FERMILAB
Technical Division

Pressure Vessel Engineering Note For the CM2 Dipole Corrector

Author: Yuriy Orlov	Date: 25 January 2011

Revision History

Revision	Date	Section No.	Revision Description
	1/25/2011	All	Initial Release
1	2/17/2012	Amendment 1	Added New Muon Lab Relief System Calculations

Table of Contents

PRESSURE VESSEL ENGINEERING NOTE PER FESHM CHAPTER 5031

Prepared by: Yuriy Orlov
Preparation date: 25 January 2011

1. Description and Identification
Fill in the label information below:

This vessel conforms to Fermilab ES&H Manual Chapter 5031

Vessel Title CM2 Dipole Helium Vessel

Vessel Number IND-151

Vessel Drawing Number D00000000858535

Maximum Allowable Working Pressures (MAWP):
Internal pressure Warm 2.03-bar (15.0 psig)@ 300°K
Internal Pressure Cold 4.0 bar (43.3 psig) @ 2°K
External Pressure 1.0-bar (14.5-psia)

Working Temperature Range -457 °F - 100 °F

Contents Superfluid helium

Designer/Manufacturer FNAL/Hi-Tech, Fermilab

Test Pressure (if tested at Fermi) Acceptance Date: ←Document per Chapter 5034 of the Fermilab ES&H Manual

(2.38 BAR)
34.5 PSID, Hydraulic ____ Pneumatic X
Accepted as conforming to standard by
Apollinari Giorgio / Giorgio Apollinari
of Division/Section TD Date: 1/26/2012 ←Actual signature required

NOTE: Any subsequent changes in contents, pressures, temperatures, valving, etc., which affect the safety of this vessel shall require another review.

Reviewed by: [signature] Date: 6/22/11

Director's signature (or designee) if the vessel is for manned areas but doesn't conform to the requirements of the chapter.

[signature] Date: 10/4/12

[signature] Date: 1/5/12
ES&H Director Concurrence

Amendment No.:	Reviewed by:	Date:
1	[signature]	2/19/12

Lab Property Number(s): ____________________

Lab Location Code: ____________________(obtain from safety officer)

Purpose of Vessel(s): Liquid Helium containment for superconducting corrector

Vessel Capacity/Size: 1.97-L Diameter: 11.8"(300mm) Length: 11.8"(300mm)

Normal Operating Pressure (OP) 0.02-bar (0.25-psia)

MAWP-OP = 28.75 PSID

List the numbers of all pertinent drawings and the location of the originals.

Drawing #	Location of Original
D00000000858535 Rev C	DESY TDM
D00000000857305 Rev B	DESY TDM
D00000000857295 Rev B	DESY TDM
MD-460856	FERMI TDM

(Above are the top-level drawings, see Appendix B, "drawing tree", in the design note)

2. Design Verification

Is this vessel designed and built to meet the Code or "In-House Built" requirements?
Yes X No ___

If "No" state the standard that was used

____

Demonstrate that design calculations of that standard have been made and that other requirements of that standard have been satisfied.

Skip to part 3 "system venting verification."

Does the vessel(s) have a U stamp? Yes_____ No X . If "Yes", complete section 2A; if "No", complete section 2B.

A. Staple photo of U stamp plate below.
Copy "U" label details to the side

Copy data here:

Provide ASME design calculations in an appendix. On the sketch below, circle all applicable sections of the ASME code per Section VIII, Division I. (Only for non-coded vessels)

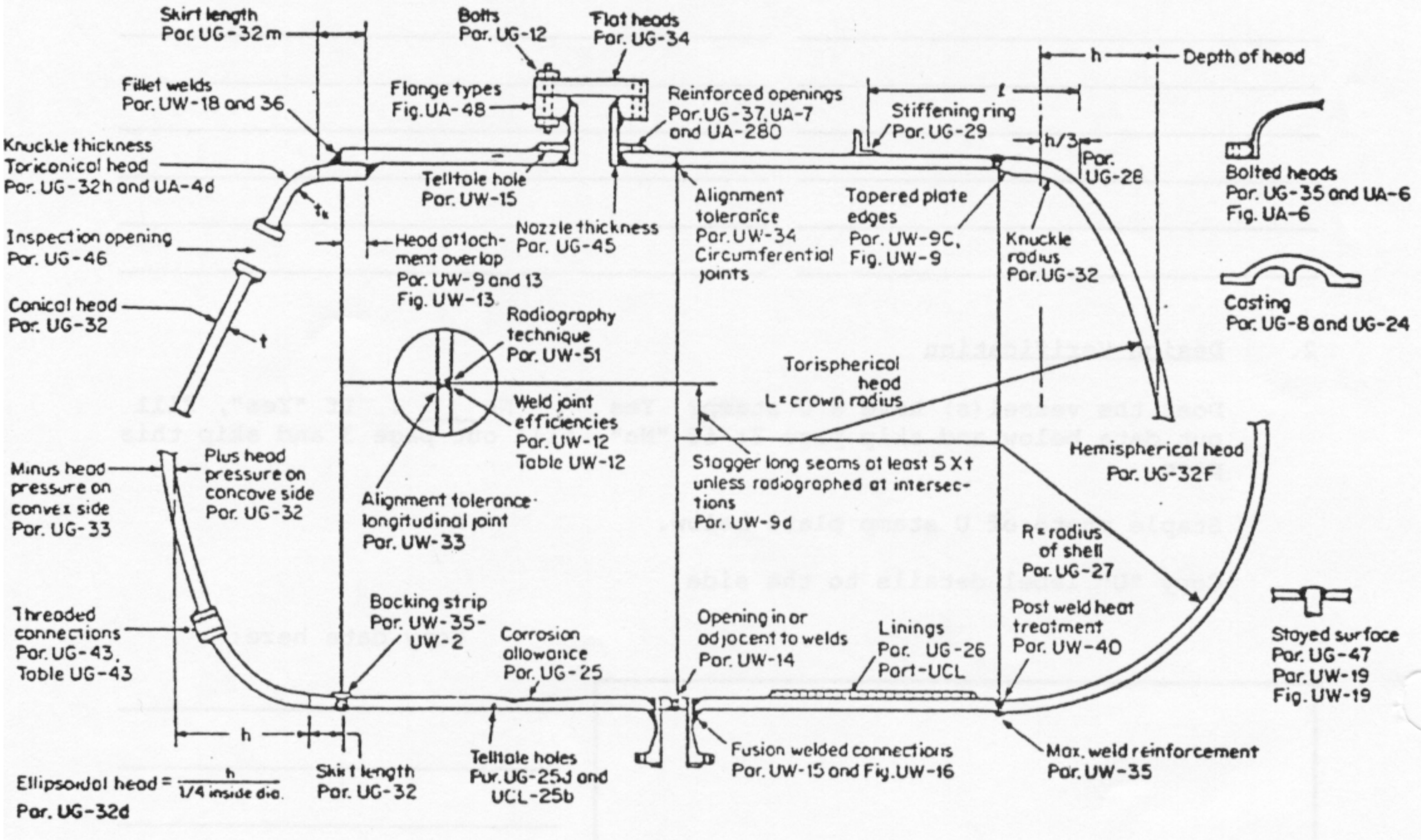


Figure 1. ASME Code: Applicable Sections

2B.

Summary of ASME Code

Item	Reference ASME Code Section	CALCULATION RESULT (Required thickness or stress level vs. actual thickness calculated stress level)
(see Design Note)		
		vs
		vs
		vs
		vs

3. System Venting Verification

Does the venting system follow the Code UG-125 through UG-137?
Yes __ No_X__

Does the venting system also follow the Compressed Gas Association Standards S-1.1 and S-1.3?
Yes __No__X___

A “no” response to both of the two proceeding questions requires a justification and statement regarding what standards were applied to verify system venting is adequate.

List of reliefs and settings:

Manufacturer	Model #	Set Pressure	Flow Rate	Size

4. Operating Procedure

Is an operating procedure necessary for the safe operation of this vessel?
Yes_____ No _X_____ (If "Yes", it must be appended)

5. Welding Information

Has the vessel been fabricated in a non-code shop? Yes _X_______ No ________
If "Yes", append a copy of the welding shop statement of welder qualification (Procedure Qualification Record, PQR) which references the Welding Procedure Specification (WPS) used to weld this vessel.
See “Welding Information” Section in Appendix A

6. Existing, Used and Unmanned Area Vessels

Is this vessel or any part thereof in the above categories?
Yes_____ No _X_____

If "Yes", follow the requirements for an Extended Engineering Note for Existing, Used and Unmanned Area Vessels.

7. Exceptional Vessels

Is this vessel or any part thereof in the above category?
Yes _X___ No _______

If "Yes", follow the requirements for an Extended Engineering Note for Exceptional Vessels

Amendment 1

Mayling Wong
17 February 2012

Update on the Dual MAWP

The design pressures and design temperatures for the dipole corrector is:

Design Pressure 1: 2.0 bar   Design Temperature 1: 80 – 300 K
Design Pressure 2: 4.0 bar   Design Temperature 2: 1.8 – 80 K

Updates on the System Venting Verification

The dipole corrector is currently part of the Cryomodule 2 (CM2) string assembly. The string assembly is made up of eight dressed cavities and the dipole corrector. This amendment shows the required helium relief capacity when CM2 is installed at New Muon Lab (NML).

This vessel has been selected to be part of Cryomodule 2, which will be tested at NML. This amendment shows the required relief capacities for the cryomodule as an assembly of eight dressed cavities and one corrector dipole. The AD/Cryo document titled "New Muon Lab Cryomodule, Feed Cap, and End Cap Relief Valve System Analysis" (located online http://ilctanmlcryo.fnal.gov/) lists the most up-to-date calculations on the available relief capacities at NML.

Table AM-1 summarizes the possible sources of helium pressure, the calculated maximum flow rate, and the capacity of the available relief valve.

Table AM-1 – Summary of Required and Available Relief Capacities at NML

Source of Helium Pressure	Required relief capacity (SCFM air)	Available relief capacity (SCFM air)	Relief type (CGA-defined)	Relief Device Name
Room temperature helium supply from cryoplant	351	951	Primary relief	SV-806-H
Fire condition	1864	8053	Secondary relief	SV-803-H
Loss of cavity vacuum	6061	8053	Secondary relief	SV-803-H
Loss of insulating vacuum	3737	8053	Secondary relief	SV-803-H

Fire Condition

The required volumetric flow rate for fire condition in vessel is calculated following the CGA S-1.3-2005, Paragraph 6.3.3:

$$Q_{a-fire} = 0.3 F G_i U A^{0.82}$$

Where:

F	correction factor for cryogenic systems	1	
G_i	gas factor for insulated containers for LHe (same as for the primary relief)	43.4	
k_{shield}	mean thermal conductivity of helium gas at between saturation temp and 1200 deg F at 1-bar (Table 3 of S-1.3)	0.122	Btu/hr-ft-F
t_{total}	assume helium gas thickness of 1-inch	1	in
		0.083	ft
U	overall heat transfer coefficient of the insulating material	1.464	Btu/hr-ft^2-F
A		267.6	ft^2
$Q_{a\ fire}$	flow capacity of relief device for fire conditions	1863.9	SCFM air

According to Paragraph 6.3, a factor of 0.3 can be used for a vessel that holds "nonflammable gas and is suitably isolated from possible engulfment in a fire." This is applicable for the vessel which holds supercritical helium and sits within a cave structure that is isolated from flammable sources.

Loss of cavity vacuum and insulating vacuum

A large rate of helium vaporization can occur due to two scenarios: the loss of RF cavity vacuum, and the loss of insulating vacuum

The equation to calculate the mass flow rate is

$$\dot{m} = \frac{AQ}{\theta}$$

And the equivalent volumetric flow rate is

$$Q_a = \frac{13.1WC_a}{60C}\sqrt{\frac{ZTM_a}{MZ_aT_a}}$$

Where:

		Cavity Vacuum Loss	Loss of Insulating Vacuum	
Q	Heat flux	4.0	2.0	W/cm^2
P_relief	110% of set pressure of 4.0-bar MAWP at	4.4	4.4	bar
	1.8-K	440	440	kPa
T	temperature when specific heat input	6.8	6.8	K
	is at a minimum for relief pressure	12.24	12.24	R
θ	specific heat input for helium at T, P_relief	23	23	J/g
A	Surface area of helium-to-vacuum boundary	6.8	8.4	m^2
m_dot	mass flow rate of helium during vaporization	11803.5	7278.2	g/sec
W	mass flow rate of helium during vaporization	93483.6	57643.7	lbm/hr
C	helium gas constant	378	378	
M	molecular weight of helium	4	4	kg/kmol
ρ	helium density at T, P_relief	53.39	53.39	kg/m^3
Z	compressibility factor for helium at flow condition	0.58	0.58	
C_a	air gas constant	356	356	
Z_a	air at Ta	1	1	
T_a	air at room temperature	520	520	R
M_a	air molecular weight	28.97	28.97	kg/kmol
Q_a	mass flow rate of helium during vaporization	6060.6	3737.1	SCFM air

For the loss of beam vacuum, the total helium-to-vacuum surface area of 6.8-m^2 includes the surface area of eight cavities (0.84-m^2 for each cavity) plus the surface area at the dipole corrector (0.067-m^2). For the loss of insulating vacuum, the total surface area of 8.9 m^2 includes the area of the eight helium vessels (1.0-m^2), the area of the dipole corrector (0.37-m^2).

