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1. Introduction

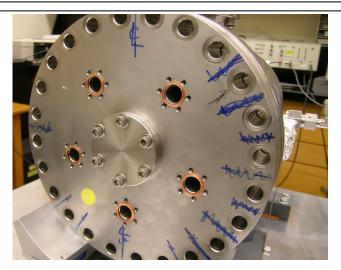
This Safety Note covers a pressure vessel and associated inert gas system for a physics research experiment involving neutrinoless double beta decay, using Xenon gas. The heart of the system is a pressure vessel recently acquired by LBNL from LLNL. There are new components both purchased, and LBNL designed (in accordance with ASME <u>Boiler and Pressure Vessel Code</u> Section VIII, Div. 1, 2007), which will be attached to this pressure vessel, which are treated in this note. This Safety Note is to assure that the Experiment meets LBNL Pressure Safety requirements of PUB-3000. Under PUB3000, sec 7.6.1, it is classified as a High Hazard Pressure System, since there are gas pressures above 150 psig. An AHD is not required for the Xenon or Argon gases, nor any of the other materials inside, but there may be pressure and process hazards, so an AHD will be formulated.

The pressure vessel will enclose a small detector called a Time Projection Chamber (TPC) with Xenon gas used as both the electron drift volume and for electrical insulation. The vessel was designed by LLNL, and used at LLNL from 2000-2009 for a similar purpose, and has not been modified from the original design. LLNL Mechanical Engineering Safety Note MESN99-020-OA (1999) contains the vessel design calculations, performed in accordance with ASME Boiler and Pressure Vessel Code Section VIII (1995), and is included here in the Appendix. It includes pressure testing procedures. Also included is a copy of the original pressure test at LLNL for the vessel and head. The attached components consist of a 2" diameter high vacuum/high pressure valve, a Kimball physics octagonal vacuum chamber, a spool connecting the octagon to the vessel lid, assorted cabling feedthroughs, and a gas handling system composed of small diameter high pressure metal tubing, purifiers, valves, and pumps. The gas system includes a cryogenic Xenon reclamation cylinder, which was designed, built, and tested by Acme Cryogenics for LLNL, for 3000 psi MOP. We will be using it here at LBNL up to a pressure of 950 psi MOP. Its design calculations and test report are also included in the Appendix (LLNL M.E. Safety Note MESN99-038-OA). The pressure vessel is shown below:

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Fig. 1 Main pressure Vessel, 850 psig MOP

Fig. 2 Flat Heat for 350 psig MOP (CF seals)

Pressures for use at LBNL

Maximum Operating Pressure Maximum Allowable Working Pressure

 $P_{MOP} := 300psi$ $P_{MAWP} := 350psi$

Initial Maximum Operating and Allowable Working Pressures

 $P_{MOP_i} := 225 psi$ $P_{MAWP_i} := 250 psi$

(to be used initially with existing Ceramtec SHV-20 connectors (see below) until higher rated feedthroughs are obtained)

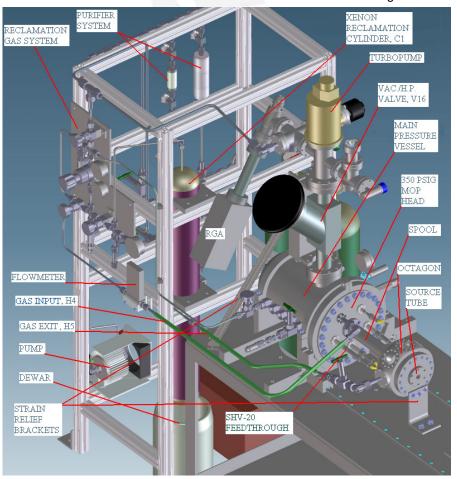


Fig. 3 LBNL configuration: pressure vessel with cabling extension spool, octagon vac. cham. & gas sys.

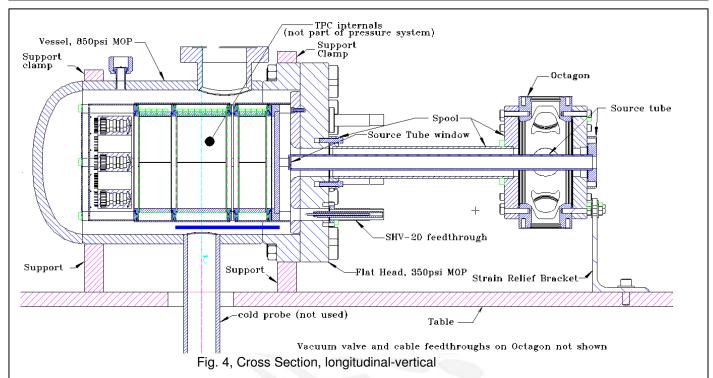
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2. System Description and Basic Operation

The main pressure vessel is approximately 8 inches in diameter and 14 inches long, (inside volume), and fabricated from 316L and 304 stainless steel. It will be operated at LBNL at a 300 psig maximum operating pressure (MOP), with a maximum allowable pressure (MAWP) of 350 psig. Minimum pressure is high vacuum. The main vessel was designed for operation up to 850 psig MOP, with a section of the chamber operated at LN2 temperature. There are two flat heads for it, only one of which will be used at LBNL, this head has an MAWP of 406 psig. At LBNL, the chamber will be used with inert gases only, mainly Xenon and Argon, as well as high vacuum. It will be operated only in temperature range of room temperature to 50C; the cryogenic section will not be used, and it will be labeled as such to prohibit use. An associated gas system is used to supply gas to the chamber, to pressurize and depressurize the vessel, and to circulate Xenon continuously through the detector, primarily to purify the Xenon gas to a high purity state, but also to eliminate any thermal convection currents from electronics inside the vessel. Argon may be used for initial flushing of air, H20, etc. when the vessel is first assembled, and perhaps for leak checking under pressure. A 5.4L stainless steel Xenon reclamation cylinder is used to condense/ freeze out Xenon in order to open up the vessel without venting the Xenon. It will be left open during some operations, and so is considered part of the vessel volume. The total system stored energy is 54 kJ for either of these monatomic gasses @MAWP = 350 psig. A schematic is shown below:

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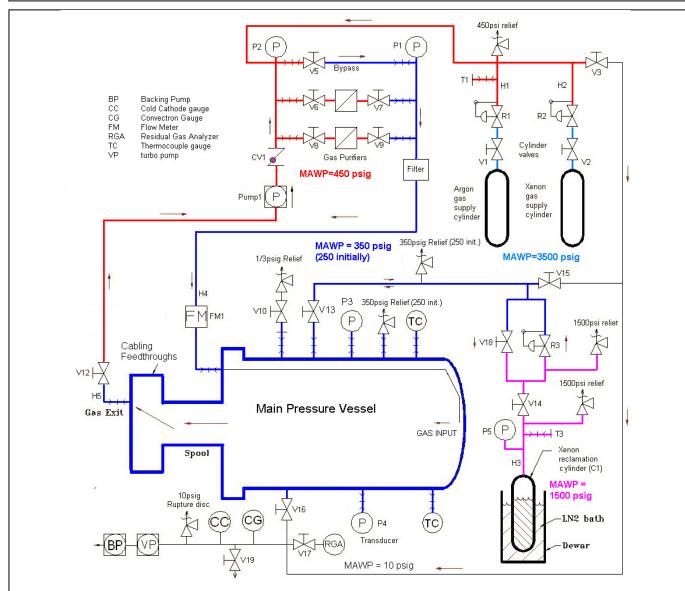


Fig. 5 Gas System Schematic

Operation of the system is treated in detail in section 8, <u>Gas System</u> below, and in the AHD (to be prepared). The basic sequence is essentially:

- 1. All valves, except the gas cylinder and vacuum purge valves, are opened (including the reclamation cylinder) and the system is pumped down to a high vacuum. Argon may be used for an initial flush, or to provide for a purge when the system is opened.
- 2. The vacuum valve is then shut and the system (including reclamation cylinder) is filled with Xenon to 300 psig (225 initially) at room temperature.
- 3. The dewar is filled with LN2; this freezes out the Xenon into the reclamation cylinder, which is then valved off.
- 4. The main system is refilled with Xenon to to 50 psig, and step 3 is repeated. This step charges the reclamation cylinder with a small amount of extra Xenon to provide for quicker refilling of the main system.
- 5. To fill the main system at the desired pressure, the reclamation cylinder is opened and regulated flow is let back into the vessel until the desired pressure is reached. Heaters on the reclamation cylinder may be needed to warm

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the gas, as it will cool upon expansion; a maximum temp. of 50C is used. The gas will cool upon expanding through the regulator, and the pressure will be lower than 300 psig (225 psig initially) until the gas warms up to room temperature. Line heaters on the refill line may be needed to reduce the amount of time needed to come back to room temperature.

- 6. The pump is then operated to circulate the Xenon through the main pressure vessel and through the gas purifiers. The gas flow rate is varied as needed, using the pump controller, and only one gas purifier is used at a time.
- 7. To open the main pressure vessel for service (to TPC), step 3 is repeated.
- 8. After closing the main pressure vessel after TPC service and pumping it down to high vacuum, step 5 is repeated.

Pressure Safety Assurance There are five pressure zones in the system:

- 1. Main Vessel with attached components, 350 psig MAWP, protected by 350 psig relief valve on main vessel (a 250 psig relief valve will be installed initially until high pressure SHV-20 connectors are procured and installed).
- 2. Gas supply and purifier loops 1000 psig MAWP, protected by 450 psig relief valve.
- 3. Reclamation cylinder, 3000 psig MAWP, protected by 1500 psig relief valve.
- 4. The gas supply cylinders themselves have their burst disks behind their valves, per standard gas cylinder practice.
- 5. The vacuum system has a 10 psig burst disk on the vacuum side.

