpha)*(X - X_{bar}) - F(\alpha)*\sin(\alpha)*(Y - Y_{bar})] * r / J$
= (152,915*cos(38.0)*(7 - 0) - 152,915*sin(38.0)*(10 - 0.4464))*13 / 752.9592
= 8,008 psi

τ_{ratio} = $\mathrm{sqr}((\tau_t + \tau_2*\cos(\theta_r))^2 + (\tau_s + \tau_2*\sin(\theta_r))^2) / \tau_{allowable} \le 1$
= $\mathrm{sqr} ((2{,}975 + 8{,}008*\cos(0.00))^2 + (2{,}325 + 8{,}008*\sin(0.00))^2) / 14{,}000$
= 0.80 Acceptable

Pad Weld Stress, tensile, bending and shear during lift:

Direct shear:

Maximum shear stress occurs at lift angle 38.00°; lift force = 152,915 lbf

A_{weld} = $2*(0.707)*t_{wp}*(L_p + B_p)$
= $2*(0.707)*0.875*(30 + 6)$ = $44.541\ in^2$

τ_t = $F_{tail}*\cos(\alpha) / A_{weld}$
= 152,915*cos(38.0) / 44.541 = 2,705 psi

τ_s = $F_{tail}*\sin(\alpha) / A_{weld}$
= 152,915*sin(38.0) / 44.541 = 2,114 psi

τ_b = M * c / I
= $3*(F_{tail}*\sin(\alpha)*Hght - F_{tail}*\cos(\alpha)*\Delta a) / (0.707*h_p*L_p*(3*W_p + L_p))$
= 3*abs(152,915*sin(38.0)*11 - 152,915*cos(38.0)*(-8)) / (890.8200)
= 5,922 psi

τ_{ratio} = $\mathrm{sqr}((\tau_t + \tau_b)^2 + \tau_s^2) / \tau_{allowable} \le 1$
= $\mathrm{sqr} ((2{,}705 + 5{,}922)^2 + (2{,}114)^2) / 14{,}000$
= 0.63 Acceptable

WRC 107 Analysis

Geometry

Height(radial):	18"	Pad Thickness:	1"
Width (circumferential):	2.6405"	Pad Width:	6"
Length	26"	Pad Length:	30"
Fillet Weld Size:	1"	Pad Weld Size:	0.875"
Located on:	Support Skirt	(0" from bottom end)	
Location Angle:	216.00°		

Applied Loads

Maximum stress ratio occurs at lift angle = 0.00° with lift force = 163,229 lbf

Radial load:	P_r =	-163,228.93	lb_f
Circumferential moment:	M_c =	0	lb_f-in
Circumferential shear:	V_c =	0	lb_f
Longitudinal moment:	M_L =	-979,373.56	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 =	57.3125	in
Shell yield stress:	S_y =	38,000	psi
Design factor:		3	

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / t = 57.3125 / 1.625 = 35.2692$

$C_1 = 2.3202$, $C_2 = 9.281$ 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) = 84,535 psi
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-60,000 psi

WRC 107: The combined stress (P_L+P_b+Q) is excessive

Maximum local primary membrane stress (P_L) = 15,147 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 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*	5.0548	0.1198	0	0	0	0	8,859	8,859	8,859	8,859
4C*	6.232	0.0972	10,922	10,922	10,922	10,922	0	0	0	0
1C	0.1658	0.0713	0	0	0	0	61,493	-61,493	61,493	-61,493
2C-1	0.1281	0.0713	47,511	-47,511	47,511	-47,511	0	0	0	0
3A*	0.6545	0.0643	0	0	0	0	0	0	0	0
1A	0.1015	0.0816	0	0	0	0	0	0	0	0
3B*	3.6734	0.102	4,225	4,225	-4,225	-4,225	0	0	0	0
1B-1	0.0504	0.0895	21,877	-21,877	-21,877	21,877	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			84,535	-54,241	32,331	-18,937	70,352	-52,634	70,352	-52,634
Primary membrane circumferential stress*			15,147	15,147	6,697	6,697	8,859	8,859	8,859	8,859
3C*	5.5799	0.0972	9,780	9,780	9,780	9,780	0	0	0	0
4C*	5.9609	0.1198	0	0	0	0	10,447	10,447	10,447	10,447
1C-1	0.1364	0.1012	50,589	-50,589	50,589	-50,589	0	0	0	0
2C	0.096	0.1012	0	0	0	0	35,605	-35,605	35,605	-35,605
4A*	0.8597	0.0643	0	0	0	0	0	0	0	0
2A	0.0534	0.1101	0	0	0	0	0	0	0	0
4B*	1.0287	0.102	2,145	2,145	-2,145	-2,145	0	0	0	0
2B-1	0.0671	0.1235	21,088	-21,088	-21,088	21,088	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			83,602	-59,752	37,136	-21,866	46,052	-25,158	46,052	-25,158
Primary membrane longitudinal stress*			11,925	11,925	7,635	7,635	10,447	10,447	10,447	10,447
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)			84,535	-59,752	37,136	-21,866	70,352	-52,634	70,352	-52,634