Appendix A-Extended Engineering Note for Exceptional Vessel

Introduction

The CM2 dipole corrector, is a superconducting magnet surrounded by a helium vessel which will be filled with liquid helium at temperatures as low as 1.8 K. The superconducting dipole corrector with 8 superconducting RF cavities form the cavity string that will be installed in Cryomodule (CM2).

Exceptional Vessel Discussion

Reasons for Exception

CM2 dipole corrector, as defined in FESHM Chapter 5031, are designed and fabricated following the ASME Boiler and Pressure Vessel Code (ref. 2). The CM2 dipole corrector, as a helium pressure vessel has complex geometry that is not conductive to complete design and fabrication following the Code. However, we show that the vessel is safe in accordance FESHM 5031. Since the vessel design and fabrication methods cannot exactly follow the guidelines given by the Code, that vessel requires a Director's Exception. Table 1a lists the specific areas of exceptions to the Code, where in the note this is addressed, and how the vessel is shown to be safe. Table 1b goes into details of why the design or the fabrication method cannot follow Code guidelines.

Analysis and use of the ASME Code

The extended engineering note presents the results of the analysis that was performed on the entire vessel.

Table 1a- Areas of Exception to the Code-Safety

Item or Procedure	Reference	Explanation for Exception	How the Vessel is Safe
Some category A (longitudinal) & B (circumferential) welds in St. Steel sub-assembly are Type 3 butt welds (welded from one side with no backing strip)	Pg. 23, 28	Category A & B joints in St. steel must be either Type 1 butt welds (welded from both sides) or Type 2 butt welds (welded from one side with backing strip) only (ref.2, UHA-21)	The evaluation of these welds is based on a de – rating of the allowable stress by a factor 0.6, the factor given in Div.1, table UW-12 for Type 3 weld when not radiographed.
Weld at the 2-phase helium pipe stub attachment to the vessel	Pg. 23, 27	Not a Code-approved design	Examination of the weld shows that it is greater in size than the minimum required thickness.
System venting verification	Pg. 24	The Code does not recognize relief valve set for pressure below 15 psig	Please see: System Venting Verification in this note.

Table 1b- Areas of Exception to the Code-Design and Manufacturing Issues

Item or Procedure	Reason
Some category A (longitudinal) & B (circumferential) welds in St. Steel sub-assembly are Type 3 butt welds (welded from one side with no backing strip)	Use the Type 3 butt weld was driven by the design requirements for maximum space between the magnet and helium vessel inside diameter, as well as being historically rooted in the helium vessel design in use at DESY for last years.
Weld at the 2-phase helium pipe stub attachment to the vessel	Mistakenly believed it was a Code weld design.
System venting verification	Pressure relief devices do not fall under Code guidelines for set pressure below 15-psig.

Analytical Tools

Analysis was done using ANSYS Workbench 11 and MathCAD version 14.

Fabrication

All production drawings for CM2 Superconducting Corrector are stored online at:

http://ilc-dms.fnal.gov/Workgroups/CryomoduleDocumentation/CM2-folder/Dipole Corrector/CM2_Dipole_Corrector.pdf

The welds documents south as the available WPS, PQR, WPQ are located at Appendix C (Extended Engineering note) and stored online at:

http://ilc-dms.fnal.gov/Workgroups/CryomoduleDocumentation/CM2-folder/Dipole Corrector/Weld_cert.pdf

Other fabrication documents such as electronic copies of material certifications are located online at:

http://ilc-dms.fnal.gov/Workgroups/CryomoduleDocumentation/CM2-folder/Dipole Corrector/Materials_cert.pdf

Hazard Analysis

The superconducting corrector is a part of cryomodule Cavity string. The Cavity string is located inside of the CM2 vacuum vessel. The vacuum vessel shell and thermal shielding are protect the personnel, when the Cryomodule will be operated at NML.

Pressure Test

The helium vessel [will be] pressure tested to 2.38 bar, which is greater than 1.16 times the MAWP of 2.05 bar. (Appendix D)

Vessel Description

Drawing 858535 Rev C (Figure 5, Appendix B) shows the He Vessel CM2 dipole corrector weldment.
Drawing 857295 Rev B (Figure 6, Appendix B) shows the St. Steel 316L Vessel outer shell weldment.
Drawing 857305 Rev B (Figure 7, Appendix B) shows the Vessel outer shell with He-Out nozzle weldment.
Drawings 858215 Rev A & 858225 Rev A (Figures 8 & 9, Appendix B) shows the Flanges vessel dipole corrector.

The flange-to-flange length of the vessel is 300.0-mm (11.8-in). The inner diameter of the outer helium vessel shell is 294-mm (11.57-in), and the outer diameter is 300-mm (11.8-in). The outer diameter of inner vessel shell is 82.5-mm (3.25-in), and the inner diameter is 76.2-mm (3.00-in) The superconducting coils are located on the inner vessel shell and welded to the inner diameter of the end flanges. The outer shell of the vessel is welded to the outer diameter of the end flanges.

The helium vessel for the CM2 Dipole Corrector has an internal maximum allowable working pressure (MAWP) of 2.0 bar at room temperature. Analysis in the engineering documentation is for 4.0 bar pressure. The external MAWP for the He vessel is 1.0 bar at room temperature (vacuum inside and atmospheric pressure outside).

A complete drawing tree is shown in Figure 4, Appendix B. In Figure 3, the helium vessel is shown. The Figures 1 & 2 shows the Dipole corrector position in Cryomodule #2.

Normally, helium pressure up to the 2 bar MAWP is inside the CM2 He Vessel and surrounds the superconducting coils on inner vessel shell. “External pressure” for the helium vessel means pressure around the outside of the He vessel with vacuum inside the helium vessel.

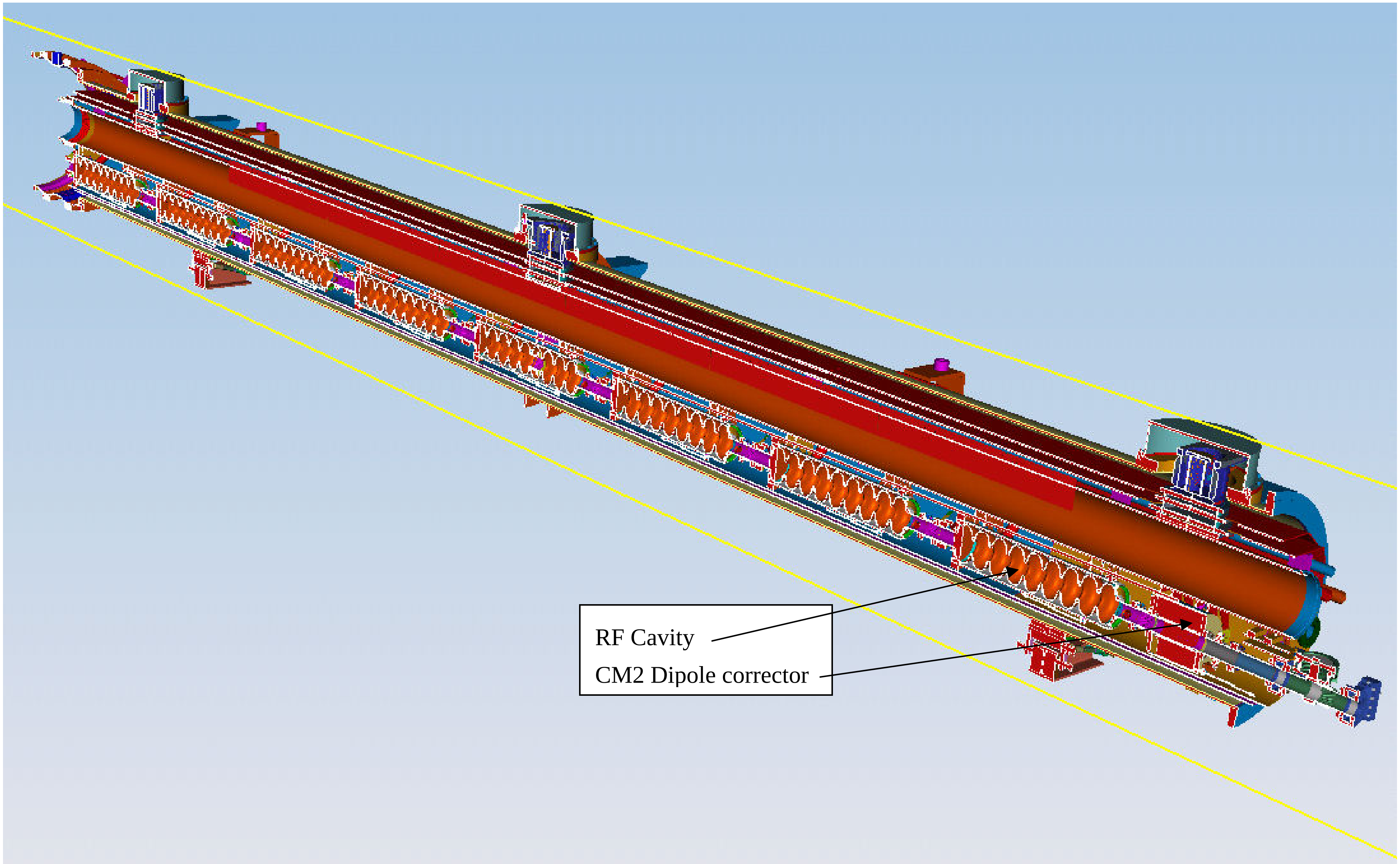


Fig 1 RF Cryomodule #2. (Section View)

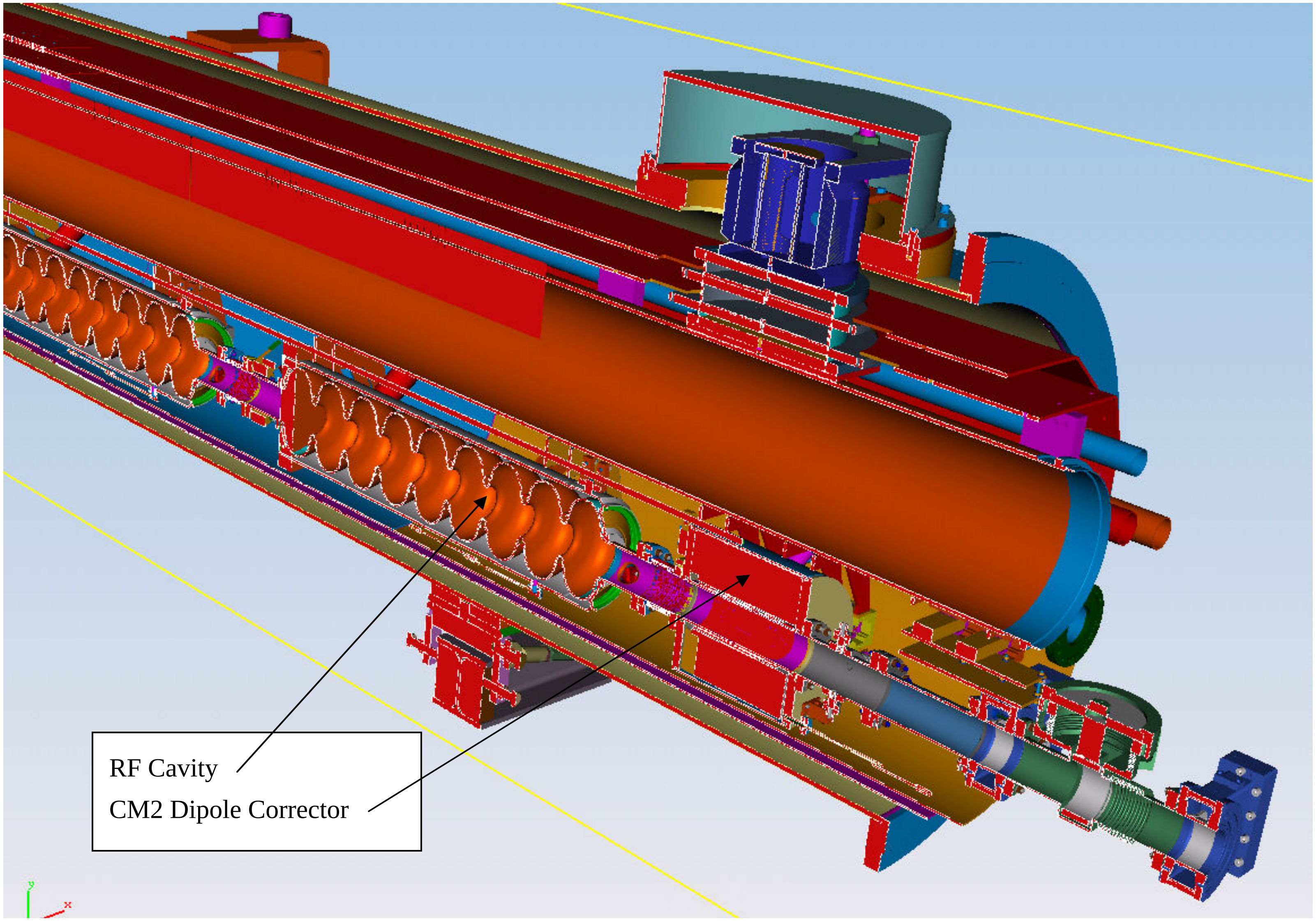


Fig. 2 RF Cryomodule # 2 (Cryomodule End Section View with dipole-corrector)

