MEG ENERGY	CHRISTINA LAKE REGIONAL PROJECT Phase 3A EPC for Central Plant Facilities SLI Project No. 511036	SNC·LAVALIN

SNC·LAVALIN		
Vendor's drawing review for conformity with specifications and design drawing.	☐ A1	Not suitable to initiate fabrication. modify as noted, resubmit for review
This review does not relieve the vendor of his responsibility for errors in design and detailing as detailed in his contract.	☐ B1	Suitable to initiate fabrication as noted. modify as noted, resubmit for review
	☐ C1	Suitable to fabricate to completion as noted. submit final documents including as-builts as required
	☐ D1	Suitable to fabricate to completion. submit final documents including as-built documents as required
	☐ E1	Not suitable as final documents as noted. modify as noted and resubmit.
	☒ F1	Suitable as final documents. no further resubmittal required (unless revised by vendor)

Vendor: Ecodyne Limited (Canada) - 12123 No.: 32125-A-2902 Rev: B

Doc. Title: L50.52 - AFTER FILTERS CALCS - Tag: 3A-F-208 A-G

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Project: MEG Phase 3A EPC

Reviewed by: [signature]

Date: Apr 12, 2013

Document No P-5675-02-0032

Submittal 02

Attached document: 12-32 CAL-R2, 146 pages

Tags: 3A-F-208 A-G

TITLE	CUSTOMER
After Filter Pressure Vessel And Nozzle Load Calculations	**MEG Energy Corporation** **c/o SNC Lavalin** **Christina Lake Phase 3A** **PO No. P-5675-02**

REV	DATE	REMARKS	BY	CHKD			
					SCALE -		
						BY	DATE
B	2013 MAR 28	PER CLIENT MARK-UP AND UPDATED VESSEL DRAWING	VEN	RJ	DRN	VEN	2013 Jan 15
A	2013 Jan 15	FIRST ISSUE	AV	RJ	CHKD	RJ	2013 Mar 28
REV	DATE	REMARKS	BY	CHKD	APPD	AV	2013 Mar 28

ECODYNE Limited

MARMON A Marmon Water/Berkshire Hathaway Company

DWG. NO.	REV.
32125-A-2902	B

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Settings Summary

COMPRESS 2013 Build 7300

Units: SI

Datum Line Location: -102.00 mm from bottom seam

Design

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric

Design or Rating:	Get Thickness from Pressure
Minimum thickness:	1.5 mm per UG-16(b)
Design for cold shut down only:	No
Design for lethal service (full radiography required):	No
Design nozzles for:	Vessel MAWP
Corrosion weight loss:	100% of theoretical loss
UG-23 Stress Increase:	1.00
Skirt/legs stress increase:	1.0
Minimum nozzle projection:	12.7 mm
Juncture calculations for α > 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

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:	None

Code Cases\Interpretations

Use Code Case 2547:	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:	Yes
UG-22(j) Test pressure and coincident static head acting during the test:	Yes

Note: UG-22(b),(c) and (f) loads only considered when supports are present.

Pressure Summary

Pressure Summary for Chamber bounded by BOTTOM HEAD and TOP HEAD

Identifier	P Design (kPa)	T Design (°C)	MAWP (kPa)	MAP (kPa)	MAEP (kPa)	T_e external (°C)	MDMT (°C)	MDMT Exemption		Impact Tested
TOP HEAD	1,034	120	1,041.57	1,279.83	224.31	120	-42.1	Note 1		No
Straight Flange on TOP HEAD	1,034	120	1,313.95	1,553.46	354.46	120	-48	Note 2		No
3962 mm O.D. SHELL	1,034	120	1,069.57	1,332.18	221.4	120	-42.46	Note 3		No
Straight Flange on BOTTOM HEAD	1,034	120	1,289.56	1,553.46	354.46	120	-48	Note 5		No
BOTTOM HEAD	1,034	120	1,065.8	1,338.64	250.06	120	-42.26	Note 4		No
SUPPORT LEG	1,034	120	1,041.57	N/A	N/A	N/A	N/A	N/A		N/A
TOP MANWAY (M1)	1,034	120	1,041.57	1,041.57	224.31	120	-47.9	Nozzle	Note 6	No
								Pad	Note 7	No
BOTTOM MANWAY (M2)	1,034	120	1,041.57	1,041.57	250.06	120	-47.36	Nozzle	Note 8	No
								Pad	Note 9	No
WATER INLET (N1)	1,034	120	1,041.57	1,041.57	224.31	120	-47.9	Nozzle	Note 10	No
								Pad	Note 11	No
WATER OUTLET (N2)	1,034	120	1,041.57	1,041.57	250.06	120	-47.26	Nozzle	Note 12	No
								Pad	Note 13	No
MEDIA REMOVAL (N3A)	1,034	120	1,041.57	1,041.57	250.06	120	-29	Note 14		No
MEDIA REMOVAL (N3B)	1,034	120	1,041.57	1,041.57	250.06	120	-29	Note 14		No
PSV/VENT (N4)	1,034	120	1,041.57	1,041.57	224.31	120	-48	Nozzle	Note 15	No
								Pad	Note 16	No
SIGHT GLASS (SG1A)	1,034	120	1,041.57	1,041.57	221.4	120	-43.36	Note 17		No
SIGHT GLASS (SG1B)	1,034	120	1,041.57	1,041.57	221.4	120	-43.16	Note 18		No

Chamber design MDMT is -28.89 °C
Chamber rated MDMT is -29 °C @ 1,041.57 kPa

Chamber MAWP hot & corroded is 1,041.57 kPa @ 120 °C

Chamber MAP cold & new is 1,041.57 kPa @ 10 °C

Chamber MAEP is 221.4 kPa @ 120 °C
Vacuum rings did not govern the external pressure rating.

Notes for MDMT Rating:

Note #	Exemption	Details
1.	Material impact test exemption temperature from Fig UCS-66M Curve D = -42.1 °C	UCS-66 governing thickness = 18.22 mm
2.	Material impact test exemption temperature from Fig UCS-66M Curve D = -38 °C Fig UCS-66.1M MDMT reduction = 11.4 °C, (coincident ratio = 0.7956) Rated MDMT of -49.4°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 22.2 mm
3.	Material impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C Fig UCS-66.1M MDMT reduction = 1.4 °C, (coincident ratio = 0.9748)	UCS-66 governing thickness = 19.05 mm
4.	Material impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C Fig UCS-66.1M MDMT reduction = 1.2 °C, (coincident ratio = 0.9784)	UCS-66 governing thickness = 19.05 mm
5.	Material impact test exemption temperature from Fig UCS-66M Curve D = -38 °C Fig UCS-66.1M MDMT reduction = 10.4 °C, (coincident ratio = 0.8139) Rated MDMT of -48.4°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 22.2 mm
6.	Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.3331).	
7.	Pad impact test exemption temperature from Fig UCS-66M Curve D = -42.1 °C Fig UCS-66.1M MDMT reduction = 5.8 °C, (coincident ratio = 0.8968)	UCS-66 governing thickness = 18.22 mm.
8.	Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.3478).	
9.	Pad impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C Fig UCS-66.1M MDMT reduction = 6.3 °C, (coincident ratio = 0.8872)	UCS-66 governing thickness = 19.05 mm.
10.	Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2293).	
11.	Pad impact test exemption temperature from Fig UCS-66M Curve D = -42.1 °C Fig UCS-66.1M MDMT reduction = 5.8 °C, (coincident ratio = 0.8957)	UCS-66 governing thickness = 18.22 mm.
12.	Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2334).	
13.	Pad impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C Fig UCS-66.1M MDMT reduction = 6.2 °C, (coincident ratio = 0.889)	UCS-66 governing thickness = 19.05 mm.
14.	Nozzle is impact test exempt per UG-20(f)	UCS-66 governing thickness = 19.05 mm.
15.	Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.1458).	
16.	Pad impact test exemption temperature from Fig UCS-66M Curve D = -48 °C Fig UCS-66.1M MDMT reduction = 5.8 °C, (coincident ratio = 0.8963) Rated MDMT of -53.8°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 12.7 mm.
17.	Nozzle impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C Fig UCS-66.1M MDMT reduction = 2.3 °C, (coincident ratio = 0.9585)	UCS-66 governing thickness = 19.05 mm.
18.	Nozzle impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C Fig UCS-66.1M MDMT reduction = 2.1 °C, (coincident ratio = 0.9629)	UCS-66 governing thickness = 19.05 mm.

Design notes are available on the Settings Summary page.

Hydrostatic Test

Shop test pressure determination for Chamber bounded by BOTTOM HEAD and TOP HEAD based on MAWP per UG-99(b)

Shop hydrostatic test gauge pressure is 1,354.04 kPa at 10 °C (the chamber MAWP = 1,041.57 kPa)

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

Identifier	Local test pressure kPa	Test liquid static head kPa	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test MPa	Allowable test stress MPa	Stress excessive?
TOP HEAD (1)	1,392.44	38.4	1	1.30	135.003	235.8	No
Straight Flange on TOP HEAD	1,392.4	38.36	1	1.30	123.552	235.8	No
3962 mm O.D. SHELL	1,392.37	38.33	1	1.30	144.094	235.8	No
Straight Flange on BOTTOM HEAD	1,392.4	38.36	1	1.30	123.552	235.8	No
BOTTOM HEAD	1,392.43	38.39	1	1.30	129.065	235.8	No
BOTTOM MANWAY (M2)	1,370.09	16.05	1	1.30	157.718	351	No
MEDIA REMOVAL (N3A)	1,380.99	26.96	1	1.30	145.856	351	No
MEDIA REMOVAL (N3B)	1,363.96	9.92	1	1.30	144.057	351	No
PSV/VENT (N4)	1,368.25	14.22	1	1.30	115.187	351	No
SIGHT GLASS (SG1A)	1,387.53	33.49	1	1.30	142.901	351	No
SIGHT GLASS (SG1B)	1,387.53	33.49	1	1.30	142.901	351	No
TOP MANWAY (M1)	1,366.11	12.08	1	1.30	166.705	351	No
WATER INLET (N1)	1,374.65	20.62	1	1.30	126.599	351	No
WATER OUTLET (N2)	1,376.14	22.11	1	1.30	136.337	351	No

Notes:
(1) TOP HEAD 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 10 °C is warmer than the minimum recommended temperature of -12 °C so the brittle fracture provision of UG-99(h) has been met.

Field test pressure determination for Chamber bounded by BOTTOM HEAD and TOP HEAD based on MAWP per UG-99(b)

Field hydrostatic test gauge pressure is 1,354.04 kPa at 10 °C (the chamber MAWP = 1,041.57 kPa)

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

Identifier	Local test pressure kPa	Test liquid static head kPa	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test MPa	Allowable test stress MPa	Stress excessive?
TOP HEAD (1)	1,368.73	14.7	1	1.30	132.704	235.8	No
Straight Flange on TOP HEAD	1,368.73	14.7	1	1.30	121.452	235.8	No
3962 mm O.D. SHELL	1,392.12	38.09	1	1.30	144.069	235.8	No
Straight Flange on BOTTOM HEAD	1,393.12	39.09	1	1.30	123.616	235.8	No
BOTTOM HEAD	1,402.74	48.7	1	1.30	130.02	235.8	No
BOTTOM MANWAY (M2)	1,406.35	52.31	1	1.30	161.892	351	No
MEDIA REMOVAL (N3A)	1,394.37	40.33	1	1.30	147.269	351	No
MEDIA REMOVAL (N3B)	1,394.37	40.33	1	1.30	147.269	351	No
PSV/VENT (N4)	1,359.19	5.16	1	1.30	114.424	351	No
SIGHT GLASS (SG1A)	1,374.07	20.03	1	1.30	141.514	351	No
SIGHT GLASS (SG1B)	1,378.87	24.83	1	1.30	142.009	351	No
TOP MANWAY (M1)	1,359.83	5.79	1	1.30	165.937	351	No
WATER INLET (N1)	1,358.44	4.4	1	1.30	125.106	351	No
WATER OUTLET (N2)	1,408.55	54.51	1	1.30	139.547	351	No

Notes:
(1) TOP HEAD 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 10 °C is warmer than the minimum recommended temperature of -12 °C so the brittle fracture provision of UG-99(h) has been met.

Nozzle Schedule

Nozzle mark	Service	Size	Materials		Impact Tested	Normalized	Fine Grain	Flange	Blind
M1	TOP MANWAY	NPS 24 XS DN 600	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 24 Class 150 WN A105	NPS 24 Class 150 A105
			Pad	SA-516 70	No	Yes	Yes		
M2	BOTTOM MANWAY	NPS 24 XS DN 600	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 24 Class 150 WN A105	NPS 24 Class 150 A105
			Pad	SA-516 70	No	Yes	Yes		
N1	WATER INLET	NPS 12 Sch 60 DN 300	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 12 Class 150 WN A105	No
			Pad	SA-516 70	No	Yes	Yes		
N2	WATER OUTLET	NPS 12 Sch 60 DN 300	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 12 Class 150 WN A105	No
			Pad	SA-516 70	No	Yes	Yes		
N3A	MEDIA REMOVAL	139.7 OD x 19.05	Nozzle	SA-105	No	No	No	NPS 4 Class 150 LWN A105	NPS 4 Class 150 A105
N3B	MEDIA REMOVAL	139.7 OD x 19.05	Nozzle	SA-105	No	No	No	NPS 4 Class 150 LWN A105	NPS 4 Class 150 A105
N4	PSV/VENT	NPS 3 Sch 160 DN 80	Nozzle	SA-106 B Smls. Pipe	No	No	No	NPS 3 Class 150 WN A105	No
			Pad	SA-516 70	No	Yes	Yes		
SG1A	SIGHT GLASS	255 OD x 54.5	Nozzle	SA-516 70	No	Yes	Yes	N/A	No
SG1B	SIGHT GLASS	255 OD x 54.5	Nozzle	SA-516 70	No	Yes	Yes	N/A	No

Nozzle Summary

Nozzle mark	OD (mm)	t_n (mm)	Req t_n (mm)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (mm)	A_a/A_r (%)
						Nom t (mm)	Design t (mm)	User t (mm)	Width (mm)	t_{pad} (mm)		
M1	609.6	12.7	6.88	Yes	Yes	18.22*	16.67		152.4	22.2	3.2	100.4
M2	609.6	12.7	6.8	Yes	Yes	19.05*	17.26		161.92	22.2	3.2	104.3
N1	323.85	14.27	13.18	Yes	Yes	18.22*	16.65		63.5	22.2	3.2	107.7
N2	323.85	14.27	13.18	Yes	Yes	19.05*	17.29		69.85	22.2	3.2	105.1
N3A	139.7	19.05	8.93	Yes	Yes	19.05*	18.59		N/A	N/A	3.2	104.6
N3B	139.7	19.05	8.93	Yes	Yes	19.05*	18.59		N/A	N/A	3.2	104.6
N4	88.9	11.13	9.14	Yes	Yes	18.22*	16.66		50.8	12.7	3.2	128.7
SG1A	255	54.5	11.31	Yes	Yes	19.05	18.39		N/A	N/A	3.2	127.9
SG1B	255	54.5	11.31	Yes	Yes	19.05	18.46		N/A	N/A	3.2	127.0

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

Thickness Summary

Component Identifier	Material	Diameter (mm)	Length (mm)	Nominal t (mm)	Design t (mm)	Total Corrosion (mm)	Joint E	Load
TOP HEAD	SA-516 70	3,962 OD	999.61	18.22*	18.12	3.2	1.00	Internal
Straight Flange on TOP HEAD	SA-516 70	3,962 OD	51	22.2	18.21	3.2	1.00	Internal
3962 mm O.D. SHELL	SA-516 70	3,962 OD	2,387	19.05	18.54	3.2	1.00	Internal
Straight Flange on BOTTOM HEAD	SA-516 70	3,962 OD	102	22.2	18.56	3.2	1.00	Internal
BOTTOM HEAD	SA-516 70	3,962 OD	1,000.03	19.05*	18.6	3.2	1.00	Internal

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 (kg) Contributed by Vessel Elements										Surface Area m2
	Metal New*	Metal Corroded*	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid		
							New	Corroded	New	Corroded	
TOP HEAD	2,618.4	2,166.2	171	9.1	208.6	0	8,668.1	8,725.7	8,562.1	8,566	19.27
3962 mm O.D. SHELL	4,396.9	3,661.2	292.1	9.1	358.6	0	28,655.4	28,749.3	28,655.4	28,655.4	29.61
BOTTOM HEAD	2,837.9	2,371	177.2	9.1	218.9	0	9,246.2	9,306.2	9,134.8	9,138.3	19.88
SUPPORT LEG	888	888	0	0	0	0	0	0	0	0	15.69
TOTAL:	**10,741.2**	**9,086.5**	**640.3**	**27.2**	**786.1**	**0**	**46,569.7**	**46,781.2**	**46,352.3**	**46,359.8**	**84.44**

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

Component	Weight (kg) Contributed by Attachments										Surface Area m2
	Body Flanges		Nozzles & Flanges		Packed Beds	Ladders & Platforms	Trays	Tray Supports	Rings & Clips	Vertical Loads	
	New	Corroded	New	Corroded							
TOP HEAD	0	0	659.1	608.6	39.5	0	0	0	0	0	2.98
3962 mm O.D. SHELL	0	0	33.4	29.4	1,848.7	0	0	0	102.5	10,474*	0.52
BOTTOM HEAD	0	0	656.7	621.6	79	0	0	0	20.6	10,409*	3.1
SUPPORT LEG	0	0	0	0	0	0	0	0	0	0	0
TOTAL:	**0**	**0**	**1,349.2**	**1,259.6**	**1,967.2**	**0**	**0**	**0**	**123.1**	**20,883***	**6.61**

* This number includes vertical loads which are not present in all conditions.
* Nozzle weight includes lining.

Vessel operating weight, Corroded: 81,554 kg
Vessel operating weight, New: 83,087 kg
Vessel empty weight, Corroded: 26,210 kg
Vessel empty weight, New: 27,954 kg
Vessel test weight, New: 63,898 kg
Vessel test weight, Corroded: 62,161 kg
Vessel surface area: 91.05 m^2

Vessel center of gravity location - from datum - lift condition

Vessel Lift Weight, New: 25,987 kg
Center of Gravity: 636.47 mm

Vessel Capacity

Vessel Capacity** (New): 46,134 liters
Vessel Capacity** (Corroded): 46,134 liters
**The vessel capacity does not include volume of nozzle, piping or other attachments.

TOP HEAD

ASME Section VIII, Division 1, 2010 Edition, A11 Addenda Metric

Component: Ellipsoidal Head
Material Specification: SA-516 70 (II-D Metric p.18, ln. 19)
Material impact test exemption temperature from Fig UCS-66M Curve D = -42.1 °C
UCS-66 governing thickness = 18.22 mm

Internal design pressure: P = 1,034 kPa @ 120 °C
External design pressure: P_e = 103.42 kPa @ 120 °C

Static liquid head:

P_s= 14.2 kPa (SG=1, H_s=1449 mm Operating head)
P_{th}= 38.4 kPa (SG=1, H_s=3919.21 mm Horizontal test head)
P_{tv}= 14.2 kPa (SG=1, H_s=1449 mm Vertical test head)

Corrosion allowance: Inner C = 3.2 mm Outer C = 0 mm

Design MDMT = -28.89°C — No impact test performed
Rated MDMT = -42.1°C — Material is normalized
Material is produced to fine grain practice
PWHT is not performed
Do not Optimize MDMT / Find MAWP

Radiography:	Category A joints -	Full UW-11(a) Type 1
	Head to shell seam -	Spot UW-11(a)(5)(b) Type 1

Estimated weight*:	new = 2,618.4 kg	corr = 2,166.2 kg
Capacity*:	new = 8,427.2 liters	corr = 8,427.2 liters

* includes straight flange

Outer diameter	=	3962 mm
Minimum head thickness	=	18.22 mm
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	1.9968 (corroded)
Straight flange length L_{sf}	=	51 mm
Nominal straight flange thickness t_{sf}	=	22.2 mm

Insulation thk*:	38 mm	density: 256.2965 kg/m^3	weight: 170.9506 kg
Insulation support ring spacing:	2,438.4 mm	individual weight: 9.0718 kg	total weight: 9.0718 kg
Lining/ref thk*:	6.35 mm	density: 1,922.214 kg/m^3	weight: 208.6338 kg

* includes straight flange if applicable

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	1.5 mm + 3.2 mm = 4.7 mm
Design thickness due to internal pressure (t)	=	18.12 mm
Design thickness due to external pressure (t_e)	=	13.41 mm
Maximum allowable working pressure (MAWP)	=	1,041.57 kPa
Maximum allowable pressure (MAP)	=	1,279.83 kPa

Maximum allowable external pressure (MAEP) = 224.31 kPa

K (Corroded)

K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (3,931.96 / (2*984.59))^2]=0.997835

K (New)

K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (3,925.56 / (2*981.39))^2]=1

Design thickness for internal pressure, (Corroded at 120 °C) Appendix 1-4(c)

t = $P*D_o*K / (2*S*E + 2*P*(K - 0.1))$ + Corrosion
= 1,048.2*3,962*0.997835 / (2*138,000*1 + 2*1,048.2*(0.997835 - 0.1)) + 3.2
= 18.11 mm

The head internal pressure design thickness is 18.12 mm.

Maximum allowable working pressure, (Corroded at 120 °C) Appendix 1-4(c)

P = $2*S*E*t / (K*D_o - 2*t*(K - 0.1)) - P_s$
= 2*138,000*1*15.02 / (0.997835*3,962 - 2*15.02*(0.997835 - 0.1)) - 14.2
= 1,041.57 kPa

The maximum allowable working pressure (MAWP) is 1,041.57 kPa.