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / t = 57.3125 / 0.625 = 91.7$

$C_1 = 3.875$, $C_2 = 15.5$ 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) = 230,802 psi
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-60,000 psi

WRC 107: The combined stress (P_L+P_b+Q) is excessive (at pad edge)

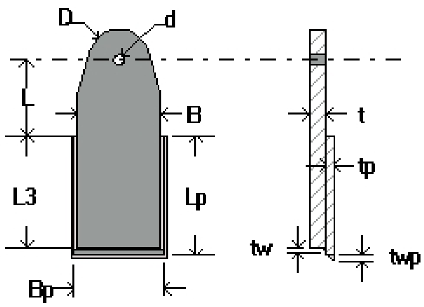
Maximum local primary membrane stress (P_L) = 65,585 psi
Allowable local primary membrane stress (P_L) = +-1.5*S = +-30,000 psi

WRC 107: The local primary membrane stress (P_L) is excessive (at pad edge)

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*	5.0301	0.2001	0	0	0	0	22,922	22,922	22,922	22,922
4C*	11.7451	0.1623	53,521	53,521	53,521	53,521	0	0	0	0
1C	0.08	0.119	0	0	0	0	200,576	-200,576	200,576	-200,576
2C-1	0.0475	0.119	119,092	-119,092	119,092	-119,092	0	0	0	0
3A*	3.5666	0.1073	0	0	0	0	0	0	0	0
1A	0.0773	0.1259	0	0	0	0	0	0	0	0
3B*	8.1818	0.1704	12,064	12,064	-12,064	-12,064	0	0	0	0
1B-1	0.0245	0.1394	46,125	-46,125	-46,125	46,125	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			230,802	-99,632	114,424	-31,510	223,498	-177,654	223,498	-177,654
Primary membrane circumferential stress*			65,585	65,585	41,457	41,457	22,922	22,922	22,922	22,922
3C*	6.8016	0.1623	30,994	30,994	30,994	30,994	0	0	0	0
4C*	10.3322	0.2001	0	0	0	0	47,083	47,083	47,083	47,083
1C-1	0.0547	0.169	137,144	-137,144	137,144	-137,144	0	0	0	0
2C	0.0364	0.169	0	0	0	0	91,262	-91,262	91,262	-91,262
4A*	6.0785	0.1073	0	0	0	0	0	0	0	0
2A	0.0324	0.1587	0	0	0	0	0	0	0	0
4B*	3.5218	0.1704	10,321	10,321	-10,321	-10,321	0	0	0	0
2B-1	0.0217	0.1928	29,542	-29,542	-29,542	29,542	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			208,001	-125,371	128,275	-86,929	138,345	-44,179	138,345	-44,179
Primary membrane longitudinal stress*			41,315	41,315	20,673	20,673	47,083	47,083	47,083	47,083
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)			230,802	-125,371	128,275	-86,929	223,498	-177,654	223,498	-177,654

Note: * denotes primary stress.