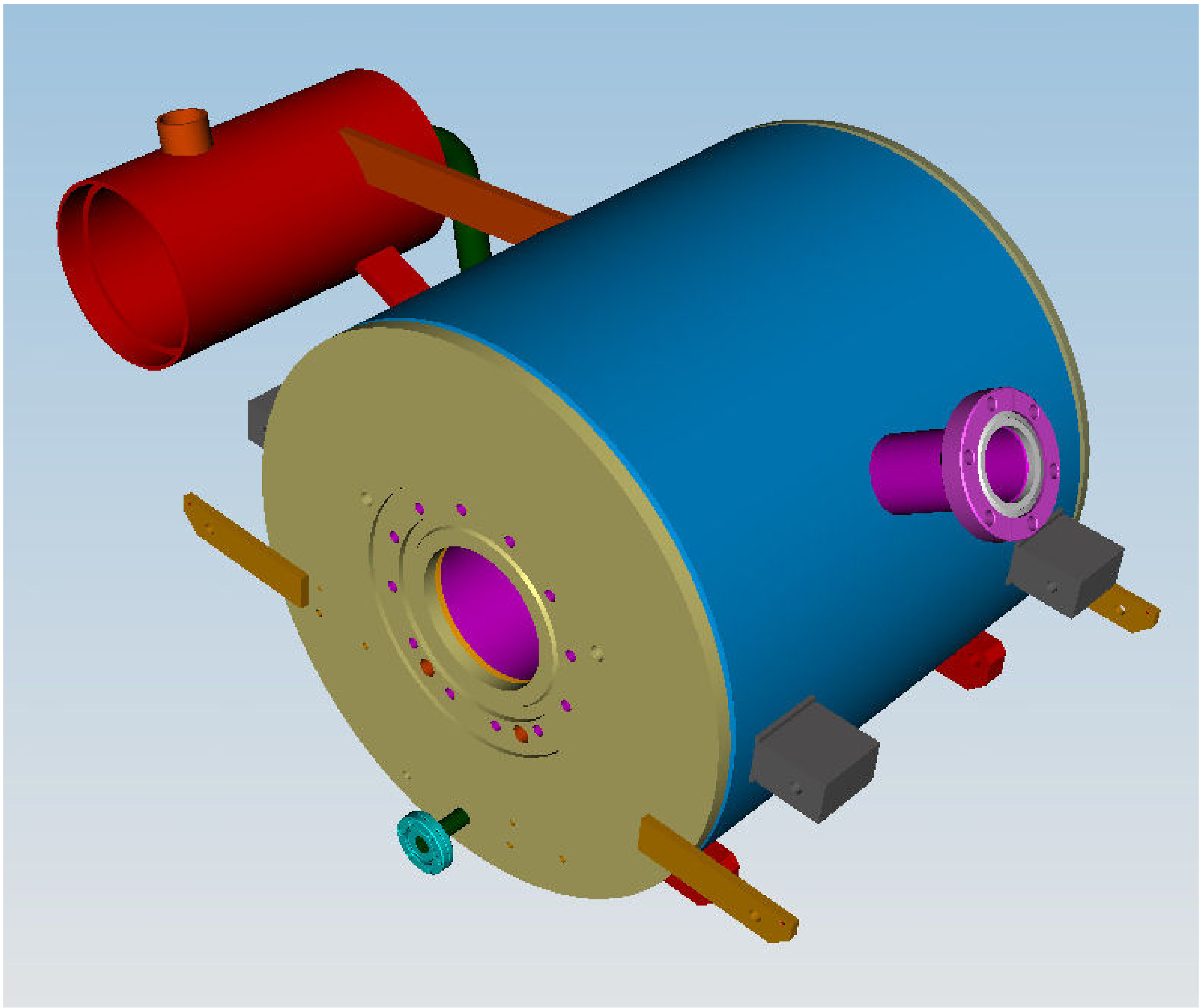


Fig 3 –Dipole Magnet He-Vessel

CM2 Vessel material properties and allowable stresses

Vessel Material: AISI Type 316L Stainless Steel

-Density = 0.289 lb/in^3= 8.00 g/cm^3

Allowable stress for Section II, Part D (Customary)
(Tab 1A):

S= 16700 psi = 115.1 MPa (plate)

Yield Strength for Section II, Part D (Customary)
(Tab. Y-1)

Sy= 25000 psi = 172.4 MPa (plate)
-Min. Tensile Strength- 70000 psi = 482.6 Mpa
-Min. Yield Strength- 25000 psi = 172.4 MPa

Module of Elasticity for Section II, Part D (Customary)
(Tab. TM-1)

E=28.3*10^6 psi = 1.95*10^5 MPa (T= 70 grad F)
E=30.3*10^6 psi = 2.09* 10^5 Mpa (T= -325 grad F)

Vessel Outer Shell Analysis

Internal Pressure:

The outer shell of the helium vessel is made of St. Steel 316L, according to its drawing (857295, as shown in Figure 6, Appendix B). Its thickness is analyzed following the ASME Code, Section VIII, Division 1, Part UG-27, "Thickness of Shells Under Internal Pressure".

Given:

$P\text{int} = 4Bar = 58$ psi (internal pressure)

$Di = 294$ mm (inner diameter of shell)

$$Ri = \frac{Di}{25.4 \cdot 2} = 5.78$$ [inch] (inner radius of vessel)

$E = 0.60$ (weld efficiency, UW-12, assuming single butt weld, no radiographic examination)

$$t_{long} = \frac{P_{\text{int}} \cdot Ri}{2 \cdot S \cdot E + 0.4 \cdot P_{\text{int}}}$$ Longitudinal Stress

$t_{long} = 0.017$ [inch]

$$t_{circum} = \frac{P_{\text{int}} \cdot Ri}{S \cdot E - 0.6 P_{\text{int}}}$$ Circumferential Stress

$t_{circum} = 0.034$ [inch]

$$t_{\text{int}\_r} = \left| \begin{array}{l} t_{long}, if \_ t_{long} > t_{circum} \\ t_{circum}, if \_ t_{long} < t_{circum} \end{array} \right.$$

$t_{\text{int}\_r} = 0.034$ [inch] (minimum allowable thickness of helium vessel for internal pressure)

The actual thickness of the shell is 3.0 mm (.118 -inch), so it meets the minimum required thickness.

External pressure:

The thickness of the outer shell is analyzed for the External pressure. (according UG-28)

Given:

$Pext = 1Bar = 14.5$ psi (external pressure)

$D_0 = 300$ mm (outer diameter of shell)

$D_0 = \frac{D_0}{25.4} = 11.81$ [inch]

$t_{shell} = 0.118$ [inch] (thickness of helium vessel =3.0 mm)

$L_{shell} = 280mm = \frac{280}{25.4} = 11.02$ [inch] (total shell length)

$$D_0 / t_{shell} = \frac{11.81}{0.118} > 10$$

$\frac{L_{shell}}{D_0} = \frac{11.02}{11.81} = 0.933$ (ratio needed to determine factor A)

$\frac{D_0}{t_{shell}} = \frac{11.81}{0.118} = 100$ (ratio needed to determine factor A)

$A = 0.0014$ determined from Fig. G in Section III, Part D)

$B = 10000$ determined from Fig. HA-4 in Section III, Part D)

$$P_a = \frac{4 \cdot B}{3 \cdot \left(\frac{D_0}{t_{shell}} \right)}$$

$P_a = 136.0$ [psi] (maximum allowable external pressure)

The specified maximum external pressure is $P_{ext} = 14.5$ psi, which is well within the maximum allowable.

$t_{ext\_r} = \frac{3 \cdot P_{ext} \cdot D_0}{4 \cdot B}$ required shell wall thickness for external pressure

$t_{ext\_r} = 0.013$ [inch]

The actual thickness of the shell is 3.0 mm (.118 -inch), so it meets the minimum required thickness.

The Permissible Out of Roundness of the Vessel Outer Shell

Calculate the permissible out-of-roundness of the vessel's cylindrical shell, following UG-80.

Internal Pressure:

Given:

$D_i = 294mm = 11.57$ [inch] Inner diameter of the vessel shell

The difference between the maximum diameter and the minimum diameter of the vessel shell at any cross section shall not exceed 1% of the nominal inner diameter:

$$0.01 \cdot D_i = 0.116 \geq D_{i\_\max} - D_{i\_\min}$$ (per section UG-80 (a)(1) of ASME VIII, Div.1)

The exception occurs at a cross section through or near an opening. Here, the permissible difference shall not exceed 2% of the nominal inner diameter:

$$0.02 \cdot D_i = 0.23 \geq D_{i\_\max} - D_{i\_\min}$$ (per section UG-80 (a)(2) of ASME VIII, Div.1)

External Pressure:

In addition to the out-of-roundness limitations prescribed for External Pressure, the shell shall meet the follow requirements at any cross section. The deviation from true circular form is calculated.

Given:

$D_o = 300mm = 11.81$ [inch]

$t_{shell} = 0.118$ [inch]

$L_{shell} = 280mm = 11.02$ [inch]

$$\frac{D_0}{t_{shell}} = 100$$

$\frac{L_{shell}}{D_0} = 0.933$

$e = 0.4 \cdot t_{shell} = 0.047$ [inch] maximum permissible deviation on radius Fig.UG-80.1

Vessel Inner Shell Analysis

External pressure:

The thickness of the inner shell is analyzed for the External pressure. (according UG-28)

Given:

$D_{0\_int} = 3.25$ [inch] (outer diameter of inner shell)

$t_{shell\_int} = 0.125$ [inch] (thickness of inner shell =3.175 mm)

$L_{shell\_} = 277\ mm = \frac{277}{25.4} = 10.906$ [inch] (total inner shell length)

$$D_{0\_int} / t_{shell\_int} = \frac{3.25}{0.125} > 10$$

$\frac{L_{shell\_int}}{D_{0\_int}} = \frac{10.906}{3.25} = 3.355$ (ratio needed to determine factor A)

$\frac{D_{0\_int}}{t_{shell\_int}} = \frac{3.25}{0.125} = 26$ (ratio needed to determine factor A)

$A = 0.0028$ determined from Fig. G in Section III, Part D)

$B = 11200$ determined from Fig. HA-4 in Section III, Part D)

$$P_{a\_int} = \frac{4 \cdot B}{3 \cdot \left(\frac{D_0}{t_{shell\_int}} \right)}$$

$P_a = 574.3$ [psi] (maximum allowable external pressure)

The specified maximum external pressure is $P_{ext} = 4Bar = 58$ psi, which is well within the maximum allowable.

$$t_{\text{int\_}r} = \frac{3 \cdot P_{ext} \cdot D_0}{4 \cdot B}$$ required shell wall thickness for external pressure

$$t_{ext} = 0.013$$ [inch]

Vessel Finite Element Analysis

A Finite Element Analysis has been performed on the Vessel to assess the stresses generated in the whole parts, due to the internal and external pressure loads.
Figure 11 shows FEA Model mesh. The load configuration and boundary conditions adopted for the analysis of vessel:

- fixed point on the face
- internal pressure of 4 bar

An additional analysis has been performed with the same boundary conditions and an external pressure of 1 bar.
The results of the analyses are presented in Figures 12 to 13; it can be noticed that nowhere in the components are there stress values higher than the maximum allowable stress S for Stainless Steel (16700 psi). For internal pressure we have a maximum value of 9225.2 psi, (55 % of the S) in a very limited area, while for external pressure we reach the maximum value of 2292.9 psi (14 % of S).