Maximum allowable pressure, (New at 10 °C) Appendix 1-4(c)

P = $2*S*E*t / (K*D_o - 2*t*(K - 0.1)) - P_s$
= 2*138,000*1*18.22 / (1*3,962 - 2*18.22*(1 - 0.1)) - 0
= 1,279.83 kPa

The maximum allowable pressure (MAP) is 1,279.83 kPa.

Design thickness for external pressure, (Corroded at 120 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.8918*3,962
= 3,533.3 mm

A = $0.125 / (R_o / t)$
= 0.125 / (3,533.3 / 10.21)
= 0.000361

From Table CS-2 Metric: B = 35.7978 MPa

P_a = $B / (R_o / t)$
= 35,797.83 / (3,533.3 / 10.21)
= 103.4213 kPa

t = 10.21 mm + Corrosion = 10.21 mm + 3.2 mm = 13.41 mm
Check the external pressure per UG-33(a)(1) Appendix 1-4(c)

t = $1.67 \cdot P_e \cdot D_o \cdot K / (2 \cdot S \cdot E + 2 \cdot 1.67 \cdot P_e \cdot (K - 0.1))$ + Corrosion
= 1.67*103.42*3,962*0.997835 / (2*138,000*1 + 2*1.67*103.42*(0.997835 - 0.1)) + 3.2
= 5.67 mm

The head external pressure design thickness (t_e) is 13.41 mm.

Maximum Allowable External Pressure, (Corroded at 120 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = $K_o \cdot D_o$
= 0.8918*3,962
= 3,533.3 mm

A = $0.125 / (R_o / t)$
= 0.125 / (3,533.3 / 15.02)
= 0.000531

From Table CS-2 Metric: B = 52.768 MPa

P_a = $B / (R_o / t)$
= 52,767.98 / (3,533.3 / 15.02)
= 224.3097 kPa

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

P = $2 \cdot S \cdot E \cdot t / ((K \cdot D_o - 2 \cdot t \cdot (K - 0.1)) \cdot 1.67) - P_{s2}$
= 2*138,000*1*15.02 / ((0.997835*3,962 - 2*15.02*(0.997835 - 0.1))*1.67) - 0
= 632.19 kPa

The maximum allowable external pressure (MAEP) is 224.31 kPa.

% Extreme fiber elongation - UCS-79(d)

EFE = $(75 \cdot t / R_f) \cdot (1 - R_f / R_o)$
= (75*22.2 / 678.45)*(1 - 678.45 / ∞)
= 2.4541%

The extreme fiber elongation does not exceed 5%.

3962 mm O.D. SHELL

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric

Component: Cylinder
Material specification: SA-516 70 (II-D Metric p. 18, ln. 19)
Material impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C
Fig UCS-66.1M MDMT reduction = 1.4 °C, (coincident ratio = 0.9748)
UCS-66 governing thickness = 19.05 mm

Internal design pressure: P = 1,034 kPa @ 120 °C
External design pressure: P_e = 103.42 kPa @ 120 °C

Static liquid head:

P_s	=	38.09 kPa	(SG = 1, H_s = 3,887 mm,Operating head)
P_{th}	=	38.33 kPa	(SG = 1, H_s = 3,912.03 mm, Horizontal test head)
P_{tv}	=	38.09 kPa	(SG = 1, H_s = 3,887 mm, Vertical test head)

Corrosion allowance Inner C = 3.2 mm Outer C = 0 mm

Design MDMT = -28.89 °C No impact test performed
Rated MDMT = -42.46 °C Material is normalized
Material is produced to Fine Grain Practice
PWHT is not performed

Radiography:	Longitudinal joint -	Full UW-11(a) Type 1
	Top circumferential joint -	Spot UW-11(a)(5)(b) Type 1
	Bottom circumferential joint -	Spot UW-11(a)(5)(b) Type 1

Estimated weight	New = 4,396.9 kg	corr = 3,661.2 kg
Capacity	New = 28,678.89 liters	corr = 28,678.89 liters

OD	= 3,962 mm					
Length L_c	= 2,387 mm					
t	= 19.05 mm					
Insulation thk:	38 mm	density:	256.3 kg/m^3	Weight:	292.1 kg
Insulation Support Spacing:	2,438.4 mm	Individual Support Weight:	9.1 kg	Total Support Weight:	9.1 kg
Lining/Refractory thickness:	6.35 mm	density:	1,922.21 kg/m^3	Weight:	358.6 kg

Design thickness, (at 120 °C) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 1,072.09*1,981 / (138,000*1.00 + 0.40*1,072.09) + 3.2
= 18.54 mm

Maximum allowable working pressure, (at 120 °C) Appendix 1-1

P = S*E*t / (R_o - 0.40*t) - P_s
= 138,000*1.00*15.85 / (1,981 - 0.40*15.85) - 38.09
= 1,069.57 kPa

Maximum allowable pressure, (at 10 °C) Appendix 1-1

P = $S*E*t / (R_o - 0.40*t)$
= 138,000*1.00*19.05 / (1,981 - 0.40*19.05)
= 1,332.18 kPa

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 3,196.26 / 3,962 = 0.8067
D_o / t = 3,962 / 11.54 = 343.4494
From table G: A = 0.000269
From table CS-2 Metric: B = 26.64 MPa

P_a = $4*B / (3*(D_o / t))$
= 4*26,640 / (3*(3,962 / 11.54))
= 103.42 kPa

Design thickness for external pressure P_a = 103.42 kPa

t_a = t + Corrosion = 11.54 + 3.2 = 14.74 mm

Maximum Allowable External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 3,196.26 / 3,962 = 0.8067
D_o / t = 3,962 / 15.85 = 249.9748
From table G: A = 0.000418
From table CS-2 Metric: B = 41.508 MPa

P_a = $4*B / (3*(D_o / t))$
= 4*41,508.05 / (3*(3,962 / 15.85))
= 221.4 kPa

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= (50*19.05 / 1,971.48)*(1 - 1,971.48 / ∞)
= 0.4831%

The extreme fiber elongation does not exceed 5%.

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

P_v = $W / (2*\pi*R_m) + M / (\pi*R_m^2)$
= $98.03*17{,}381.9 / (2*\pi*1{,}973.08) + 10000*34{,}208.7 / (\pi*1{,}973.08^2)$
= 165.4676 N/cm

α = $P_v / (P_e*D_o)$
= 100*165.4676 / (103.42*3,962)
= 0.0404

n = 7

m = $1.23 / (L / D_o)^2$

$= 1.23 / (3{,}196.26 / 3{,}962)^2$
$= 1.8900$

Ratio P_e $= (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (7^2 - 1 + 1.8900 + 1.8900*0.0404) / (7^2 - 1 + 1.8900)$
$= 1.0015$

Ratio $P_e * P_e \leq$ MAEP design cylinder thickness is satisfactory.

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

P_v $= W / (2*\pi*R_m) + M / (\pi*R_m^2)$
$= 98.03*-62{,}474.3 / (2*\pi*1{,}973.08) + 10000*5{,}638.6 / (\pi*1{,}973.08^2)$
$= -489.5850$ N/cm

α $= P_v / (P_e*D_o)$
$= 100*-489.5850 / (103.42*3{,}962)$
$= -0.1195$

n $= 7$

m $= 1.23 / (L / D_o)^2$
$= 1.23 / (3{,}196.26 / 3{,}962)^2$
$= 1.8900$

Ratio P_e $= (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (7^2 - 1 + 1.8900 + 1.8900*-0.1195) / (7^2 - 1 + 1.8900)$
$= 1.0000$

Ratio $P_e * P_e \leq$ MAEP design cylinder thickness is satisfactory.

Design thickness = 18.54 mm

The governing condition is due to internal pressure.

The cylinder thickness of 19.05 mm is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Pressure P (kPa)	Allowable Stress Before UG-23 Stress Increase (MPa)		Temperature (°C)	Corrosion C (mm)	Location	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c						
Operating, Hot & Corroded	1,034	138	84.8	120	3.2	Top	Seismic	7.27	7.23
						Bottom	Seismic	7.71	7.71
Operating, Hot & New	1,034	138	89.29	120	0	Top	Seismic	7.25	7.21
						Bottom	Seismic	7.7	7.7
Hot Shut Down, Corroded	0	138	84.8	120	3.2	Top	Seismic	0.13	0.2
						Bottom	Seismic	0.36	0.35
Hot Shut Down, New	0	138	89.29	120	0	Top	Seismic	0.13	0.2
						Bottom	Seismic	0.36	0.36
Empty, Corroded	0	138	84.8	21.11	3.2	Top	Seismic	0.15	0.18
						Bottom	Seismic	0.09	0.09
Empty, New	0	138	89.29	21.11	0	Top	Seismic	0.15	0.18
						Bottom	Seismic	0.1	0.09
Vacuum	-103.42	138	84.8	120	3.2	Top	Seismic	1.33	1.39
						Bottom	Seismic	0.61	0.62
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	138	84.8	120	3.2	Top	Weight	0.16	0.17
						Bottom	Weight	0.36	0.36

BOTTOM HEAD

ASME Section VIII, Division 1, 2010 Edition, A11 Addenda Metric

Component: Ellipsoidal Head
Material Specification: SA-516 70 (II-D Metric p.18, ln. 19)
Material impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C
Fig UCS-66.1M MDMT reduction = 1.2 °C, (coincident ratio = 0.9784)
UCS-66 governing thickness = 19.05 mm

Internal design pressure: P = 1,034 kPa @ 120 °C
External design pressure: P_e = 103.42 kPa @ 120 °C

Static liquid head:

P_s= 48.73 kPa (SG=1, H_s=4973.18 mm Operating head)
P_{th}= 38.39 kPa (SG=1, H_s=3918.38 mm Horizontal test head)
P_{tv}= 48.7 kPa (SG=1, H_s=4969.98 mm Vertical test head)

Corrosion allowance: Inner C = 3.2 mm Outer C = 0 mm

Design MDMT = -28.89°C
Rated MDMT = -42.26°C

No impact test performed
Material is normalized
Material is produced to fine grain practice
PWHT is not performed
Do not Optimize MDMT / Find MAWP

Radiography:	Category A joints -	Full UW-11(a) Type 1
	Head to shell seam -	Spot UW-11(a)(5)(b) Type 1

Estimated weight*:	new = 2,837.9 kg	corr = 2,371 kg
Capacity*:	new = 9,028 liters	corr = 9,028 liters

* includes straight flange

Outer diameter	=	3962 mm
Minimum head thickness	=	19.05 mm
Head ratio D/2h	=	2 (new)
Head ratio D/2h	=	1.9967 (corroded)
Straight flange length L_{sf}	=	102 mm
Nominal straight flange thickness t_{sf}	=	22.2 mm

Insulation thk*:	38 mm	density: 256.2965 kg/m^3	weight: 177.2262 kg
Insulation support ring spacing:	2,438.4 mm	individual weight: 9.0718 kg	total weight: 9.0718 kg
Lining/ref thk*:	6.35 mm	density: 1,922.214 kg/m^3	weight: 218.9171 kg

* includes straight flange if applicable

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	1.5 mm + 3.2 mm = 4.7 mm
Design thickness due to internal pressure (t)	=	18.6 mm
Design thickness due to external pressure (t_e)	=	13.41 mm
Maximum allowable working pressure (MAWP)	=	1,065.8 kPa

Maximum allowable pressure (MAP) = 1,338.64 kPa
Maximum allowable external pressure (MAEP) = 250.06 kPa

K (Corroded)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (3{,}930.3 / (2*984.18))^2]=0.997834$

K (New)

$K=(1/6)*[2 + (D / (2*h))^2]=(1/6)*[2 + (3{,}923.9 / (2*980.98))^2]=1$

Design thickness for internal pressure, (Corroded at 120 °C) Appendix 1-4(c)

$t = P*D_o*K / (2*S*E + 2*P*(K - 0.1)) + Corrosion$
$= 1{,}082.73*3{,}962*0.997834 / (2*138{,}000*1 + 2*1{,}082.73*(0.997834 - 0.1)) + 3.2$
$= 18.6$ mm

The head internal pressure design thickness is 18.6 mm.

Maximum allowable working pressure, (Corroded at 120 °C) Appendix 1-4(c)

$P = 2*S*E*t / (K*D_o - 2*t*(K - 0.1)) - P_s$
$= 2*138{,}000*1*15.85 / (0.997834*3{,}962 - 2*15.85*(0.997834 - 0.1)) - 48.73$
$= 1{,}065.8$ kPa

The maximum allowable working pressure (MAWP) is 1,065.8 kPa.

Maximum allowable pressure, (New at 10 °C) Appendix 1-4(c)

$P = 2*S*E*t / (K*D_o - 2*t*(K - 0.1)) - P_s$
$= 2*138{,}000*1*19.05 / (1*3{,}962 - 2*19.05*(1 - 0.1)) - 0$
$= 1{,}338.64$ kPa

The maximum allowable pressure (MAP) is 1,338.64 kPa.

Design thickness for external pressure, (Corroded at 120 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
$R_o = K_o*D_o$
$= 0.8914*3{,}962$
$= 3{,}531.84$ mm

$A = 0.125 / (R_o / t)$
$= 0.125 / (3{,}531.84 / 10.2)$
$= 0.000361$

From Table CS-2 Metric: B = 35.7978 MPa

$P_a = B / (R_o / t)$
$= 35{,}797.85 / (3{,}531.84 / 10.2)$
$= 103.4214$ kPa

$t = 10.2$ mm + Corrosion = 10.2 mm + 3.2 mm = 13.4 mm

Check the external pressure per UG-33(a)(1) Appendix 1-4(c)

t = $1.67*P_e*D_o*K / (2*S*E + 2*1.67*P_e*(K - 0.1))$ + Corrosion
= 1.67*103.42*3,962*0.997834 / (2*138,000*1 + 2*1.67*103.42*(0.997834 - 0.1)) + 3.2
= 5.67 mm

The head external pressure design thickness (t_e) is 13.4 mm.

Maximum Allowable External Pressure, (Corroded at 120 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.8914*3,962
= 3,531.84 mm

A = 0.125 / (R_o / t)
= 0.125 / (3,531.84 / 15.85)
= 0.000561

From Table CS-2 Metric: B = 55.7213 MPa

P_a = B / (R_o / t)
= 55,721.34 / (3,531.84 / 15.85)
= 250.0571 kPa

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

P = $2*S*E*t / ((K*D_o - 2*t*(K - 0.1))*1.67) - P_{s2}$
= 2*138,000*1*15.85 / ((0.997834*3,962 - 2*15.85*(0.997834 - 0.1))*1.67) - 0
= 667.38 kPa

The maximum allowable external pressure (MAEP) is 250.06 kPa.

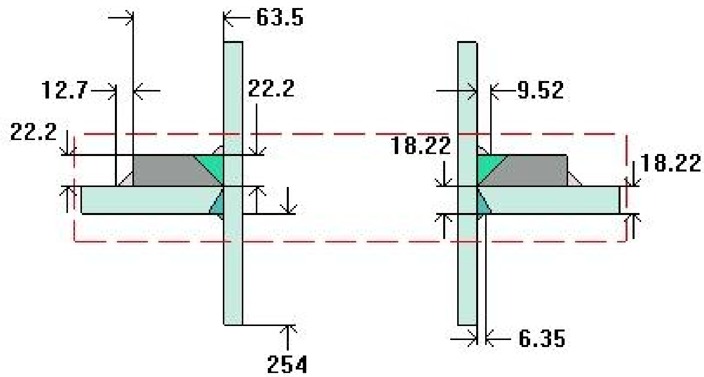
% Extreme fiber elongation - UCS-79(d)

EFE = $(75*t / R_f)*(1 - R_f / R_o)$
= $(75*22.2 / 678.16)*(1 - 678.16 / \infty)$
= 2.4552%

The extreme fiber elongation does not exceed 5%.

WATER INLET (N1)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 18.22 mm
Leg_{41} = 9.53 mm
$t_{w(upper)}$ = 22.2 mm
Leg_{42} = 12.7 mm
Leg_{43} = 6.35 mm
h_{new} = 254 mm
D_p = 450.85 mm
t_e = 22.2 mm

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

Location and Orientation

Located on:	TOP HEAD
Orientation:	0°
End of nozzle to datum line:	3,989 mm
Calculated as hillside:	No
Distance to head center, R:	0 mm
Passes through a Category A joint:	No

Nozzle

Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Description:	NPS 12 Sch 60 DN 300
Inside diameter, new:	295.3 mm
Nominal wall thickness:	14.27 mm
Corrosion allowance:	3.2 mm
Projection available outside vessel, Lpr:	338.43 mm
Internal projection, h_{new}:	254 mm
Projection available outside vessel to flange face, Lf:	452.73 mm
Local vessel minimum thickness:	18.22 mm
Liquid static head included:	4.5816 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 18, ln. 19) (normalized)
Diameter:	450.85 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 12 Class 150 WN A105

Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Blind included:	No
Rated MDMT:	-48°C per UCS-66(b)(1)(b)
Liquid static head:	0 kPa
MAWP rating:	1,694 kPa @ 120°C
MAP rating:	1,960 kPa @ 10°C
Hydrotest rating:	3,000 kPa @ 10°C
PWHT performed:	No
Circumferential joint radiography:	None UW-11(c) Type 1

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,046.15 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
41.0175	44.1876	4.6781	6.249	2.6511	28.194	2.4155	11.53	12.49

UG-41 Weld Failure Path Analysis Summary (N) 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
505,581	508,273	1,057,615	173,154	2,265,967	584,489	1,440,724

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.51	8.89	weld size is adequate
Nozzle to pad groove (Upper)	7.75	22.2	weld size is adequate

Calculations for internal pressure 1,046.15 kPa @ 120 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2293).
External nozzle loadings per UG-22 govern the coincident ratio used.

Pad impact test exemption temperature from Fig UCS-66M Curve D = -42.1 °C
Fig UCS-66.1M MDMT reduction = 5.8 °C, (coincident ratio = 0.8957).

Nozzle UCS-66 governing thk:	12.49 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	18.22 mm
Pad rated MDMT:	-47.9 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(301.7, 150.85 + (14.27 - 3.2) + (18.22 - 3.2))
= 301.7 mm

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*(18.22 - 3.2), 2.5*(14.27 - 3.2) + 22.2)
= 37.55 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(2.5*(18.22 - 3.2), 2.5*(14.27 - 3.2 - 3.2))
= 19.69 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,046.1486*150.85 / (118,000*1 - 0.6*1,046.1486)
= 1.34 mm

Required thickness t_r from UG-37(a)(c)

t_r = P*K_1*D_o / (2*S*E + 0.8*P)
= 1,046.1486*0.8985*3,962 / (2*138,000*1 + 0.8*1,046.1486)
= 13.45 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

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})
= (301.7*13.45*1 + 2*11.07*13.45*1*(1 - 0.8551)) / 100
= 41.0175 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 4.6781 cm^2

= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (301.7*(1*15.02 - 1*13.45) - 2*11.07*(1*15.02 - 1*13.45)*(1 - 0.8551)) / 100
= 4.6781 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.02 + 11.07)*(1*15.02 - 1*13.45) - 2*11.07*(1*15.02 - 1*13.45)*(1 - 0.8551)) / 100
= 0.7677 cm^2

A_2 = smaller of the following= 6.249 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(11.07 - 1.34)*0.8551*15.02) / 100
= 6.249 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(11.07 - 1.34)*(2.5*11.07 + 22.2)*0.8551) / 100
= 8.3026 cm^2

A_3 = smaller of the following= 2.6511 cm^2

= $5*t*t_i*f_{r2}$
= (5*15.02*7.87*0.8551) / 100
= 5.0566 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*7.87*7.87*0.8551) / 100
= 2.6511 cm^2

= $2*h*t_i*f_{r2}$
= (2*250.8*7.87*0.8551) / 100
= 33.7747 cm^2

A_{41} = Leg^2*f_{r3}
= $(9.53^2*0.8551) / 100$
= 0.7755 cm^2

A_{42} = Leg^2*f_{r4}
= $(12.7^2*1) / 100$
= 1.6129 cm^2

A_{43} = Leg^2*f_{r2}
= $(1.78^2*0.8551) / 100$
= 0.0271 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((450.85 - 301.7 - 2*11.07)*22.2*1) / 100
= 28.194 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 4.6781 + 6.249 + 2.6511 + 0.7755 + 1.6129 + 0.0271 + 28.194

= 44.1876 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 11.07 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.02 mm
$t_{w(min)}$ = 0.5*t_{min} = 7.51 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

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
= 1,046.1486*150.85 / (118,000*1 - 0.6*1,046.1486) + 3.2
= 4.54 mm

$t_{a\ UG-22}$ = 5.33 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[4.54 , 5.33]
= 5.33 mm

t_{b1} = 18.08 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[18.08 , 4.7]
= 18.08 mm

t_b = min[t_{b3} , t_{b1}]
= min[11.53 , 18.08]
= 11.53 mm

t_{UG-45} = max[t_a , t_b]
= max[5.33 , 11.53]
= 11.53 mm

Available nozzle wall thickness new, t_n = 0.875*14.27 = 12.49 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa
Lower fillet weld in shear:	0.49*118 =	57.82 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*323.85*9.53*57.82 = 280,160.5 N

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*450.85*12.7*67.62 = 608,178.28 N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*312.78*11.07*82.6 = 449,436.31 N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*323.85*15.02*102.12 = 780,248.65 N

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*323.85*1.78*57.82 = 52,296.63 N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*323.85*22.2*102.12 = 1,153,261.07 N

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

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (4,101.7539 - 467.8055 + 2*11.07*0.8551*(1*15.02 - 1*13.45))*138
= 505,581.34 N

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (624.902 + 2,819.4 + 77.5482 + 161.29)*138
= 508,273.42 N

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (624.902 + 265.1074 + 77.5482 + 2.7097 + 2*11.07*15.02*0.8551)*138
= 173,154.19 N

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (624.902 + 265.1074 + 2,819.4 + 77.5482 + 161.29 + 2.7097 + 2*11.07*15.02*0.8551)*138
= 584,489.47 N