Hazards Analysis

There are no toxic, flammable, biological, or radioactive gasses or materials inside the vessel with the possible exception of some small low intensity sealed gamma ray sources. The inside detector is composed of common metals, Teflon, Mylar, Kapton and PEEK polymers, glass, signal cabling and some semiconductor ICs. There will be high voltage components inside, operating as high as +/-20 kV, but at low stored energy, and there will be no organic liquids, gases, or aerosols, and no oxygen present when operating, so there is no explosion hazard. There are 19 photomultiplier tubes (PMTs) 1 inch diameter by 2 inches long which are known to withstand use at 20 bar; they have the possibility of imploding under excessive pressure, but this is not expected to create any hazard from excessive transient pressure, or other hazard since they are surrounded by a dense gas, not a liquid, as is the case in some neutrino detectors. These PMTs will be hydrostatically pressure tested before use at 110-125% MOP = 375 psig (275 psig initially). There are no toxic or radioactive materials inside the PMT's. These PMTs are the limiting factor for the experiment, and set the MOP to 300 psig. There are, initially three SHV-20 high voltage feedthrus that are rated for use at 250 psi; this is the lowest MAWP of the entire system and thus a 250 psig relief valve will be initially installed on the pressure vessel until a high pressure (800 psig MAWP) version of this feedthrough is procured; at which time the MAWP will be changed to 350 psig.

There will be people present near the vessel when it is under full pressure. Under PUB3000, sec 7.6.1, it is classified as a High Hazard Pressure System, since there are gas pressures above 150 psig. An AHD is not required for the Xenon or Argon gases, nor any of the other materials inside, but there may be pressure and process hazards, so an AHD will be formulated.

Main Vessel Description

The vessel is constructed from Schedule 80 316L S.S. pipe and the flanges and heads are 304 S.S. (if not 304L). There are no brittle materials used. Welds were made by ASME certified welders according to the LLNL Note. Welds were designed with an efficiency factor of 0.7 to eliminate the need to radiograph welds.

As mentioned above, the main vessel has a Maximum Operating Pressure (MOP) of 850 psig when used with a specially made blank flat head which seals against the vessel flange with a C-type face gasket. Maximum allowable Pressure (MAWP) is 976 psig with this head. This vessel and head combination has been pressure tested to 1.5xMAWP=1467 psig. However there is no plan to operate the vessel at LBNL using this head.

It has an MOP of 350 psig when used with a different specially made flat head (labeled AAA-99-104240-00) which has a number of openings for instrumentation, each of which seals with a CF-type (conflat) flange. This flat head is not a standard CF type flange but has increased thickness and uses double the number of clamping bolts. It seals using a standard CF gasket and knife edge design, however. Maximum allowable Pressure (MAWP) is 406

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psig. It has been pressure tested to 1.5xMAWP = 609 psig with this head (openings blanked off).

The vessel can only, and will only be used at LBNL with the 350 psig MOP head. There are a number of valves, pipes and electrical feedthru's that will attach to the head and vessel; all will be either rated by the manufacturer for 350 psig operation (MAWP at min.), and, if not, will be analyzed for pressure safety and pressure tested, either in conjunction with this vessel or separately. The strength of this vessel and head have no dependency on any attached components, nor do any attached components rely on this vessel or head for strength.

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As stated above, there are no toxic, flammable, biological, or radioactive gasses or materials used inside the vessel with the exception of some small low intensity sealed gamma sources. Argon gas will be used as a purge gas, most likely at low pressure but perhaps up to the MOP e.g. for leak checking. There is a cold probe welded to the main tank vessel which was used to condense Xenon inside the vessel, using a surrounding dewar of LN2, however, there are no plans at LBNL to use this feature, and it will be labeled to prohibit use.

As stated above, there are also some new components which will be attached to the vessel and flat head, some of which are pressure rated by the manufacturer, some which are not rated by the manufacturer but which are suitable for safely holding pressure, and some which will be designed and built by LBNL. These latter two categories are analyzed in this note for sufficient strength and will be proof tested separately.

LLNL Safety Note MESN99-020-OA (1999) shows calculations performed in accordance with ASME Pressure Vessel Code Section VIII-1-1997. The analysis appears to be fairly complete and correct with respect to ASME Pressure Vessel Code Section VIII-1-2007, which this author has access to. There is an analysis of the 350 psi MOP head which uses a non-ASME method involving stress concentration factors, however there is also an analysis based on ASME methods. This document is reproduced in the Appendix. Also in the Appendix are the two pressure test reports from LLNL, plus two notes on pressure capacity of CF flanges, one from LLNL and one from ANL.

What follows are basic calculations for this experimental system and additional calculations for the added components:

3. Basic System Calculations

Stored Energy, U, @ 350 psig MAWP

from PUB3000, Chapter 7, Appendix E:

$$U = \frac{P_h V_h}{\gamma - 1} \left[1 - \left(\frac{P_1}{P_h} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

where:

$$P_h := P_{MAWP} + 14.7psi$$
 $P_h = 364.7psi$ $P_1 := 14.7psi$ $\gamma := 1.666$ (for monatomic gases)

Volume includes vessel, cabling octagon, connecting spool, valve and gas system tubing:

$$\begin{array}{lll} d_{ves} \coloneqq 7.63 \mathrm{in} & l_{ves} \coloneqq 13.5 \mathrm{in} & \text{main vessel inner dimensions} \\ d_{LNxt} \coloneqq 2 \mathrm{in} & l_{LNxt} \coloneqq 8 \mathrm{in} & LN2 \text{ extension (cold probe)} \\ d_{oct} \coloneqq 8 \mathrm{in} & l_{oct} \coloneqq 3.0 \mathrm{in} & \text{Kimball octagon for cabling} \\ d_{spool} \coloneqq 2 \mathrm{in} & l_{spool} \coloneqq 10 \mathrm{in} & \text{connection spool, flat head to octagon} \\ d_{tubing} \coloneqq 0.5 \mathrm{in} & l_{tubing} \coloneqq 20 \mathrm{ft} & \text{gas system tubing and purifiers (est.)} \\ d_{valve} \coloneqq 2 \mathrm{in} & l_{valve} \coloneqq 4 \mathrm{in} & \text{high pressure volume of closed vacuum valve and tank stub} \\ d_{rc} \coloneqq 3.43 \mathrm{in} & l_{rc} \coloneqq 36 \mathrm{in} & \text{reclamation cylinder} \\ \end{array}$$

$$\begin{aligned} V_{h} &\coloneqq \frac{\pi}{4} \cdot \left(d_{ves}^{2} \cdot l_{ves} + d_{LNxt}^{2} \cdot l_{LNxt} + d_{spool}^{2} \cdot l_{spool} + d_{oct}^{2} \cdot l_{oct} + d_{tubing}^{2} \cdot l_{tubing} + d_{valve}^{2} \cdot l_{valve} + d_{rc}^{2} l_{rc} \right) \\ V_{h} &= 1.2 \times 10^{3} \text{ in}^{3} \quad V_{h} = 19.9 \, L \end{aligned} \qquad V_{ves} \coloneqq \frac{\pi}{4} d_{ves}^{2} \cdot l_{ves} \qquad V_{ves} = 10.115 \, L \end{aligned}$$

Stored Energy @ 350 psig MAWP

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 $U_{v} := \left. \frac{P_{h} \cdot V_{h}}{\gamma - 1} \right| 1 - \left(\frac{P_{l}}{P_{h}} \right)^{\frac{\gamma}{\gamma}}$

Mass of Xenon in System at operating pressure

$$P_{MOP} = 300 \text{ psi}$$
 $R := 8.314 \text{J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ $T_{amb} := 300 \text{K}$ $M_{a \text{ Xe}} := 131.3 \text{gm} \cdot \text{mol}^{-1}$

Critical Pressure, temperature of Xenon:

$$P_{c Xe} := 58.40 \text{bar}$$
 $T_{c Xe} := 15.6 \text{K} + 273 \text{K}$

reduced pressure:

$$P_r := \frac{315psi}{P_{C,Xe}} \qquad P_r = 0.361 \qquad T_r := \frac{T_{amb}}{T_{C,Xe}}$$

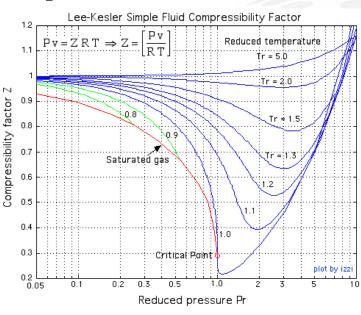
$$T_r := \frac{T_{amb}}{T_{c Xe}}$$

$$T_r = 1.04$$

Compressibility Factor:

from chart for pure gasses shown below

$$Z_{\text{Xe 20bar}} := 0.88$$



ref: A Generalized Thermodynamic Correlation based on Three-Parameter Corresponding States, B.I.Lee & M.G.Kesler, AIChE Journal, Volume 21, Issue 3, 1975, pp. 510-527' (secondary ref. from:http://www.ent.ohiou.edu/~thermo/

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Fig. 6 Compressibility Factor, pure gasses

Number of moles:

molar density

$$n_{Xe} := \frac{P_{MOP} \cdot V_h}{Z_{Xe_20bar} \cdot R \cdot T_{amb}} \qquad n_{Xe} = 18.793 \text{ mol}$$

$$n_{Xe} = 18.793 \text{ mol}$$

$$\rho_{\text{mol}} := \frac{^{\text{n}}\text{Xe}}{V_{\text{h}}}$$

$$\rho_{\text{mol}} := \frac{^{\text{n}}\text{Xe}}{V_{\text{h}}}$$
 $\rho_{\text{mol}} = 0.942 \frac{\text{mol}}{L}$