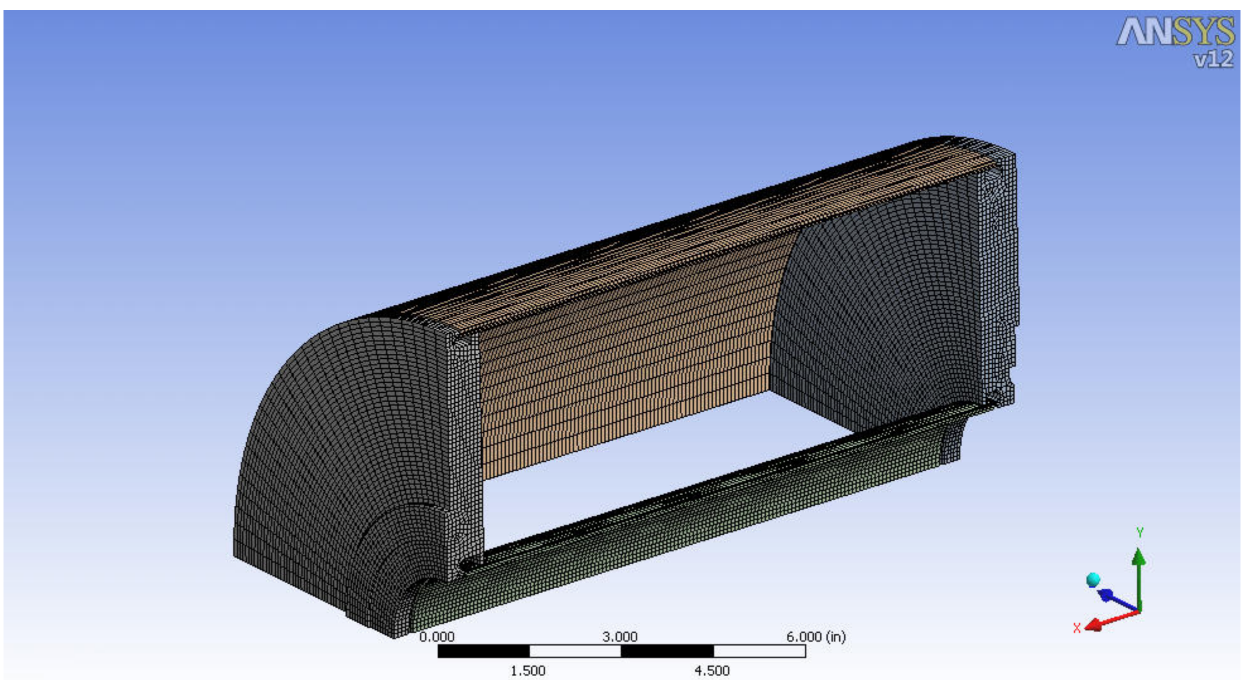


Figure 11– Vessel FEA model mesh

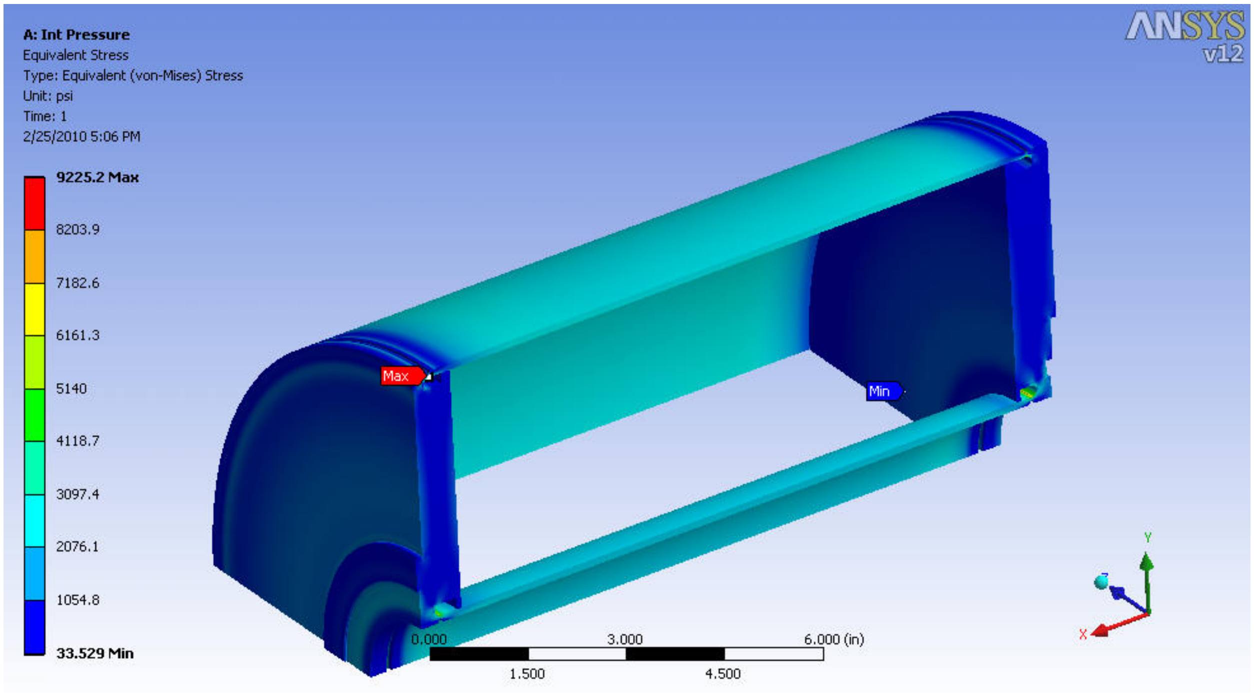


Figure 12– Vessel Stress result (Internal Pressure)

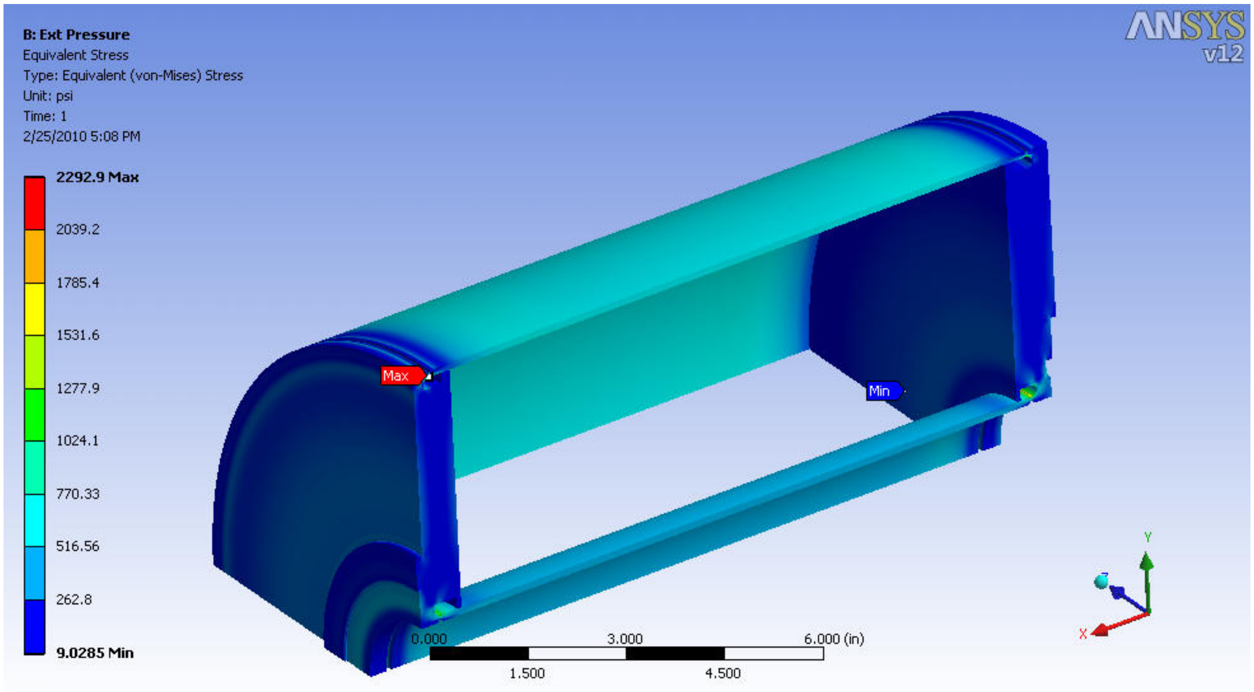


Figure 13– Vessel Stress result (External Pressure)

Vessel Opening Reinforcement

Inner pressure

Helium vessel shell opening, Dr. 857305, Fig. 7, Appendix B (according Part UG-37).

$$t_{n\_r} = \frac{P_{\text{int}} \cdot R_n}{S_n \cdot E - 0.6 \cdot P_{\text{int}}}$$ wall thickness nozzle required

$S_n = 16700$ [psi] maximum allowable stress for nozzle material (St. Steel 316L)

$R_n = \frac{d}{2} = 0.667$ [inch] nozzle inner radius

$E = 0.60$ (weld efficiency, UW-12, assuming single butt weld, no radiographic examination)

$t_{n\_r} = 0.04$ [inch]

The actual thickness of the shell is 2.1 mm (.083 -inch), so it meets the minimum required thickness.

The size and reinforcement for opening must follow the specification according to the Code.
For internal pressure, the required area of reinforcement (A_{req_int}) for opening follow UG-37(c).

$$A_{req\_\text{int}} = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F(1 - f_{r1})$$

$d = 33.9mm = 1.335$ [inch] inner diameter of opening

$t_r = 0.034$ [inch] required thickness of vacuum vessel shell for internal pressure

$F = 1.0$ correction factor

$t_n = 2.1mm = 0.083$ [inch] nozzle wall thickness

$f_{r1} = \frac{S_n}{S_v} = 1.0$ strength reduction factor

$S_v = 16700$ [psi] maximum allowable stress for vessel material (St. Steel 316L)

$A_{req\_\text{int}} = 0.045$ [sq. inch]

Area of reinforcement available.

Shell:

$$A_{1\_int} = d \cdot (E_1 \cdot t_{shell} - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t_{shell} - F \cdot t_r) \cdot (1 - f_{r1}),$$ or

$$A_{1\_int} = 2 \cdot (t_{shell} + t_n) \cdot (E_1 \cdot t_{shell} - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t_{shell} - F \cdot t_r) \cdot (1 - f_{r1})$$

$E_1 = 1.0$ weld join efficiency for nozzle that does not pass through a weld

$A_{1\_int} = 0.1128, or$

$A_{1\_int} = 0.0340$ [sq. inch] (use larger value)

Nozzle:

$$A_{2\_int} = 5 \cdot (t_n - t_{n\_r}) \cdot f_{r2} \cdot t_{shell},$$ or

$$A_{2\_int} = 5 \cdot (t_n - t_{n\_r}) \cdot f_{r2} \cdot t_n$$

$f_{r2} = \frac{S_n}{S_v} = 1.0$ weld join efficiency for nozzle that does not pass through a weld

$A_{2\_int} = 0.0467, or$

$A_{2\_int} = 0.0328$ [sq. inch] (use smaller value)

Weld:

$$A_{41\_int} = (2 \cdot 0.5 \cdot a^2) \cdot f_{r2}$$

$a = \frac{2}{25,4} = 0.078$ [inch] fillet weld parameter

$A_{41\_int} = 0.0062$ [sq. inch] (use larger value)

$A_{int} = A_{1\_int} + A_{2\_int} + A_{41} = 0.1518$ [sq. inch]

The total available are of reinforcement is greater than the require area of reinforcement, so the opening design follow the Code.

External pressure

$t_{r\_n} = \frac{3 \cdot P_{ext} \cdot d_1}{4 \cdot B}$ wall thickness nozzle required

$P_{ext} = 14.5$ [psi] externall pressure

$d_1 = 38.1mm = 1.5$ [inch] nozzle outer diameter

$A = 0.00133$ determined from Fig. G in Section III, Part D

$B = 11500$ determined from Fig. HA-4 in Section III, Part D

$t_{r\_n} = 1.42 \cdot 10^{-3}$ [inch]

For external pressure, the required area of reinforcement (A_{req_ext}) for opening follow UG-37(c).

$$A_{req\_ext} = 0.5[d \cdot t_{shell} \cdot F + 2 \cdot t_n \cdot t_{shell} \cdot F(1 - f_{r1})]$$

$A_{req\_ext} = 0.017$ [sq. inch]

Area of reinforcement available.

Shell:

$$A_{1\_ext} = d \cdot (E_1 \cdot t_{shell} - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t_{shell} - F \cdot t_r) \cdot (1 - f_{r1}),$$ or

$$A_{1\_ext} = 2 \cdot (t_{shell} + t_n) \cdot (E_1 \cdot t_{shell} - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t_{shell} - F \cdot t_r) \cdot (1 - f_{r1})$$

$E_1 = 1.0$ weld join efficiency for nozzle that does not pass through a weld

$A_{1\_ext} = 0.140, or$

$A_{1\_ext} = 0.042$ [sq. inch] (use larger value)

Nozzle:

$$A_{2\_ext} = 5 \cdot (t_n - t_{n\_r}) \cdot f_{r2} \cdot t_{shell},$$ or

$$A_{2\_ext} = 5 \cdot (t_n - t_{n\_r}) \cdot f_{r2} \cdot t_n$$

$f_{r2} = \frac{S_n}{S_v} = 1.0$ weld join efficiency for nozzle that does not

pass through a weld

$A_{2\_ext} = 0.048, or$

$A_{2\_ext} = 0.034$ [sq. inch] (use smaller value)

Weld:

$$A_{41\_ext} = a^2 \cdot f_{r2} \cdot t_{shell}$$

$a = \frac{2}{25,4} = 0.078$

[inch] fillet weld parameter

$A_{41\_ext} = 0.006$ [sq. inch]

$A_{int} = A_{1\_int} + A_{2\_int} + A_{41} = 0.1806$ [sq. inch]

The total available are of reinforcement is greater than the require area of reinforcement, so the opening design follow the Code

Vessel Welding Information

Weld #1

Weld #1 (Appendix A, Fig. 1, Drawing # 857295) is longitudinal, Category A, according UW-3, UW-9 and UW-35 with full penetration. Weld # 1 is not use radiographic examination (UW-11 and UW-12). The vessel outer shell thickness: see part "Vessel outer shell analysis" at this note.

Welds ## 2&3

Welds ##2&3 (Fig. 5, Drawing # 858535) are circumferential, Category B, according UW-3, UW-9 and UW-35 with full penetration. Welds #2 are not use radiographic examination (UW-11 and UW-12). The Weld #3 geometric parameters are according Fig UW-13.3, sketch (b). Vessel Flanges are Fig. 8 & 9 (Drawings 858215 and 858225). The parameters for inner & outer shells and flanges see parts "Vessel Flanges Analysis", "Vessel Outer Shell Analysis" and "Vessel Inner Shell analysis".

Weld #4

Weld #4 (Fig. 7, Drawing # 857305) has Category D, according UW-3 and UW-9 with full penetration. Welds #4 are not use radiographic examination (UW-11).The geometric parameters Weld #3 meets with Fig. UW-16-1, sketch (d) ASME Code.

The vendors welding support documents are located at Appendix B.

System Venting Verification

Summary

The superconducting dipole corrector with 8 superconducting RF cavities form the cavity **s**tring Cryomodule 2 (CM2). That Cryomodule will be installed in NML. More information about venting system and reliefs, see Dr. # ME-458097, "Piping and Instrumentation Diagram ILCTIA Cryomodule One and Feedbox" (Appendix B)

Detailed Calculations for the System Venting

Temperature of relief flow (CGA S-1.3—2008 paragraph 6.1.3)

The CGA specifies a temperature to calculate the flow capacities of pressure relief devices for both critical and supercritical fluids. The temperature to be used is determined by calculating the square root of fluid's specific volume and dividing it by the specific heat input at the flow rating pressure. The sizing temperature would be when this calculation is at a maximum. For the relief pressure of 12-psig, the temperature is 6.0°K. The temperature of 10.0°K is used as a conservative way to calculate the flow capacities and size the relief device.