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 505,581.34 N

Path 1-1 through (2) & (3) = 608,178.28 + 449,436.31 = 1,057,614.59 N
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} = 173,154.19 N
Path 2-2 through (1), (4), (5), (6) = 280,160.5 + 780,248.65 + 52,296.63 + 1,153,261.07 = 2,265,966.84 N
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} = 505,581.34 N
Path 3-3 through (2), (4), (5) = 608,178.28 + 780,248.65 + 52,296.63 = 1,440,723.56 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Applied Loads

Radial load:	P_r =	-9,880	N
Circumferential moment:	M_1 =	12,390	N-m
Circumferential shear:	V_2 =	12,100	N
Longitudinal moment:	M_2 =	12,390	N-m
Longitudinal shear:	V_1 =	12,100	N
Torsion moment:	M_t =	17,520	N-m
Internal pressure:	P =	1,046.15	kPa
Head yield stress:	S_y =	236	MPa

Maximum stresses due to the applied loads at the pad edge (includes pressure)

Mean dish radius R_m = 3,554.18 mm

U = r_o / Sqr(R_m*t) = 0.976
Pressure stress intensity factor, I = 1 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =123.52 MPa

Maximum combined stress (P_L+P_b+Q) = 266.86 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 145.62 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

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*	0.0684	2.992	2.992	2.992	2.992	2.992	2.992	2.992	2.992
SR-2	0.0366	9.618	-9.618	9.618	-9.618	9.618	-9.618	9.618	-9.618
SR-3*	0.0804	0	0	0	0	-19.112	-19.112	19.112	19.112
SR-3	0.0781	0	0	0	0	-111.392	111.392	111.392	-111.392
SR-3*	0.0804	-19.112	-19.112	19.112	19.112	0	0	0	0
SR-3	0.0781	-111.392	111.392	111.392	-111.392	0	0	0	0
Pressure stress*		123.52	123.52	123.52	123.52	123.52	123.52	123.52	123.52
Total O_x stress		5.626	209.173	266.634	24.614	5.626	209.173	266.634	24.614
Membrane O_x stress*		107.4	107.4	145.624	145.624	107.4	107.4	145.624	145.624
SR-2*	0.0212	0.931	0.931	0.931	0.931	0.931	0.931	0.931	0.931
SR-2	0.011	2.889	-2.889	2.889	-2.889	2.889	-2.889	2.889	-2.889
SR-3*	0.0242	0	0	0	0	-5.75	-5.75	5.75	5.75
SR-3	0.0235	0	0	0	0	-33.515	33.515	33.515	-33.515
SR-3*	0.0242	-5.75	-5.75	5.75	5.75	0	0	0	0
SR-3	0.0235	-33.515	33.515	33.515	-33.515	0	0	0	0
Pressure stress*		123.52	123.52	123.52	123.52	123.52	123.52	123.52	123.52
Total O_y stress		88.074	149.327	166.605	93.796	88.074	149.327	166.605	93.796
Membrane O_y stress*		118.7	118.7	130.201	130.201	118.7	118.7	130.201	130.201
Shear from M_t		3.654	3.654	3.654	3.654	3.654	3.654	3.654	3.654
Shear from V_1		0	0	0	0	-1.138	-1.138	1.138	1.138
Shear from V_2		1.138	1.138	-1.138	-1.138	0	0	0	0
Total Shear stress		4.792	4.792	2.517	2.517	2.517	2.517	4.792	4.792
Combined stress (P_L+P_b+Q)		88.349	209.552	266.696	93.886	88.149	209.277	266.862	94.127

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)

Mean dish radius R_m = 3,554.18 mm

U = r_o / Sqr(R_m*t) = 0.445
Pressure stress intensity factor, I = 0.47135 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =58.219 MPa

Maximum combined stress (P_L+P_b+Q) = 109.39 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 63 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

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*	0.1465	1.048	1.048	1.048	1.048	1.048	1.048	1.048	1.048
SR-2	0.0933	3.992	-3.992	3.992	-3.992	3.992	-3.992	3.992	-3.992
SR-3*	0.1518	0	0	0	0	-3.73	-3.73	3.73	3.73
SR-3	0.285	0	0	0	0	-42.051	42.051	42.051	-42.051
SR-3*	0.1518	-3.73	-3.73	3.73	3.73	0	0	0	0
SR-3	0.285	-42.051	42.051	42.051	-42.051	0	0	0	0
Pressure stress*		58.219	58.219	58.219	58.219	58.219	58.219	58.219	58.219
Total O_x stress		17.478	93.596	109.041	16.954	17.478	93.596	109.041	16.954
Membrane O_x stress*		55.537	55.537	62.997	62.997	55.537	55.537	62.997	62.997
SR-2*	0.0439	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
SR-2	0.0284	1.213	-1.213	1.213	-1.213	1.213	-1.213	1.213	-1.213
SR-3*	0.0463	0	0	0	0	-1.138	-1.138	1.138	1.138
SR-3	0.0872	0	0	0	0	-12.866	12.866	12.866	-12.866
SR-3*	0.0463	-1.138	-1.138	1.138	1.138	0	0	0	0
SR-3	0.0872	-12.866	12.866	12.866	-12.866	0	0	0	0
Pressure stress*		58.219	58.219	58.219	58.219	58.219	58.219	58.219	58.219
Total O_y stress		45.74	69.044	73.746	45.588	45.74	69.044	73.746	45.588
Membrane O_y stress*		57.392	57.392	59.667	59.667	57.392	57.392	59.667	59.667
Shear from M_t		2.854	2.854	2.854	2.854	2.854	2.854	2.854	2.854
Shear from V_1		0	0	0	0	-0.641	-0.641	0.641	0.641
Shear from V_2		0.641	0.641	-0.641	-0.641	0	0	0	0
Total Shear stress		3.496	3.496	2.213	2.213	2.213	2.213	3.496	3.496
Combined stress (P_L+P_b+Q)		46.167	94.086	109.178	45.761	45.912	93.796	109.385	46.009

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

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 1{,}046.15 / 1000*150.85 / (2*9.29) - -9{,}880 / (\pi*(161.93^2 - 150.85^2)) + 1.7522E+07*161.93 / 1.3324E+08$
= 30.695 MPa

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 = 118 MPa)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (12{,}100^2 + 12{,}100^2)^{0.5} / (\pi*150.85*11.07)$
= 3.26 MPa

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 17{,}520 / (2*\pi*150.85^2*11.07)$

= 11.064 MPa

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 3.26 + 11.064
= 14.325 MPa

UG-45: The total combined shear stress (14.325 MPa) is below than the allowable (0.7*S_n = 0.7*118 = 82.6 MPa)

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 224.31 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
22.898	39.3231	--	6.0626	2.6511	28.194	2.4155	6.41	12.49

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.51	8.89	weld size is adequate
Nozzle to pad groove (Upper)	7.75	22.2	weld size is adequate

Calculations for external pressure 224.31 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(301.7, 150.85 + (14.27 - 3.2) + (18.22 - 3.2))
= 301.7 mm

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*(18.22 - 3.2), 2.5*(14.27 - 3.2) + 22.2)
= 37.55 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(2.5*(18.22 - 3.2), 2.5*(14.27 - 3.2 - 3.2))
= 19.69 mm

Nozzle required thickness per UG-28 t_{rn} = 1.63 mm

From UG-37(d)(1) required thickness t_r = 15.02 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= (0.5*(301.7*15.02*1 + 2*11.07*15.02*1*(1 - 0.8551))) / 100
= 22.898 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (301.7*(1*15.02 - 1*15.02) - 2*11.07*(1*15.02 - 1*15.02)*(1 - 0.8551)) / 100
= 0 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.02 + 11.07)*(1*15.02 - 1*15.02) - 2*11.07*(1*15.02 - 1*15.02)*(1 - 0.8551)) / 100
= 0 cm^2

A_2 = smaller of the following= 6.0626 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(11.07 - 1.63)*0.8551*15.02) / 100
= 6.0626 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(11.07 - 1.63)*(2.5*11.07 + 22.2)*0.8551) / 100
= 8.0548 cm^2

A_3 = smaller of the following= 2.6511 cm^2

= $5*t*t_i*f_{r2}$
= (5*15.02*7.87*0.8551) / 100
= 5.0566 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*7.87*7.87*0.8551) / 100
= 2.6511 cm^2

$= 2*h*t_i*f_{r2}$
$= (2*250.8*7.87*0.8551) / 100$
$=$ 33.7747 cm^2

$A_{41} = Leg^2*f_{r3}$
$= (9.53^2*0.8551) / 100$
$=$ 0.7755 cm^2

$A_{42} = Leg^2*f_{r4}$
$= (12.7^2*1) / 100$
$=$ 1.6129 cm^2

$A_{43} = Leg^2*f_{r2}$
$= (1.78^2*0.8551) / 100$
$=$ 0.0271 cm^2

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= ((450.85 - 301.7 - 2*11.07)*22.2*1) / 100$
$=$ 28.194 cm^2

Area $= A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
$= 0 + 6.0626 + 2.6511 + 0.7755 + 1.6129 + 0.0271 + 28.194$
$=$ 39.3231 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 11.07 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.02 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7.51 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-28}$ = 4.83 mm

$t_{a\ UG-22}$ = 4.53 mm

t_a	=	max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
	=	max[4.83 , 4.53]
	=	4.83 mm

t_{b2} = 6.41 mm

t_{b2}	=	max[t_{b2} , $t_{b\ UG16}$]
	=	max[6.41 , 4.7]
	=	6.41 mm

t_b	=	min[t_{b3} , t_{b2}]
	=	min[11.53 , 6.41]
	=	6.41 mm

$t_{UG\text{-}45}$	=	max[t_a , t_b]
	=	max[4.83 , 6.41]
	=	6.41 mm

Available nozzle wall thickness new, t_n = 0.875*14.27 = 12.49 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o	=	452.73 / 323.85	=	1.3980
D_o / t	=	323.85 / 1.63	=	198.2439
From table G:		A	=	0.000337
From table CS-2 Metric:		B	=	33.3504 MPa

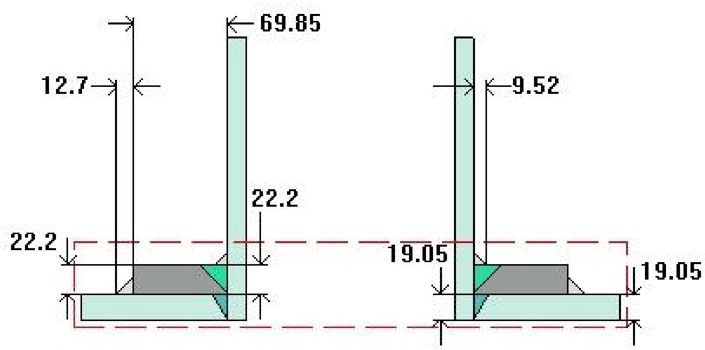
P_a	=	4*B / (3*(D_o / t))
	=	4*33,350.43 / (3*(323.85 / 1.63))
	=	224.31 kPa

Design thickness for external pressure P_a = 224.31 kPa

t_a = t + Corrosion = 1.63 + 3.2 = 4.83 mm

WATER OUTLET (N2)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 19.05 mm
Leg_{41} = 9.53 mm
$t_{w(upper)}$ = 22.2 mm
Leg_{42} = 12.7 mm
D_p = 463.79 mm
t_e = 22.2 mm

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

Location and Orientation

Located on:	BOTTOM HEAD
Orientation:	180°
End of nozzle to datum line:	-1,574 mm
Calculated as hillside:	Yes
Distance to head center, R:	152 mm
Passes through a Category A joint:	No

Nozzle

Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Description:	NPS 12 Sch 60 DN 300
Inside diameter, new:	295.3 mm
Nominal wall thickness:	14.27 mm
Corrosion allowance:	3.2 mm
Opening chord length:	301.93 mm
Projection available outside vessel, Lpr:	459.69 mm
Projection available outside vessel to flange face, Lf:	573.99 mm
Local vessel minimum thickness:	19.05 mm
Liquid static head included:	54.3224 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 18, ln. 19) (normalized)
Diameter:	463.79 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 12 Class 150 WN A105

Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Blind included:	No
Rated MDMT:	-48°C per UCS-66(b)(1)(b)
Liquid static head:	54.5086 kPa
MAWP rating:	1,694 kPa @ 120°C
MAP rating:	1,960 kPa @ 10°C
Hydrotest rating:	3,000 kPa @ 10°C
PWHT performed:	No
Circumferential joint radiography:	None UW-11(c) Type 1

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,095.89 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
42.9946	45.2076	5.2561	6.5497	--	31.0134	2.3884	11.53	12.49

UG-41 Weld Failure Path Analysis Summary (N) 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
525,389	551,330	1,075,072	142,514	2,256,788	592,757	1,449,002

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.92	8.89	weld size is adequate
Nozzle to pad groove (Upper)	7.75	22.2	weld size is adequate

Calculations for internal pressure 1,095.89 kPa @ 120 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.2334).
External nozzle loadings per UG-22 govern the coincident ratio used.

Pad impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C
Fig UCS-66.1M MDMT reduction = 6.2 °C, (coincident ratio = 0.889).

Nozzle UCS-66 governing thk:	12.49 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	19.05 mm
Pad rated MDMT:	-47.26 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \text{MAX}(d, R_n + (t_n - C_n) + (t - C))$$
$$= \text{MAX}(301.93, 150.96 + (14.27 - 3.2) + (19.05 - 3.2))$$
$$= 301.93 \text{ mm}$$

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*(19.05 - 3.2), 2.5*(14.27 - 3.2) + 22.2)
= 39.62 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,095.8895*150.85 / (118,000*1 - 0.6*1,095.8895)
= 1.41 mm

Required thickness t_r from UG-37(a)(c)

t_r = P*K_1*D_o / (2*S*E + 0.8*P)
= 1,095.8895*0.8985*3,962 / (2*138,000*1 + 0.8*1,095.8895)
= 14.09 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

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})
= (301.93*14.09*1 + 2*11.07*14.09*1*(1 - 0.8551)) / 100
= 42.9946 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 5.2561 cm^2

= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (301.93*(1*15.85 - 1*14.09) - 2*11.07*(1*15.85 - 1*14.09)*(1 - 0.8551)) / 100
= 5.2561 cm^2

= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (2*(15.85 + 11.07)*(1*15.85 - 1*14.09) - 2*11.07*(1*15.85 - 1*14.09)*(1 - 0.8551)) / 100
= 0.891 cm^2

A_2 = smaller of the following= 6.5497 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(11.07 - 1.41)*0.8551*15.85) / 100
= 6.5497 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(11.07 - 1.41)*(2.5*11.07 + 22.2)*0.8551) / 100
= 8.2458 cm^2

A_{41} = Leg^2*f_{r3}
= (9.53^2*0.8551) / 100
= 0.7755 cm^2

A_{42} = Leg^2*f_{r4}
= (12.7^2*1) / 100
= 1.6129 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((463.79 - 324.09)*22.2*1) / 100
= 31.0134 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 5.2561 + 6.5497 + 0.7755 + 1.6129 + 31.0134
= 45.2076 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 11.07 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.85 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7.92 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

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
= 1,096.0756*150.85 / (118,000*1 - 0.6*1,096.0756) + 3.2
= 4.61 mm

$t_{a\ UG\text{-}22}$ = 5.37 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[4.61 , 5.37]
= 5.37 mm

t_{b1} = 18.79 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[18.79 , 4.7]
= 18.79 mm

t_b = min[t_{b3} , t_{b1}]
= min[11.53 , 18.79]
= 11.53 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[5.37 , 11.53]
= 11.53 mm

Available nozzle wall thickness new, t_n = 0.875*14.27 = 12.49 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*323.85*9.53*57.82 = 280,160.5 N

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*463.79*12.7*67.62 = 625,635.56 N

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*312.78*11.07*82.6 = 449,436.31 N

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*323.85*15.85*102.12 = 823,366.07 N

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*323.85*22.2*102.12 = 1,153,261.07 N

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

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (4,299.4557 - 525.6119 + 2*11.07*0.8551*(1*15.85 - 1*14.09))*138$
$=$ 525,389.29 N

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (654.9664 + 3,101.34 + 77.5482 + 161.29)*138$
$=$ 551,330.04 N

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (654.9664 + 0 + 77.5482 + 0 + 2*11.07*15.85*0.8551)*138$
$=$ 142,513.73 N

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (654.9664 + 0 + 3,101.34 + 77.5482 + 161.29 + 0 + 2*11.07*15.85*0.8551)*138$
$=$ 592,756.73 N

Load for path 1-1 lesser of W or W_{1-1} = 525,389.29 N
Path 1-1 through (2) & (3) = 625,635.56 + 449,436.31 = 1,075,071.87 N
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} = 142,513.73 N
Path 2-2 through (1), (4), (6) = 280,160.5 + 823,366.07 + 1,153,261.07 = 2,256,787.63 N
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} = 525,389.29 N
Path 3-3 through (2), (4) = 625,635.56 + 823,366.07 = 1,449,001.62 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Applied Loads

Radial load:	P_r =	-9,880	N
Circumferential moment:	M_1 =	12,390	N-m
Circumferential shear:	V_2 =	12,100	N
Longitudinal moment:	M_2 =	12,390	N-m
Longitudinal shear:	V_1 =	12,100	N
Torsion moment:	M_t =	17,520	N-m
Internal pressure:	P =	1,095.89	kPa
Head yield stress:	S_y =	236	MPa

Maximum stresses due to the applied loads at the pad edge (includes pressure)

Mean dish radius R_m = 3,554.59 mm

U = r_o / Sqr(R_m*t) = 0.976
Pressure stress intensity factor, I = 1 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =122.616 MPa

Maximum combined stress (P_L+P_b+Q) = 248.24 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 142.01 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

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*	0.0684	2.689	2.689	2.689	2.689	2.689	2.689	2.689	2.689
SR-2	0.0366	8.639	-8.639	8.639	-8.639	8.639	-8.639	8.639	-8.639
SR-3*	0.0804	0	0	0	0	-16.706	-16.706	16.706	16.706
SR-3	0.0781	0	0	0	0	-97.375	97.375	97.375	-97.375
SR-3*	0.0804	-16.706	-16.706	16.706	16.706	0	0	0	0
SR-3	0.0781	-97.375	97.375	97.375	-97.375	0	0	0	0
Pressure stress*		122.616	122.616	122.616	122.616	122.616	122.616	122.616	122.616
Total O_x stress		19.864	197.335	248.025	35.998	19.864	197.335	248.025	35.998
Membrane O_x stress*		108.599	108.599	142.011	142.011	108.599	108.599	142.011	142.011
SR-2*	0.0212	0.834	0.834	0.834	0.834	0.834	0.834	0.834	0.834
SR-2	0.011	2.592	-2.592	2.592	-2.592	2.592	-2.592	2.592	-2.592
SR-3*	0.0242	0	0	0	0	-5.026	-5.026	5.026	5.026
SR-3	0.0235	0	0	0	0	-29.296	29.296	29.296	-29.296
SR-3*	0.0242	-5.026	-5.026	5.026	5.026	0	0	0	0
SR-3	0.0235	-29.296	29.296	29.296	-29.296	0	0	0	0
Pressure stress*		122.616	122.616	122.616	122.616	122.616	122.616	122.616	122.616
Total O_y stress		91.721	145.128	160.365	96.589	91.721	145.128	160.365	96.589
Membrane O_y stress*		118.424	118.424	128.477	128.477	118.424	118.424	128.477	128.477
Shear from M_t		3.275	3.275	3.275	3.275	3.275	3.275	3.275	3.275
Shear from V_1		0	0	0	0	-1.048	-1.048	1.048	1.048
Shear from V_2		1.048	1.048	-1.048	-1.048	0	0	0	0
Total Shear stress		4.323	4.323	2.227	2.227	2.227	2.227	4.323	4.323
Combined stress (P_L+P_b+Q)		91.983	197.693	248.08	96.671	91.79	197.431	248.239	96.899

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)

Mean dish radius R_m = 3,554.59 mm

U = r_o / Sqr(R_m*t) = 0.44
Pressure stress intensity factor, I = 0.51997 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =63.756 MPa

Maximum combined stress (P_L+P_b+Q) = 113.02 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 68.31 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

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*	0.148	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007
SR-2	0.0946	3.875	-3.875	3.875	-3.875	3.875	-3.875	3.875	-3.875
SR-3*	0.1526	0	0	0	0	-3.551	-3.551	3.551	3.551
SR-3	0.29	0	0	0	0	-40.493	40.493	40.493	-40.493
SR-3*	0.1526	-3.551	-3.551	3.551	3.551	0	0	0	0
SR-3	0.29	-40.493	40.493	40.493	-40.493	0	0	0	0
Pressure stress*		63.756	63.756	63.756	63.756	63.756	63.756	63.756	63.756
Total O_x stress		24.594	97.83	112.681	23.945	24.594	97.83	112.681	23.945
Membrane O_x stress*		61.212	61.212	68.313	68.313	61.212	61.212	68.313	68.313
SR-2*	0.0444	0.303	0.303	0.303	0.303	0.303	0.303	0.303	0.303
SR-2	0.0288	1.179	-1.179	1.179	-1.179	1.179	-1.179	1.179	-1.179
SR-3*	0.0466	0	0	0	0	-1.082	-1.082	1.082	1.082
SR-3	0.0884	0	0	0	0	-12.342	12.342	12.342	-12.342
SR-3*	0.0466	-1.082	-1.082	1.082	1.082	0	0	0	0
SR-3	0.0884	-12.342	12.342	12.342	-12.342	0	0	0	0
Pressure stress*		63.756	63.756	63.756	63.756	63.756	63.756	63.756	63.756
Total O_y stress		51.814	74.139	78.662	51.621	51.814	74.139	78.662	51.621
Membrane O_y stress*		62.977	62.977	65.142	65.142	62.977	62.977	65.142	65.142
Shear from M_t		2.792	2.792	2.792	2.792	2.792	2.792	2.792	2.792
Shear from V_1		0	0	0	0	-0.627	-0.627	0.627	0.627
Shear from V_2		0.627	0.627	-0.627	-0.627	0	0	0	0
Total Shear stress		3.42	3.42	2.165	2.165	2.165	2.165	3.42	3.42
Combined stress (P_L+P_b+Q)		52.235	98.312	112.819	51.787	51.986	98.023	113.019	52.035