Top Lifting Lug



Geometry Inputs

Attached To	Cylinder #1
Material	SA-516-70
Distance of Lift Point From Datum	704.0025"
Angular Position	126.00° and 306.00°
Length of Lug, L	24"
Width of Lug, B	28"
Thickness of Lug, t	2.8301"
Hole Diameter, d	3.375"
Pin Diameter, Dp	3.25"
Lug Diameter at Pin, D	20"
Weld Size, t_w	1"
Width of Pad, B_p	30"
Length of Pad, L_p	40"
Pad Thickness, t_p	1.25"
Pad Weld Size, t_{wp}	1"
Weld Length, L_3	38"
Load Angle from Vertical, ϕ	0.0000 °
Has Brace Plate	No

Intermediate Values

Load Factor	2.0000
Vessel Weight (new, incl. Load Factor), W	350402 lb
Lug Weight (new), W_{lug}	3851 lb (Qty=2)
Distance from Center of Gravity to Top Lug, l_1	370.337"
Distance from Center of Gravity to Tail Lug, l_2	424.6619"
Distance from Vessel Center Line to Tail Lug, l_3	68.625"
Allowable Stress, Tensile, σ_t	20000 psi
Allowable Stress, Shear, σ_s	14000 psi
Allowable Stress, Bearing, σ_p	20000 psi
Allowable Stress, Bending, σ_b	20000 psi
Allowable Stress, Weld Shear, $\tau_{allowable}$	14000 psi
Allowable Stress set to 1/3 Sy per ASME B30.20	No

Summary Values

Required Lift Pin Diameter, d_{reqd}	2.8226"
Required Lug Thickness, t_{reqd}	2.6954"
Lug Stress Ratio, σ_{ratio}	0.31
Weld Shear Stress Ratio, τ_{ratio}	0.47
Lug Design	Acceptable
Local Stresses	Acceptable
Maximum Out of Plane Lift Angle - Weak Axis Bending	10.08°

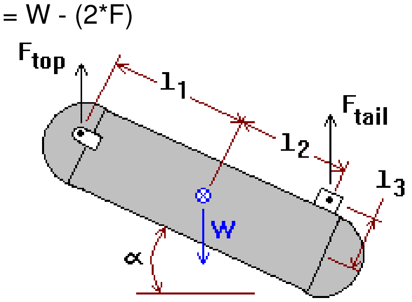
INSPECT recommends a spreader beam be used to prevent weak axis bending of the top lugs.
No consideration is given for any bracing plate from the lug to the vessel.

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	93,587	163,229
15	95,431	159,539
30	97,461	155,480
45	100,072	150,258
60	104,201	141,999
75	113,473	123,455
90	175,201	0
15[1]	95,431	159,539
9[2]	94,687	161,028
9[3]	94,687	161,028
[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} = $(2*F_v / (\pi*\sigma_s))^{0.5}$
= $(2*175{,}201 / (\pi*14{,}000))^{0.5}$ = 2.8226"

d_{reqd} / D_p = 2.8226 / 3.25 = 0.87 Acceptable

σ = F_v / A
= $F_v / (2*(0.25*\pi*D_p^2))$
= $175{,}201 / (2*(0.25*\pi*3.25^2))$ = 10,560 psi

σ / σ_s = 10,560 / 14,000 = 0.75 Acceptable

Lug Thickness - Tensile stress

t_{reqd} = $F_v / ((D - d)*\sigma_t)$
= 175,201 / ((20 - 3.375)*20,000) = 0.5269"

t_{reqd} / t = 0.5269 / 2.8301 = 0.19 Acceptable

σ = F_v / A
= $F_v / ((D - d)*t)$
= 175,201 / ((20 - 3.375)*2.8301) = 3,724 psi

σ / σ_t = 3,724 / 20,000 = 0.19 Acceptable

Lug Thickness - Bearing stress

t_{reqd} = F_v / (D_p*σ_p)
= 175,201 / (3.25*20,000) = 2.6954"

t_{reqd} / t = 2.6954 / 2.8301 = 0.95 Acceptable

σ = F_v / $A_{bearing}$
= F_v / (D_p*(t))
= 175,201 / (3.25*(2.8301)) = 19,048 psi

σ / σ_p = 19,048 / 20,000 = 0.95 Acceptable

Lug Thickness - Shear stress

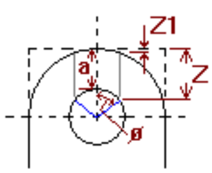
t_{reqd} = [F_v / σ_s] / (2*L_{shear})
= (175,201 / 14,000) / (2*8.8742) = 0.7051"

t_{reqd} / t = 0.7051 / 2.8301 = 0.25 Acceptable

τ = F_v / A_{shear}
= F_v / (2*t*L_{shear})
= 175,201 / (2*2.8301*8.8742) = 3,488 psi

τ / σ_s = 3,488 / 14,000 = 0.25 Acceptable

Shear stress length (per Pressure Vessel and Stacks, A. Keith Escoe)