Primary relief sizing (CGA S-1.3—2008 paragraph 6.2.2)

The required flow capacity for primary relief is calculated:

$$Q_a = \frac{(590 - T)}{4 * (1660 - T)} F * G_i * U * A$$

Where:

Q_a	primary relief flow capacity	18.04	SCFM air
T	helium temperature	18	°R
F	correction factor for cryogenic systems	1	
U	overall heat transfer coefficient of insulating material	0.779(*)	Btu/(hr-ft^2-°F)
G_i	gas factor for insulated containers of liquid helium	52.5	
A	arithmetic mean of the inner and outer surface areas of insulation	5.07	ft^2

(*) see reference #7

Fire relief sizing (CGA S-1.3—2008 paragraph 6.3.3)

The required flow capacity for fire relief is calculated

$$Q_{a\_fire} = F * G_i * U * A^{0.82}$$

Where:

Q_{a_fire}	primary relief flow capacity	154.7	SCFM air
F	correction factor for cryogenic systems	1	
U	overall heat transfer coefficient of insulating material	0.779 (*)	Btu/(hr-ft^2-°F)
G_i	gas factor for insulated containers of liquid helium	52.5	
A	arithmetic mean of the inner and outer surface areas of insulation	5.07	ft^2

(*) see reference #7

Secondary relief sizing – Loss of Corrector Magnet (Beam) Vacuum and Loss of Insulating Vacuum

The secondary relief requirement considers two independent scenarios in calculating the helium boil-off: helium vaporization due to the loss of dipole Corrector magnet (beam) vacuum and helium vaporization due to the loss of insulating vacuum. The helium boil-off during the loss of dipole Corrector Magnet vacuum is calculated based on the total surface area of the Magnet, which is 3756-cm^2 (0.37-m^2). For a loss of magnet vacuum due to an air leak, the heat flux of 2.0-W/cm^2 is used [(8)]. For helium at the relief pressure of 12.0-psig, the heat absorbed per unit mass of efflux, equivalent to a latent heat but including the effect of significant vapor density is 14.5-J/g. The maximum mass flow rate can be calculated:

$$\dot{m}_{magnet} = \frac{A_{\_magnet} * Q}{LH}$$

Where:

$m_{\_magnet\ (1)}$	Mass flow rate	187	g/sec
A_{magnet}	Total surface area of corrector magnet to beam	0.067	m^2
		677.9	cm^2
LH	Effective latent heat @ 5K (maximum specific heat input for 12-psig)	14.5	J/g
Q	Heat efflux due to air leak into magnet	4	W/cm^2

$m_{\_magnet\ (2)}$	Mass flow rate	518	g/sec
A_{magnet}	Total surface area of corrector magnet to vacuum	0.37	m^2
		3755.8	cm^2
LH	Effective latent heat @ 5K (maximum specific heat input for 12-psig)	14.5	J/g
Q	Heat efflux due to air leak into magnet	2	W/cm^2

Appendix B – Drawings

	HE VESSEL XFEL MAGNET (HISTORY TREE)		
Drawings #			Description
858535			HE VESSEL XFEL MAG WLDMT
	857305		SHELL DIPOLE WLDMT
		857595	SHELL-He MAG VESSEL
		857315	ROLLER-PADDIPOLE
		861285	SUPPORT INST DIPOLE
		864645	PIPE DIPOLE HE-OUT
	857375		BOX INSTR LEADS CONNECT WLDMT
		857395	BOX DIPOLE INSTR LEADS CONNCT
		857415	PIPE INSTR DIPOLE OUT
		857425	PORT INSTR OUT
		857405	FLANGE INSTR LEADS CONNECT
	861615		FLANGE XFEL VESSEL US WLDMT
		858225	FLANGE XFEL VESSEL US
		861485	BRACKET SENSOR SPRT
	861475		FLANGE XFEL VESSEL DS WLDMT
		858215	FLANGE XFEL VESSEL DS
		861485	BRACKET SENSOR SPRT
	857365		SUPPORT BAR UPPER
	857355		SUPPORT BAR LOWER
	MD-460856		DIPOLE CORRECTOR ASSY (FNAL)

Figure 4–CM2 Dipole Box (drawing tree)

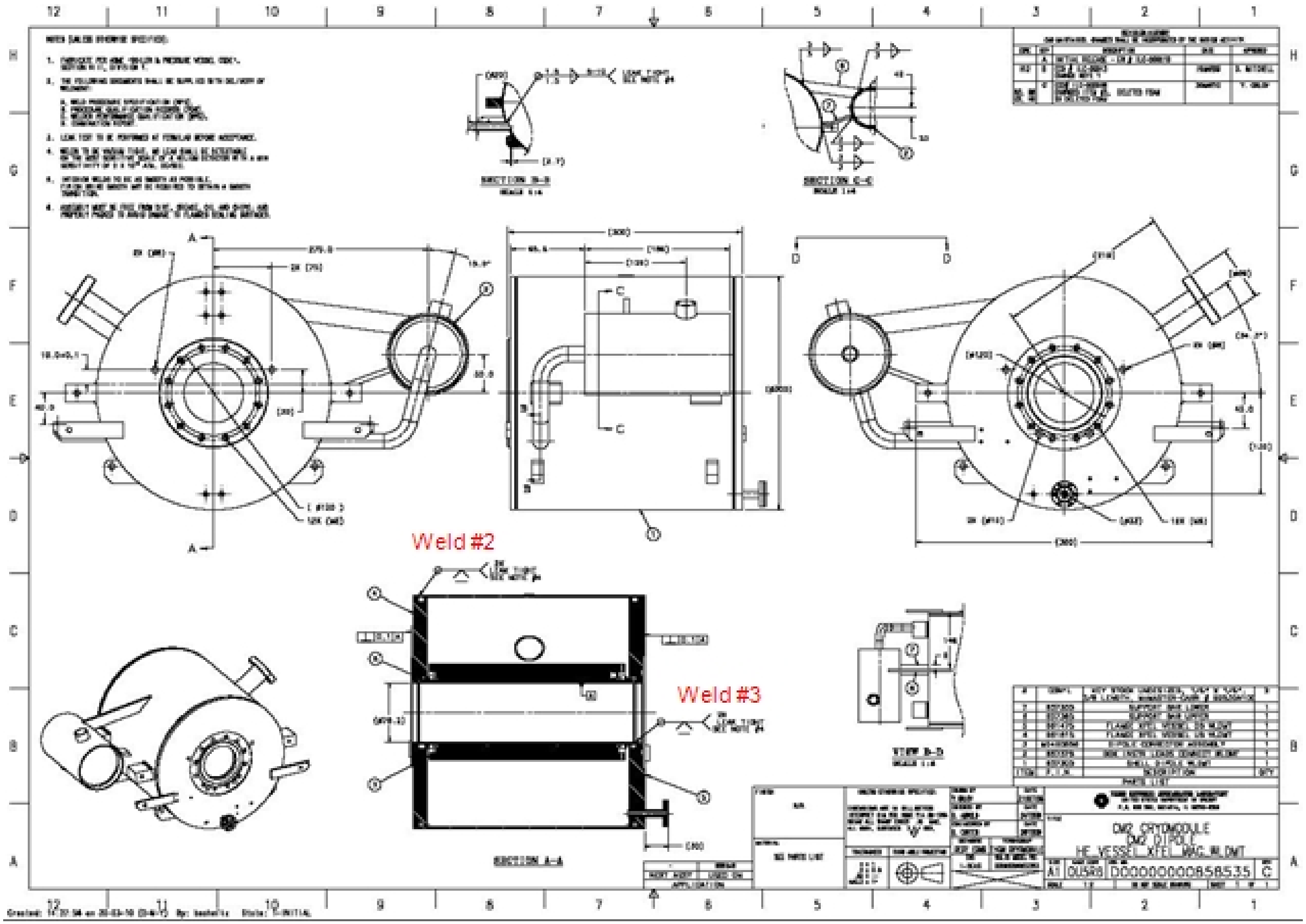


Figure 5– CM2 He-Vessel XFEL Magnet WLDMT (Drawings 858535)

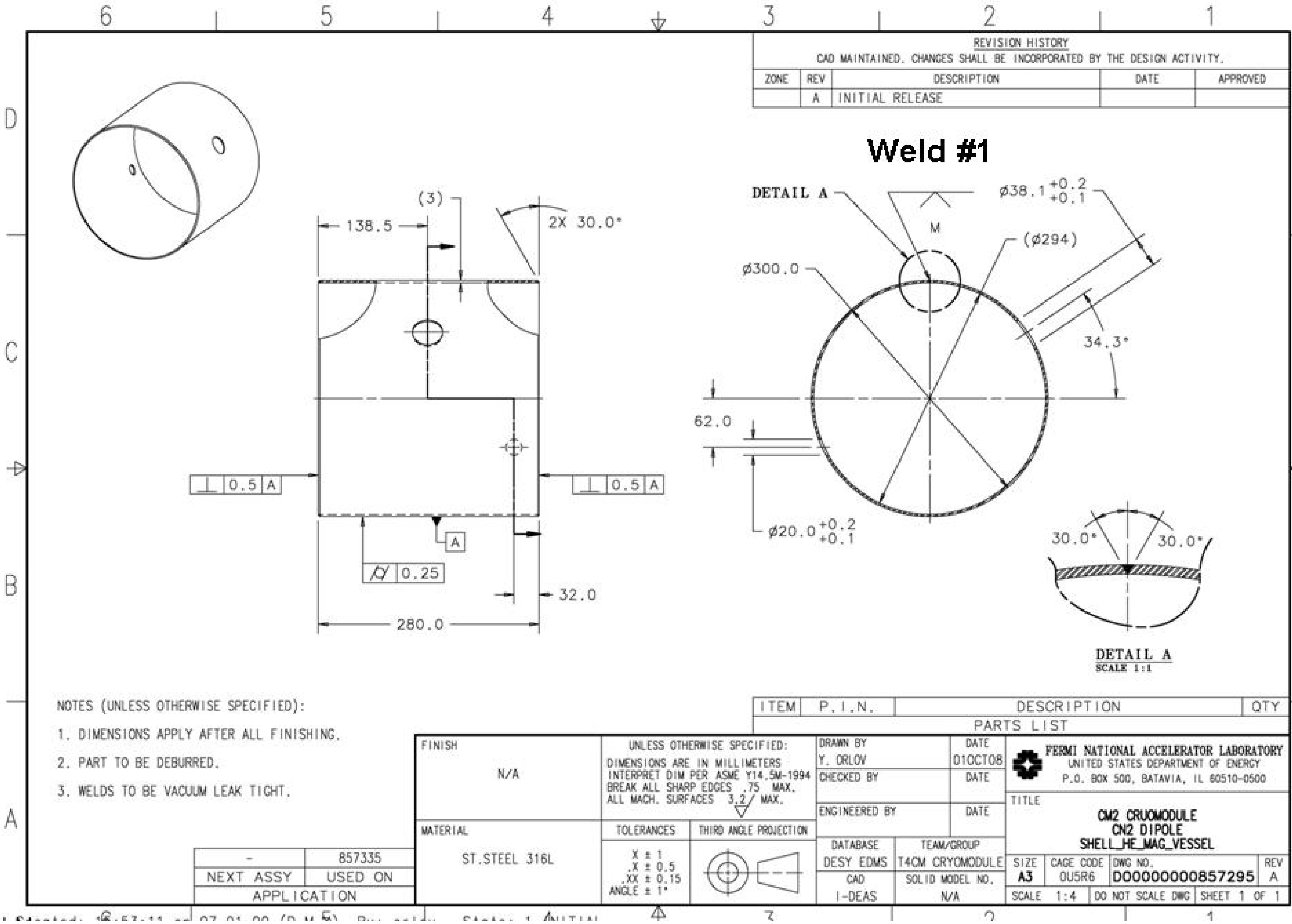


Figure 6– Shell He magnet Vessel (Drawing 857295)