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
= 1,095.89 / 1000*150.85 / (2*9.29) - -9,880 / (π*(161.93^2 - 150.85^2)) + 1.7522E+07*161.93 / 1.3324E+08
= 31.099 MPa

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 = 118 MPa)

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)
= (12,100^2 + 12,100^2)$^{0.5}$ / (π*150.85*11.07)
= 3.26 MPa

$\sigma_{torsion}$ = M_t / (2*π*R_i^2*t_n)
= 17,520 / (2*π*150.85^2*11.07)

= 11.064 MPa

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 3.26 + 11.064
= 14.325 MPa

UG-45: The total combined shear stress (14.325 MPa) is below than the allowable (0.7*S_n = 0.7*118 = 82.6 MPa)

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 250.06 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
24.1817	39.634	--	6.2322	--	31.0134	2.3884	6.78	12.49

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.92	8.89	weld size is adequate
Nozzle to pad groove (Upper)	7.75	22.2	weld size is adequate

Calculations for external pressure 250.06 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(301.93, 150.96 + (14.27 - 3.2) + (19.05 - 3.2))
= 301.93 mm

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*(19.05 - 3.2), 2.5*(14.27 - 3.2) + 22.2)
= 39.62 mm

Nozzle required thickness per UG-28 t_{rn} = 1.88 mm

From UG-37(d)(1) required thickness t_r = 15.85 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= (0.5*(301.93*15.85*1 + 2*11.07*15.85*1*(1 - 0.8551))) / 100
= 24.1817 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (301.93*(1*15.85 - 1*15.85) - 2*11.07*(1*15.85 - 1*15.85)*(1 - 0.8551)) / 100
= 0 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 11.07)*(1*15.85 - 1*15.85) - 2*11.07*(1*15.85 - 1*15.85)*(1 - 0.8551)) / 100
= 0 cm^2

A_2 = smaller of the following= 6.2322 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(11.07 - 1.88)*0.8551*15.85) / 100
= 6.2322 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(11.07 - 1.88)*(2.5*11.07 + 22.2)*0.8551) / 100
= 7.8471 cm^2

A_{41} = Leg^2*f_{r3}
= $(9.53^2*0.8551) / 100$
= 0.7755 cm^2

A_{42} = Leg^2*f_{r4}
= $(12.7^2*1) / 100$
= 1.6129 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((463.79 - 324.09)*22.2*1) / 100
= 31.0134 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0 + 6.2322 + 0.7755 + 1.6129 + 31.0134
= 39.634 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 11.07 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.85 mm
$t_{w(min)}$ = 0.5*t_{min} = 7.92 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-28}$ = 5.08 mm

$t_{a\ UG-22}$ = 4.55 mm

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[5.08 , 4.55]
= 5.08 mm

t_{b2} = 6.78 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[6.78 , 4.7]
= 6.78 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.53 , 6.78]
= 6.78 mm

t_{UG-45} = max[t_a , t_b]
= max[5.08 , 6.78]
= 6.78 mm

Available nozzle wall thickness new, t_n = 0.875*14.27 = 12.49 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o	=	586.61 / 323.85	=	1.8114
D_o / t	=	323.85 / 1.88	=	172.4849
From table G:	A	=	0.000326	
From table CS-2 Metric:	B	=	32.3485 MPa	

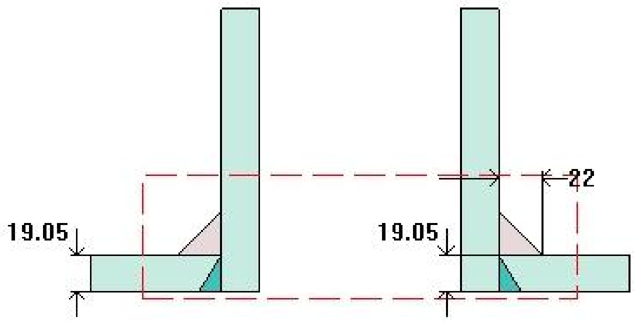
P_a = 4*B / (3*(D_o / t))
= 4*32,348.52 / (3*(323.85 / 1.88))
= 250.06 kPa

Design thickness for external pressure P_a = 250.06 kPa

t_a = t + Corrosion = 1.88 + 3.2 = 5.08 mm

MEDIA REMOVAL (N3A)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 19.05 mm
Leg_{41} = 22 mm

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

Location and Orientation	
Located on:	BOTTOM HEAD
Orientation:	250°
Nozzle center line offset to datum line:	-76 mm
Calculated as hillside:	Yes (perpendicular)
Distance to head center, R:	2,184 mm
Passes through a Category A joint:	No
Nozzle	
Material specification:	SA-105 (II-D Metric p. 18, ln. 5)
Inside diameter, new:	101.6 mm
Nominal wall thickness:	19.05 mm
Corrosion allowance:	3.2 mm
Opening chord length:	109.19 mm
Projection available outside vessel, Lpr:	179.16 mm
Projection available outside vessel to flange face, Lf:	203.04 mm
Local vessel minimum thickness:	19.05 mm
Liquid static head included:	40.3288 kPa
Longitudinal joint efficiency:	1
ASME B16.5-2009 Flange	
Description:	NPS 4 Class 150 LWN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Blind included:	Yes
Rated MDMT:	-48°C per UCS-66(b)(1)(b)
Liquid static head:	39.831 kPa
MAWP rating:	1,694 kPa @ 120°C
MAP rating:	1,960 kPa @ 10°C

Hydrotest rating:	3,000 kPa @ 10 °C
PWHT performed:	No

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,081.9 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
16.803	17.5677	0.5032	12.2245	--	--	4.84	8.93	19.05

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 (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	15.4	weld size is adequate

Calculations for internal pressure 1,081.9 kPa @ 120 °C

Nozzle is impact test exempt per UG-20(f).

Nozzle UCS-66 governing thk: 19.05 mm

Nozzle rated MDMT: -29 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(109.19, 54.59 + (19.05 - 3.2) + (19.05 - 3.2))
= 109.19 mm

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*(19.05 - 3.2), 2.5*(19.05 - 3.2) + 0)
= 39.62 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,081.8959*54 / (138,000*1 - 0.6*1,081.8959)
= 0.42 mm

Required thickness t_r from UG-37(a)

t_r = $P*D_o*K / (2*S*E + 2*P*(K - 0.1))$
= 1,081.9*3,962*0.997834 / (2*138,000*1 + 2*1,081.9*(0.997834 - 0.1))
= 15.39 mm

Area required per UG-37(c)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (109.19*15.39*1 + 2*15.85*15.39*1*(1 - 1)) / 100
= 16.803 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.5032 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (109.19*(1*15.85 - 1*15.39) - 2*15.85*(1*15.85 - 1*15.39)*(1 - 1)) / 100
= 0.5032 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 15.85)*(1*15.85 - 1*15.39) - 2*15.85*(1*15.85 - 1*15.39)*(1 - 1)) / 100
= 0.2923 cm^2

A_2 = smaller of the following= 12.2245 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(15.85 - 0.42)*1*15.85) / 100
= 12.2245 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t_n$
= (5*(15.85 - 0.42)*1*15.85) / 100
= 12.2251 cm^2

A_{41} = Leg^2*f_{r2}
= $(22^2*1) / 100$
= 4.84 cm^2

Area = $A_1 + A_2 + A_{41}$

= 0.5032 + 12.2245 + 4.84
= 17.5677 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*22 = 15.4 mm

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

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,081.8959*54 / (138,000*1 - 0.6*1,081.8959) + 3.2
= 3.62 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.62 , 0]
= 3.62 mm

t_{b1} = 18.59 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[18.59 , 4.7]
= 18.59 mm

t_b = min[t_{b3} , t_{b1}]
= min[8.93 , 18.59]
= 8.93 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[3.62 , 8.93]
= 8.93 mm

Available nozzle wall thickness new, t_n = 19.05 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 250.06 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
8.653	16.7903	--	11.9503	--	--	4.84	6.78	19.05

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	15.4	weld size is adequate

Calculations for external pressure 250.06 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(109.19, 54.59 + (19.05 - 3.2) + (19.05 - 3.2))
= 109.19 mm

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*(19.05 - 3.2), 2.5*(19.05 - 3.2) + 0)
= 39.62 mm

Nozzle required thickness per UG-28 t_{rn} = 0.77 mm

From UG-37(d)(1) required thickness t_r = 15.85 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

$A = 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
$= (0.5*(109.19*15.85*1 + 2*15.85*15.85*1*(1 - 1))) / 100$
$= 8.653\ cm^2$

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= (109.19*(1*15.85 - 1*15.85) - 2*15.85*(1*15.85 - 1*15.85)*(1 - 1)) / 100$
$= 0\ cm^2$

$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= (2*(15.85 + 15.85)*(1*15.85 - 1*15.85) - 2*15.85*(1*15.85 - 1*15.85)*(1 - 1)) / 100$
$= 0\ cm^2$

A_2 = smaller of the following= 11.9503 cm^2

$= 5*(t_n - t_{rn})*f_{r2}*t$
$= (5*(15.85 - 0.77)*1*15.85) / 100$
$= 11.9503\ cm^2$

$= 5*(t_n - t_{rn})*f_{r2}*t_n$
$= (5*(15.85 - 0.77)*1*15.85) / 100$
$= 11.9509\ cm^2$

$A_{41} = Leg^2*f_{r2}$
$= (22^2*1) / 100$
$= 4.84\ cm^2$

$Area = A_1 + A_2 + A_{41}$
$= 0 + 11.9503 + 4.84$
$= 16.7903\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*22 = 15.4 mm

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

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-28}$ = 3.97 mm

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[3.97 , 0]
= 3.97 mm

t_{b2} = 6.78 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[6.78 , 4.7]
= 6.78 mm

t_b = min[t_{b3} , t_{b2}]
= min[8.93 , 6.78]
= 6.78 mm

t_{UG-45} = max[t_a , t_b]
= max[3.97 , 6.78]
= 6.78 mm

Available nozzle wall thickness new, t_n = 19.05 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 224.18 / 139.7 = 1.6047
D_o / t = 139.7 / 0.77 = 181.4152
From table G: A = 0.000343
From table CS-2 Metric: B = 34.0228 MPa

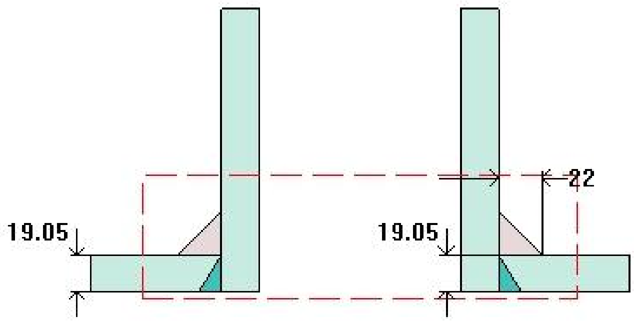
P_a = 4*B / (3*(D_o / t))
= 4*34,022.83 / (3*(139.7 / 0.77))
= 250.05 kPa

Design thickness for external pressure P_a = 250.05 kPa

t_a = t + Corrosion = 0.77 + 3.2 = 3.97 mm

MEDIA REMOVAL (N3B)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 19.05 mm
Leg_{41} = 22 mm

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

Location and Orientation

Located on:	BOTTOM HEAD
Orientation:	60°
Nozzle center line offset to datum line:	-76 mm
Calculated as hillside:	Yes (perpendicular)
Distance to head center, R:	2,184 mm
Passes through a Category A joint:	No

Nozzle

Material specification:	SA-105 (II-D Metric p. 18, ln. 5)
Inside diameter, new:	101.6 mm
Nominal wall thickness:	19.05 mm
Corrosion allowance:	3.2 mm
Opening chord length:	109.19 mm
Projection available outside vessel, Lpr:	179.16 mm
Projection available outside vessel to flange face, Lf:	203.04 mm
Local vessel minimum thickness:	19.05 mm
Liquid static head included:	40.3288 kPa
Longitudinal joint efficiency:	1

ASME B16.5-2009 Flange

Description:	NPS 4 Class 150 LWN A105
Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Blind included:	Yes
Rated MDMT:	-48°C per UCS-66(b)(1)(b)
Liquid static head:	39.831 kPa
MAWP rating:	1,694 kPa @ 120°C
MAP rating:	1,960 kPa @ 10°C

Hydrotest rating:	3,000 kPa @ 10°C
PWHT performed:	No

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,081.9 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
16.803	17.5677	0.5032	12.2245	--	--	4.84	8.93	19.05

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 (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	15.4	weld size is adequate

Calculations for internal pressure 1,081.9 kPa @ 120 °C

Nozzle is impact test exempt per UG-20(f).

Nozzle UCS-66 governing thk: 19.05 mm

Nozzle rated MDMT: -29 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(109.19, 54.59 + (19.05 - 3.2) + (19.05 - 3.2))
= 109.19 mm

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*(19.05 - 3.2), 2.5*(19.05 - 3.2) + 0)
= 39.62 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,081.8959*54 / (138,000*1 - 0.6*1,081.8959)
= 0.42 mm

Required thickness t_r from UG-37(a)

t_r = $P*D_o*K / (2*S*E + 2*P*(K - 0.1))$
= 1,081.9*3,962*0.997834 / (2*138,000*1 + 2*1,081.9*(0.997834 - 0.1))
= 15.39 mm

Area required per UG-37(c)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (109.19*15.39*1 + 2*15.85*15.39*1*(1 - 1)) / 100
= 16.803 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.5032 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (109.19*(1*15.85 - 1*15.39) - 2*15.85*(1*15.85 - 1*15.39)*(1 - 1)) / 100
= 0.5032 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 15.85)*(1*15.85 - 1*15.39) - 2*15.85*(1*15.85 - 1*15.39)*(1 - 1)) / 100
= 0.2923 cm^2

A_2 = smaller of the following= 12.2245 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(15.85 - 0.42)*1*15.85) / 100
= 12.2245 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t_n$
= (5*(15.85 - 0.42)*1*15.85) / 100
= 12.2251 cm^2

A_{41} = Leg^2*f_{r2}
= $(22^2*1) / 100$
= 4.84 cm^2

Area = $A_1 + A_2 + A_{41}$

= 0.5032 + 12.2245 + 4.84
= 17.5677 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*22 = 15.4 mm

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

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,081.8959*54 / (138,000*1 - 0.6*1,081.8959) + 3.2
= 3.62 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[3.62 , 0]
= 3.62 mm

t_{b1} = 18.59 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[18.59 , 4.7]
= 18.59 mm

t_b = min[t_{b3} , t_{b1}]
= min[8.93 , 18.59]
= 8.93 mm

t_{UG-45} = max[t_a , t_b]
= max[3.62 , 8.93]
= 8.93 mm

Available nozzle wall thickness new, t_n = 19.05 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 250.06 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
8.653	16.7903	--	11.9503	--	--	4.84	6.78	19.05

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	15.4	weld size is adequate

Calculations for external pressure 250.06 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(109.19, 54.59 + (19.05 - 3.2) + (19.05 - 3.2))
= 109.19 mm

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*(19.05 - 3.2), 2.5*(19.05 - 3.2) + 0)
= 39.62 mm

Nozzle required thickness per UG-28 t_{rn} = 0.77 mm

From UG-37(d)(1) required thickness t_r = 15.85 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

$A = 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
$= (0.5*(109.19*15.85*1 + 2*15.85*15.85*1*(1 - 1))) / 100$
$= 8.653\ cm^2$

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= (109.19*(1*15.85 - 1*15.85) - 2*15.85*(1*15.85 - 1*15.85)*(1 - 1)) / 100$
$= 0\ cm^2$

$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
$= (2*(15.85 + 15.85)*(1*15.85 - 1*15.85) - 2*15.85*(1*15.85 - 1*15.85)*(1 - 1)) / 100$
$= 0\ cm^2$

A_2 = smaller of the following= 11.9503 cm^2

$= 5*(t_n - t_{rn})*f_{r2}*t$
$= (5*(15.85 - 0.77)*1*15.85) / 100$
$= 11.9503\ cm^2$

$= 5*(t_n - t_{rn})*f_{r2}*t_n$
$= (5*(15.85 - 0.77)*1*15.85) / 100$
$= 11.9509\ cm^2$

$A_{41} = Leg^2*f_{r2}$
$= (22^2*1) / 100$
$= 4.84\ cm^2$

$Area = A_1 + A_2 + A_{41}$
$= 0 + 11.9503 + 4.84$
$= 16.7903\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*22 = 15.4 mm

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

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}28}$ = 3.97 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[3.97 , 0]
= 3.97 mm

t_{b2} = 6.78 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[6.78 , 4.7]
= 6.78 mm

t_b = min[t_{b3} , t_{b2}]
= min[8.93 , 6.78]
= 6.78 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[3.97 , 6.78]
= 6.78 mm

Available nozzle wall thickness new, t_n = 19.05 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 224.18 / 139.7 = 1.6047
D_o / t = 139.7 / 0.77 = 181.4152
From table G: A = 0.000343
From table CS-2 Metric: B = 34.0228 MPa

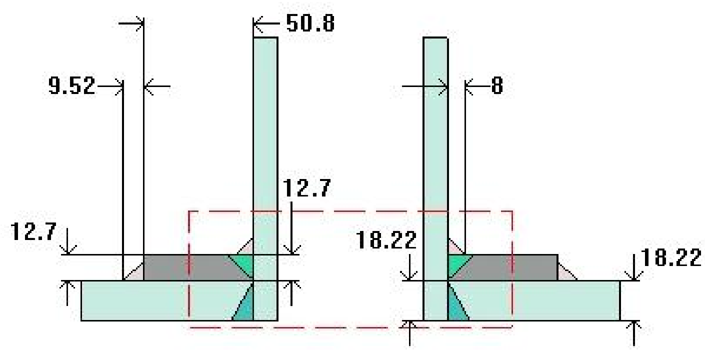
P_a = 4*B / (3*(D_o / t))
= 4*34,022.83 / (3*(139.7 / 0.77))
= 250.05 kPa

Design thickness for external pressure P_a = 250.05 kPa

t_a = t + Corrosion = 0.77 + 3.2 = 3.97 mm

PSV/VENT (N4)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 18.22 mm
Leg_{41} = 8 mm
$t_{w(upper)}$ = 12.7 mm
Leg_{42} = 9.53 mm
D_p = 192.42 mm
t_e = 12.7 mm

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

Location and Orientation

Located on:	TOP HEAD
Orientation:	45°
End of nozzle to datum line:	3,989 mm
Calculated as hillside:	Yes
Distance to head center, R:	762 mm
Passes through a Category A joint:	No

Nozzle

Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Description:	NPS 3 Sch 160 DN 80
Inside diameter, new:	66.65 mm
Nominal wall thickness:	11.13 mm
Corrosion allowance:	3.2 mm
Opening chord length:	74.66 mm
Projection available outside vessel, Lpr:	447.42 mm
Projection available outside vessel to flange face, Lf:	517.27 mm
Local vessel minimum thickness:	18.22 mm
Liquid static head included:	5.3352 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 18, ln. 19) (normalized)
Diameter:	192.42 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 3 Class 150 WN A105

Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Blind included:	No
Rated MDMT:	-48°C per UCS-66(b)(1)(b)
Liquid static head:	0 kPa
MAWP rating:	1,694 kPa @ 120°C
MAP rating:	1,960 kPa @ 10°C
Hydrotest rating:	3,000 kPa @ 10°C
PWHT performed:	No
Circumferential joint radiography:	None UW-11(c) Type 1

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,046.9 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
10.3595	13.3284	1.1271	4.2258	--	7.4284	0.5471	8	9.73

UG-41 Weld Failure Path Analysis Summary (N) 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
130,320	168,377	277,940	93,959	459,887	196,470	408,861

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	5.55	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	6.35	6.67	weld size is adequate
Nozzle to pad groove (Upper)	5.55	12.7	weld size is adequate

Calculations for internal pressure 1,046.9 kPa @ 120 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.1458).
External nozzle loadings per UG-22 govern the coincident ratio used.

Pad impact test exemption temperature from Fig UCS-66M Curve D = -48 °C
Fig UCS-66.1M MDMT reduction = 5.8 °C, (coincident ratio = 0.8963)
Rated MDMT of -53.8°C is limited to -48°C by UCS-66(b)(2).