ϕ = 55*D_p / d
= 55*3.25 / 3.375
= 52.963°
Z = 0.5*(D - d) + 0.5*D_p*(1 - cos(ϕ))
= 0.5*(20 - 3.375) + 0.5*3.25*(1 - cos(52.963))
= 8.9587"
Z1 = 0.5*D - sqr(0.25*D*D - (0.5*D_p*sin(ϕ))^2)
= 0.5*20 - sqr(0.25*20*20 - (0.5*3.25*sin(52.963))^2)
= 0.0845"
L_{shear} = Z - Z1
= 8.8742"

Lug Plate Stress

Lug stress, tensile + bending, during rotational lift:

σ_{ratio} = $[F_{ten} / (A_{ten}*\sigma_t)] + [M_{bend} / (Z_{bend}*\sigma_b)] \le 1$

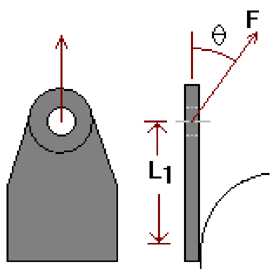
= $[(F_{top}(\alpha)*\sin(\alpha)) / (t*B*\sigma_t)] + [(6*F_{top}(\alpha)*L*\cos(\alpha)) / (t*B^2 * \sigma_b)] \le 1$

= 95,431*sin(15.0) / (2.8301*28*20,000) + 6*(95,431)*24*cos(15.0) / (2.8301*28^2*20,000)

= 0.31 Acceptable

Weak Axis Bending Stress

Maximum lift cable angle from vertical θ = 10.08°



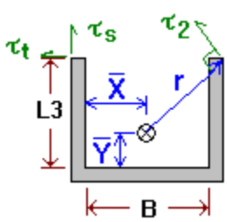
σ_b = M / Z = $(F*\sin(\theta)*L_1) / Z$

$F*\cos(\theta)$ = 0.5*W => $F = 0.5*W / \cos(\theta)$

θ = $\arctan((2*\sigma_b*Z) / (W*L_1))$

θ = arctan((2*20,000*(28*2.8301^2/6)) / (350,402*24)) = 10.08°

Weld Stress



Weld stress, direct and torsional shear, during rotational lift:

Direct shear:

Maximum weld shear stress occurs at lift angle 9.00°; lift force = 94,687 lbf

A_{weld} = $0.707*t_w*(2*L_3 + B)$

= 0.707*1*(2*38 + 28) = 73.528 in^2

τ_t = $F_r*\cos(\alpha) / A_{weld}$

= 94,687*cos(9.0) / 73.528 = 1,272 psi

τ_s = $F_r*\sin(\alpha) / A_{weld}$

$= 94{,}687 * \sin(9.0) / 73.528 \quad = 201$ psi

Torsional shear:

Weld centroid:

$Y_{bar} = L_3^2 / (2 * L_3 + B)$
$= 38^2 / (2 * 38 + 28) \quad = 13.8846"$

Second polar moment of area:

$J = 0.707 * t_w * ((8 * L_3^3 + 6 * L_3 * B^2 + B^3) / 12 - L_3^4 / (2 * L_3 + B))$
$= 0.707 * 1 * ((8 * 38^3 + 6 * 38 * 28^2 + 28^3) / 12 - 38^4 / (2 * 38 + 28)) \quad = 23512.9\ in^4$

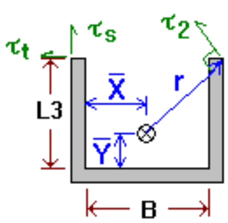
Radial distance from centroid to weld:

$r = \text{sqr}((X_{bar})^2 + (L_3 - Y_{bar})^2)$
$= \text{sqr}((0.5 * 28)^2 + (38 - 13.8846)^2) \quad = 27.8846"$

$\theta_r = \arctan((L_3 - Y_{bar}) / (X_{bar}))$
$= \arctan(24.1154 / 14) \quad = 59.86°$

$\tau_2 = M * r / J$
$= [F(\alpha) * \cos(\alpha) * (L + L_3 - Y_{bar})] * r / J$
$= (94{,}687 * \cos(9.0) * 48.1154) * 27.8846 / 23512.8984$
$= 5{,}336$ psi