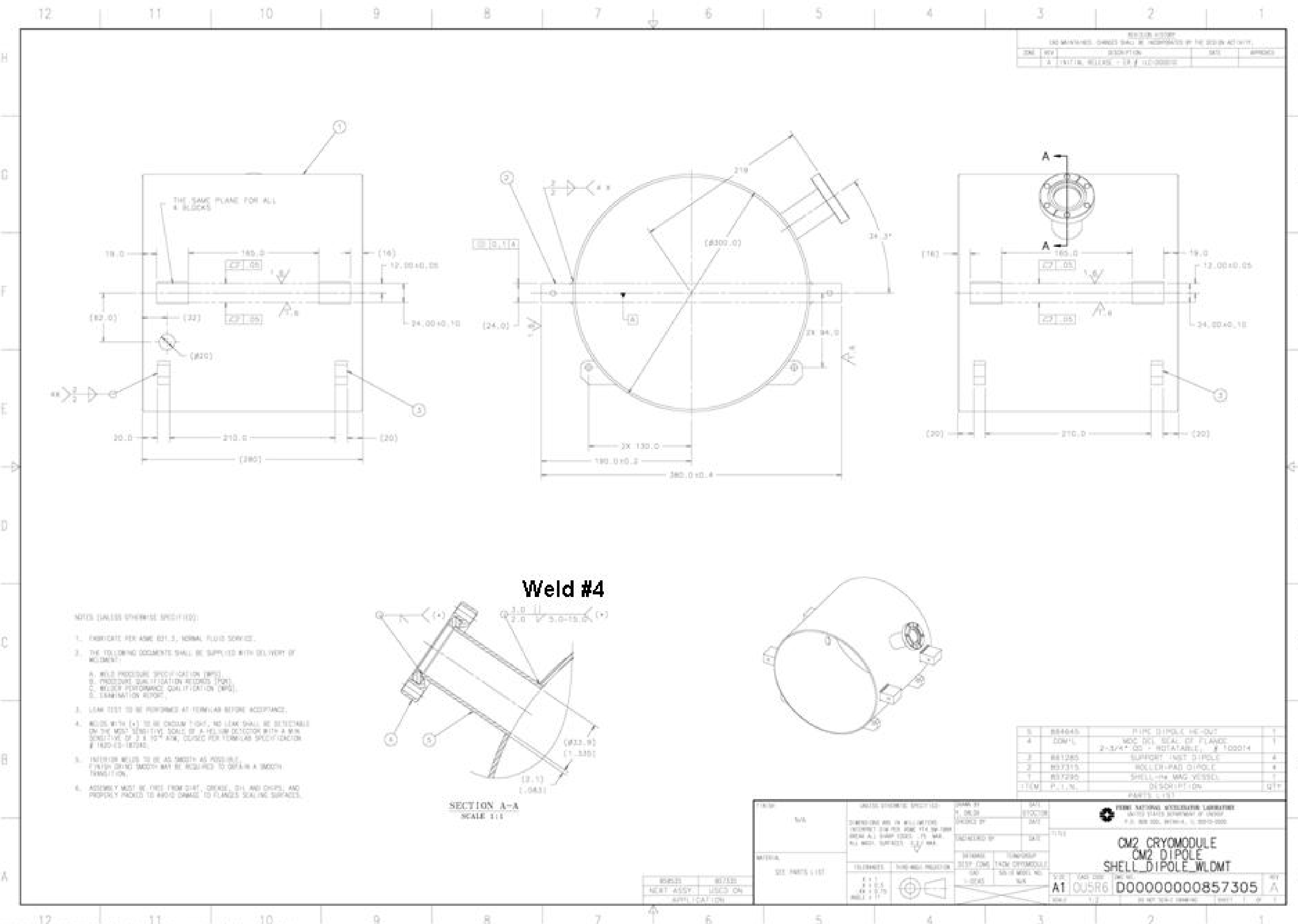


Figure 7– CM2 Shell dipole weldment (Drawing 857305)

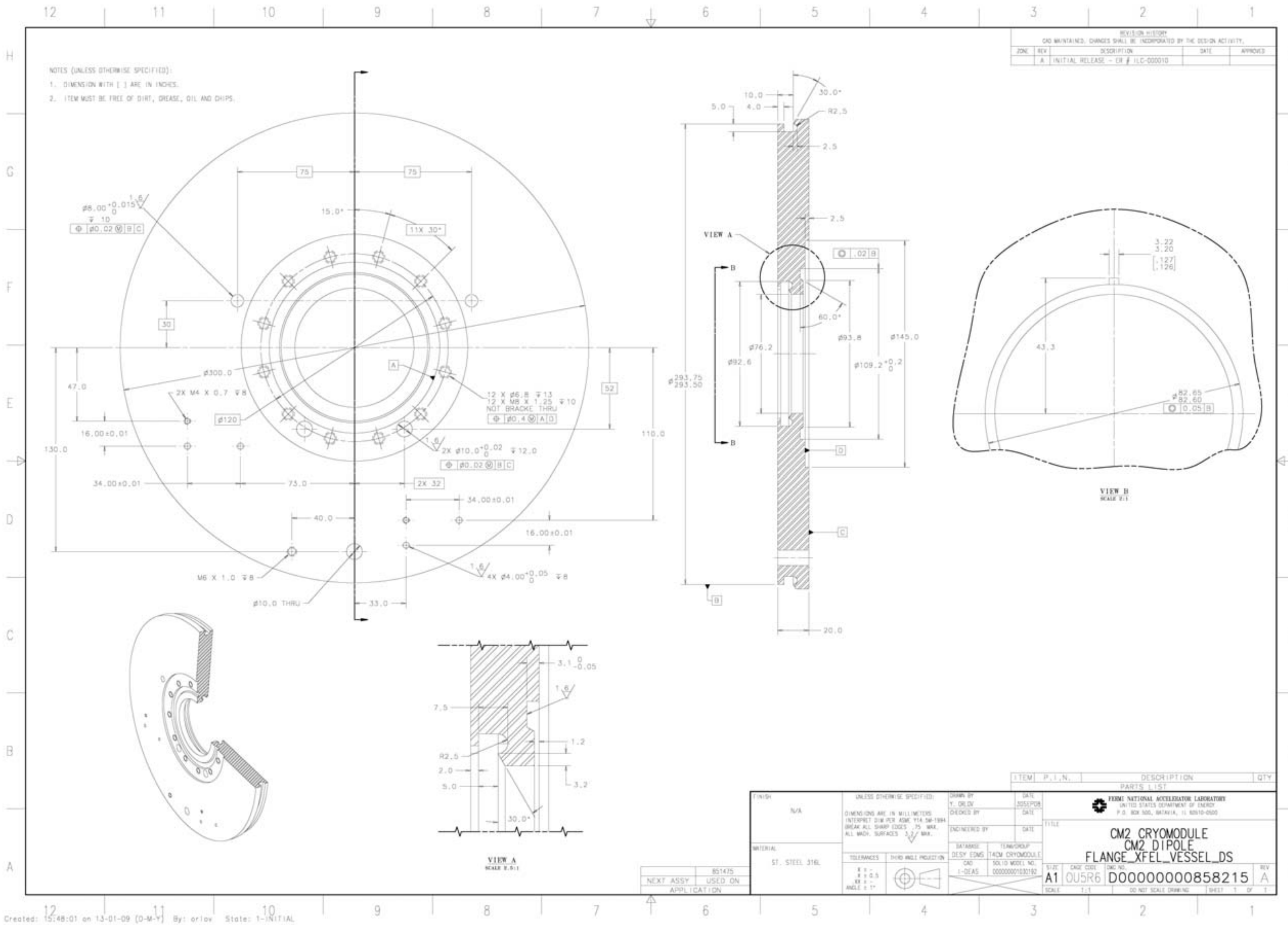


Figure 8– CM2 Flange XFEL Vessel Upstream (Drawing 858215)

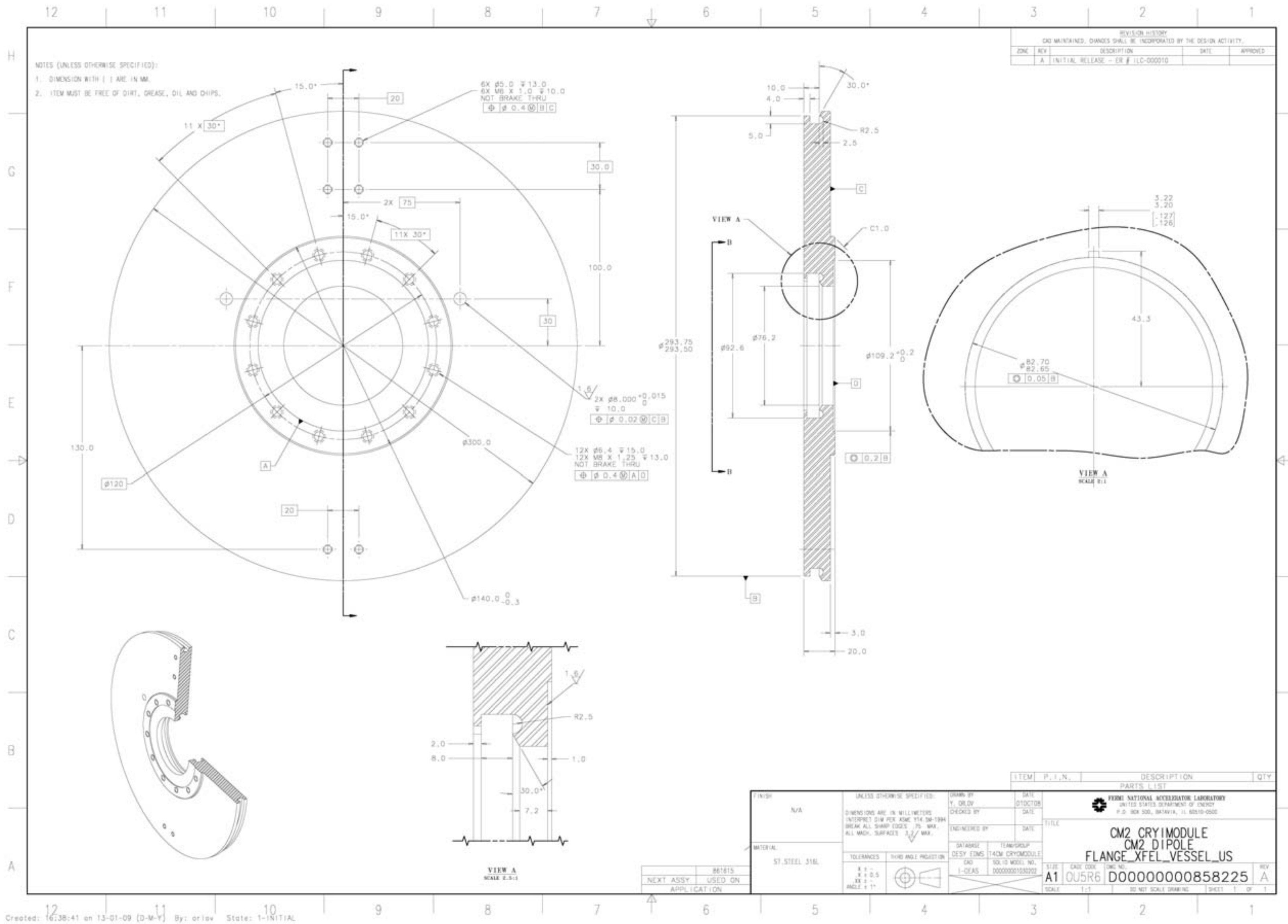
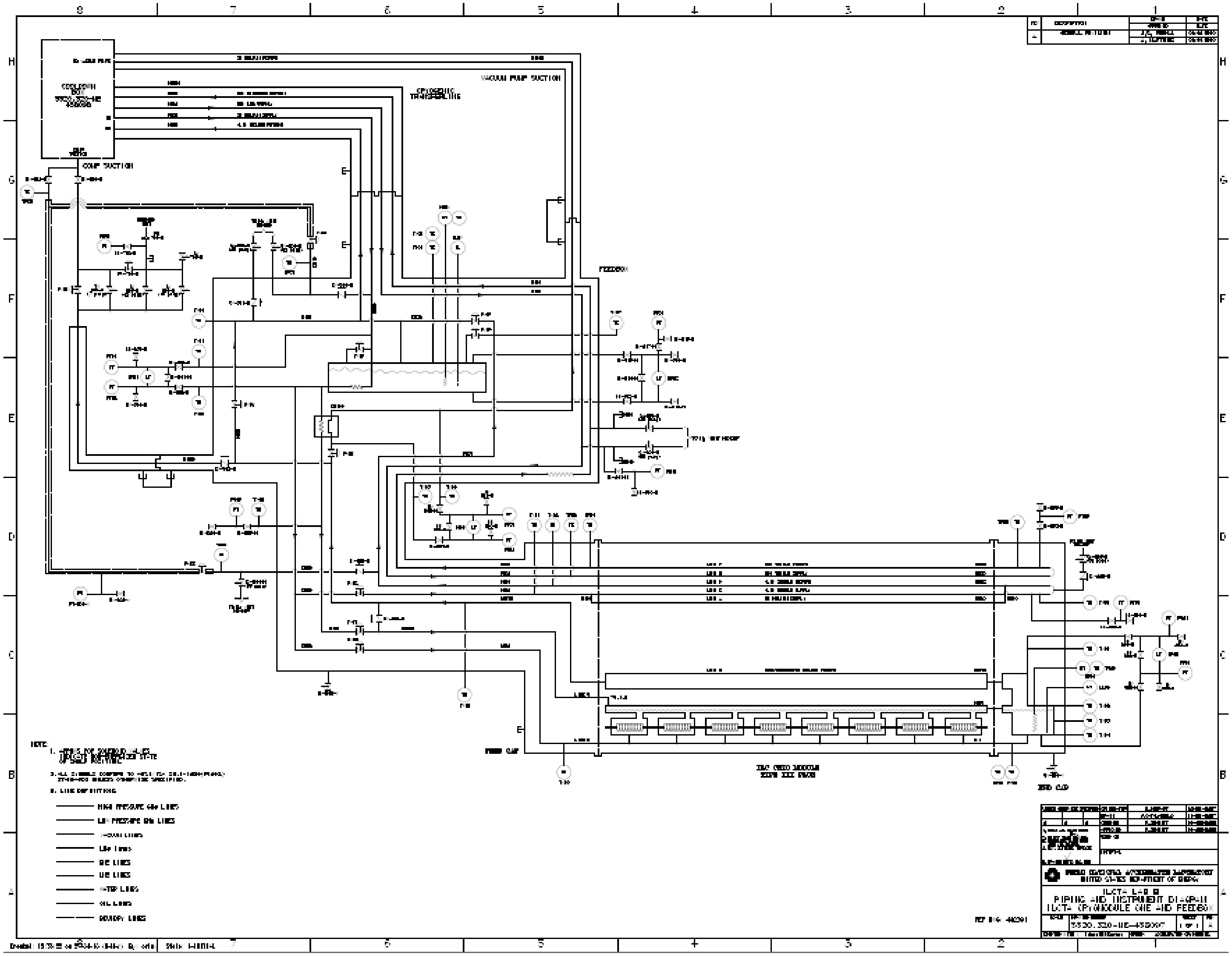