Nozzle UCS-66 governing thk:	9.73 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	12.7 mm
Pad rated MDMT:	-48 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(74.66, 37.33 + (11.13 - 3.2) + (18.22 - 3.2))
= 74.66 mm

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*(18.22 - 3.2), 2.5*(11.13 - 3.2) + 12.7)
= 32.51 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 1,046.9022*36.52 / (118,000*1 - 0.6*1,046.9022)
= 0.33 mm

Required thickness t_r from UG-37(a)(c)

t_r = P*K_1*D_o / (2*S*E + 0.8*P)
= 1,046.9022*0.8985*3,962 / (2*138,000*1 + 0.8*1,046.9022)
= 13.46 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

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})
= (74.66*13.46*1 + 2*7.93*13.46*1*(1 - 0.8551)) / 100
= 10.3595 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.1271 cm^2

= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (74.66*(1*15.02 - 1*13.46) - 2*7.93*(1*15.02 - 1*13.46)*(1 - 0.8551)) / 100
= 1.1271 cm^2

= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (2*(15.02 + 7.93)*(1*15.02 - 1*13.46) - 2*7.93*(1*15.02 - 1*13.46)*(1 - 0.8551)) / 100
= 0.6787 cm^2

A_2 = smaller of the following= 4.2258 cm^2

$= 5*(t_n - t_{rn})*f_{r2}*t$
$= (5*(7.93 - 0.33)*0.8551*15.02) / 100$
$= 4.8806\ cm^2$

$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
$= (2*(7.93 - 0.33)*(2.5*7.93 + 12.7)*0.8551) / 100$
$= 4.2258\ cm^2$

$A_{41} = Leg^2*f_{r3}$
$= (8^2*0.8551) / 100$
$= 0.5471\ cm^2$

$A_{42} = Leg^2*f_{r4}$
$= (0^2*1) / 100$
$= 0\ cm^2$

(Part of the weld is outside of the limits)

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= ((149.31 - 90.82)*12.7*1) / 100$
$= 7.4284\ cm^2$

$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$
$= 1.1271 + 4.2258 + 0.5471 + 0 + 7.4284$
$= 13.3284\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 7.93 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 5.55 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12.7 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 6.35 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-27} = P*R / (S*E - 0.6*P) + Corrosion$

$= 1{,}046.9022*36.52 / (118{,}000*1 - 0.6*1{,}046.9022) + 3.2$
$= 3.53$ mm

$t_{a\ UG\text{-}22} = 4.15$ mm

$t_a = \max[\ t_{a\ UG\text{-}27}\ ,\ t_{a\ UG\text{-}22}\ ]$
$= \max[\ 3.53\ ,\ 4.15\ ]$
$= 4.15$ mm

$t_{b1} = 18.1$ mm

$t_{b1} = \max[\ t_{b1}\ ,\ t_{b\ UG16}\ ]$
$= \max[\ 18.1\ ,\ 4.7\ ]$
$= 18.1$ mm

$t_b = \min[\ t_{b3}\ ,\ t_{b1}\ ]$
$= \min[\ 8\ ,\ 18.1\ ]$
$= 8$ mm

$t_{UG\text{-}45} = \max[\ t_a\ ,\ t_b\ ]$
$= \max[\ 4.15\ ,\ 8\ ]$
$= 8$ mm

Available nozzle wall thickness new, $t_n = 0.875*11.13 = 9.73$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*$S_i = (\pi / 2)*88.9*8*57.82 = 64{,}593.64$ N

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*$S_o = (\pi / 2)*192.42*9.53*67.62 = 194{,}675.29$ N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*$t_n*S_n = (\pi / 2)*80.97*7.93*82.6 = 83{,}264.54$ N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*$t_w*S_g = (\pi / 2)*88.9*15.02*102.12 = 214{,}185.9$ N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*$t_w*S_g = (\pi / 2)*88.9*12.7*102.12 = 181{,}107.42$ N

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

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (1,035.9528 - 112.7095 + 2*7.93*0.8551*(1*15.02 - 1*13.46))*138$
$=$ 130,320.47 N

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (422.5798 + 742.8372 + 54.7096 + 0)*138$
$=$ 168,377.49 N

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (422.5798 + 0 + 54.7096 + 0 + 2*7.93*15.02*0.8551)*138$
$=$ 93,958.72 N

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (422.5798 + 0 + 742.8372 + 54.7096 + 0 + 0 + 2*7.93*15.02*0.8551)*138$
$=$ 196,470.27 N

Load for path 1-1 lesser of W or W_{1-1} = 130,320.47 N
Path 1-1 through (2) & (3) = 194,675.29 + 83,264.54 = 277,939.83 N
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} = 93,958.72 N
Path 2-2 through (1), (4), (6) = 64,593.64 + 214,185.9 + 181,107.42 = 459,886.96 N
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} = 130,320.47 N
Path 3-3 through (2), (4) = 194,675.29 + 214,185.9 = 408,861.2 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Applied Loads

Radial load:	P_r =	-1,510	N
Circumferential moment:	M_1 =	585	N-m
Circumferential shear:	V_2 =	1,850	N
Longitudinal moment:	M_2 =	585	N-m
Longitudinal shear:	V_1 =	1,850	N
Torsion moment:	M_t =	825	N-m
Internal pressure:	P =	1,046.9	kPa
Head yield stress:	S_y =	236	MPa

Maximum stresses due to the applied loads at the pad edge (includes pressure)

Mean dish radius R_m = 3,554.18 mm

U = r_o / Sqr(R_m*t) = 0.412
Pressure stress intensity factor, I = 1 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =123.602 MPa

Maximum combined stress (P_L+P_b+Q) = 152.02 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 126.42 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

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*	0.1564	1.048	1.048	1.048	1.048	1.048	1.048	1.048	1.048
SR-2	0.1019	4.095	-4.095	4.095	-4.095	4.095	-4.095	4.095	-4.095
SR-3*	0.1571	0	0	0	0	-1.765	-1.765	1.765	1.765
SR-3	0.318	0	0	0	0	-21.415	21.415	21.415	-21.415
SR-3*	0.1571	-1.765	-1.765	1.765	1.765	0	0	0	0
SR-3	0.318	-21.415	21.415	21.415	-21.415	0	0	0	0
Pressure stress*		123.602	123.602	123.602	123.602	123.602	123.602	123.602	123.602
Total O_x stress		105.566	140.205	151.926	100.905	105.566	140.205	151.926	100.905
Membrane O_x stress*		122.885	122.885	126.415	126.415	122.885	122.885	126.415	126.415
SR-2*	0.0469	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317
SR-2	0.031	1.248	-1.248	1.248	-1.248	1.248	-1.248	1.248	-1.248
SR-3*	0.0483	0	0	0	0	-0.545	-0.545	0.545	0.545
SR-3	0.0951	0	0	0	0	-6.405	6.405	6.405	-6.405
SR-3*	0.0483	-0.545	-0.545	0.545	0.545	0	0	0	0
SR-3	0.0951	-6.405	6.405	6.405	-6.405	0	0	0	0
Pressure stress*		123.602	123.602	123.602	123.602	123.602	123.602	123.602	123.602
Total O_y stress		118.218	128.532	132.117	116.811	118.218	128.532	132.117	116.811
Membrane O_y stress*		123.375	123.375	124.464	124.464	123.375	123.375	124.464	124.464
Shear from M_t		0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965
Shear from V_1		0	0	0	0	-0.414	-0.414	0.414	0.414
Shear from V_2		0.414	0.414	-0.414	-0.414	0	0	0	0
Total Shear stress		1.379	1.379	0.552	0.552	0.552	0.552	1.379	1.379
Combined stress (P_L+P_b+Q)		118.369	140.363	151.94	116.832	118.238	140.232	152.023	116.928

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)

Mean dish radius R_m = 3,554.18 mm

U = r_o / Sqr(R_m*t) = 0.142
Pressure stress intensity factor, I = 0.42229 (derived from PVP-Vol. 399, pages 77-82)

Local pressure stress = I*P*R_i / (2*t) =52.2 MPa

Maximum combined stress (P_L+P_b+Q) = 72.53 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 53.04 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

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*	0.254	0.496	0.496	0.496	0.496	0.496	0.496	0.496	0.496
SR-2	0.2512	2.965	-2.965	2.965	-2.965	2.965	-2.965	2.965	-2.965
SR-3*	0.1426	0	0	0	0	-0.345	-0.345	0.345	0.345
SR-3	1.096	0	0	0	0	-15.948	15.948	15.948	-15.948
SR-3*	0.1426	-0.345	-0.345	0.345	0.345	0	0	0	0
SR-3	1.096	-15.948	15.948	15.948	-15.948	0	0	0	0
Pressure stress*		52.2	52.2	52.2	52.2	52.2	52.2	52.2	52.2
Total O_x stress		39.369	65.335	71.954	34.129	39.369	65.335	71.954	34.129
Membrane O_x stress*		52.352	52.352	53.041	53.041	52.352	52.352	53.041	53.041
SR-2*	0.0773	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152
SR-2	0.0732	0.862	-0.862	0.862	-0.862	0.862	-0.862	0.862	-0.862
SR-3*	0.043	0	0	0	0	-0.103	-0.103	0.103	0.103
SR-3	0.3404	0	0	0	0	-4.957	4.957	4.957	-4.957
SR-3*	0.043	-0.103	-0.103	0.103	0.103	0	0	0	0
SR-3	0.3404	-4.957	4.957	4.957	-4.957	0	0	0	0
Pressure stress*		52.2	52.2	52.2	52.2	52.2	52.2	52.2	52.2
Total O_y stress		48.153	56.344	58.274	46.636	48.153	56.344	58.274	46.636
Membrane O_y stress*		52.248	52.248	52.455	52.455	52.248	52.248	52.455	52.455
Shear from M_t		2.399	2.399	2.399	2.399	2.399	2.399	2.399	2.399
Shear from V_1		0	0	0	0	-0.476	-0.476	0.476	0.476
Shear from V_2		0.476	0.476	-0.476	-0.476	0	0	0	0
Total Shear stress		2.875	2.875	1.924	1.924	1.924	1.924	2.875	2.875
Combined stress (P_L+P_b+Q)		49.008	66.176	72.216	46.926	48.553	65.728	72.533	47.264

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

$\sigma_{n\ (Pm)} = P*R_i / (2*t_n) - P_r / (\pi*(R_o^2 - R_i^2)) + M*R_o / I$
$= 1,046.9 / 1000*36.52 / (2*6.53) - -1,510 / (\pi*(44.45^2 - 36.52^2)) + 827,314.7*44.45 / 1,668,246$
= 25.718 MPa

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 = 118 MPa)

Shear stress in the nozzle wall due to external loads

$\sigma_{shear} = (V_L^2 + V_c^2)^{0.5} / (\pi*R_i*t_n)$
$= (1,850^2 + 1,850^2)^{0.5} / (\pi*36.52*7.93)$
= 2.877 MPa

$\sigma_{torsion} = M_t / (2*\pi*R_i^2*t_n)$
$= 825 / (2*\pi*36.52^2*7.93)$

= 12.419 MPa

$\sigma_{total} = \sigma_{shear} + \sigma_{torsion}$
= 2.877 + 12.419
= 15.296 MPa

UG-45: The total combined shear stress (15.296 MPa) is below than the allowable ($0.7*S_n$ = 0.7*118 = 82.6 MPa)

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 224.31 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
5.7789	11.9168	--	3.9413	--	7.4284	0.5471	6.41	9.73

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	5.55	5.6	weld size is adequate
Pad to shell fillet (Leg_{42})	6.35	6.67	weld size is adequate
Nozzle to pad groove (Upper)	5.55	12.7	weld size is adequate

Calculations for external pressure 224.31 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(74.66, 37.33 + (11.13 - 3.2) + (18.22 - 3.2))
= 74.66 mm

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*(18.22 - 3.2), 2.5*(11.13 - 3.2) + 12.7)
= 32.51 mm

Nozzle required thickness per UG-28 t_{rn} = 0.84 mm

From UG-37(d)(1) required thickness t_r = 15.02 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= (0.5*(74.66*15.02*1 + 2*7.93*15.02*1*(1 - 0.8551))) / 100
= 5.7789 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (74.66*(1*15.02 - 1*15.02) - 2*7.93*(1*15.02 - 1*15.02)*(1 - 0.8551)) / 100
= 0 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.02 + 7.93)*(1*15.02 - 1*15.02) - 2*7.93*(1*15.02 - 1*15.02)*(1 - 0.8551)) / 100
= 0 cm^2

A_2 = smaller of the following= 3.9413 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(7.93 - 0.84)*0.8551*15.02) / 100
= 4.5516 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(7.93 - 0.84)*(2.5*7.93 + 12.7)*0.8551) / 100
= 3.9413 cm^2

A_{41} = Leg^2*f_{r3}
= $(8^2*0.8551)$ / 100
= 0.5471 cm^2

A_{42} = Leg^2*f_{r4}
= (0^2*1) / 100
= 0 cm^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((149.31 - 90.82)*12.7*1) / 100
= 7.4284 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0 + 3.9413 + 0.5471 + 0 + 7.4284
= 11.9168 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 7.93 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 5.55 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8 = 5.6 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12.7 mm
$t_{w(min)}$ = 0.5*t_{min} = 6.35 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}28}$ = 4.04 mm

$t_{a\ UG\text{-}22}$ = 3.87 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[4.04 , 3.87]
= 4.04 mm

t_{b2} = 6.41 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[6.41 , 4.7]
= 6.41 mm

t_b = min[t_{b3} , t_{b2}]
= min[8 , 6.41]
= 6.41 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[4.04 , 6.41]
= 6.41 mm

Available nozzle wall thickness new, t_n = 0.875*11.13 = 9.73 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 535.97 / 88.9 = 6.0289
D_o / t = 88.9 / 0.84 = 106.1560
From table G: A = 0.000181
From table CS-2 Metric: B = 17.8584 MPa

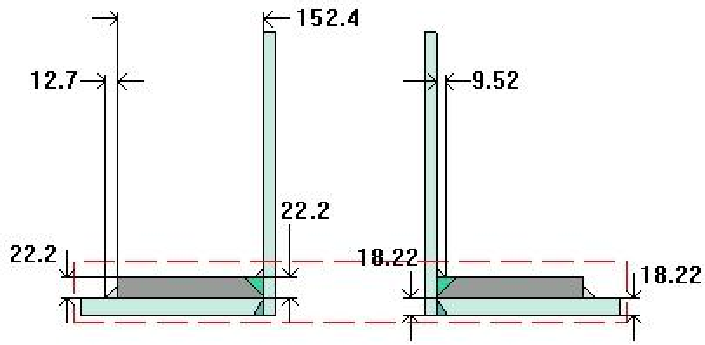
P_a = 4*B / (3*(D_o / t))
= 4*17,858.37 / (3*(88.9 / 0.84))
= 224.3 kPa

Design thickness for external pressure P_a = 224.3 kPa

t_a = t + Corrosion = 0.84 + 3.2 = 4.04 mm

TOP MANWAY (M1)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 18.22 mm
Leg_{41} = 9.53 mm
$t_{w(upper)}$ = 22.2 mm
Leg_{42} = 12.7 mm
D_p = 942.38 mm
t_e = 22.2 mm

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

Location and Orientation

Located on:	TOP HEAD
Orientation:	0°
End of nozzle to datum line:	3,989 mm
Calculated as hillside:	Yes
Distance to head center, R:	1,016 mm
Passes through a Category A joint:	No

Nozzle

Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Description:	NPS 24 XS DN 600
Inside diameter, new:	584.2 mm
Nominal wall thickness:	12.7 mm
Corrosion allowance:	3.2 mm
Opening chord length:	618.14 mm
Projection available outside vessel, Lpr:	363.63 mm
Projection available outside vessel to flange face, Lf:	516.03 mm
Local vessel minimum thickness:	18.22 mm
Liquid static head included:	5.9681 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 18, ln. 19) (normalized)
Diameter:	942.38 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 24 Class 150 WN A105

Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Blind included:	Yes
Rated MDMT:	-48°C per UCS-66(b)(1)(b)
Liquid static head:	0 kPa
MAWP rating:	1,694 kPa @ 120°C
MAP rating:	1,960 kPa @ 10°C
Hydrotest rating:	3,000 kPa @ 10°C
PWHT performed:	No
Circumferential joint radiography:	Spot UW-11(b) Type 1

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,047.54 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
83.6347	83.9972	9.5355	4.4077	--	67.6656	2.3884	5.84	11.11

UG-41 Weld Failure Path Analysis Summary (N) 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
1,026,043	1,027,572	2,010,912	105,203	4,166,909	1,061,247	2,739,930

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.51	8.89	weld size is adequate
Nozzle to pad groove (Upper)	6.65	22.2	weld size is adequate

Calculations for internal pressure 1,047.54 kPa @ 120 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.3331).

Pad impact test exemption temperature from Fig UCS-66M Curve D = -42.1 °C
Fig UCS-66.1M MDMT reduction = 5.8 °C, (coincident ratio = 0.8968).

Nozzle UCS-66 governing thk:	11.11 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	18.22 mm
Pad rated MDMT:	-47.9 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(618.14, 309.07 + (12.7 - 3.2) + (18.22 - 3.2))
= 618.14 mm

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*(18.22 - 3.2), 2.5*(12.7 - 3.2) + 22.2)

= 37.55 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,047.5351*295.3 / (118,000*1 - 0.6*1,047.5351)
= 2.64 mm

Required thickness t_r from UG-37(a)(c)

t_r = $P*K_1*D_o / (2*S*E + 0.8*P)$
= 1,047.5351*0.8985*3,962 / (2*138,000*1 + 0.8*1,047.5351)
= 13.47 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (618.14*13.47*1 + 2*9.5*13.47*1*(1 - 0.8551)) / 100
= 83.6347 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 9.5355 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (618.14*(1*15.02 - 1*13.47) - 2*9.5*(1*15.02 - 1*13.47)*(1 - 0.8551)) / 100
= 9.5355 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.02 + 9.5)*(1*15.02 - 1*13.47) - 2*9.5*(1*15.02 - 1*13.47)*(1 - 0.8551)) / 100
= 0.7174 cm^2

A_2 = smaller of the following= 4.4077 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(9.5 - 2.64)*0.8551*15.02) / 100
= 4.4077 cm^2

$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
$= (2*(9.5 - 2.64)*(2.5*9.5 + 22.2)*0.8551) / 100$
$= 5.3935\ cm^2$

$A_{41} = Leg^2*f_{r3}$
$= (9.53^2*0.8551) / 100$
$= 0.7755\ cm^2$

$A_{42} = Leg^2*f_{r4}$
$= (12.7^2*1) / 100$
$= 1.6129\ cm^2$

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= ((942.38 - 637.58)*22.2*1) / 100$
$= 67.6656\ cm^2$

Area $= A_1 + A_2 + A_{41} + A_{42} + A_5$
$= 9.5355 + 4.4077 + 0.7755 + 1.6129 + 67.6656$
$= 83.9972\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 9.5 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.02 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7.51 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

UG-45 Nozzle Neck Thickness Check (Access Opening)

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG-27} = P*R / (S*E - 0.6*P) + Corrosion$
$= 1,047.5351*295.3 / (118,000*1 - 0.6*1,047.5351) + 3.2$
$= 5.84\ mm$

$t_a = max[\ t_{a\ UG-27}\ ,\ t_{a\ UG-22}\ ]$
$= max[\ 5.84\ ,\ 0\ ]$

= 5.84 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*609.6*9.53*57.82 = 527,360.92 N

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*942.38*12.7*67.62 = 1,271,226.21 N

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*600.1*9.5*82.6 = 739,685.65 N

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*609.6*15.02*102.12 = 1,468,703.3 N

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*609.6*22.2*102.12 = 2,170,844.31 N

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

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (8,363.4683 - 953.5465 + 2*9.5*0.8551*(1*15.02 - 1*13.47))*138
= 1,026,043.39 N

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (440.7733 + 6,766.56 + 77.5482 + 161.29)*138
= 1,027,571.82 N

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (440.7733 + 0 + 77.5482 + 0 + 2*9.5*15.02*0.8551)*138
= 105,203.42 N

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (440.7733 + 0 + 6,766.56 + 77.5482 + 161.29 + 0 + 2*9.5*15.02*0.8551)*138
= 1,061,246.85 N

Load for path 1-1 lesser of W or W_{1-1} = 1,026,043.39 N
Path 1-1 through (2) & (3) = 1,271,226.21 + 739,685.65 = 2,010,911.87 N
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} = 105,203.42 N
Path 2-2 through (1), (4), (6) = 527,360.92 + 1,468,703.3 + 2,170,844.31 = 4,166,908.53 N
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} = 1,026,043.39 N
Path 3-3 through (2), (4) = 1,271,226.21 + 1,468,703.3 = 2,739,929.51 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 224.31 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
46.6259	74.343	0.0006	4.2884	--	67.6656	2.3884	6.02	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.51	8.89	weld size is adequate
Nozzle to pad groove (Upper)	6.65	22.2	weld size is adequate

Calculations for external pressure 224.31 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(618.12, 309.06 + (12.7 - 3.2) + (18.22 - 3.2))
= 618.12 mm

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*(18.22 - 3.2), 2.5*(12.7 - 3.2) + 22.2)
= 37.55 mm

Nozzle required thickness per UG-28 t_{rn} = 2.82 mm

From UG-37(d)(1) required thickness t_r = 15.02 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= (0.5*(618.12*15.02*1 + 2*9.5*15.02*1*(1 - 0.8551))) / 100
= 46.6259 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.0006 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (618.12*(1*15.02 - 1*15.02) - 2*9.5*(1*15.02 - 1*15.02)*(1 - 0.8551)) / 100
= 0.0006 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.02 + 9.5)*(1*15.02 - 1*15.02) - 2*9.5*(1*15.02 - 1*15.02)*(1 - 0.8551)) / 100
= 0 cm^2

A_2 = smaller of the following= 4.2884 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(9.5 - 2.82)*0.8551*15.02) / 100
= 4.2884 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(9.5 - 2.82)*(2.5*9.5 + 22.2)*0.8551) / 100
= 5.2477 cm^2

A_{41} = Leg^2*f_{r3}
= $(9.53^2*0.8551) / 100$
= 0.7755 cm^2

A_{42} = Leg^2*f_{r4}
= $(12.7^2*1) / 100$
= 1.6129 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((942.38 - 637.58)*22.2*1) / 100
= 67.6656 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0.0006 + 4.2884 + 0.7755 + 1.6129 + 67.6656
= 74.343 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 9.5 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.02 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7.51 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

UG-45 Nozzle Neck Thickness Check (Access Opening)

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}28}$ = 6.02 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[6.02 , 0]
= 6.02 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o	=	703.99 / 609.6	=	1.1548
D_o / t	=	609.6 / 2.82	=	216.0111
From table G:	A	=	0.000367	
From table CS-2 Metric:	B	=	36.3403 MPa	