$\tau_{ratio} = \text{sqr}((\tau_t + \tau_2 * \sin(\theta_r))^2 + (\tau_s + \tau_2 * \cos(\theta_r))^2) / \tau_{allowable} \le 1$
$= \text{sqr} ((1{,}272 + 5{,}336 * \sin(59.86))^2 + (201 + 5{,}336 * \cos(59.86))^2) / 14{,}000$
$= 0.47$ Acceptable



Pad Weld Stress

Direct shear:

Maximum weld shear stress occurs at lift angle 9.00°; lift force = 94,687 lbf

$A_{weld} = 0.707 * t_{wp} * (2 * L_p + B_p)$
$= 0.707 * 1 * (2 * 40 + 30) \quad = 77.77\ in^2$

$\tau_t = F_r * \cos(\alpha) / A_{weld}$
$= 94{,}687 * \cos(9.0) / 77.77 \quad = 1{,}203$ psi

$\tau_s = F_r * \sin(\alpha) / A_{weld}$
$= 94{,}687 * \sin(9.0) / 77.77 \quad = 190$ psi

Torsional shear:

Weld centroid:

Y_{barp} = L_p^2 / (2*L_p + B_p)
= 40^2 / (2*40 + 30) = 14.5455"

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*1* ((8*40^3 + 6*40*30^2 + 30^3) / 12 - 40^4 / (2*40 + 30)) = 28028.27 in^4

Radial distance from centroid to weld:

r_p = sqr($(X_{barp})^2$ + $(L_p - Y_{barp})^2$)
= sqr($(0.5*30)^2$ + $(40 - 14.5455)^2$) = 29.5455"

θ_r = arctan((L_p - Y_{barp}) / (X_{barp}))
= arctan(25.4545 / 15) = 59.49°

τ_2 = M * r_p / J_p
= [F(α)*cos(α)*(L + L_p - Y_{barp})] * r_p / J_p
= (94,687*cos(9.0)*49.4545)*29.5455 / 28028.2652
= 4,875 psi

τ_{ratio} = sqr($(\tau_t + \tau_2 \sin(\theta_r))^2 + (\tau_s + \tau_2 \cos(\theta_r))^2$) / $\tau_{allowable} \leq 1$
= sqr ($(1{,}203 + 4{,}875*\sin(59.49))^2$ + $(190 + 4{,}875*\cos(59.49))^2$) / 14,000
= 0.43 Acceptable

WRC 107 Analysis

Geometry

Height(radial):	2.8301"	Pad Thickness:	1.25"
Width (circumferential):	28"	Pad Width:	30"
Length	38"	Pad Length:	40"
Fillet Weld Size:	1"	Pad Weld Size:	1"
Located on:	Cylinder #1	(38" from top end)	
Location Angle:	126.00° and 306.00°		

Applied Loads

Maximum stress ratio occurs at lift angle = 14.00° with lift force = 95,306 lbf

Radial load:	P_r =	0	lb_f
Circumferential moment:	M_c =	246,450.77	lb_f-in
Circumferential shear:	V_c =	92,474.89	lb_f
Longitudinal moment:	M_L =	61,447.08	lb_f-in
Longitudinal shear:	V_L =	23,056.58	lb_f
Torsion moment:	M_t =	3,976,420.23	lb_f-in
Internal pressure:	P =	0	psi
Mean shell radius:	R_m =	57.845	in
Shell yield stress:	S_y =	38,000	psi
Design factor:		3	

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / t = 57.845 / 2.31 = 25.0411$