Figure 9– CM2 Flange XFEL Vessel Downstream (Drawing 858225)



CM1 Piping and Instruments diagram (Dr. # ME-458097)

Appendix C –Support documents by vendors. (WELDING)

Fermilab

WELDER QUALIFICATION TEST RECORD

Welder's Name Dan Watkins Ident. No. 25 Date 3-9-84

Welding Process(es) GTAW Type Manual

Test in Accordance with WPS No. 155001

Material Spec. Spec/Grade No. SA 213T304 to Spec/Grade SA 213T304

P No. 8 to P No. 8 Thick. .277 Dia. 6"

Filler Metal Spec. No. SFA 5.9 Class. No. ER308 F No. 6

Backing None

Position 6G Weld Progression Upward

Gas Type Argon Composition 100%

Electrical Characteristics: Current DC Polarity Straight

Other Qualifies up to .554" Thickness

FOR INFORMATION ONLY

Filler Metal Diameter and Trade Name Techalloy 1/16"

Submerged Arc Flux Trade Name N/A

Gas Metal Arc Welding Shield Gas Trade Name N/A

GUIDED BEND TEST RESULTS

Specimen No.	Type	Figure No.	Results
1	Face	QW 462.3a	Acceptable
2	Root	QW 462.3a	Acceptable
3	Face	QW 462.3a	Acceptable
4	Root	QW 462.3a	Acceptable

RADIOGRAPHIC TEST RESULTS
(FOR ALTERNATIVE QUALIFICATION BY RADIOGRAPHY)

Radiographic Results N/A

Test Conducted by IFR Engineering Test No. 008-15

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordace with the requirements of Section IX of the ASME Code.

WPQ

By: [illegible]

Date: 4/6/84

WPS ES155001
Supporting PQR 900-1-A

QW-482 SUGGESTED FORMAT F N (WPS)
(See QW-201.1, Section

Welding Procedure

Company Name Fermi Nat'l. Acc. Lab. By: ______

Welding Procedure Specification No. ES155001** Date ______ Supporting PQR No.(s) ~~820329~~ 900-1-A

Revision No. ______ Date ______

Welding Process(es) GTAW Type(s) Manual (Automatic, Manual, Machine, or Semi-Auto.)

JOINTS (QW-402)

Details

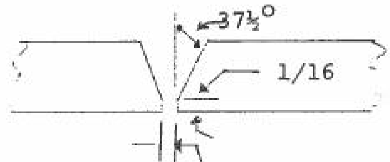
Joint Design V Groove 37½°, 3/32 gap 1/32 to 1/16 gap

Backing (Yes) ______ (No) ______

Backing Material (Type) ______

Sketches, Production Drawings, Weld Symbols or Written Description should show the general arrangement of the parts to be welded. Where applicable, the root spacing and the details of weld groove may be specified.

(At the option of the Mfgr., sketches may be attached to illustrate joint design, weld layers and bead sequence, e.g. for notch toughness procedures, for multiple process procedures, etc.)



*BASE METALS (QW-403)

P-No. 8 Group No. 1 to P-No. 8 Group No. 1

OR

Specification type and grade 304-SA

to Specification type and grade ______

OR

Chem. Analysis and Mech. Prop. 18CR-8-NI

to Chem. Analysis and Mech. Prop. ______

Thickness Range:

Base Metal: Groove 37½° Fillet ______

Deposited Weld Metal

Pipe Dia. Range: Groove 6" dia. SCH 40 (277 wall) Fillet ______

Other ______

*FILLER METALS (QW-404)

F-No. 6 Other ______

A-No. 8 Other ______

Spec. No. (SFA) 5.9.77

AWS No. (Class) A5.9.77

Size of filler metals 1/16" to 3/32 dia.

(Electrode, Cold Wire, Hot Wire, etc.)

Electrode-Flux (Class) NA

Flux Trade Name NA

Consumable Insert NA

*Each base metal-filler metal combination should be recorded individually.

** Formerly FNL- WP-900

(6/30/79) This form (E00006) may be obtained from the Order Dept., ASME, 345 E. 47 St., N.Y., N.Y. 10017

WPS

QW-482 (Back)

POSITIONS (QW-405)
Position(s) of Groove 6 G
Welding Progression: Up X Down
Position(s) of Fillet

PREHEAT (QW-406)
Preheat Temp. Min. NONE
Interpass Temp. Max. 350°F max.
Preheat Maintenance
(Continuous or special heating where applicable should be recorded)

POSTWELD HEAT TREATMENT (QW-407)
Temperature Range NA
Time Range NA

GAS (QW-408)
Shielding Gas(es)
Percent Composition (mixtures)
Flow Rate
Gas Backing
Trailing Shielding Gas Composition

ELECTRICAL CHARACTERISTICS (QW-409)
Current AC or DC DC Polarity STRAIGHT
Amps (Range) 55 to 75 Volts (Range) 9-12
(Amps and volts range should be recorded for each electrode size, position, and thickness, etc. This information may be listed in a tabular form similar to that shown below.)
Tungsten Electrode Size and Type 2% Thoriated 3/32" dia.
(Pure Tungsten, 2% Thoriated, etc.)
Mode of Metal Transfer for GMAW NA
(Spray arc, short circuiting arc, etc.)
Electrode Wire feed speed range NA

TECHNIQUE (QW-410)
String or Weave Bead STRINGER
Orifice or Gas Cup Size #6 (5/16" 3/8)
Initial and Interpass Cleaning (Brushing, Grinding, etc.) BRUSHING AND/OR GRIND
Method of Back Gouging NA
Oscillation MINIMAL *
Contact Tube to Work Distance NA
Multiple or Single Pass (per side) MULTIPLE
Multiple or Single Electrodes SINGLE
Travel Speed (Range) 4 to 8
Peening NA
Other

Weld Layer(s)	Process	Filler Metal Class	Filler Metal Dia.	Current Type Polar.	Current Amp Range	Volt Range	Travel Speed Range	Other (e.g., Remarks, Comments, Hot Wire Addition, Technique, Torch Angle, Etc.)
1	GTAW	ER308	1/16	DCSP	70-110	10-14	As Required	
2-Final	GTAW	ER308	3/32	DCSP	100-225	14-20	As Required	

*Bead Width Should not Appreciably Exceed Gas Orifice Diameter.

WPS

Supports WPS [illegible]

AS A MUTU[AL] ... ARE SUBMIT[TED] ... FOR PUBLIC[ATION] ... OUR REPORTS IS RESERVED PENDING OUR WRITTEN APPROVAL.

Formerly FNL-WP-900

Order No. GH 3514

Date 10-21-75

P.O.# 0356-61

PHYSICAL TEST REPORT OF WELDING PROCEDURE QUALIFICATION TESTS

Client Nuclear Welding Inc.
P. O. Box 254, La Grange, Illinois 60525

Specification No. FNL-WP 900 | Date

Welding Process GTAW | Manual or Machine Manual

Material Specification CR-NI to | of Group No. to Group No.

Thickness (if pipe, diameter and wall thickness) 0.280 Pipe

Thickness Range this test qualifies

Filler Metal Classification

Weld Metal Analysis No. A- (ASME Sec. 9 only)

For oxyacetylene welding — State if Filler Metal is silicon or aluminum killed.

FLUX OR ATMOSPHERE

Flux Trade Name or Composition

Inert Gas Composition

Trade Name Flow Rate

Is Backing Strip used? Preheat Temp. Range

Postheat Treatment

Position 6-G

(For plate, flat, horizontal, vertical, or overhead; if vertical, state whether up or down, For pipe: Axis of pipe vertical, horizontal fixed, or horizontal rolled).

WELDING PROCEDURE

Single or Multiple Pass

Single or Multiple Arc

— For Information Only —

Filler Wire — Diameter

Trade Name

Type of Backing

WELDING TECHNIQUES

Joint Dimensions Accord with

amps volts inches per min.

Above information by PTL ☐ Client ☒ Other

Preparation of specimens witnessed by PTL Yes ☐ No ☒

REDUCED SECTION TENSILE TEST

SPECIMEN NO.	DIMENSIONS-INCHES		AREA SQ. IN.	ULTIMATE TOTAL LOAD, LBS.	ULTIMATE UNIT STRESS, PSI	CHARACTER OF FAILURE AND LOCATION
	WIDTH	THICKNESS				
Tensile 1	1.577	.270	.425	43,000	101200	BM
Tensile 2	1.580	.268	.423	42,500	100500	BM

GUIDED BEND TESTS

TYPE AND FIGURE NO.	RESULT	TYPE AND FIGURE NO.	RESULT
FACE	PASS	FACE	PASS
ROOT	PASS	ROOT	PASS

Welder's Name James Forgator Clock No. 3S5351-20-21.0 Stamp No. TS-930-1.2

Did the welder by virtue of these tests meet welder performance requirements? ☒ Yes ☐ No

Test witnessed by Nuclear Welding Inc. Test No. 1407

per Client

Results of tests (do) (do not) meet requirements of
ASME Sect. IX & III

PITTSBURGH TESTING LABORATORY

By [signature]

David A. Dunn, Chicago

PQR

PITTSBURGH, PA.

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Order No. CH 5698

Date 8/5/82

PO #43643

PHYSICAL TEST REPORT OF WELDER PERFORMANCE QUALIFICATION TESTS

Client: Fermi National Accelerator Laboratory

P. O. Box 500, Batavia, Illinois 60510

Welder Name M. REYNOLDS Clock No. 3993 Stamp No. 48

Welding Process GTAW

Position (For vertical weld state whether upward or downward) 6G
(For Plate: Flat, horizontal, vertical, or overhead; For Pipe: Axis of pipe vertical, horizontal fixed or horizontal rolled).

In accordance with Procedure Specification No. ES155001 Formerly FNA-WP-900

Material – Specification SA312 to SA312 of P-No. 8 to P-No. 8

Diameter and Wall Thickness (if pipe) otherwise Joint Thickness 6" SCH 40 (.280 Wall)

Thickness Range this qualifies 1/16 to .560

FILLER METAL

Specification No. SAF 5.9

Describe Filler Metal ER-308L

Is Backing Strip Used? N/A

– For Information Only –

Filler Metal Diameter and Trade Name N/A Flux for Submerged Arc or Gas for Inert Gas Shielded Arc Welding N/A

Above Information by: PTL ☐ Client ☒ Other

Preparation of specimen witnessed by PTL Yes ☐ No ☒

GUIDED BEND TEST RESULTS

TYPE AND FIGURE NO.	RESULT	FIGURE NO.	RESULT
Face	PASS	Face	PASS
Root	PASS	Root	PASS

Test Witnessed by Client Test No. 10691

per

Results of tests (do) (do not) meet requirements of ASME SECT IX

Remarks machined and tested by P.T.L.

dl
1cc: Client

PITTSBURGH TESTING LABORATORY

By [signature]

WPQ

WELDER OR WELDING OPERATOR QUALIFICATION TEST RECORD

Type of welder Welder
Name Stainislaw Tracz   Identification No. 1710
Welding Procedure Specification No. WPS 100   Rev. ______   Date 12-7-07

Variables	Record Actual Values Used in Qualification	Qualification Range
Process / Type	GTAW	GTAW / Single Electrode
Electrode (single or multiple)	Single	
Current / Polarity	DCEN	Qualifies DCEN Flat grooves & fillets
Position	1G	
Weld Progression		
Backing (YES or NO)	No	with or without
Material / Spec.	ASTM –A-36 to Same	any in table 3.2
Base Metal		
Thickness: (Plate)	3/8"	1/16" to ¾"
Groove		1/16" to ¾"
Thickness: (Pipe / Tube)		
Groove		See tables 4.3 & 4.4
Fillet		
Diameter: (Pipe)		
Groove		
Fillet		
Filler Metal		
Spec No.	AWS – A5.9	Qualifies to any F-6 specification in table 4.5
Class	ER 309/309L	
F-No.	F-6	
Gas / Flux Type	Argon 100%	Argon 100%
Other		

STEVE P. TARRANT
CWI 06110581
QC1 EXP. 11/09

VISUAL INSPECTION

Acceptable YES or NO Yes

Guided Bend Test Results

Type	Result	Type	Result
(1) Face	Acceptable	N/A	
(1) Root	Acceptable	N/A	

Fillet Test Results

Appearance ______   Fillet Size ______
Fracture Test Root Penetration ______   Macroetch ______
(Describe the location, nature, and size of any crack or tearing of the specimen.)
Inspected by Steve Tarrant   Test Number 270
Organization Weldstar   Date 12-12-07

RADIOGRAPHIC TEST RESULTS

Film Identification Number	Results	Remarks	Film Identification Number	Results	Remarks

Interpreted by ______   Test Number ______
Organization ______   Date ______

We the undersigned certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Clause 4 of AWS D1.6 2007 Structural Welding Guide Stainless Steel

Manufacturer or Contractor Hi-Tech Manufacturing   Authorized By Simon Sorsher
Date 12-7-07

Welding Procedure Specification (WPS)
Code AWS D1.6 / D1.6 M

Prequalified X   Qualified by Testing____   Procedure Qualification Records____

Company Name Hi – Tech Manufacturing
Welding Process(es) GTAW
Supporting PQR No.(s) ____