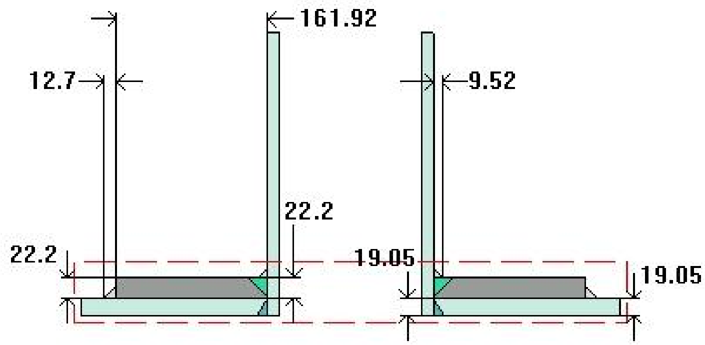
P_a = $4*B / (3*(D_o / t))$
= 4*36,340.3 / (3*(609.6 / 2.82))
= 224.31 kPa

Design thickness for external pressure P_a = 224.31 kPa

t_a = t + Corrosion = 2.82 + 3.2 = 6.02 mm

BOTTOM MANWAY (M2)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 19.05 mm
Leg_{41} = 9.53 mm
$t_{w(upper)}$ = 22.2 mm
Leg_{42} = 12.7 mm
D_p = 951.77 mm
t_e = 22.2 mm

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

Location and Orientation

Located on:	BOTTOM HEAD
Orientation:	315°
End of nozzle to datum line:	-1,350 mm
Calculated as hillside:	Yes
Distance to head center, R:	863 mm
Passes through a Category A joint:	No

Nozzle

Material specification:	SA-106 B Smls. Pipe (II-D Metric p. 10, ln. 40)
Description:	NPS 24 XS DN 600
Inside diameter, new:	584.2 mm
Nominal wall thickness:	12.7 mm
Corrosion allowance:	3.2 mm
Opening chord length:	608.66 mm
Projection available outside vessel, Lpr:	238.1 mm
Projection available outside vessel to flange face, Lf:	390.5 mm
Local vessel minimum thickness:	19.05 mm
Liquid static head included:	52.1271 kPa
Longitudinal joint efficiency:	1

Reinforcing Pad

Material specification:	SA-516 70 (II-D Metric p. 18, ln. 19) (normalized)
Diameter:	951.77 mm
Is split:	No

ASME B16.5-2009 Flange

Description:	NPS 24 Class 150 WN A105

Bolt Material:	SA-193 B7 Bolt <= 64 (II-D Metric p. 334, ln. 32)
Blind included:	Yes
Rated MDMT:	-48°C per UCS-66(b)(1)(b)
Liquid static head:	52.314 kPa
MAWP rating:	1,694 kPa @ 120°C
MAP rating:	1,960 kPa @ 10°C
Hydrotest rating:	3,000 kPa @ 10°C
PWHT performed:	No
Circumferential joint radiography:	Spot UW-11(b) Type 1

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,093.69 kPa @ 120 °C The opening is adequately reinforced							**UG-45 Nozzle Wall Thickness Summary (mm)** The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
85.9763	89.6863	10.8316	4.5716	--	71.8947	2.3884	5.95	11.11

UG-41 Weld Failure Path Analysis Summary (N) 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
1,041,005	1,088,195	2,023,586	109,326	4,248,071	1,123,731	2,833,766

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.92	8.89	weld size is adequate
Nozzle to pad groove (Upper)	6.65	22.2	weld size is adequate

Calculations for internal pressure 1,093.69 kPa @ 120 °C

Fig UCS-66.2 general note (1) applies.

Nozzle is impact test exempt to -105 °C per UCS-66(b)(3) (coincident ratio = 0.3478).

Pad impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C
Fig UCS-66.1M MDMT reduction = 6.3 °C, (coincident ratio = 0.8872).

Nozzle UCS-66 governing thk:	11.11 mm
Nozzle rated MDMT:	-105 °C
Pad UCS-66 governing thickness:	19.05 mm
Pad rated MDMT:	-47.36 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(608.66, 304.33 + (12.7 - 3.2) + (19.05 - 3.2))$$
$$= 608.66 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(19.05 - 3.2), 2.5*(12.7 - 3.2) + 22.2)$$

= 39.62 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,093.6942*295.3 / (118,000*1 - 0.6*1,093.6942)
= 2.75 mm

Required thickness t_r from UG-37(a)(c)

t_r = $P*K_1*D_o / (2*S*E + 0.8*P)$
= 1,093.6942*0.8985*3,962 / (2*138,000*1 + 0.8*1,093.6942)
= 14.06 mm

Area required per UG-37(c)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (608.66*14.06*1 + 2*9.5*14.06*1*(1 - 0.8551)) / 100
= 85.9763 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 10.8316 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (608.66*(1*15.85 - 1*14.06) - 2*9.5*(1*15.85 - 1*14.06)*(1 - 0.8551)) / 100
= 10.8316 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 9.5)*(1*15.85 - 1*14.06) - 2*9.5*(1*15.85 - 1*14.06)*(1 - 0.8551)) / 100
= 0.8574 cm^2

A_2 = smaller of the following= 4.5716 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(9.5 - 2.75)*0.8551*15.85) / 100
= 4.5716 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(9.5 - 2.75)*(2.5*9.5 + 22.2)*0.8551) / 100
= 5.3019 cm^2

A_{41} = Leg^2*f_{r3}
= $(9.53^2*0.8551) / 100$
= 0.7755 cm^2

A_{42} = Leg^2*f_{r4}
= $(12.7^2*1) / 100$
= 1.6129 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((951.77 - 627.92)*22.2*1) / 100
= 71.8947 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 10.8316 + 4.5716 + 0.7755 + 1.6129 + 71.8947
= 89.6863 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 9.5 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.85 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7.92 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

UG-45 Nozzle Neck Thickness Check (Access Opening)

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,093.881*295.3 / (118,000*1 - 0.6*1,093.881) + 3.2
= 5.95 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[5.95 , 0]

= 5.95 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	0.74*138 =	102.12 MPa
Nozzle wall in shear:	0.7*118 =	82.6 MPa
Inner fillet weld in shear:	0.49*118 =	57.82 MPa
Outer fillet weld in shear:	0.49*138 =	67.62 MPa
Upper groove weld in tension:	0.74*138 =	102.12 MPa

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*609.6*9.53*57.82 = 527,360.92 N

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*951.77*12.7*67.62 = 1,283,900.31 N

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*600.1*9.5*82.6 = 739,685.65 N

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*609.6*15.85*102.12 = 1,549,865.49 N

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*609.6*22.2*102.12 = 2,170,844.31 N

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

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (8,597.6263 - 1,083.1591 + 2*9.5*0.8551*(1*15.85 - 1*14.06))*138
= 1,041,004.67 N

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
= (457.1604 + 7,189.47 + 77.5482 + 161.29)*138
= 1,088,194.83 N

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (457.1604 + 0 + 77.5482 + 0 + 2*9.5*15.85*0.8551)*138
= 109,325.75 N

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (457.1604 + 0 + 7,189.47 + 77.5482 + 161.29 + 0 + 2*9.5*15.85*0.8551)*138
= 1,123,730.78 N

Load for path 1-1 lesser of W or W_{1-1} = 1,041,004.67 N
Path 1-1 through (2) & (3) = 1,283,900.31 + 739,685.65 = 2,023,585.96 N
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} = 109,325.75 N
Path 2-2 through (1), (4), (6) = 527,360.92 + 1,549,865.49 + 2,170,844.31 = 4,248,070.72 N
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} = 1,041,004.67 N
Path 3-3 through (2), (4) = 1,283,900.31 + 1,549,865.49 = 2,833,765.8 N
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 250.06 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
48.4523	78.9315	--	4.6484	--	71.8947	2.3884	5.84	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.67	weld size is adequate
Pad to shell fillet (Leg_{42})	7.92	8.89	weld size is adequate
Nozzle to pad groove (Upper)	6.65	22.2	weld size is adequate

Calculations for external pressure 250.06 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(608.65, 304.32 + (12.7 - 3.2) + (19.05 - 3.2))
= 608.65 mm

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*(19.05 - 3.2), 2.5*(12.7 - 3.2) + 22.2)
= 39.62 mm

Nozzle required thickness per UG-28 t_{rn} = 2.64 mm

From UG-37(d)(1) required thickness t_r = 15.85 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 118, S_v = 138, S_p = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= (0.5*(608.65*15.85*1 + 2*9.5*15.85*1*(1 - 0.8551))) / 100
= 48.4523 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (608.65*(1*15.85 - 1*15.85) - 2*9.5*(1*15.85 - 1*15.85)*(1 - 0.8551)) / 100
= 0 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 9.5)*(1*15.85 - 1*15.85) - 2*9.5*(1*15.85 - 1*15.85)*(1 - 0.8551)) / 100
= 0 cm^2

A_2 = smaller of the following= 4.6484 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(9.5 - 2.64)*0.8551*15.85) / 100
= 4.6484 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(9.5 - 2.64)*(2.5*9.5 + 22.2)*0.8551) / 100
= 5.3903 cm^2

A_{41} = Leg^2*f_{r3}
= $(9.53^2*0.8551)$ / 100
= 0.7755 cm^2

A_{42} = Leg^2*f_{r4}
= (12.7^2*1) / 100
= 1.6129 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((951.77 - 627.92)*22.2*1) / 100
= 71.8947 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 0 + 4.6484 + 0.7755 + 1.6129 + 71.8947
= 78.9315 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 9.5 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.53 = 6.67 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 15.85 mm
$t_{w(min)}$ = 0.5*t_{min} = 7.92 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12.7 = 8.89 mm

UG-45 Nozzle Neck Thickness Check (Access Opening)

Interpretation VIII-1-83-66 has been applied.

$t_{a\ UG\text{-}28}$ = 5.84 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[5.84 , 0]
= 5.84 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 542.21 / 609.6 = 0.8895
D_o / t = 609.6 / 2.64 = 230.8405
From table G: A = 0.000436
From table CS-2 Metric: B = 43.2924 MPa

P_a = 4*B / (3*(D_o / t))
= 4*43,292.45 / (3*(609.6 / 2.64))
= 250.06 kPa

Design thickness for external pressure P_a = 250.06 kPa

t_a = t + Corrosion = 2.64 + 3.2 = 5.84 mm

SIGHT GLASS (SG1A)

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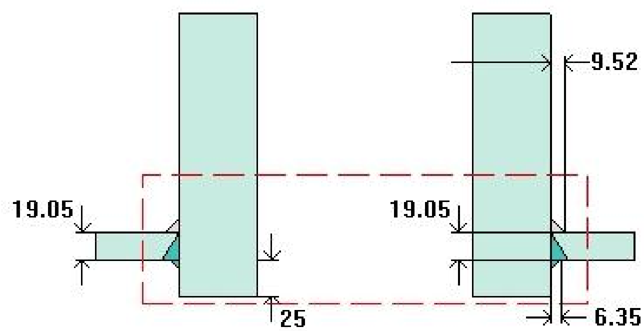


$t_{w(lower)}$ = 19.05 mm
Leg_{41} = 9.52 mm
Leg_{43} = 6.35 mm
h_{new} = 25 mm

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

Location and Orientation

Located on:	3962 mm O.D. SHELL
Orientation:	225°
Nozzle center line offset to datum line:	2,018 mm
End of nozzle to shell center:	1,993.7 mm
Passes through a Category A joint:	No

Dwg shows 2028
-10mm will not change the calculation

Nozzle

Material specification:	SA-516 70 (II-D Metric p. 18, ln. 19) (normalized)
Inside diameter, new:	146 mm
Nominal wall thickness:	54.5 mm
Corrosion allowance:	3.2 mm
Projection available outside vessel, Lpr:	12.7 mm
Internal projection, h_{new}:	25 mm
Local vessel minimum thickness:	19.05 mm
Liquid static head included:	20.0279 kPa
Longitudinal joint efficiency:	1

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,061.59 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
27.9921	35.791	1.0013	12.8806	20.971	--	0.9381	11.31	54.5

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 (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	6.66	weld size is adequate

Calculations for internal pressure 1,061.59 kPa @ 120 °C

Nozzle impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C
Fig UCS-66.1M MDMT reduction = 2.3 °C, (coincident ratio = 0.9585).

Nozzle UCS-66 governing thk: 19.05 mm
Nozzle rated MDMT: -43.36 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(152.4, 76.2 + (54.5 - 3.2) + (19.05 - 3.2))
= 152.4 mm

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*(19.05 - 3.2), 2.5*(54.5 - 3.2) + 0)
= 39.62 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(2.5*(19.05 - 3.2), 2.5*(54.5 - 3.2 - 3.2))
= 39.62 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,061.5949*76.2 / (138,000*1 - 0.6*1,061.5949)
= 0.59 mm

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 1,061.5949*1,981 / (138,000*1 + 0.4*1,061.5949)
= 15.19 mm

Area required per UG-37(c)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$ + Tapped hole area loss
= (152.4*15.19*1 + 2*51.3*15.19*1*(1 - 1)) / 100 + 4.8387
= 27.9921 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.0013 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (152.4*(1*15.85 - 1*15.19) - 2*51.3*(1*15.85 - 1*15.19)*(1 - 1)) / 100
= 1.0013 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 51.3)*(1*15.85 - 1*15.19) - 2*51.3*(1*15.85 - 1*15.19)*(1 - 1)) / 100
= 0.8826 cm^2

A_2 = smaller of the following= 12.8806 cm^2

= $2*(t_n - t_{rn})*f_{r2}*L_{pr}$
= (2*(51.3 - 0.59)*1*12.7) / 100
= 12.8806 cm^2

= $2*(t_n - t_{rn})*f_{r2}*L_{pr}$
= (2*(51.3 - 0.59)*1*12.7) / 100
= 12.8806 cm^2

A_3 = smaller of the following= 20.971 cm^2

= $5*t*t_i*f_{r2}$
= (5*15.85*48.1*1) / 100
= 38.118 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*48.1*48.1*1) / 100
= 115.6786 cm^2

= $2*h*t_i*f_{r2}$
= (2*21.8*48.1*1) / 100
= 20.971 cm^2

A_{41} = Leg^2*f_{r2}
= $(9.52^2*1) / 100$
= 0.9065 cm^2

A_{43} = Leg^2*f_{r2}
= $(1.78^2*1) / 100$
= 0.0316 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{43}$
= 1.0013 + 12.8806 + 20.971 + 0.9065 + 0.0316
= 35.791 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.52 = 6.66 mm

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,061.5949*76.2 / (138,000*1 - 0.6*1,061.5949) + 3.2
= 3.79 mm

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

= max[3.79 , 0]
= 3.79 mm

t_{b1} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 1,061.5949*1,981 / (138,000*1 + 0.4*1,061.5949) + 3.2
= 18.39 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[18.39 , 4.7]
= 18.39 mm

t_b = min[t_{b3} , t_{b1}]
= min[11.31 , 18.39]
= 11.31 mm

t_{UG-45} = max[t_a , t_b]
= max[3.79 , 11.31]
= 11.31 mm

Available nozzle wall thickness new, t_n = 54.5 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 221.4 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
16.9161	34.8323	--	12.9232	20.971	--	0.9381	6.38	54.5

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	6.66	weld size is adequate

Calculations for external pressure 221.4 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(152.4, 76.2 + (54.5 - 3.2) + (19.05 - 3.2))
= 152.4 mm

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*(19.05 - 3.2), 2.5*(54.5 - 3.2) + 0)
= 39.62 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(2.5*(19.05 - 3.2), 2.5*(54.5 - 3.2 - 3.2))
= 39.62 mm

Nozzle required thickness per UG-28 t_{rn} = 0.42 mm

From UG-37(d)(1) required thickness t_r = 15.85 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$ + Tapped hole area loss
= (0.5*(152.4*15.85*1 + 2*51.3*15.85*1*(1 - 1))) / 100 + 4.8387
= 16.9161 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (152.4*(1*15.85 - 1*15.85) - 2*51.3*(1*15.85 - 1*15.85)*(1 - 1)) / 100
= 0 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 51.3)*(1*15.85 - 1*15.85) - 2*51.3*(1*15.85 - 1*15.85)*(1 - 1)) / 100
= 0 cm^2

A_2 = smaller of the following= 12.9232 cm^2

= $2*(t_n - t_{rn})*f_{r2}*L_{pr}$
= (2*(51.3 - 0.42)*1*12.7) / 100
= 12.9232 cm^2

= $2*(t_n - t_{rn})*f_{r2}*L_{pr}$
= (2*(51.3 - 0.42)*1*12.7) / 100
= 12.9232 cm^2

A_3 = smaller of the following= 20.971 cm^2

= $5*t*t_i*f_{r2}$
= (5*15.85*48.1*1) / 100
= 38.118 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*48.1*48.1*1) / 100
= 115.6786 cm^2

= $2*h*t_i*f_{r2}$
= (2*21.8*48.1*1) / 100
= 20.971 cm^2

A_{41} = Leg^2*f_{r2}
= $(9.52^2*1) / 100$
= 0.9065 cm^2

A_{43} = Leg^2*f_{r2}
= $(1.78^2*1) / 100$
= 0.0316 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{43}$
= 0 + 12.9232 + 20.971 + 0.9065 + 0.0316
= 34.8323 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.52 = 6.66 mm

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 3.62 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[3.62 , 0]
= 3.62 mm

t_{b2} = $P*R_o / (S*E + 0.4*P)$ + Corrosion
= 221.3986*1,981 / (138,000*1 + 0.4*221.3986) + 3.2
= 6.38 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[6.38 , 4.7]
= 6.38 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.31 , 6.38]
= 6.38 mm

t_{UG-45} = max[t_a , t_b]
= max[3.62 , 6.38]
= 6.38 mm

Available nozzle wall thickness new, t_n = 54.5 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 16.81 / 255 = 0.0659
D_o / t = 255 / 0.42 = 604.2399
From table G: A = 0.001822
From table CS-2 Metric: B = 100.3343 MPa

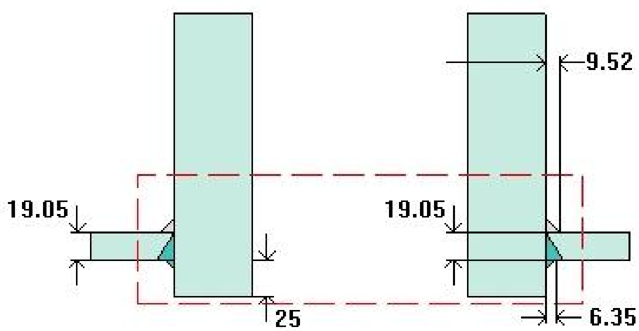
P_a = 4*B / (3*(D_o / t))
= 4*100,334.25 / (3*(255 / 0.42))
= 221.4 kPa

Design thickness for external pressure P_a = 221.4 kPa

t_a = t + Corrosion = 0.42 + 3.2 = 3.62 mm

SIGHT GLASS (SG1B)

ASME Section VIII Division 1, 2010 Edition, A11 Addenda Metric



$t_{w(lower)}$ = 19.05 mm
Leg_{41} = 9.52 mm
Leg_{43} = 6.35 mm
h_{new} = 25 mm

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

Location and Orientation

Located on:	3962 mm O.D. SHELL
Orientation:	225°
Nozzle center line offset to datum line:	1,528 mm
End of nozzle to shell center:	1,993.7 mm
Passes through a Category A joint:	No

Nozzle

Material specification:	SA-516 70 (II-D Metric p. 18, ln. 19) (normalized)
Inside diameter, new:	146 mm
Nominal wall thickness:	54.5 mm
Corrosion allowance:	3.2 mm
Projection available outside vessel, Lpr:	12.7 mm
Internal projection, h_{new}:	25 mm
Local vessel minimum thickness:	19.05 mm
Liquid static head included:	24.8294 kPa
Longitudinal joint efficiency:	1

Reinforcement Calculations for Chamber MAWP

UG-37 Area Calculation Summary (cm^2) For P = 1,066.4 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
28.0966	35.6859	0.8968	12.88	20.971	--	0.9381	11.31	54.5

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 (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	6.66	weld size is adequate

Calculations for internal pressure 1,066.4 kPa @ 120 °C

Nozzle impact test exemption temperature from Fig UCS-66M Curve D = -41.06 °C
Fig UCS-66.1M MDMT reduction = 2.1 °C, (coincident ratio = 0.9629).