Weight:

$$W_{Xe} := M_{a Xe} \cdot n_{Xe}$$
 $W_{Xe} = 2.47 \text{ kg}$

$$W_{Xe} = 2.47 \, kg$$

Volume of LXe in reclamation cylinder (at freeze-out)

density:
$$\rho_{LXe} := 3.05 \frac{gm}{mL}$$

$$V_{LXe} := \frac{W_{Xe}}{\rho_{LXe}} \qquad V_{LXe} = 0.809 L$$

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Xenon reclamation cylinder volume

$$V_{rc} := \frac{\pi}{4} \cdot d_{rc}^2 \cdot l_{rc}$$
 $V_{rc} = 5.451 L$

$$V_{rc} = 5.451 L$$

Pressure in Reclamation Cylinder

we need to guess initial value and iterate to find Z. From Lee-Kesler chart above it looks like it could be as low as 0.4, but heated to 50C it could be:

$$\rho_{\text{mol_rc}} := \frac{{}^{n}Xe}{V_{rc}}$$

$$\rho_{mol_rc} \coloneqq \frac{^{n}Xe}{V_{rc}} \qquad \qquad \rho_{mol_rc} = 3.448 \frac{mol}{L}$$

$$P_{rc_guess} := 3 \cdot P_{MOP}$$
 $P_{rc_guess} = 60.2 \, bar$

$$P_{rc\ guess} = 60.2 \, bar$$

$$P_{r_rc} := \frac{P_{rc_guess}}{P_{c_Xe}}$$
 $P_{r_rc} = 1.032$
 $T_{hot} := (273 + 50)K$
 $T_{r_hot} := \frac{T_{hot}}{T_{c_Xe}}$
 $T_{r_hot} = 1.12$

$$P_{r_rc} = 1.032$$

$$T_{hot} := (273 + 50)K$$

$$T_{r_hot} := \frac{T_{hot}}{T_{c_Xe}}$$

$$T_{r_hot} = 1.12$$

from chart above:

$$Z_{Xe_rb_press} := .7$$

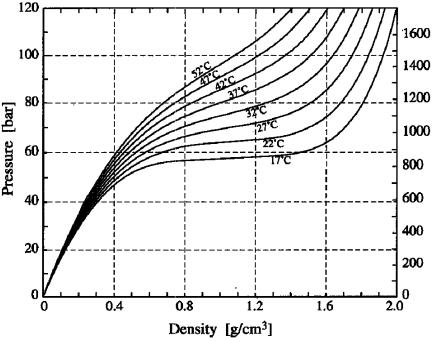
$$P_{rc} := \frac{{}^{n}Xe^{\cdot Z}Xe_rb_press^{\cdot R \cdot T}amb}{V_{rc}} \qquad P_{rc} = 58.4 \text{ bar} \qquad P_{rc} = 873 \text{ psi}$$

$$P_{rc} = 58.4 \, bar$$

$$P_{rc} = 873 \text{ psi}$$

close enough to guess

Alternately, we can use a pressure density curve:



ref: Thermophysical Properties of Neon, Argon, Krypton, and Xenon V.A. Rabinovitch, A.A. Vasserman, V.I Nedostup, L.I. Veksler, Hemisphere Publishing Co (1985) via:

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A Portable Gamma Ray Spectrometer using Compressed Xenon G.J. Mahler, et. al. IEEE Trans. Nuc. Sci. 45(3) p. 1029(1998)

Fig. 7 Pressure-Density Curves for Xenon

$$\text{for } \rho_{mass_rc} \coloneqq \rho_{mol_rc} \cdot M_{a_Xe}$$

$$\rho_{mass_rc} \coloneqq \rho_{mol_rc} \cdot M_{a_Xe} \qquad \qquad \rho_{mass_rc} = 0.453 \frac{gm}{cm^3}$$

we find a maximum pressure of

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$$P_{\text{max rc}} := 63bar$$

$$P_{\text{max_rc}} = 941 \text{ psi}$$

at 50C, which is the maximum temperature we expect to see. The gas purifiers have a maximum temperature of 40C.

Note: The reclamation cylinder will not be heated when condensing out, or when full. It will only be heated as needed to assist in refilling; this will only happen at a low pressure, after the vessel has been mostly refilled. As such it's typical maximum pressure will be determined by the room ambient temperature. Assuming this is 30C:

$$P_{typ_max_rc} := 57bar$$

$$P_{typ_max_rc} = 852 \text{ psi}$$

Stored Energy in Reclamation cylinder

$$U_{rc} := \frac{P_{max_rc} \cdot V_{rc}}{\gamma - 1} \left[1 - \left(\frac{P_l}{P_{max_rc}} \right)^{\frac{\gamma - 1}{\gamma}} \right] \quad U_{rc} = 43 \,\text{kJ} \qquad \text{@50C}$$

4. Vacuum Valve:

Valve is a Carten HF2000 process valve which is designed not only to hold high vacuum, but also to hold high pressure:

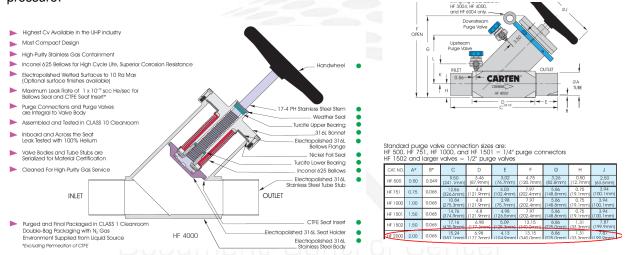


Fig. 8 Carten HF2000 process valve

Fig. 9 Carten HF2000 process valve dimensions

Note: manufacturer has agreed to weld valve to a 4 5/8" CF flange and pressure certify to 350 psig MOP. Nevertheless, here are some calculations. We see that the pressure capability of this valve, in the closed position will be determined by the wall thickness B. From ASME Section VIII UG-27 Thickness of Shells under Internal Pressure:

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(c) Cylindrical Shells. The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2) below.

(1) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed 0.385SE, the following formulas shall apply:

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t} \tag{1}$$

(2) Longitudinal Stress (Circumferential Joints). 16 When the thickness does not exceed one-half of the inside radius, or P does not exceed 1.25SE, the following formulas shall apply:

$$t = \frac{PR}{2SE + 0.4P}$$
 or $P = \frac{2SEt}{R - 0.4t}$ (2)

MAWP

Weld efficiency

$$P_{MAWP} = 350 \text{ psi}$$

$$E_{w} := 0.7$$
 (est.)

Maximum Allowable Stress, 304 stainless steel:

Pipe and Tube:

From ASME Pressure Vessel Code (2007) Section II, Materials

TABLE 1A (CONT'D)

SECTION I; SECTION III, CLASSES 2 AND 3.* SECTION VIII, DIVISION 1; AND SECTION XII

MAXIMUM ALLOWABLE STRESS VALUES 5 FOR FERROUS MATERIALS

(*See Maximum Temperature Limits for Restrictions on Class)

TABLE 1A (CONT'D)

SECTION I; SECTION III, CLASSES 2 AND 3;* SECTION VIII, DIVISION 1; AND SECTION XII

MAXIMUM ALLOWABLE STRESS VALUES SFOR FERROUS MATERIALS

(*See Maximum Temperature Limits for Restrictions on Class)

Alloy Class/ Designation/Condition/ Group Maximum Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metail Temperature, °F, Not Exceeding																								
No. Nomi	nal Composition	Product Form	Spec No.	Type/Grade	UN	S No.	Temper	Size/Thickness, in. P-	No. No.	No.	-20 to 100	150	200	250	300	400	500	600	650	700	750	800	850	900
15 18Cr-8Ni 16 18Cr-8Ni 17 18Cr-8Ni 18 18Cr-8Ni		Smls. & wld. pipe Smls. & wld. pipe Wld. pipe Wld. pipe	SA-312 SA-312 SA-312 SA-312	TP304 TP304 TP304 TP304	\$30400 \$30400 \$30400 \$30400			8 8 8	1 1 1 1	15 16 17 18	20.0 20.0 17.0 17.0		20.0 16.7 17.0 14.2		18.9 15.0 16.1 12.7	18.3 13.8 15.5 11.7	17.5 12.9 14.8 11.0	16.6 12.3 14.1 10.4	16.2 12.0 13.8 10.2	15.8 11.7 13.5 10.0	15.5 11.5 13.2 9.8	15.2 11.2 12.9 9.6	14.9 11.0 12.6 9.4	14.6 10.8 12.4 9.2
			pg.	90						•						pg	. 92							

note: lower 17 ksi values include joint efficiency E= 0.85 (N.A. here)

 $S_{TP304} := 20 ksi$

Flange is fabricated (typically) from 304 plate. Strength of 304 plate, also from Section II, Materials pgs. 90,92:

										Maximum Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding														
Line	e . Nominal Composition	Product Form	Spec No.	Type/Grade	Designation/ UNS No.	Condition/ Temper	Size/Thickness, in.	P-No.	Group No.	No.	-20 to 100	150	200	250	300	400	500	600	650	700	750	800	850	900
1 2 3 4	18Cr-8Ni 18Cr-8Ni 18Cr-8Ni 18Cr-8Ni	Plate Plate Plate Plate	SA-240 SA-240 SA-240 SA-240	302 302 304 304	\$30200 \$30200 \$30400 \$30400			8 8 8	1 1 1	1 2 3 4	20.0 20.0 20.0 20.0		20.0 16.7 16.7 20.0		18.9 15.0 15.0 18.9	18.3 13.8 13.8 18.3	17.5 12.9 12.9 17.5	16.6 12.3 12.3 16.6	16.2 12.0 12.0 16.2	15.8 11.7 11.7 15.8	15.5 11.5 11.5 15.5	 11.2 15.2	11.0 14.9	10.8 14.6