Identification No. WPS 100
Revision: ____ Date:____ By:____
Authorized By Simon Sorsher Date: 12/7/07
Type: Manual: ( ) Semi – Automatic (x)
Machine ( ) Automatic ( )

Joint Design Used

Type: Single ( ) Double Weld (x)
Backing: Yes ( ) No (x)
Backing Material ____
Root Opening 1/8" Root Face Dimension ____
Groove Angle 60° Radius (J-U) ____
Back Gouging: Yes (x) No ( )Method Grinding

Position

Position of Groove 1G Fillet ____
Vertical Progression: Up ( ) Down ( )

Electrical Characteristics

Transfer Mode (GMAW)
Short Circuiting ( ) Globular ( ) Spray ( )
Current AC ( ) DCEP ( ) DCEN (x) Pulse ( )
Other ____
Tungsten Electrode (GTAW)
Size: 3/32"
Type: 2% Thoriated

Base Metals

Material Spec. UNS S30403 (304 L)
Type or Grade ____
Thickness: Groove 3/8" Fillet ____
Diameter (pipe) ____

Filler Metals

AWS Specification A 5.9
AWS Classification ER 309/309L

Shielding

Flux ____ Gas Argon Flow Rate 22 CFH
Composition 100%
Electrode Flux Class____ Gas Cup Size 3/8

Preheat

Preheat Temp., Min. Sufficient to remove moisture
Interpass Temp., Min. ____
Max. 350°F

Technique

Stringer of weave Stringer
Multiple or Single Pass (per side) Multi-pass
Number of Electrodes 1
Electrode Spacing: Longitudinal____
Lateral____
Angle____
Contact Tube to Work Distance____
Peening____
Interpass Cleaning Wire Brush / Grinding

Postweld Heat Treatment

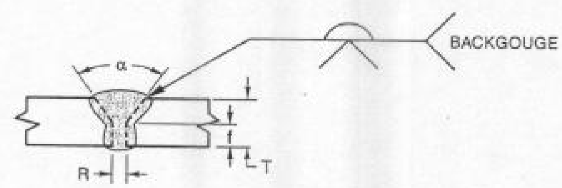
Temp. ____
Time ____

See page 2 for welding Procedure

Welding Procedure

Pass or Weld Layers	Process	Filler Metals Class	Filler Metals Diameter	Current Type and Polarity	Amps or Wire Feed Speed	Volts	Travel Speed
All	GTAW	ER 309/309L	3/32	DCEN	225		6 IPM

Single-V-groove weld (2)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation			Permitted Welding Positions	Notes
			Root Opening Root Face Groove Angle	Tolerances			
		T		As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW GTAW	B-U2	U	$R = 0$ to $T/2 \le 1/8$ $f = 0$ to $T/2 \le 1/8$ $\alpha = 60°$	$+T/4 \le 1/16, -0$ $+T/4 \le 1/16, -0$ $+10°, -0°$	$+1/16, -T/2 \le 1/8$ Not limited[a] $+10°, -5°$	All	d, k, o
	B-L2	2 max.					
GMAW FCAW	B-U2-GF	U	$R = 0$ to $T/2 \le 1/8$ $f = 0$ to $T/2 \le 1/8$ $\alpha = 45°$	$+T/4 \le 1/16, -0$ $+T/4 \le 1/16, -0$ $+10°, -0°$	$+1/16, -T/2 \le 1/8$ Not limited[a] $+10°, -5°$	All	a, d, k, o
SAW	B-L2c-S	Over 1/2 to 1	$R = 0$ $f = 1/4$ max. $\alpha = 60°$	$R = \pm 0$ $f = +0, -1/16$ $\alpha = +10°, -0°$	$+1/16, -0$ $\pm 1/16$ $+10°, -5°$	F	d, k
		Over 1 to 1-1/2	$R = 0$ $f = 1/2$ max. $\alpha = 60°$				
		Over 1-1/2 to 2	$R = 0$ $f = 5/8$ max. $\alpha = 60°$				

[a] Limited by a minimum groove depth.

Figure 3.5

Appendix D – Pressure Test

Date: February 10, 2011

Pressure Testing Permit*

Type of Test: [ ]Hydrostatic [X] Pneumatic

Test Pressure 34.5 Psid **Maximum Allowable Working Pressure** 29.7 Psid

Items to be Tested
CM2 corrector coil magnet helium vessel.

Location of Test CAF-MP9 **Date and Time** 2/16/11

Hazards Involved
Contact with high velocity jet of the test gas.

Safety Precautions Taken
System designed, fabricated, and inspected per ASME Boiler & Vessels code. Test will be conducted by trained Personnel as described in ASME code. Access to test area will be limited only to those involved in the test during pressurization.

Special Conditions or Requirements
Operating pressure = 29.7 PSI, test pressure = 1.15*OP=34.5 PSI, pneumatic per ASME code.

1. First pressurize to 9.0 PSI and check for leaks.
2. Repeat at 17.0 PSI.
3. Increase pressure gradually to the test pressure. Hold for 5 minutes.
4. Reduce pressure to the design pressure.
5. Close valve on regulator.
6. Maintain test for the least 10 minutes without loss of pressure.

Qualified Person and Test Coordinator Youri Orlov, Tug Arkan Y. Orlov
Dept/Date TD / SRF DEV

Division/Section Safety Officer Rich Ruthe Richard Ruthe
Dept/Date TD / SRF DEV

Results

Pressure maintained at 30 psig without dropping. Passed test.

Witness Richard Ruth(?) Dept/Date ESH/ 2/16/11

(Safety Officer or Designee)

- Must be signed by division/section safety officer prior to conducting test. It is the responsibility of the test coordinator to obtain signatures.

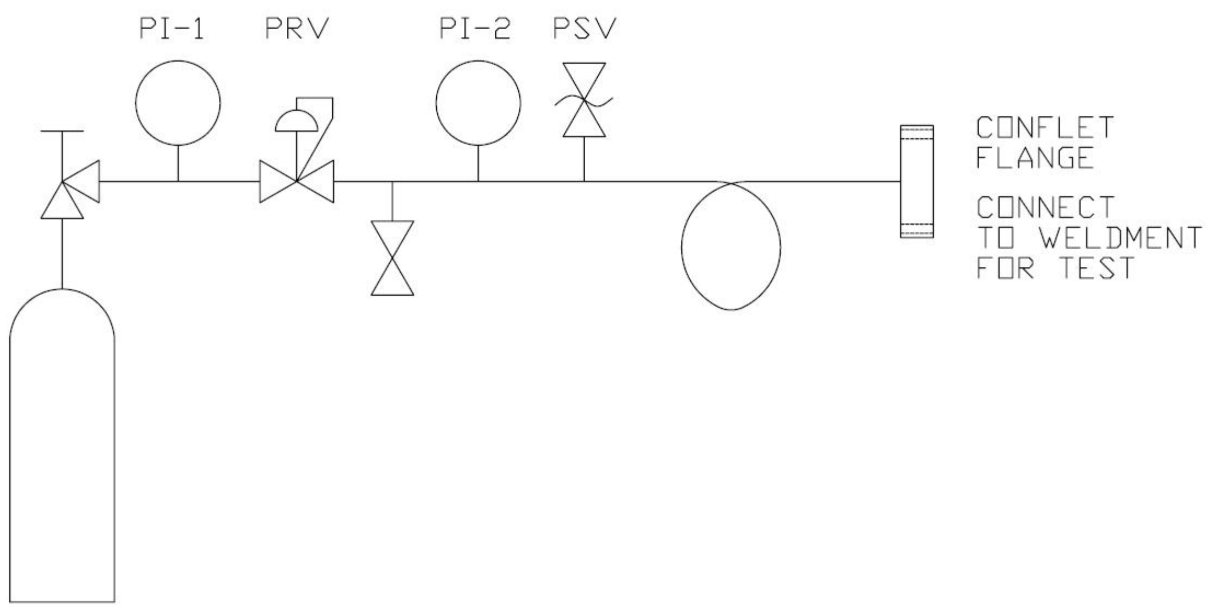
Test Procedure

The table bellow shows the pressure levels for each pause and what should be done at that pressure. Total time for the test, not including setup and tear-down time, will about 20 minutes.

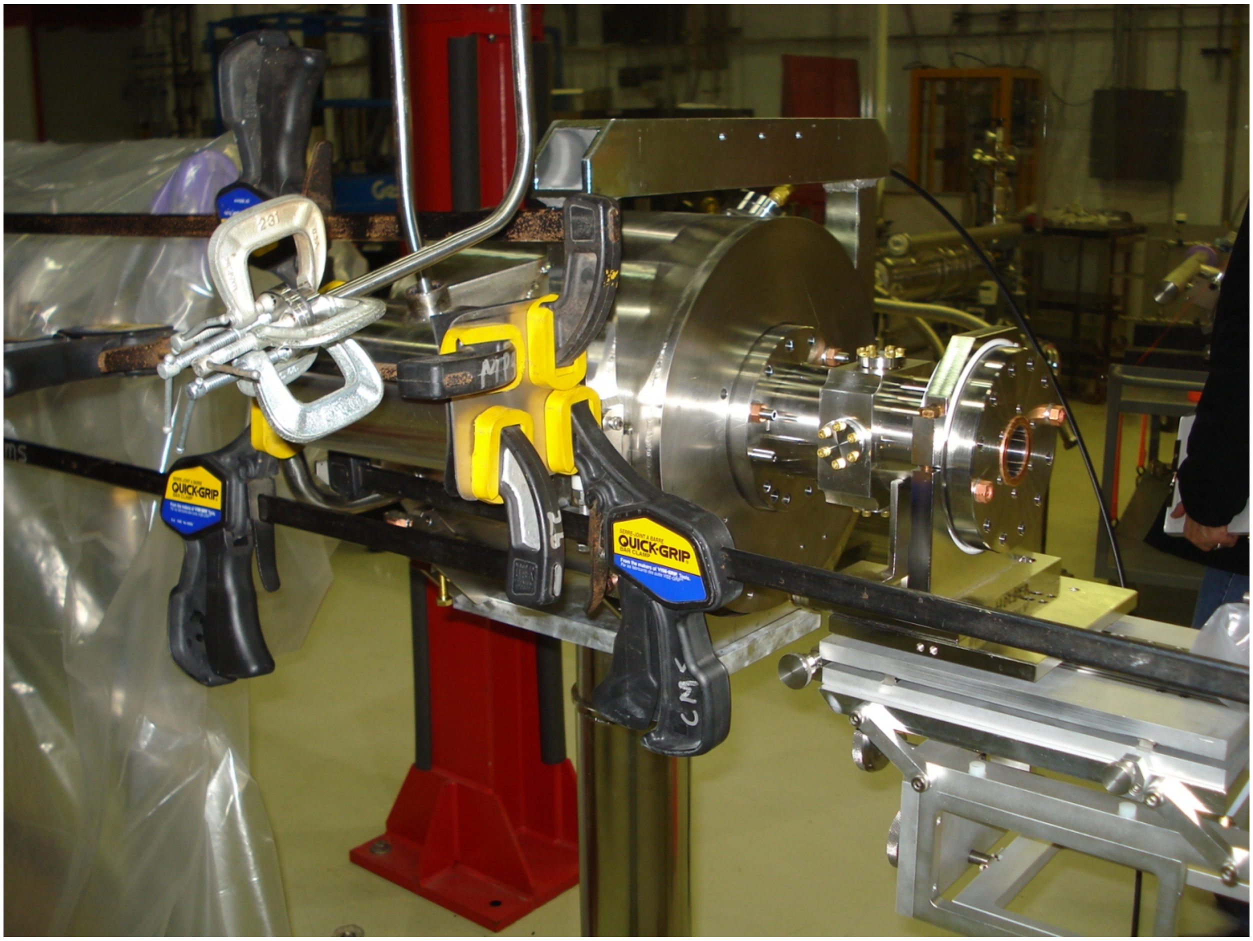
Pressure (psig) (psig equals differential pressure for this test)	Dwell time (minutes)	Activity at pressure
0	--	
9.0	As needed	Snoop line fitting
17.0	As needed	Snoop line fitting
20.5	~1	
24.0	As needed	
27.0	~1	
31.0	As needed	
34.5	5	Peak test pressure of 1.15 x MAWP
30.0	10*	Test pressure hold point
25.0	As needed	
17.0	As needed	Visual inspection
0	--	

*The pressure hold point of 30 psig is approximately the MAWP. Dwell time in set long enough to assure us that pressure is not dropping.

TEST SETUP



Test Pressure	PI-2	PSV
34.5 psig	0-100 psig	35.4 psig relief



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1. Fermilab's ES&H Manual Chapter 5031 (Pressure Vessels).
2. ASME, Boiler & Pressure Vessel Code, 2007.
3. DOE, Federal Register, 10 CFR Part 851, Appendix A, Section 4 ("Pressure Safety"), pg 6941, February 2000
4. Compressed Gas Association, "CGA S-1.3-2005: Pressure Relief Device Standards Part 3 – Stationaery Storage Containers for Compressed Gases," 7th Edition, 2005.
5. Kropschot, R.H., et al, Technology of Liquid Helium, National Bureau of Standards Monograph 111, U.S. Department of Commerce, October 1968.
6. "Pressure Vessel Engineering Note for the 3.9-GHz Helium Vessel, Cavity #5", IND-102, July 2008.
7. "Pressure Vessel Engineering Note For the 1.3-GHz Helium Vessel, Dressed Cavity AES-4", IND-138, April 2009.