Nozzle UCS-66 governing thk: 19.05 mm
Nozzle rated MDMT: -43.16 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(152.4, 76.2 + (54.5 - 3.2) + (19.05 - 3.2))
= 152.4 mm

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*(19.05 - 3.2), 2.5*(54.5 - 3.2) + 0)
= 39.62 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(2.5*(19.05 - 3.2), 2.5*(54.5 - 3.2 - 3.2))
= 39.62 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 1,066.3964*76.2 / (138,000*1 - 0.6*1,066.3964)
= 0.59 mm

Required thickness t_r from UG-37(a)

t_r = $P*R_o / (S*E + 0.4*P)$
= 1,066.3964*1,981 / (138,000*1 + 0.4*1,066.3964)
= 15.26 mm

Area required per UG-37(c)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$ + Tapped hole area loss
= (152.4*15.26*1 + 2*51.3*15.26*1*(1 - 1)) / 100 + 4.8387
= 28.0966 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.8968 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (152.4*(1*15.85 - 1*15.26) - 2*51.3*(1*15.85 - 1*15.26)*(1 - 1)) / 100
= 0.8968 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(15.85 + 51.3)*(1*15.85 - 1*15.26) - 2*51.3*(1*15.85 - 1*15.26)*(1 - 1)) / 100
= 0.7903 cm^2

A_2 = smaller of the following= 12.88 cm^2

= $2*(t_n - t_{rn})*f_{r2}*L_{pr}$
= (2*(51.3 - 0.59)*1*12.7) / 100
= 12.88 cm^2

= $2*(t_n - t_{rn})*f_{r2}*L_{pr}$
= (2*(51.3 - 0.59)*1*12.7) / 100
= 12.88 cm^2

A_3 = smaller of the following= 20.971 cm^2

= $5*t*t_i*f_{r2}$
= (5*15.85*48.1*1) / 100
= 38.118 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*48.1*48.1*1) / 100
= 115.6786 cm^2

= $2*h*t_i*f_{r2}$
= (2*21.8*48.1*1) / 100
= 20.971 cm^2

A_{41} = Leg^2*f_{r2}
= $(9.52^2*1) / 100$
= 0.9065 cm^2

A_{43} = Leg^2*f_{r2}
= $(1.78^2*1) / 100$
= 0.0316 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{43}$
= 0.8968 + 12.88 + 20.971 + 0.9065 + 0.0316
= 35.6859 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.52 = 6.66 mm

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R / (S*E - 0.6*P) + Corrosion
= 1,066.3964*76.2 / (138,000*1 - 0.6*1,066.3964) + 3.2
= 3.79 mm

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

$= \max[\ 3.79\ ,\ 0\ ]$

$= 3.79$ mm

$t_{b1} = P*R_o / (S*E + 0.4*P) + Corrosion$

$= 1{,}066.3964*1{,}981 / (138{,}000*1 + 0.4*1{,}066.3964) + 3.2$

$= 18.46$ mm

$t_{b1} = \max[\ t_{b1}\ ,\ t_{b\ UG16}\ ]$

$= \max[\ 18.46\ ,\ 4.7\ ]$

$= 18.46$ mm

$t_b = \min[\ t_{b3}\ ,\ t_{b1}\ ]$

$= \min[\ 11.31\ ,\ 18.46\ ]$

$= 11.31$ mm

$t_{UG-45} = \max[\ t_a\ ,\ t_b\ ]$

$= \max[\ 3.79\ ,\ 11.31\ ]$

$= 11.31$ mm

Available nozzle wall thickness new, t_n = 54.5 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2) For Pe = 221.4 kPa @ 120 °C The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (mm) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
16.9161	34.8323	--	12.9232	20.971	--	0.9381	6.38	54.5

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	6.66	weld size is adequate

Calculations for external pressure 221.4 kPa @ 120 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(152.4, 76.2 + (54.5 - 3.2) + (19.05 - 3.2))
= 152.4 mm

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*(19.05 - 3.2), 2.5*(54.5 - 3.2) + 0)
= 39.62 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(2.5*(19.05 - 3.2), 2.5*(54.5 - 3.2 - 3.2))
= 39.62 mm

Nozzle required thickness per UG-28 t_{rn} = 0.42 mm

From UG-37(d)(1) required thickness t_r = 15.85 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 138, S_v = 138 MPa

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

A = 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})) + Tapped hole area loss
= (0.5*(152.4*15.85*1 + 2*51.3*15.85*1*(1 - 1))) / 100 + 4.8387
= 16.9161 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (152.4*(1*15.85 - 1*15.85) - 2*51.3*(1*15.85 - 1*15.85)*(1 - 1)) / 100
= 0 cm^2

= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (2*(15.85 + 51.3)*(1*15.85 - 1*15.85) - 2*51.3*(1*15.85 - 1*15.85)*(1 - 1)) / 100
= 0 cm^2

A_2 = smaller of the following= 12.9232 cm^2

= 2*(t_n - t_{rn})*f_{r2}*L_{pr}
= (2*(51.3 - 0.42)*1*12.7) / 100
= 12.9232 cm^2

= 2*(t_n - t_{rn})*f_{r2}*L_{pr}
= (2*(51.3 - 0.42)*1*12.7) / 100
= 12.9232 cm^2

A_3 = smaller of the following= 20.971 cm^2

= 5*t*t_i*f_{r2}
= (5*15.85*48.1*1) / 100
= 38.118 cm^2

= 5*t_i*t_i*f_{r2}
= (5*48.1*48.1*1) / 100
= 115.6786 cm^2

= 2*h*t_i*f_{r2}
= (2*21.8*48.1*1) / 100
= 20.971 cm^2

A_{41} = Leg^2*f_{r2}
= $(9.52^2*1) / 100$
= 0.9065 cm^2

A_{43} = Leg^2*f_{r2}
= $(1.78^2*1) / 100$
= 0.0316 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{43}$
= 0 + 12.9232 + 20.971 + 0.9065 + 0.0316
= 34.8323 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 15.85 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9.52 = 6.66 mm

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 3.62 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[3.62 , 0]
= 3.62 mm

t_{b2} = $P*R_o$ / (S*E + 0.4*P) + Corrosion
= 221.3986*1,981 / (138,000*1 + 0.4*221.3986) + 3.2
= 6.38 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[6.38 , 4.7]
= 6.38 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.31 , 6.38]
= 6.38 mm

t_{UG-45} = max[t_a , t_b]
= max[3.62 , 6.38]
= 6.38 mm

Available nozzle wall thickness new, t_n = 54.5 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 120 °C) UG-28(c)

L / D_o = 16.81 / 255 = 0.0659
D_o / t = 255 / 0.42 = 604.2399

From table G:	A	=	0.001822
From table CS-2 Metric:	B	=	100.3343 MPa

P_a = 4*B / (3*(D_o / t))
= 4*100,334.25 / (3*(255 / 0.42))
= 221.4 kPa

Design thickness for external pressure P_a = 221.4 kPa

t_a = t + Corrosion = 0.42 + 3.2 = 3.62 mm

Seismic Code

Method of seismic analysis:	**NBC Canada 2005**
Importance Factor:	I_E = 1.3000
Location:	Fort McMurray, Alberta
5% Damped Spectral Response Accel. at T = 0.2s	S_a(0.2) = 0.1200
5% Damped Spectral Response Accel. at T = 0.5s	S_a(0.5) = 0.0560
5% Damped Spectral Response Accel. at T = 1.0s	S_a(1.0) = 0.0230
5% Damped Spectral Response Accel. at T = 2.0s	S_a(2.0) = 0.0060
Site Class:	D
Acceleration-based Site Coefficient:	F_a = 1.3000
Velocity-based Site Coefficient:	F_v = 1.4000
Ductility-related force modification factor:	R_d = 2.5000
Overstrength-related force modification factor:	R_o = 1.0000
Vertical Accelerations Considered:	No

Vessel Characteristics

Vessel height: 19.0735 ft (5.81 m)
Vessel Weight:
Operating, Corroded: 179,796 lb (81,554 kg)
Empty, Corroded: 57,783 lb (26,210 kg)
Vacuum, Corroded: 179,796 lb (81,554 kg)

Period of Vibration Calculation

Fundamental Period, T:
Operating, Corroded: 0.484 sec (f = 2.1 Hz)
Empty, Corroded: 0.272 sec (f = 3.7 Hz)
Vacuum, Corroded: 0.484 sec (f = 2.1 Hz)

The fundamental period of vibration T (above) is calculated using the Rayleigh method of approximation:

T = 2 * PI * Sqr({Sum(W_i * y_i^2)} / {g * Sum(W_i * y_i)}), where

W_i is the weight of the i^{th} lumped mass, and
y_i is its deflection when the system is treated as a cantilever beam.

Seismic Shear Reports:

Operating, Corroded
Empty, Corroded
Vacuum, Corroded
Base Shear Calculations

Seismic Shear Report: Operating, Corroded

Component	Elevation of bottom above base (mm)	Elastic modulus E (MPa)	Inertia I (m^4)	Seismic shear at Bottom (N)	Bending Moment at Bottom (N-m)
TOP HEAD	4,763	196,800.0	*	4,973.2	7,175.1
3962 mm O.D. SHELL (top)	2,376	196,800.0	0.3825	17,682.1	34,208.7
SUPPORT LEG	0	199,948.0	0.0352	22,865.5	90,036.9
3962 mm O.D. SHELL (bottom)	2,376	196,800.0	0.3825	5,098.3	5,638.6
BOTTOM HEAD	2,376	196,800.0	*	5,026.7	5,510
*Moment of Inertia I varies over the length of the component					

Seismic Shear Report: Empty, Corroded

Component	Elevation of bottom above base (mm)	Elastic modulus E (MPa)	Inertia I (m^4)	Seismic shear at Bottom (N)	Bending Moment at Bottom (N-m)
TOP HEAD	4,763	202,272.2	*	1,981.1	6,083.8
3962 mm O.D. SHELL (top)	2,376	202,272.2	0.3825	5,030.2	13,794.3
SUPPORT LEG	0	199,948.0	0.0352	9,266.9	37,983.3
3962 mm O.D. SHELL (bottom)	2,376	202,272.2	0.3825	4,092.8	4,926.9
BOTTOM HEAD	2,376	202,272.2	*	4,075	4,823.2
*Moment of Inertia I varies over the length of the component					

Seismic Shear Report: Vacuum, Corroded

Component	Elevation of bottom above base (mm)	Elastic modulus E (MPa)	Inertia I (m^4)	Seismic shear at Bottom (N)	Bending Moment at Bottom (N-m)
TOP HEAD	4,763	196,800.0	*	4,973.2	7,175.1
3962 mm O.D. SHELL (top)	2,376	196,800.0	0.3825	17,682.1	34,208.7
SUPPORT LEG	0	199,948.0	0.0352	22,865.5	90,036.9
3962 mm O.D. SHELL (bottom)	2,376	196,800.0	0.3825	5,098.3	5,638.6
BOTTOM HEAD	2,376	196,800.0	*	5,026.7	5,510
*Moment of Inertia I varies over the length of the component					

Base Shear Calculations

Operating, Corroded
Empty, Corroded
Vacuum, Corroded

Base Shear Calculations: Operating, Corroded

Fundamental Period computed by Rayleigh approximation: 0.484
The design spectral response acceleration, $S(T_a)$ per 4.1.8.4.(6): 0.0826
Higher mode factor, M_v per 4.1.8.11.(5): 1.0000

$V = 2/3 * S(T_a) * M_v * I_E * W / (R_d * R_o)$
$= 2/3 * 0.0826 * 1.0000 * 1.3000 * 179{,}796.4375 / (2.5000 * 1.0000)$
$= 5{,}147.9604$ lb (2,335.08 kg)

Per 4.1.8.11.(2), the minimum lateral earthquake force, V, shall be no less than V_{min}:

V_{min} = 2/3 * S(2.0) * M_v * I_E * W / (R_d * R_o)
= 2/3 * 0.0084 * 1.0000 * 1.3000 * 179,796.4375 / (2.5000 * 1.0000)
= 523.57 lb (237.49 kg)

When R_d is greater than or equal to 1.5, V shall be no more than V_{max}:

V_{max} = 2/3 * 2/3 * S(0.2) * I_E * W / (R_d * R_o)
= 2/3 * 2/3 * 0.1560 * 1.3000 * 179,796.4375 / (2.5000 * 1.0000)
= 6,482.26 lb (2,940.30 kg)

V = 5,147.96 lb (2,335.08 kg)

Base Shear Calculations: Empty, Corroded

Fundamental Period computed by Rayleigh approximation: 0.272
The design spectral response acceleration, S(T_a) per 4.1.8.4.(6): 0.1375
Higher mode factor, M_v per 4.1.8.11.(5): 1.0000

V = 2/3 * S(T_a) * M_v * I_E * W / (R_d * R_o)
= 2/3 * 0.1375 * 1.0000 * 1.3000 * 57,783.3125 / (2.5000 * 1.0000)
= 2,753.9648 lb (1,249.18 kg)

Per 4.1.8.11.(2), the minimum lateral earthquake force, V, shall be no less than V_{min}:

V_{min} = 2/3 * S(2.0) * M_v * I_E * W / (R_d * R_o)
= 2/3 * 0.0084 * 1.0000 * 1.3000 * 57,783.3125 / (2.5000 * 1.0000)
= 168.2650 lb (76.32 kg)

When R_d is greater than or equal to 1.5, V shall be no more than V_{max}:

V_{max} = 2/3 * 2/3 * S(0.2) * I_E * W / (R_d * R_o)
= 2/3 * 2/3 * 0.1560 * 1.3000 * 57,783.3125 / (2.5000 * 1.0000)
= 2,083.2810 lb (944.96 kg)

V = 2,083.28 lb (944.96 kg)

Base Shear Calculations: Vacuum, Corroded

Fundamental Period computed by Rayleigh approximation: 0.484
The design spectral response acceleration, S(T_a) per 4.1.8.4.(6): 0.0826
Higher mode factor, M_v per 4.1.8.11.(5): 1.0000

V = 2/3 * S(T_a) * M_v * I_E * W / (R_d * R_o)
= 2/3 * 0.0826 * 1.0000 * 1.3000 * 179,796.4375 / (2.5000 * 1.0000)
= 5,147.9604 lb (2,335.08 kg)

Per 4.1.8.11.(2), the minimum lateral earthquake force, V, shall be no less than V_{min}:

V_{min} = 2/3 * S(2.0) * M_v * I_E * W / (R_d * R_o)
= 2/3 * 0.0084 * 1.0000 * 1.3000 * 179,796.4375 / (2.5000 * 1.0000)

= 523.5673 lb (237.49 kg)

When R_d is greater than or equal to 1.5, V shall be no more than V_{max}:

V_{max} = 2/3 * 2/3 * S(0.2) * I_E * W / (R_d * R_o)
= 2/3 * 2/3 * 0.1560 * 1.3000 * 179,796.4375 / (2.5000 * 1.0000)
= 6,482.2607 lb (2,940.30 kg)

V = 5,147.96 lb (2,335.08 kg)

SUPPORT LEG

Leg material:			CSA G40.21-350W
Leg description:			W 10x49 (Flange in)
Number of legs:	N =	4	
Overall length:		2,529	mm
Base to girth seam length:		2,376	mm
Pad length:		460	mm
Pad width:		356	mm
Pad thickness:		12.7	mm
Bolt circle:		3,781.6	mm
Anchor bolt size:		1	inch coarse threaded
Anchor bolt material:			SA 36
Anchor bolts/leg:		2	
Anchor bolt allowable stress:	S_b =	103.42	MPa
Anchor bolt corrosion allowance:		0	mm
Anchor bolt hole clearance:		10	mm
Base plate width:		330	mm
Base plate length:		330	mm
Base plate thickness:		25.4	mm (12.34 mm required)
Base plate allowable stress:		165.474	MPa
Foundation allowable bearing stress:		5.171	MPa
User defined leg eccentricity:		12.7	mm
Effective length coefficient:	K =	1.2	
Coefficient:	C_m =	0.85	
Leg yield stress:	F_y =	350	MPa
Leg elastic modulus:	E =	199,947.953	MPa
Leg to pad fillet weld:		17	mm (16.33 mm required)
Pad to shell fillet weld:		9.5	mm (3.14 mm required)
Legs braced:		No	

Note: The support attachment point is assumed to be 25.4 mm up from the cylinder circumferential seam.

Conditions Investigated (Only Governing Condition Reported)

Weight operating corroded
Weight operating new
Weight empty corroded
Weight empty new
Weight test new
Weight vacuum corroded
Seismic operating corroded
Seismic operating new
Seismic empty corroded
Seismic empty new
Seismic vacuum corroded

Loading	Force attack angle °	Leg position °	Axial end load N	Shear resisted N	Axial f_a MPa	Bending f_{bx} MPa	Bending f_{by} MPa	Ratio H_{1-1}	Ratio H_{1-2}
Governing Condition Seismic operating new Moment = 36,442.7 N-m	0	0	192,097.8	2,934.7	20.677	31.083	0	0.2368	0.2330
		90	201,237.2	8,546.5	21.661	8.349	23.067	0.2415	0.2391
		180	210,376.7	2,934.7	22.645	31.842	0	0.2514	0.2457
		270	201,237.2	8,546.5	21.661	8.349	23.067	0.2415	0.2391
	45	0	192,097.8	5,740.6	20.677	39.94	10.956	0.3117	0.3188
		90	192,097.8	5,740.6	20.677	39.94	10.956	0.3117	0.3188
		180	210,376.7	5,740.6	22.645	40.698	10.956	0.3265	0.3314
		270	210,376.7	5,740.6	22.645	40.698	10.956	0.3265	0.3314
	56	0	192,097.8	6,791.7	20.677	37.882	15.197	0.3196	0.3282
		90	192,097.8	4,689.5	20.677	38.59	7.078	0.2920	0.2962
		180	210,376.7	6,791.7	22.645	38.64	15.197	0.3344	0.3409
		270	210,376.7	4,689.5	22.645	39.348	7.078	0.3068	0.3088

Leg Calculations (AISC manual ninth edition)

Axial end load, P_1 **(Based on vessel total bending moment acting at leg attachment elevation)**

$P_1 = W_t / N + 4*M_t / (N*D)$
= 804,948.88 / 4 + 4*1e3*36,442.7 / (4*3,987.4)
= 210,376.67 N

Allowable axial compressive stress, F_a (AISC chapter E)

$C_c = Sqr(2*\pi^2*E / F_y)$
= Sqr(2*π²*199,948 / 350)
= 106.1914

K*l / r = 1.2*2,410.9 / 64.69 = 44.7234

$F_a = 1 * (1 - (K*l / r)^2 / (2*C_c^2))*F_y / (5 / 3 + 3*(K*l / r) / (8*C_c)-(K*l / r)^3 / (8*C_c^3))$
$= 1 * (1 - (44.7234)^2 / (2*106.1914^2))*350 / (5 / 3 + 3*(44.7234) / (8*106.1914)-(44.7234)^3 / (8*106.1914^3))$
= 175.71 MPa

Allowable axial compression and bending (AISC chapter H)

$F'_{ex} = 1*12*\pi^2*E / (23*(K*l / r)^2)$
$= 1*12*\pi^2*199,948 / (23*(44.7234)^2)$
= 514.756 MPa

$F'_{ey} = 1*12*\pi^2*E / (23*(K*l / r)^2)$
$= 1*12*\pi^2*199,948 / (23*(26.2074)^2)$
= 1,499.074 MPa

$F_b = 1*0.66*F_y$
= 1*0.66*350
= 231 MPa

Compressive axial stress

$f_a = P_1 / A$
= 210,376.67 / 9,290.3038
= 22.645 MPa

Bending stresses

$f_{bx} = F*\cos(\alpha)*L / (I_x / C_x) + P_1*E_{cc} / (I_x / C_x)$
= 6,791.73*cos(56)*2,410.9 / (1e4*3,887.6013 / 127) + 210,376.67*12.7 / (1e4*3,887.6013 / 127)
= 38.64 MPa

$f_{by}= F*\sin(\alpha)*L / (I_y / C_y)$
= 6,791.73*sin(56)*2,410.9 / (1e4*11,321.49 / 126.75)
= 15.197 MPa

AISC equation H_{1-1}

$H_{1-1} = f_a / F_a + C_{mx}*f_{bx} / ((1 - f_a / F'_{ex})*F_{bx}) + C_{my}*f_{by} / ((1 - f_a / F'_{ey})*F_{by})$
= 22.645 / 175.71 + 0.85*38.64 / ((1 - 22.645 / 514.756)*231) + 0.85*15.197 / ((1 - 22.645 / 1,499.074)*231)
= 0.3344

AISC equation H_{1-2}

$H_{1-2} = f_a / (0.6*1*F_y) + f_{bx} / F_{bx} + f_{by} / F_{by}$
= 22.645 / (0.6*1*350) + 38.64 / 231 + 15.197 / 231
= 0.3409

4, W 10x49 legs are adequate.

Anchor bolts - Seismic empty corroded condition governs

Tensile loading per leg (2 bolts per leg)

R = 4*M / (N*BC) - W / N
= 4*37,983.3 / (4*3.7816) - 257,033 / 4
= -54,214 N
There is no net uplift (R is negative).

1 inch coarse threaded bolts are satisfactory.

Check the leg to pad fillet weld, Bednar 10.3, Seismic operating new governs

Note: continuous welding is assumed for all support leg fillet welds.

The following leg attachment weld analysis assumes the fillet weld is present on three sides (leg top closure plate is used).

$Z_w = (2*b*d + d^2) / 3$
= $(2*25.3492*11.81 + 11.81^2) / 3$
= 246.0747 cm^2

$J_w = (b + 2*d)^3 / 12 - d^2*(b + d)^2 / (b + 2*d)$
= $(25.3492 + 2*11.81)^3 / 12 - 11.81^2*(25.3492 + 11.81)^2 / (25.3492 + 2*11.81)$
= 5,852.7376 cm^3

$E = d^2 / (b + 2*d)$
$= 118.1^2 / (253.49 + 2*118.1)$
= 28.48 mm

Governing weld load f_x = Cos(56)*6,791.73 = 3,797.89 N
Governing weld load f_y = Sin(56)*6,791.73 = 5,630.6 N

$f_1 = P_1 / L_{weld}$
= 210,376.67 / 48.9692
= 4,296.1 N/cm (V_L direct shear)

$f_2 = f_y*L_{leg}*0.5*b / J_w$
= 5,630.6*241.09*0.5*25.3492 / 5,852.7376
= 2,939.74 N/cm (V_L torsion shear)

$f_3 = f_y / L_{weld}$
= 5,630.6 / 48.9692
= 114.98 N/cm (V_c direct shear)

$f_4 = f_y*L_{leg}*E / J_w$
= 5,630.6*241.09*2.8482 / 5,852.7376
= 660.62 N/cm (V_c torsion shear)

$f_5 = (f_x*L_{leg} + P_1*E_{cc}) / Z_w$
= (3,797.89*241.09 + 210,376.67*1.27) / 246.0747
= 4,806.71 N/cm (M_L bending)

$f_6 = f_x / L_{weld}$
= 3,797.89 / 48.9692
= 77.56 N/cm (Direct outward radial shear)

$f = Sqr((f_1 + f_2)^2 + (f_3 + f_4)^2 + (f_5 + f_6)^2)$
$= Sqr((4,296.1 + 2,939.74)^2 + (114.98 + 660.62)^2 + (4,806.71 + 77.56)^2)$
= 8,764.42 N/cm (Resultant shear load)

Required leg to pad fillet weld leg size (welded both sides + top)

$t_w = f / (0.707*0.55*S_a)$
= 876.44 / (0.707*0.55*138)
= 16.33 mm

The 17 mm leg to pad attachment fillet weld size is adequate.