 $S_{304} := 20000 psi$

wall thickness

inner radius

$$t_{neck} = .065in$$
 $R_{i_neck} = 1.0in$

$$t_{neck_min_circ} \coloneqq \frac{P_{MAWP} \cdot R_{i_neck}}{S_{304} \cdot E_w - 0.6 \cdot P_{MAWP}} \qquad \qquad t_{neck_min_circ} = 0.025 \, \text{in} \qquad \text{OK}$$

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$$t_{neck_min_long} := \frac{P_{MAWP} \cdot R_{i_neck}}{2S_{304} \cdot E_w + 0.4P_{MAWP}} \qquad t_{neck_min_long} = 0.012 \text{ in } OK$$

5. Spool

A connecting spool will be attached to the central 2.75" CF integral flange of the 350 psi MOP head. This spool will carry signal and power cabling to a Kimball Physics octagon vacuum chamber (AKA octagon) having (8) 2.75" CF ports. The spool has a 2.75" CF flange on one end and a 6" CF flange on the other end. To prevent additional loading of the tube from impact or handling forces applied to the octagon or attached cabling, the octagon will be secured by an angle bracket to the table top, which is a 3/4" thick aluminum plate. See figs 3,

4. We include moment from static weight of octagon and cabling per subsection UG-22 Loadings:

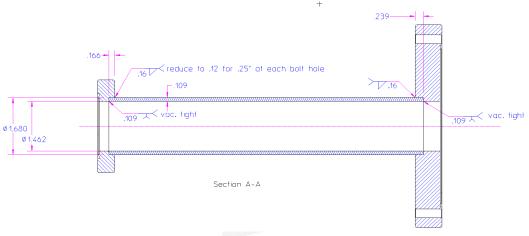


Fig. 10, Spool cross section

Spool Tube

Spool tube is a 1.25" schedule 10S pipe TP304 stainless steel, per ASME SA-312 specification (ASTM A 312) spool tube diameter, length,thickness, inner radius:

$$\begin{aligned} &d_{o_sp_tube} \coloneqq 1.66 in & l_{tube} \coloneqq 9.5 in & t_{sp_tube} \coloneqq .109 in \\ &d_{i_sp_tube} \coloneqq d_{o_sp_tube} - 2t_{sp_tube} & R_{i_sp_tube} \coloneqq 0.5 d_{i_sp_tube} & R_{i_sp_tube} = 0.721 in \end{aligned}$$

First we calculate minimum thickness required for tube to support weight of octagon and cables. This weight load occurs before the angle bracket restraint can be tightened and is "frozen in by the bracket" before pressure is applied. The load produces a bending moment on the tube which is highest where it is welded to the 2.75 in CF flange. This results in a longitudinal stress. We will then add this minimum thickness to that calculated for longitudinal stress due to pressure.

Weights:

octagon cabling and feedthrus CF flanges source insertion tube and flange

$$W_{\text{oct}} := 13 \text{lbf}$$
 $W_{\text{cables}} := 5 \text{lbf}$ $W_{\text{6in CF}} := 5.5 \text{lbf}$ $W_{\text{so tube}} := 2 \text{lbf}$ $l_{\text{oct}} = 0.076 \, \text{m}$

$$W_{cp_tot} := W_{oct} + W_{cables} + 2 \cdot W_{6in_CF} + W_{so_tube}$$

$$M_{sp_tube} := (l_{tube} + 0.5l_{oct}) \cdot W_{cp_tot}$$
 $M_{sp_tube} = 341 lbf \cdot in$

$$I_{\text{sp_tube}} := \frac{\pi}{64} \left(d_{\text{o_sp_tube}}^{4} - d_{\text{i_sp_tube}}^{4} \right) \qquad I_{\text{sp_tube}} = 0.16 \, \text{in}^{4}$$

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$$\sigma_{\text{sp_tube_mom}} := \frac{M_{\text{sp_tube}} \cdot 0.5d_{\text{o_sp_tube}}}{I_{\text{sp_tube}}} \qquad \qquad \sigma_{\text{sp_tube_mom}} = 1763 \text{ psi}$$

Since ASME Pressure Vessel code calculates required thickness, we can perform a similar calculation for the minimum thickness required to withstand the applied bending moment and add this thickness to that require for pressure containment. Using an alternative approximate formula for moment of Inertia, I (using average diameter and thickness):

$$d_{avg_sp_tube} \coloneqq 0.5 \left(d_{i_sp_tube} + d_{o_sp_tube} \right)$$

$$I_{sp_tube2} := \frac{\pi}{16} d_{avg_sp_tube}^{3} \cdot t$$

 $I_{sp_tube2} := \frac{\pi}{16} d_{avg_sp_tube} \cdot t$ Note: Equations (assignments) which have a small black square in their upper right corner are disabled (not active).

$$\sigma := \frac{Mc}{I} \qquad \sigma := \frac{M \cdot c}{\frac{\pi}{16} \cdot d^3 t} \qquad \sigma := S \cdot E$$

Solving for t (we need weld efficiency E): $E_{W_{-}fW} := 0.55$ double fillet weld from Table UW-12 (see weld calc below)

$$t_{sp_tube_M} := \frac{M_{sp_tube} \cdot 0.5d_{avg_sp_tube}}{\frac{\pi}{16}d_{avg_sp_tube}^{3} \cdot S_{TP304} \cdot E_{w_fw}}$$
$$t_{sp_tube_M} = 0.033 \text{ in}$$

Minimum tube thickness required for pressure load, as above, from UG-27:

$$t_{sp_tube_min_circ} \coloneqq \frac{P_{MAWP} \cdot R_{i_sp_tube}}{S_{TP304} \cdot E_{w_fw} - 0.6 \cdot P_{MAWP}} \qquad t_{sp_tube_min_circ} = 0.023 \, \text{in} \qquad \text{OK}$$

$$t_{sp_tube_min_circ} \coloneqq \frac{P_{MAWP} \cdot R_{i_sp_tube}}{S_{TP304} \cdot E_{w_fw} - 0.6 \cdot P_{MAWP}} \qquad t_{sp_tube_min_circ} = 0.023 \, in \qquad \text{OK}$$

$$t_{sp_tube_min_long} \coloneqq \frac{P_{MAWP} \cdot R_{i_sp_tube}}{2S_{TP304} \cdot E_{w_fw} + 0.4P_{MAWP}} \qquad t_{sp_tube_min_long} = 0.011 \, in \qquad \text{OK}$$

Adding the two minimum thicknesses required for longitudinal stress:

$$t_{sp_tube_long_total} := t_{sp_tube_min_long} + t_{sp_tube_M}$$
 $t_{sp_tube_long_total} = 0.044 in$ OK

This total required thickness is greater than that required for circumferential pressure, but still less than actual thickness.

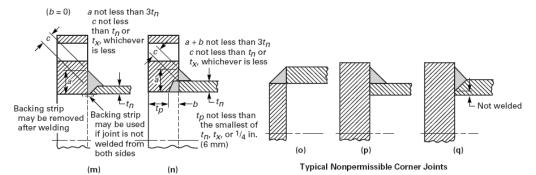
Weld design:

From fig. UW-12 welds on both ends of tube are type 4 double full fillet welds, Category C weld (subsection UW-9 Design of Welded Joints, fig. UW-3) of type (n) below and must conform to rules in the figure

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FIG. UW-13.2 ATTACHMENT OF PRESSURE PARTS TO FLAT PLATES TO FORM A CORNER JOINT (CONT'D)



Typical Bolted Flange Connections c, $t_{\rm II}$, and $t_{\rm X}$ are as defined in 2-3

weld dimensions:

outer

inner

$$h_{osp} := .16in$$

$$\mathsf{h}_{i_sp} \coloneqq .082\mathsf{in}$$

dimensions for fig (n) above:

$$c_{sp} := \frac{\sqrt{2}}{2} h_{o_sp}$$
 $c_{sp} = 0.113 \text{ in}$ $t_{n_sp} := t_{sp_tube}$

$$c_{sp} = 0.113 \text{ ir}$$

$$t_{n_sp} := t_{sp_tube}$$

$$a_{sp} := t_{sp_tube} + h_{o_sp}$$
 $a_{sp} = 0.269 \text{ in}$ $b_{sp} := h_{i_sp}$

$$a_{sp} = 0.269 \, \text{in}$$

$$b_{sp} := h_{i_sp}$$

weld criteria for fig (n) above:

$$c_{sp} = 0.113 \text{ in}$$

$$c_{sp} = 0.113 \, \text{in}$$
 > $t_{n_sp} = 0.109 \, \text{in}$ OK

$$a_{sp} + b_{sp} = 0.351 \text{ in}$$
 > $3t_{n_sp} = 0.327 \text{ in}$

$$3t_{n,sp} = 0.327 \text{ in}$$

OK

CF flange calcs

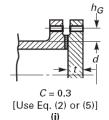
First we consider blank flanges, then consider those with central openings no larger that 0.5D; these are both considered flat unstayed heads. This is the case for the 6 in CF flange of the spool connecting to the octagon, and also for the 6 inch CF flange on the back of the octagon, which will have a central 2.75CF (1.5in dia) opening. From subsection UG-34, Unstayed Flat Heads and Covers:

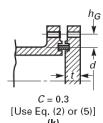
(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE} \tag{1}$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3}$$





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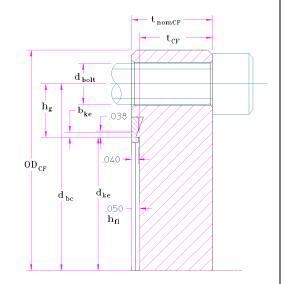
Eq. 2 is applicable, and we can use mathCAD's ability to analyze a large number of CF flanges simultaneously. The following calculations are parallel calculations (not matrix or vector calcs). Read straight across from

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desired flange size, $\mathrm{OD}_{\mathrm{CF}}\,$, in order to find associated quantities:

Fla	ange siz	е	Numb	oer o	f bolts	Knife edge diameter							
	(1.33 \)		(6)	1		(.72						
	1.33 2.125			4			1.09						
	2.75		NI	6			1.65						
	3.375			8			2.20						
OD .	4.5	in		N	8	ن .		3.04	:				
OD _{CF} :=	4.5 4.625	$ ^{\text{In}}$ $ ^{\text{NCF}} = $	$ ^{\text{In}} ^{\text{N}}\text{CF} := $	$^{\text{In}}$ $^{\text{NCF}} = $	$N_{CF} :=$	$^{N}CF :=$	n $^{N}CF := $	$^{\text{in}}$ $^{\text{NCF}} = $	10	10 dke	$d_{ke} :=$	3.35	in
	6			16			4.54						
	8							6.54					
	10			24			8.54						
	13.25)		(30)			11.35						



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Fig. 11 CF (conflat) flange dimensions

Flange size Bolt			It circle	dia. Fla	inge th	ickness	Bolt dia	. He	Height of bolt flange			
	(1.33)	١		(1.062)		(.285)		(.16)	(.05)	
	2.125		1.625		.47	¥	.25		.05			
	2.75		2.312		.5		.3125		.05			
	3.375		2.85		.62		.3125		.05			
OD	4.5		3.628		.68		.3125		.05	i		
$OD_{CF} =$	4.625		a _{bc} :=	4.03		.75	in d _{bolt} :=	.3125	in $h_{fl} := $:= .05	in	
	6			5.128		.78		.3125		.05		
	8			7.128		.88		.3125		.05		
	10	F	9.128		.97		.3125		.05			
	(13.25			12.06		(1.12		.375	81	.05)	

Bolt Load W:

We have several choices here, use the flange mfr.'s recommended bolt torque (T_{CF_MDC}) , a torque found to pull flanges together (T_{CF-ANL} ; see ANL note in Appendix) or use a value bolt torque (T_{rec}) back calculated to withstand the required pressure (times a suitable safety factor) without exceeding ASME allowable flange stress for loose flanges, which the 2.75 OD flange is. This is the controlling configuration, and is treated in the section below for Flanges with Large Central Openings. It turns out that higher torques are not necessarily better, the additional edge moment creates flange stresses higher than allowed. If the joint fully closes (flange faces fully touching under bolts), then the joint design is changed and edge moment is reduced or eliminated, however this is not a reliably achievable condition. The Appendix contains a note testing this method (no pressure tests however). We use this back calculated torque T_{rec} (recommended torque) below by assigning T_{rec} to T_{CF}: Note that under ASME code Section VIII, non mandatory Appendix S-1 certain allowances can be made to use higher than calculated bolt tensions if needed in order to achieve sealing under unusual circumstances. Use of annealed copper gaskets is recommended. Sustituting elastomeric O-rings (Vition, Buna-N, PTFE) is also possible; this eliminates edge moments from tightening. The procedure here will be to start by using annealed Copper gaskets; tightening bolts initially to Trec then leak checking during pressure testing; additional torque is to be used only if necessary. Safety will achieved via the pressure test, and also by noting the previous experience and testing of others as documented in the LLNL Safety Note END 92-072 (in

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Appendix), showing that CF flanges will leak before breaking from pressure loads.

Torques, bolt

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} \text{ in } \quad T_{CF_ANL} := \begin{pmatrix} 40 \\ 163 \\ 163 \\ 197 \\ 217 \\ 190 \\ 217 \\ 246 \\ 260 \\ 330 \end{pmatrix} \text{ from ref. 3, } \quad ANL CF \\ pressure \\ capacity \\ document, \\ torque \\ required to \\ pull CF \\ flanges fully \\ together \end{pmatrix} \quad T_{CF_MDC} := \begin{pmatrix} 7 \\ 12 \\ 15 \\ 15 \\ 15 \\ 15 \\ 15 \\ 15 \\ 26 \end{pmatrix} \text{ lbf} \cdot \text{ft} \quad T_{rec} := \begin{pmatrix} .65 \\ 5 \\ 4 \\ 6.5 \\ 12.5 \\ 9.5 \\ 10.5 \\ 11 \\ 15 \end{pmatrix}$$

Torque Used:

$$T_{CF} := T_{rec}$$

Total Bolt Load:

$$W_{CF} := \frac{\overrightarrow{N_{CF} \cdot 5T_{CF}}}{d_{bolt}}$$

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} \text{ in } W_{CF} = \begin{pmatrix} 1463 \\ 4800 \\ 4608 \\ 9984 \\ 19200 \\ 18240 \\ 29184 \\ 40320 \\ 50688 \\ 72000 \end{pmatrix} \text{ lbf}$$

1.33

Flange Thickness, effective:

effective:
$$t_{CF} := \overline{\left(t_{nomCF} - h_{fl}\right)} \quad OD_{CF} = \begin{bmatrix} 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{bmatrix}$$

$$t_{CF} = \begin{pmatrix} 0.235 \\ 0.42 \\ 0.45 \\ 0.57 \\ 0.63 \\ 0.7 \\ 0.73 \\ 0.83 \\ 0.92 \\ 1.07 \end{pmatrix}$$
 in

1.33

2.125

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radial distance from gasket load center to bolt circle:

$$h_{g} := 0.5 \overline{\left(d_{bc} - d_{ke}\right)} \quad OD_{CF} = \begin{pmatrix} 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} \text{ in }$$

$$h_g = \begin{pmatrix} 0.171 \\ 0.267 \\ 0.331 \\ 0.325 \\ 0.294 \\ 0.34 \\ 0.294 \\ 0.294 \\ 0.294 \\ 0.355 \end{pmatrix}$$
 in

$$E := 1$$
 $C_j := 0.3$

Solving for pressure in eq (2) above:

$$P_{j} \coloneqq \frac{S_{304} \cdot E}{C_{j}} \left(\frac{t_{CF}^{2}}{d_{ke}^{2}} - \frac{1.9 \cdot W_{CF} \cdot h_{g}}{S_{304} \cdot E \cdot d_{ke}^{3}} \right)$$

$$P_{j} = \begin{vmatrix} 2808 \\ 2545 \\ 1591 \\ 1866 \\ 1143 \\ 805 \\ 622 \end{vmatrix} psi$$

2858

3619

All pressures are greater than:

$$P_{MAWP} = 350 \text{ psi}$$

so all CF blank flanges are suitable for use, when torqued to $T_{\rm rec}$

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CF gasket calculations

From Appendix 2 Section VIII-Div. 1 Rules for Bolted Flange Connections with Ring type Gaskets subsection 2-5, <u>Bolt Loads:</u>

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The required bolt load for the operating conditions W_{m1} is determined in accordance with eq. (1).

$$W_{m1} = H + H_p$$

= 0.785 $G^2P + (2b \times 3.14GmP)$ (1)

(2) Before a tight joint can be obtained, it is necessary to seat the gasket or joint-contact surface properly by applying a minimum initial load (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load required for this purpose W_{m2} shall be determined in accordance with eq. (2).

$$W_{m2} = 3.14bGy \tag{2}$$

where G is the gasket diameter

for flat copper gaskets (from Table 2-5.1):

$$m_{\text{Cu_flat}} := 4.75$$
 $y_{\text{Cu_flat}} := 13000 \text{psi}$

effective width b is taken to be 80% of the width of the interference (.0384 in) of the knife edge (to allow for less than full joint closure) and the gasket (.08" thk.):

 $b_{ke} \coloneqq 80\% \cdot .0384 \text{ in. measured from 2.75 in flange MDC CAD model; assume same for all flanges}$

 $b_{ke} = 0.031 in$

 $G := d_{ke} + 2b_{ke}$ outer diameter of effective compressed gasket area

solving eq (1) above for maximum pressure, (in two stages, to allow concurrent calculation)

$$p_{m1} := \frac{1}{\left(0.785G^2 + 2\pi b_{ke} \cdot m_{Cu_flat} \cdot G\right)}$$

$$P_{m1} := \overrightarrow{(p_{m1} \cdot W_{CF})}$$

and eq(2):

$$W_{m2} := 3.14b_{ke} \cdot G \cdot y_{Cu_flat}$$

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} \text{ in } P_{m1} = \begin{pmatrix} 1223 \\ 2290 \\ 1191 \\ 1640 \\ 1847 \\ 1487 \\ 1400 \\ 1001 \\ 768 \\ 639 \end{pmatrix} \text{ psi } W_{m2} = \begin{pmatrix} 980 \\ 1444 \\ 2146 \\ 2836 \\ 3889 \\ 4278 \\ 5770 \\ 8278 \\ 10786 \\ 10786 \\ 14310 \end{pmatrix} \text{ lbf } \text{ compare--> } W_{CF} = \begin{pmatrix} 1463 \\ 4800 \\ 4608 \\ 9984 \\ 19200 \\ 18240 \\ 29184 \\ 40320 \\ 50688 \\ 72000 \end{pmatrix}$$

We see that the gasket preloading requirement W_{m2} is easily exceeded by the actual preload W_{CF} , and that the gaskets can theoretically hold far higher pressure than necessary (350 psi).