$C_1 = 15$, $C_2 = 20$ 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) = 2,769 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) = -215 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 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*	1.5452	0.3473	0	0	0	0	0	0	0	0
4C*	2.9755	0.3194	0	0	0	0	0	0	0	0
1C	0.061	0.2875	0	0	0	0	0	0	0	0
2C-1	0.0262	0.2875	0	0	0	0	0	0	0	0
3A*	1.101	0.2854	0	0	0	0	-109	-109	109	109
1A	0.0746	0.318	0	0	0	0	-1,124	1,124	1,124	-1,124
3B*	2.2168	0.3141	-49	-49	49	49	0	0	0	0
1B-1	0.02	0.3088	-77	77	77	-77	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			-126	28	126	-28	-1,233	1,015	1,233	-1,015
Primary membrane circumferential stress*			-49	-49	49	49	-109	-109	109	109
3C*	1.713	0.3194	0	0	0	0	0	0	0	0
4C*	2.8114	0.3473	0	0	0	0	0	0	0	0
1C-1	0.0495	0.3244	0	0	0	0	0	0	0	0
2C	0.03	0.3244	0	0	0	0	0	0	0	0
4A*	2.117	0.2854	0	0	0	0	-215	-215	215	215
2A	0.0335	0.3578	0	0	0	0	-449	449	449	-449
4B*	1.0442	0.3141	-29	-29	29	29	0	0	0	0
2B-1	0.0333	0.3423	-116	116	116	-116	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			-145	87	145	-87	-664	234	664	-234
Primary membrane longitudinal stress*			-29	-29	29	29	-215	-215	215	215
Shear from M_t			717	717	717	717	956	956	956	956
Circ shear from V_c			667	667	-667	-667	0	0	0	0
Long shear from V_L			0	0	0	0	-125	-125	125	125
Total Shear stress			1,384	1,384	50	50	831	831	1,081	1,081
Combined stress (P_L+P_b+Q)			2,768	2,769	186	116	-1,827	1,836	2,236	2,299

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the pad edge (includes pressure)

$\gamma = R_m / t = 57.845 / 1.06 = 54.5708$

$C_1 = 16$, $C_2 = 21$ 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) = 5,686 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) = -1,081 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*	1.797	0.3652	0	0	0	0	0	0	0	0
4C*	4.9623	0.337	0	0	0	0	0	0	0	0
1C	0.0631	0.3048	0	0	0	0	0	0	0	0
2C-1	0.0123	0.3048	0	0	0	0	0	0	0	0
3A*	1.6974	0.3028	0	0	0	0	-325	-325	325	325
1A	0.0587	0.3322	0	0	0	0	-4,021	4,021	4,021	-4,021
3B*	3.1225	0.3316	-143	-143	143	143	0	0	0	0
1B-1	0.0113	0.3226	-199	199	199	-199	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			-342	56	342	-56	-4,346	3,696	4,346	-3,696
Primary membrane circumferential stress*			-143	-143	143	143	-325	-325	325	325
3C*	2.0472	0.337	0	0	0	0	0	0	0	0
4C*	4.5739	0.3652	0	0	0	0	0	0	0	0
1C-1	0.0241	0.342	0	0	0	0	0	0	0	0
2C	0.03	0.342	0	0	0	0	0	0	0	0
4A*	5.2784	0.3028	0	0	0	0	-1,081	-1,081	1,081	1,081
2A	0.0232	0.3685	0	0	0	0	-1,432	1,432	1,432	-1,432
4B*	1.7278	0.3316	-94	-94	94	94	0	0	0	0
2B-1	0.0187	0.3572	-297	297	297	-297	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			-391	203	391	-203	-2,513	351	2,513	-351
Primary membrane longitudinal stress*			-94	-94	94	94	-1,081	-1,081	1,081	1,081
Shear from M_t			1,374	1,374	1,374	1,374	1,803	1,803	1,803	1,803
Circ shear from V_c			1,363	1,363	-1,363	-1,363	0	0	0	0
Long shear from V_L			0	0	0	0	-259	-259	259	259
Total Shear stress			2,737	2,737	11	11	1,544	1,544	2,062	2,062
Combined stress (P_L+P_b+Q)			5,474	5,476	393	-204	-5,225	4,552	5,686	5,310

Note: * denotes primary stress.
WRC 107 does not consider torsional moments for rectangular attachments.
As such, Shear from M_t is calculated based on Blodgett p. 7.4-6, Table 5.

Trays #1

Number of trays in group:	19
Distance from bottom tray to datum:	184"
Space between trays:	24"
Tray weight:	12.00lb/ft^2
Tray diameter	114"
Support weight:	500 lb each
Operating liquid depth on tray:	0"
Tray liquid specific gravity:	1.00
Estimated tray weight, Empty:	1,350.6 lb each
Estimated tray weight, Operating	1,350.6 lb each
Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes
Number of Passes:	1

Vertical Load #1

Load Orientation	Vertical Load
Elevation above datum:	300"
Direction angle:	0.00 degrees
Distance from center of vessel:	0"
Magnitude of force:	15,000 lb
Present when operating:	Yes
Included in vessel lift weight:	Yes
Present when vessel is empty:	Yes
Present during hydrotest:	Yes