Check the pad to vessel fillet weld, Bednar 10.3, Seismic operating new governs

$Z_w = b*d + d^2 / 3$
$= 356*460 + 460^2 / 3$
$= 234,293.3\ cm^2$

$J_w = (b + d)^3 / 6$
$= (35.6 + 46)^3 / 6$
$= 90,556.42\ cm^3$

$f_1 = P_1 / L_{weld}$
= 210,376.67 / 163.2

= 1,289.07 N/cm (V_L direct shear)

f_2= f_y*L_{leg}*0.5*b / J_w
= 5,630.6*2,410.9*0.5*356 / 9,055,641.6
= 266.83 N/cm (V_L torsion shear)

f_3 = f_y / L_{weld}
= 5,630.6 / 163.2
= 34.5 N/cm (V_c direct shear)

f_4 = f_y*L_{leg}*0.5*d / J_w
= 5,630.6*2,410.9*0.5*460 / 9,055,641.6
= 344.78 N/cm (V_c torsion shear)

f_5 = (f_x*L_{leg} + P_1*E_{cc}) / Z_w
= (3,797.89*241.09 + 210,376.67*12.7) / 2,342.9333
= 504.84 N/cm (M_L bending)

f_6 = f_x / L_{weld}
= 3,797.89 / 163.2
= 23.27 N/cm (Direct outward radial shear)

f = Sqr((f_1 + f_2)^2 + (f_3 + f_4)^2 + (f_5 + f_6)^2)
= Sqr((1,289.07 + 266.83)^2 + (34.5 + 344.78)^2 + (504.84 + 23.27)^2)
= 1,686.29 N/cm (Resultant shear load)

Required pad to vessel fillet weld leg size (welded all around the pad edge)

t_w = f / (0.707*0.55*S_a)
= 168.63 / (0.707*0.55*138)
= 3.14 mm

9.5 mm pad to vessel attachment fillet weld size is adequate.

Base plate thickness check, AISC 3-106

f_p = P / (B*N)
= 227,452.37 / (330*330)
= 2.089 MPa

m = (N - 0.95*d) / 2
= (330 - 0.95*253.49) / 2
= 44.59 mm

n = (B - 0.8*b) / 2
= (330 - 0.8*254) / 2
= 63.4 mm

L = 0.5*(d + b) / 2 - Sqr((0.5*(d + b))^2 / 4 - P / (4*F_p))
= 0.5*(253.49 + 254) / 2 - Sqr((0.5*(253.49 + 254))^2 / 4 - 227,452.37 / (4*5.171))
= 55.46 mm

t_b = Largest(m, n, L)*Sqr(3*f_p / S_b)
= 63.4*Sqr(3*2.089 / 165.474)
= 12.34 mm

The base plate thickness is adequate.

Check the leg to vessel attachment stresses, WRC-107 (Seismic operating corroded governs)

Applied Loads

Radial load:	P_r =	-4,042.08	N
Circumferential moment:	M_c =	0	N-m
Circumferential shear:	V_c =	0	N
Longitudinal moment:	M_L =	12,367	N-m
Longitudinal shear:	V_L =	206,452.07	N
Torsion moment:	M_t =	0	N-m
Internal pressure:	P =	1,079.65	kPa
Mean shell radius:	R_m =	1,974.68	mm
Local shell thickness:	t =	15.85	mm
Shell yield stress:	S_y =	236	MPa

Maximum stresses due to the applied loads at the pad edge (includes pressure)

R_m / t = 1,974.68 / 15.85 = 124.5883

C_1 = 178, C_2 = 365.1 mm

Local circumferential pressure stress = P*R_i / t =133.972 MPa

Local longitudinal pressure stress = P*R_i / (2*t) =66.989 MPa

Maximum combined stress (P_L+P_b+Q) = 179.38 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 148.04 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad edge per WRC Bulletin 107										
Figure	**value**	β	A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	6.923	0.1714	0	0	0	0	0.896	0.896	0.896	0.896
4C*	15.3881	0.1467	1.986	1.986	1.986	1.986	0	0	0	0
1C	0.0733	0.1185	0	0	0	0	7.074	-7.074	7.074	-7.074
2C-1	0.04	0.1185	3.861	-3.861	3.861	-3.861	0	0	0	0
3A*	4.8662	0.1145	0	0	0	0	0	0	0	0
1A	0.0749	0.1192	0	0	0	0	0	0	0	0
3B*	10.9883	0.1455	-12.087	-12.087	12.087	12.087	0	0	0	0
1B-1	0.0234	0.1274	-27.476	27.476	27.476	-27.476	0	0	0	0
Pressure stress*			133.972	133.972	133.972	133.972	133.972	133.972	133.972	133.972
Total circumferential stress			100.257	147.486	179.381	116.708	141.942	127.794	141.942	127.794
Primary membrane circumferential stress*			123.871	123.871	148.044	148.044	134.868	134.868	134.868	134.868
3C*	8.4277	0.1467	1.089	1.089	1.089	1.089	0	0	0	0
4C*	14.0988	0.1714	0	0	0	0	1.82	1.82	1.82	1.82
1C-1	0.0544	0.1512	5.254	-5.254	5.254	-5.254	0	0	0	0
2C	0.036	0.1512	0	0	0	0	3.475	-3.475	3.475	-3.475
4A*	9.331	0.1145	0	0	0	0	0	0	0	0
2A	0.0319	0.1436	0	0	0	0	0	0	0	0
4B*	4.5615	0.1455	-7.467	-7.467	7.467	7.467	0	0	0	0
2B-1	0.0231	0.153	-22.587	22.587	22.587	-22.587	0	0	0	0
Pressure stress*			66.989	66.989	66.989	66.989	66.989	66.989	66.989	66.989
Total longitudinal stress			43.278	77.945	103.387	47.705	72.285	65.335	72.285	65.335
Primary membrane longitudinal stress*			60.612	60.612	75.546	75.546	68.81	68.81	68.81	68.81
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	-8.922	-8.922	8.922	8.922
Total Shear stress			0	0	0	0	-8.922	-8.922	8.922	8.922
Combined stress (P_L+P_b+Q)			100.257	147.486	179.381	116.708	143.066	129.042	143.066	129.042

Note: * denotes primary stress.

Maximum stresses due to the applied loads at the leg edge (includes pressure)

R_m / t = 1,974.68 / 28.55 = 69.1665

C_1 = 126.75, C_2 = 93.74 mm

Local circumferential pressure stress = P*R_i / t =133.972 MPa

Local longitudinal pressure stress = P*R_i / (2*t) =66.989 MPa

Maximum combined stress (P_L+P_b+Q) = 194.79 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

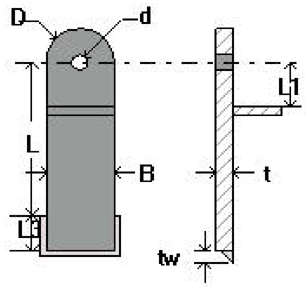
Maximum local primary membrane stress (P_L) = 145.24 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the leg 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*	12.2189	0.0546	0	0	0	0	0.876	0.876	0.876	0.876
4C*	12.278	0.0596	0.883	0.883	0.883	0.883	0	0	0	0
1C	0.1509	0.0601	0	0	0	0	4.488	-4.488	4.488	-4.488
2C-1	0.1133	0.0601	3.372	-3.372	3.372	-3.372	0	0	0	0
3A*	1.6404	0.058	0	0	0	0	0	0	0	0
1A	0.0988	0.0646	0	0	0	0	0	0	0	0
3B*	5.3396	0.0525	-10.384	-10.384	10.384	10.384	0	0	0	0
1B-1	0.0542	0.0541	-46.181	46.181	46.181	-46.181	0	0	0	0
Pressure stress*			133.972	133.972	133.972	133.972	133.972	133.972	133.972	133.972
Total circumferential stress			81.662	167.281	194.791	95.685	139.336	130.359	139.336	130.359
Primary membrane circumferential stress*			124.471	124.471	145.238	145.238	134.848	134.848	134.848	134.848
3C*	11.8358	0.0596	0.848	0.848	0.848	0.848	0	0	0	0
4C*	12.3682	0.0546	0	0	0	0	0.889	0.889	0.889	0.889
1C-1	0.1565	0.0565	4.654	-4.654	4.654	-4.654	0	0	0	0
2C	0.118	0.0565	0	0	0	0	3.509	-3.509	3.509	-3.509
4A*	2.2612	0.058	0	0	0	0	0	0	0	0
2A	0.0576	0.0618	0	0	0	0	0	0	0	0
4B*	1.4808	0.0525	-2.579	-2.579	2.579	2.579	0	0	0	0
2B-1	0.09	0.0548	-75.746	75.746	75.746	-75.746	0	0	0	0
Pressure stress*			66.989	66.989	66.989	66.989	66.989	66.989	66.989	66.989
Total longitudinal stress			-5.833	136.351	150.816	-9.984	71.388	64.369	71.388	64.369
Primary membrane longitudinal stress*			65.259	65.259	70.416	70.416	67.879	67.879	67.879	67.879
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	-19.285	-19.285	19.285	19.285
Total Shear stress			0	0	0	0	-19.285	-19.285	19.285	19.285
Combined stress (P_L+P_b+Q)			-87.494	167.281	194.791	-105.669	144.424	135.579	144.424	135.579

Note: * denotes primary stress.

LIFTING LUG



Geometry Inputs

Attached To	3962 mm O.D. SHELL
Material	A516-70
Distance of Lift Point From Datum	3,036 mm
Angular Position	90.00° and 270.00°
Length of Lug, L	547 mm
Width of Lug, B	254 mm
Thickness of Lug, t	32 mm
Hole Diameter, d	57 mm
Pin Diameter, Dp	50.8 mm
Lug Diameter at Pin, D	254 mm
Weld Size, t_w	22 mm
Weld Length, L_3	152 mm
Length to Brace Plate, L_1	165 mm
Load Angle from Vertical, ϕ	0.0000 °
Has Brace Plate	Yes

Intermediate Values

Load Factor	2.0000
Vessel Weight (new, incl. Load Factor), W	51974 kg
Lug Weight (new), W_{lug}	103 kg (Qty=2)
Distance from Center of Gravity to Top Lug, l_1	2,399.53 mm
Distance from Center of Gravity to Tail Lug, l_2	830.41 mm
Distance from Vessel Center Line to Tail Lug, l_3	1,575.76 mm
Allowable Stress, Tensile, σ_t	157.200 MPa
Allowable Stress, Shear, σ_s	104.800 MPa
Allowable Stress, Bearing, σ_p	235.801 MPa
Allowable Stress, Bending, σ_b	172.921 MPa
Allowable Stress, Weld Shear, $\tau_{allowable}$	104.800 MPa
Allowable Stress set to 1/3 Sy per ASME B30.20	No

Summary Values

Required Lift Pin Diameter, d_{reqd}	39.35 mm
Required Lug Thickness, t_{reqd}	21.28 mm
Lug Stress Ratio, σ_{ratio}	0.91
Weld Shear Stress Ratio, τ_{ratio}	0.95
Lug Design	Acceptable
Local Stresses	Acceptable
Maximum Out of Plane Lift Angle - Weak Axis Bending	10.11°

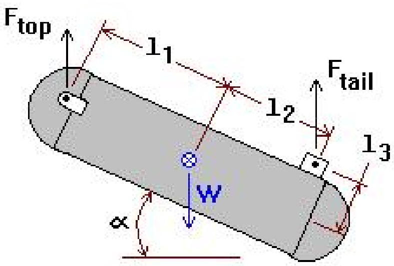
COMPRESS recommends a spreader beam be used to prevent weak axis bending of the top lugs.
No consideration is given for any bracing plate from the lug to the vessel.

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}[N]	F_{tail}[N]
0	65,520.3	378,652.7
15	87,407.3	334,878.7
30	107,128.8	295,435.7
45	127,599.3	254,494.6
60	152,229.4	205,234.5
75	187,728.9	134,235.5
90	254,846.6	0
38[1]	117,771.7	274,149.9
38[2]	117,771.7	274,149.9
[1]Lift angle at maximum lug stress.		
[2]Lift angle at maximum weld stress.		
Shell angle at lift lug		0.00°

Lug Pin Diameter - Shear stress

d_{reqd} = $(2*F_v / (\pi*\sigma_s))^{0.5}$
= $(2*254,846.6 / (\pi*104.8))^{0.5}$ = 39.35 mm

d_{reqd} / D_p = 39.35 / 50.8 = 0.77 Acceptable

σ = F_v / A
= $F_v / (2*(0.25*\pi*D_p^2))$
= $254,846.6 / (2*(0.25*\pi*50.8^2))$ = 62.87 MPa

σ / σ_s = 62.87 / 104.8 = 0.6 Acceptable

Lug Thickness - Tensile stress

t_{reqd} = $F_v / ((D - d)*\sigma_t)$
= 254,846.6 / ((254 - 57)*157.2) = 8.23 mm

t_{reqd} / t = 8.23 / 32 = 0.26 Acceptable

σ = F_v / A

$= F_v / ((D - d)*t)$
$= 254,846.6 / ((254 - 57)*32) = 40.43$ MPa

$\sigma / \sigma_t = 40.43 / 157.2 = 0.26$ Acceptable

Lug Thickness - Bearing stress

$t_{reqd} = F_v / (D_p*\sigma_p)$
$= 254,846.6 / (50.8*235.8) =$ 21.28 mm

$t_{reqd} / t = 21.28 / 32 = 0.66$ Acceptable

$\sigma = F_v / A_{bearing}$
$= F_v / (D_p*(t))$
$= 254,846.6 / (50.8*(32)) = 156.77$ MPa

$\sigma / \sigma_p = 156.77 / 235.8 = 0.66$ Acceptable

Lug Thickness - Shear stress

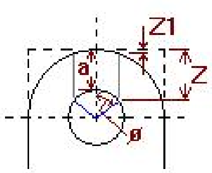
$t_{reqd} = [F_v / \sigma_s] / (2*L_{shear})$
$= (254,846.6 / 104.8) / (2*105.79) =$ 11.49 mm

$t_{reqd} / t = 11.49 / 32 = 0.36$ Acceptable

$\tau = F_v / A_{shear}$
$= F_v / (2*t*L_{shear})$
$= 254,846.6 / (2*32*105.79) = 37.64$ MPa

$\tau / \sigma_s = 37.64 / 104.8 = 0.36$ Acceptable

Shear stress length (per Pressure Vessel and Stacks, A. Keith Escoe)



$\phi = 55*D_p / d$
$= 55*50.8 / 57$
$= 49.0175°$
$Z = 0.5*(D - d) + 0.5*D_p*(1 - \cos(\phi))$
$= 0.5*(254 - 57) + 0.5*50.8*(1 - \cos(49.0175))$
$= 107.24$ mm
$Z1 = 0.5*D - sqr(0.25*D*D - (0.5*D_p*\sin(\phi))^2)$

= $0.5*254 - sqr(0.25*254*254 - (0.5*50.8*\sin(49.0175))^2)$
= 1.46 mm

L_{shear} = Z - Z1
= 105.79 mm

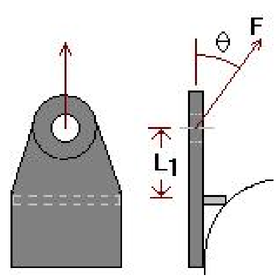
Lug Plate Stress

Lug stress, tensile + bending, during rotational lift:

σ_{ratio} = $[F_{ten} / (A_{ten}*\sigma_t)] + [M_{bend} / (Z_{bend}*\sigma_b)] \le 1$
= $[(F_{top}(\alpha)*\sin(\alpha)) / (t*B*\sigma_t)] + [(6*F_{top}(\alpha) *L*\cos(\alpha)) / (t*B^2 * \sigma_b)] \le 1$
= $117{,}771.7*\sin(38.0) / (32*254*157.2) + 6*(117{,}771.7)*547*\cos(38.0) / (32*254^2*172.92)$
= 0.91 Acceptable

Weak Axis Bending Stress

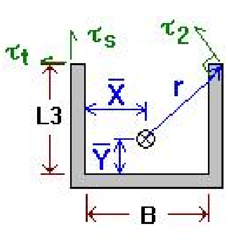
Maximum lift cable angle from vertical $\theta = 10.11°$



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 = $\arctan((2*172.92*(254*32^2/6)) / (509{,}693.3*165))$ = 10.11°

Loading on brace plate and head are not considered.

Weld Stress



Weld stress, direct and torsional shear, during rotational lift:

Direct shear:

Maximum weld shear stress occurs at lift angle 38.00°; lift force = 117,771.7 N

A_{weld} = $0.707*t_w*(2*L_3 + B)$
= 0.707*22*(2*152 + 254) = 8,679.13 mm^2

τ_t = $F_r*\cos(\alpha) / A_{weld}$
= 117,771.7*cos(38.0) / 8,679.13 = 10.69 MPa

τ_s = $F_r*\sin(\alpha) / A_{weld}$
= 117,771.7*sin(38.0) / 8,679.13 = 8.35 MPa

Torsional shear:

Weld centroid:

Y_{bar} = $L_3^2 / (2*L_3 + B)$
= 152^2 / (2*152 + 254) = 41.41 mm

Second polar moment of area:

J = $0.707*t_w*((8*L_3^3 + 6*L_3*B^2 + B^3) / 12 - L_3^4 / (2*L_3 + B))$
= $0.707*22* ((8*152^3 + 6*152*254^2 + 254^3) / 12 - 152^4 / (2*152 + 254))$ = 119040808 mm^4

Radial distance from centroid to weld:

r = $sqr((X_{bar})^2 + (L_3 - Y_{bar})^2)$
= $sqr((0.5*254)^2 + (152 - 41.41)^2)$ = 168.41 mm

θ_r = $\arctan((L_3 - Y_{bar}) / (X_{bar}))$
= arctan(110.59 / 127) = 41.05°

τ_2 = M * r / J
= $[F(\alpha)*\cos(\alpha)*(L + L_3 - Y_{bar})] * r / J$
= (117,771.7*cos(38.0)*657.59)*168.41 / 119040804.1994
= 86.34 MPa

τ_{ratio} = $sqr((\tau_t + \tau_2*\sin(\theta_r))^2 + (\tau_s + \tau_2*\cos(\theta_r))^2) / \tau_{allowable} \leq 1$
= $sqr ((10.69 + 86.34*\sin(41.05))^2 + (8.35 + 86.34*\cos(41.05))^2) / 104.8$
= 0.95 Acceptable

WRC 107 Analysis

Geometry

Height(radial):	32 mm
Width (circumferential):	254 mm
Length	152 mm
Fillet Weld Size:	22 mm
Located on:	3962 mm O.D. SHELL (152 mm from top end)
Location Angle:	90.00° and 270.00°

Applied Loads

Maximum stress ratio occurs at lift angle = 90.00° with lift force = 254,846.6 N

Radial load:	P_r =	0	N
Circumferential moment:	M_c =	0	N-m
Circumferential shear:	V_c =	0	N
Longitudinal moment:	M_L =	4,077.55	N-m
Longitudinal shear:	V_L =	254,846.63	N
Torsion moment:	M_t =	0	N-m
Internal pressure:	P =	0	kPa
Mean shell radius:	R_m =	1,971.48	mm
Shell yield stress:	S_y =	262	MPa

Maximum stresses due to the applied loads at the lug edge (includes pressure)

R_m / t = 1,971.48 / 19.05 = 103.4895

C_1 = 149, C_2 = 98 mm

Local circumferential pressure stress = P*R_i / t =0 MPa

Local longitudinal pressure stress = P*R_i / (2*t) =0 MPa

Maximum combined stress (P_L+P_b+Q) = 68.26 MPa
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = -8.73 MPa
Allowable local primary membrane stress (P_L) = +-1.5*S = +-207 MPa

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*	16.8522	0.0603	0	0	0	0	0	0	0	0
4C*	17.4561	0.0685	0	0	0	0	0	0	0	0
1C	0.117	0.0694	0	0	0	0	0	0	0	0
2C-1	0.0801	0.0694	0	0	0	0	0	0	0	0
3A*	3.2011	0.0657	0	0	0	0	0	0	0	0
1A	0.0913	0.0713	0	0	0	0	0	0	0	0
3B*	9.5855	0.0572	-8.729	-8.729	8.729	8.729	0	0	0	0
1B-1	0.0476	0.0591	-27.531	27.531	27.531	-27.531	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			-36.26	18.802	36.26	-18.802	0	0	0	0
Primary membrane circumferential stress*			-8.729	-8.729	8.729	8.729	0	0	0	0
3C*	15.6668	0.0685	0	0	0	0	0	0	0	0
4C*	17.8502	0.0603	0	0	0	0	0	0	0	0
1C-1	0.1291	0.0634	0	0	0	0	0	0	0	0
2C	0.089	0.0634	0	0	0	0	0	0	0	0
4A*	4.652	0.0657	0	0	0	0	0	0	0	0
2A	0.0535	0.0671	0	0	0	0	0	0	0	0
4B*	2.831	0.0572	-2.062	-2.062	2.062	2.062	0	0	0	0
2B-1	0.0763	0.0588	-44.361	44.361	44.361	-44.361	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			-46.422	42.299	46.422	-42.299	0	0	0	0
Primary membrane longitudinal stress*			-2.062	-2.062	2.062	2.062	0	0	0	0
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	-34.129	-34.129	34.129	34.129
Total Shear stress			0	0	0	0	-34.129	-34.129	34.129	34.129
Combined stress (P_L+P_b+Q)			-46.422	42.299	46.422	-42.299	68.258	68.258	68.258	68.258

Note: * denotes primary stress.