CF Blank Flange maximum opening diameter:

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UG-39(b) Single and multiple openings in flat heads

that have diameters equal to or less than one-half the head diameter may be reinforced as follows:

UG-39(b)(1) Flat heads that have a single opening with a diameter that does not exceed one-half the head diameter or shortest span, as defined in UG-34, shall have a total cross-sectional area of reinforcement for all planes through the center of the opening not less than that given by the formula

$$A = 0.5dt + tt_n (1 - f_{r1})$$

where d, t_n , and f_{r1} are defined in UG-37 and t in UG-34.

The 2.75 inch CF flange of the spool does not meet the above requirement, and is considered a loose flange, in a subsequent section. Nevertheless it is useful at this point to check to see if flanges that meet the requirement above are adequately reinforced for MAWP. Assume in formula above, that nozzle thickness is zero. First we determine minimum thickness required: t (here t_{min}). From subsection UG-34:

from sketches (j), (k) C := 0.3

weld efficiency: E := 1 (assume stock flanges only

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE}$$
 (1)

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3}$$
 (2)

$$t_{min_CF} \coloneqq \left(OD_{CF} \cdot \sqrt{\frac{C \cdot P_{MAWP}}{S_{304} \cdot E} + \frac{1.9W_{CF} \cdot h_g}{S_{304} \cdot E \cdot OD_{CF}}^3} \right)$$

minimum flange thickness

thickness available for reinforcement

$$t_{min_CF} = \begin{pmatrix} 0.165 \\ 0.285 \\ 0.304 \\ 0.389 \\ 0.475 \\ 0.49 \\ 0.57 \\ 0.69 \\ 0.816 \\ 1.051 \end{pmatrix} \text{ in } t_{CF} - t_{min_CF} = \begin{pmatrix} 0.07 \\ 0.135 \\ 0.146 \\ 0.181 \\ 0.155 \\ 0.21 \\ 0.16 \\ 0.14 \\ 0.104 \\ 0.019 \end{pmatrix} \text{ in }$$

Area available for reinforcement

$$A_{rein_CF} := \overline{\left[0.5 \cdot OD_{CF} \cdot \left(t_{CF} - t_{min_CF}\right)\right]}$$

A_{rein_CF} =

0.047

0.144

0.201

0.306

0.1990.349 0.342 0.487 0.446 0.48 0.537 0.558

 $d_{i_max_CF} \coloneqq \frac{A_{rein_CF}}{\iota}$

Maximum central opening diameter:

Note that the above bolt torques, calculated to give maxim allowable flange stress, essentially "use up" the reserve thickness in the flange so that only small central openings are permitted. These torques can be modified if needed to give larger central openings.

d_{i max CF} = 0.518 0.695 0.125 0.658 0.672

> 0.563 0.117

0.554

in

CF flanges with large central openings (ID>0.5OD):

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For the small 2.75 inch flange on the spool (or for any central opening larger than that computed above) we consider this as a loose flange, per mandatory Appendix 2 of Section VIII- Div. 1, Rules for Bolted Flange Conections with Ring-type Gaskets, subsection 2-4 Circular Flange Types, as the attached tube does not contribute any strength to the flange. From subsection 2-6 Flange Moments:

$$M_0 := W \cdot \frac{(C - G)^{\bullet}}{2}$$
 $M_0 := \overline{(W_{CF} \cdot h_g)}$

$$\mathbf{M}_0 \coloneqq \overrightarrow{\left(\mathbf{W}_{\mathbf{CF}} \cdot \mathbf{h}_{\mathbf{g}}\right)}$$

$$M_0 = \begin{pmatrix} 1284 \\ 1525 \\ 3245 \\ 5645 \\ 6202 \\ 8580 \\ 11854 \\ 14902 \\ 25560 \end{pmatrix}$$
 lbf·in

250

Flange Stresses:

From mandatory Appendix 2, subsection 2-7 Flange Stresses:

First, compute several factors:

$$A := OD_{CF} \quad A = \begin{bmatrix} 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \end{bmatrix}$$

10

13.25

$$ID_{CF} := \begin{vmatrix} 1\\ 1.75\\ 2\\ 2.5\\ 3\\ 4\\ 6\\ 8 \end{vmatrix} in$$

.625

10.75

$$B := ID_{CF} \quad B = \begin{vmatrix} 1.75 \\ 2 \\ 2.5 \\ 3 \\ 4 \\ 6 \\ 8 \end{vmatrix}$$
 in

(2.726)

0.625

1

10.75

$$K := \frac{\overset{\longrightarrow}{A}}{B}$$

$$K = \begin{bmatrix} 1.571 \\ 1.688 \\ 1.8 \\ 1.542 \\ 1.5 \\ 1.333 \\ 1.25 \end{bmatrix}$$

1.233

(2.128)

2.125

$$Y := \left[\frac{1}{K - 1} \left[0.66845 + 5.717 \cdot \left(\frac{K^2 \cdot \log(K)}{K^2 - 1} \right) \right] \right]$$

$$Y = \begin{bmatrix} 2.731 \\ 4.47 \\ 3.885 \\ 3.474 \\ 4.659 \\ 4.961 \\ 6.903 \\ 8.83 \\ 9.406 \end{bmatrix}$$

Bolt Torque used:

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19751 1.33 Flange Stresses (eqs. 9): 19878 2.125 19240 2.75 $S_{304} = 2 \times 10^4 \text{ psi}$ Tangential: 19398 3.375 $S_T < S_{304}$ OK OD_{CF} = 19764 4.5 19657 4.625 19969 6 Radial and Axial stresses = 0 19798 8 19433 10 19534 13.25

6. Kimball Physics Octagon

This is a 304 stainless steel machined octagonal vacuum chamber. It has eight 2.75 in CF ports, which will be used for feedthroughs and as above, we use subsection UG-27:

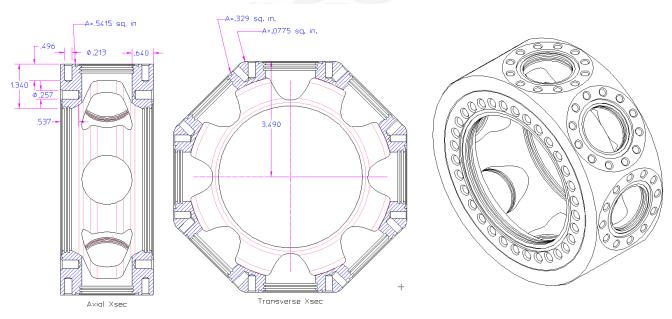


Fig. 12 Kimball Physics octagonal vacuum chamber ("octagon")

Areas, minimum of half cross sections:

$$A_{circ} := 2.0.5415in^{2} \qquad A_{circ} = 1.083 in^{2} \qquad A_{long} := 4.(0.329 + 0.0775) in^{2} \qquad A_{long} = 1.626 in^{2}$$



Fig. 13, section area measurements, octagon

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Radii:

$$R_{i_oct} := 3.5in$$

note: this is largest radius (at the 2.75 in CF flanges)

Equivalent thicknesses (by dividing out radius)

$$t_{oct_circ} := \frac{A_{circ}}{R_{i_oct}} \qquad t_{oct_circ} = 0.309 \text{ in}$$

$$t_{oct_long} := \frac{A_{long}}{R_{i_oct}} \qquad t_{oct_long} = 0.465 \text{ in}$$

$$t_{\text{oct_long}} := \frac{A_{\text{long}}}{R_{\text{i_oct}}}$$
 $t_{\text{oct_long}} = 0.465 \text{ in}$

Weld Efficiency:

$$E = 1$$
 machined, not welded

Minimum equivalent thicknesses:

$$t_{oct_min_circ} \coloneqq \frac{P_{MAWP} \cdot R_{i_oct}}{S_{304} \cdot E - 0.6 \cdot P_{MAWP}} \qquad t_{oct_min_circ} = 0.062 \, \text{in} \quad \text{compare -->} \quad t_{oct_circ} = 0.309 \, \text{in}$$

$$t_{oct_min_long} \coloneqq \frac{P_{MAWP} \cdot R_{i_oct}}{2S_{304} \cdot E + 0.4P_{MAWP}} \qquad t_{oct_min_long} = 0.031 \, \text{in} \quad \text{compare -->} \quad t_{oct_long} = 0.465 \, \text{in}$$

7. Source Tube

This is a closed end tube welded to a 2.75 " CF flange for the purpose of introducing a small radioactive source into the chamber without opening up the vessel. The vessel pressure acts on the end and outer diameter of the tube, thus tube buckling is a possible failure mode. We use subsection UG-28 Thickness of Shells and Tubes Under External Pressure:

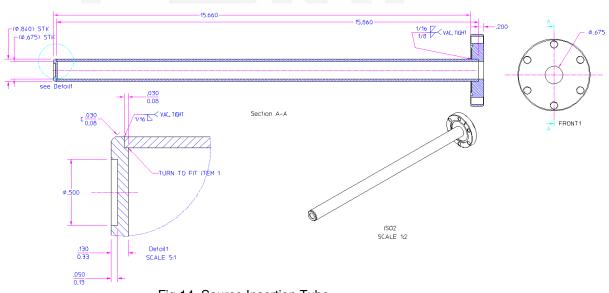


Fig 14, Source Insertion Tube

Tube is a 1/2 in. schedule 10S, ASME SA312 TP304 stainless pipe

$$D_{o st} := .84in$$
 $L_{st} := 16in$ $t_{st} := .083in$

External pressure, maximum: $P_{st} := -P_{MAWP}$

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The maximum allowable working external pressure is determined by the following procedure:

Compute the following two dimensionless constants:

$$\frac{L_{st}}{D_{o,st}} = 19$$

$$\frac{D_{o_st}}{t_{st}} = 10$$

From the above two quantities, we find, from fig. G in subpart 3 of Section II, the factor:

$$A_{st} := .012$$

Using the factor A in the applicable material (304 S.S.) chart (HA-1) in Subpart 3 of Section II, Part D, we

$$B_{st} := 14000 psi$$

FIG. G GEOMETRIC CHART FOR COMPONENTS UNDER EXTERNAL OR COMPRESSIVE LOADINGS (FOR ALL MATERIALS) [NOTE (14)]

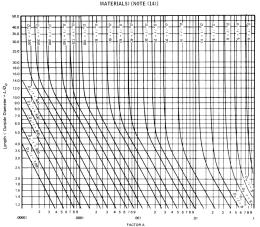
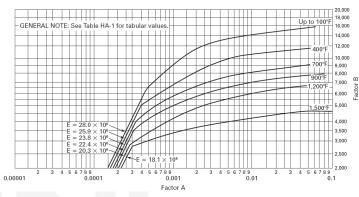


FIG. HA-1 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE DEVELOPED FOR AUSTENITIC STEEL 18Cr-8N; TYPE 304



The maximum allowable working external pressure is then given by:

$$P_{\text{max_st}} := \frac{4B_{\text{st}}}{3\left(\frac{D_{\text{o_st}}}{t_{\text{st}}}\right)} \qquad P_{\text{max_st}} = 1844 \, \text{psi} \quad \text{(external)}$$

$$P_{max_st} = 1844 \, psi$$
 (external)

 $P_{\text{max st}} > 1.5 P_{\text{MAWP}}$

so the source tube is safe from buckling under test pressure load

There is a bending moment on the tube where welded to the flange from the weight of the source collimator

Tube weight:

$$W_{st} := \rho_{SS} \cdot \pi \cdot D_{o_st} \cdot t_{st} \cdot L_{st} \cdot g \qquad \rho_{SS} := 8 \frac{gm}{cm^3} \qquad W_{st} = 1.013 \, lbf$$

$$o_{SS} := 8 \frac{gm}{m}$$

$$W_{st} = 1.013 \, lbf$$

Collimator is either tungsten (19.3 gm/cc) or hevimet (19gm/cc). Maximum possible dimensions:

$$l_{col} := L_s$$

$$d_{col} := D_{o_st} - 2t_{st}$$

$$d_{col} = 0.674 \, \text{in}$$

$$l_{col} := L_{st}$$
 $d_{col} := D_{o_st} - 2t_{st}$ $d_{col} = 0.674 \text{ in}$ $\rho_W := 19.3 \frac{\text{gm}}{\text{cm}^3}$

Weight of collimator:

$$W_{col} := \frac{\pi}{4} d_{col}^2 \cdot l_{col} \cdot \rho_{W} \cdot g$$
 $W_{col} = 3.98 \, lbf$

$$W_{col} = 3.98 \, lbf$$

Moment on tube

Moment of Inertia, source tube

$$\mathbf{M_{st}} \coloneqq \mathbf{W_{col}} \cdot \left(\mathbf{L_{st}} - 0.5 \mathbf{I_{col}} \right) + \mathbf{W_{st}} \cdot 0.5 \mathbf{I} \, \mathbf{M_{st}} = 39.9 \, \text{lbf} \cdot \text{in} \qquad \quad \mathbf{I_{st}} \coloneqq \frac{\pi}{64} \left(\mathbf{D_{o_st}}^4 - \mathbf{d_{col}}^4 \right) \qquad \quad \mathbf{I_{st}} = 0.014 \, \text{in}^4 + 1.00 \, \text{in}^4$$

$$I_{st} := \frac{\pi}{64} \left(D_{o_st}^{4} - d_{col}^{4} \right) \qquad I_{st}$$

$$I_{st} = 0.014 \, \text{in}^4$$

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(1)

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Stress, bending:

$$\sigma_{st} \coloneqq \frac{M_{st} \cdot 0.5 D_{o_st}}{I_{st}} \qquad \qquad \sigma_{st} = 1172 \, psi \qquad \quad \text{negligible}$$

Axial Compressive Stress on tube:

The tube is relatively long and may be subject to Euler buckling. ASME code treats this as an alternate maximum allowable stress, rather than a maximum loading. From subsection UG-23 Maximum Allowable Stress Values, maximum allowable axial compressive stress, is smaller of :

S, from above (20 ksi) or:

B, as computed below

First, determine minimum required thickness (not sure why actual thickness is not used here):

$$t_{st\ min} := .023in$$
 found using external presssure formula above for 500 psi (test pressure)

Then, determine the quantity:

$$A_{stl} := \frac{0.125}{\left\lceil \frac{\left(0.5D_{o_st}\right)}{t_{st_min}} \right\rceil} \qquad A_{stl} = 0.007$$

From Subpart 3 of Section II, Part D, chart HA-1:

$$B_{st\ max} := 13500psi$$

Actual compressive stress (at test pressure of 1.5x MAWP):

$$\sigma_{st_ax} := \frac{1.5P_{MAWP} \cdot D_{o_st}}{4t_{st}} \qquad \sigma_{st_ax} = 1328 \, psi \qquad \text{OK}$$

Welds are nonstructural, and do not carry pressure loads (other than vacuum); they are primarily for sealing. Window stress (mtl:304SS):

From subsection UG-34, Unstayed Flat Heads and Covers:

$$t_W := 1.5 \text{mm}$$
 $R_W := .25 \text{in}$ (2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula: $t_W = 0.7$ (outside HAZ, but use any)

$$E_{\rm W}$$
 = 0.7 (outside HAZ, but use any)
$$t = d\sqrt{CP/SE}$$

$$t_{\rm min_W} \coloneqq 2R_{\rm W} \cdot \sqrt{\frac{C \cdot P_{\rm MAWP}}{S_{304} \cdot E_{\rm W}}} \qquad t_{\rm min_W} = 1.1 \, {\rm mm} \qquad {\rm OK}$$

Fig. 15. Gas system (same as fig. 5)

Description:

This TPC (Time Projection Chamber) gas system is designed to circulate Xenon gas, through the pressure vessel and a purifier system at various pressures up to 300psig MOP (225 psig MOP initially with Ceramtec SHV-20 feedthroughs installed). It also includes a cryogenic Xenon reclamation section, as described previously. The AHD will initially specify only an 250psig MAWP (225psig MOP) with these feedthroughs, then it will be updated to the higher pressure MAWP (= 350 psig) only when these feedthroughs are replaced with higher pressure rated feedthroughs.

The gas system can be divided into 5 subsections, each having different MAWPs:

- 1.Gas supply subsystem MAWP =3500 psig (or gas cyl burst disk pressure)
- 2. Vacuum subsystem MAWP= 10 psig.
- ${\it 3. Pressure \ vessel\ and\ purifier\ downstream\ subsection,} MAWP\ as\ above$

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4. Purifier upstream subsection; this MAWP is set 100 psi higher than the pressure vessel since Pump1 can deliver 130 psi maximum differential pressure if downstream flow is blocked; we desire not to vent Xenon gas should this occur (pump operated erroneously with [V3+V5+(V6 or V7)+(V8 or V9)] all closed.

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5. Reclamation subsystem, MAWP =1500 psig

Operations

In operation, the procedures are sequential, unless otherwise indicated. There are steps inserted for checking valve status, **Valves** listed in **bold red** are **closed**; Valves listed in nonbold green are open. Note that there is no V4 or V11; these valves were present in an earlier draft configuration and have been removed. Valves have not been renumbered to avoid confusion.

1. Complete system pump-down

- a. Close V1, V2 and V10. Open R1, R2, and R3 one turn each.
- b. Open V5, V13-V16, V18. DO NOT open V6-V9.
- c. V1 V2 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- d. Turn on the backing pump and convectron gauge controller
- e. When the convectron gauge reads < 1e-2 torr, turn on the turbo pump and cold cathode gauge controller. Open V3 and V12.
- f. When the cold cathode gauge reads < 5e-5 torr, open V17 and turn on the RGA.
- g. If the system pressure and RGA scan are acceptable, turn off the RGA. If not, continue to pump until the pressure improves to an acceptable level.
- h. Close V3, V13-V18. Back off R1, R2, and R3.
- i. Turn off pumps and controllers.
- j. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- k. Proceed to step 3.

2. System pump-down with xenon in the Xenon reclamation cylinder

- a. Close V1, V2 and V10. Open R1, R2, and R3 one turn each.
- b. Open V5, V12-V13, V16, V18. DO NOT open V6-V9.
- c. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- d. Turn on the backing pump and convectron gauge controller
- e. When the convectron gauge reads < 1e-2 torr, turn on the turbo pump and cold cathode gauge controller. Open V3.
- f. When the cold cathode gauge reads < 5e-5 torr, open V17 and turn on the RGA.
- g. If the system pressure and RGA scan are acceptable, turn off the RGA.
- h. Close V3, V13, V16 and V17. Back off R1 and R2.
- i. Turn off pumps and controllers.
- j. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- k. Proceed to step 3.

3. Argon purge

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Back off R1. Open V1.
- c. Set R1 to 20psig.
- d. Open V4.
- e. Wait for P3 to read > 5 psi. Open V10 1/4 turn. Argon will bleed out the 5psig relief.
- f. Wait 5 minutes, then close V10.
- g. Start Pump1.
- h. Once P3 reads 20psi, close V1 and V4. Back off R1.
- i. Continue pumping for desired interval.
- j. Turn off Pump1.
- k. Open V10 to vent argon.
- I. When P3 reads < 6psi, close V10, V12.
- m. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- n. Proceed to step 4

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4. Post-purge pump-down

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Check that P3 reads < 6psi. Open V10 to relieve pressure. Close V10 when done.
- c. Open V4 and crank down R1 1 turn.
- d. Start the backing pump and convectron gauge controller.
- e. Slowly open V16.
- f. When the convectron gauge reads < 1e-2 torr, turn on the turbo pump and cold cathode gauge controller.
- g. When the cold cathode gauge reads < 5e-5 torr, open V17 and turn on the RGA.
- h. Close V4 and back off R1.
- i. If the system pressure and RGA scan are acceptable, turn off the RGA, close V16 and V17.
- j. Turn off pumps and controllers.
- k. V1 V2 V3 V4 V5 V6 V7 V8 V9 V10 V11 V12 V13 V14 V15 V16 V17 V18 V19
- I. If the partial pressures are not acceptable, repeat procedure from step 3.
- m. If the Xenon reclamation cylinder is filled, proceed to step 6.

5. Xenon reclamation cylinder fill procedure

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Back off R2. Open V2 and V12.
- c. Open V13, V14, and V18. Check that V10 is closed. Check that V5 is open.
- d. Slowly set R2 to 200psig.
- e. Read the gas temperature at the TC. When T > 15 deg C, continue to next step.
- f. Slowly set R2 to 300psig (225psig initial)
- g. Once P3 reads 300psig (225psig initial), close V2 and back off R2.
- h. Chill C1 with LN until P4 bases out.
- i. Close V14.
- j. Open V2. Slowly set R2 to 50 psig.
- k. Check P5 is based out.
- I. Once P3 reads 50 psig, close V2, and back off R2.
- m. Open V14.
- n. Continue to chill C1 with LN until P4 bases out.
- o. Close V13, V14 and V18. Stop chilling C1.
- p. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- q. Proceed to step 6.

6. Chamber fill from Xenon reclamation cylinder

- a. V1 V2 V3 V4 V5 V6 V7 V8 V9 V10 V11 V12 V13 V14 V15 V16 V17 V18 V19
- b. Back off R3. Check that V18 is closed. Open V14.
- c. If P5 < 300psig (225psig initial) at any point in step 6, turn on heat to C1.
- d. Once P5 > 300psig (225psig initial), set R3 to 200psig(150psig initial); turn off C1 heat.
- e. Open V13.
- f. Open V5.
- g. When P3 reads 200psig, close V13.
- h. Check the temperature at the TC. When T > 15 deg C, continue
- i. Set R3 to 300psig (225psig initial).
- j. Open V13.
- k. When P3= 300psig (225psig initial), close V13 and V14.
- I. Back off R3.
- m. TPC is ready to operate.
- n. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19

7. TPC operation

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Start pump1; set to desired flow rate
- c. Open V6,V7 or V8,V9 as needed to control flow and purification (usually close V5 but may be left open)
- d. Monitor total flow with FM1. Adjust pump controller as required.

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- e. Log flow and pressure at P4, if desired.
- f. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19 (V8,V9 may be open instead of V6,V7)

8. TPC shutdown

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19(V8, V9 may be open instead of V6, V7)
- b. Stop pump1
- c. Close V6-V9, Open V5.
- d. Stop data logger.
- e. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19

9. Cryogenic Xenon reclamation from TPC

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Open V13, V14, V18. Check V5 and V12 are open. Check R3 is fully backed off.
- c. Chill C1 with LN.
- d. Once P4 bases out, operate Pump1 (to rattle piston valves, hopefully releasing gas trapped between Pump1 and CV1); check for pressure spike; allow to base out.
- e. Close V13, V14, V18.
- f. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19

10. Let-up TPC to Argon

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Back off R1. Open V1.
- c. Slowly open R1 to 2 psig.
- d. When P3 > 2 psig, close V1. Back off R1 until desired purge gas flow is achieved.
- e. Open V10. Leave open during servicing.
- f. Proceed with service or disassembly of TPC. When removing lid, leave 1 main flange bolt loosely in place until lid is fully separated from vessel, and any residual pressure is vented.
- g. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19

11. Replacement of Argon gas supply cylinder

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Make certain V1 is closed. Back off R1.
- c. Disconnect R1 from Ar cylinder.
- d. Connect new Ar cylinder to R1.
- e. Crank down R1 1 turn.
- f. Open V3.
- g. Start backing pump and convectron gauge.
- h. When the convectron gauge reads < 1e-2 torr, turn on the turbo pump and cold cathode gauge controller.
- i. When the cold cathode gauge reads < 5e-5 torr, close V3 and turn off pumps.
- j. Back off R1.
- k. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19

12. Replacement of Xenon gas supply cylinder

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Make certain V2 is closed. Back off R2.
- c. Disconnect R2 from Xe cylinder.
- d. Connect new Xe cylinder to R1.
- e. Crank down R2 1 turn.
- f. Open V3
- g. Start backing pump and convectron gauge
- h. When the convectron gauge reads < 1e-2 torr, turn on the turbo pump and cold cathode gauge controller.
- i. When the cold cathode gauge reads < 5e-5 torr, close V3 and turn off pumps.
- j. Back off R2.
- k. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19

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13. Reclamation of Xenon back into Xenon gas supply cylinder (at end of experiment, or to repair or reconfigure reclamation gas subsystem; assume entire system is filled with Xe and reclamation cyl. C1 is not isolatable)

- a. V1 V2 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19
- b. Back off R2. Open V2. Check that V5 and V12 are open.
- c. Chill Xe supply cyl. with LN until P3, P4 and R2 high side bases out. Maintain LN temp.
- d. Open V13, V18, and V14. Wait until P3, P4 and R2 high side base out. Maintain LN temp.
- e. Start Pump1 (to rattle piston valves, hopefully releasing gas trapped between Pump1 and CV1).
- f. Close V2, V5, V12, V13, V18, V14. Plug high side of R2.
- g. Back off and disconnect R2 from Xe cylinder.
- h. V1 V3 V5 V6 V7 V8 V9 V10 V12 V13 V14 V15 V16 V17 V18 V19

Relief Valve Capacity

There are no operating conditions whereby a sudden pressure rise can occur, such as a sudden release of energy leading to rapid gas heating, or loss of insulating vacuum. We consider some extraordinary circumstances:

Pressure Rise under Gas Cylinder Regulator Failure

This is probably the most credible mechanism for accidental overpressure (someone accidently screws a regulator all the way in, then opens a valve downstream) Regulators are Matheson Dual Stage High Purity Stainless Steel, model 3810:

maximum flow rate (@2500 psi N2 inlet pressure)

$$Q_{reg} := 300SCFH$$
 $Q_{reg} = 5SCFM$

Pressure Relief valve is a Swagelok R4. From relief valve catalog ms-01-141.pdf, flow curves are:

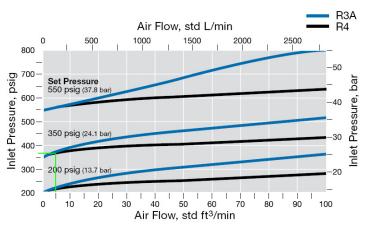


Fig 16. Pressure Relief Pressure Drop

For a set pressure of 350 psig, and a flow rate Q_{req}, we find (green lines) an inlet pressure of:

P_{inlet} := 370psi ASME Boiler and Pressure Vessel Code, Section VIII subsection UG-125 <u>Overpressure Protection</u> subsection (c) calls for (in this case) a maximum of 10% vessel overpressure under relief condition.

$$\frac{P_{\text{inlet}}}{350 \text{nsi}} - 1 = 5.7 \%$$
 OK

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		<u> </u>	n parts list	Pressure
ID	MFR. Part Nun	nber lex	Note/Product Description	rating (psi
1.0	Swagelok		Total Towns Door No	ranning (por
V3,V4,V10,V1		1/2" va	lve Female VCR	1000
" (mixed)	SS-8BG-VCR-VD		lve Male VCR	1000
(IIIIXCO)	SS-R4M8F8-SC1		valve .25 orifice	6000
	SS-4R3A5		valve .14 orifice	6000
	177-R3A-K1-A		O psi spring kit for line 6	-
	177-R3A-K1-A		osi spring kit for line 6	_
	177-13K-R4-A	0-350	osi spring kit for line 5	
	SS-FM4RM4RF4	-12 1///" \//	CR hose M/F fittings 12" lg	3100
3	SS-4-VCR-7-8VC		1/4" VCR reducing adapter	14300
	SS-8-WVCR-6-DI		CR close coupling	5800
	SS-8-VCR-T-SC1			10900
	Ni8-VCR-2-SC1		g plated Ni VCR gasket	10300
<u> </u>	Ni-4-VCR-2-SC11		g plated Ni VCR gasket g plated Ni VCR gasket	-
	SS-8-VCR-CP-S0		g plated Ni VCR gasket CR cap	
	SS-8-VCR-P-SC1		CR plug	
	SS-8-VCR-9-SC1		CR elbow	10900
	SS-4-VCR-2-4-S(CR elbow	14300
! Filter	SS-6TF2-15-SC1		ron TF type filter 3/8 MPT	
			T to 1/2" VCR female connector	3000 5300
1	SS-8-VCR-7-6-S0		T to 1/2 VCR female connector	4900
;	SS-8-VCR-7-8-S0			
<u> </u> 	SS-4-VCR-1-4-S0		T to 1/4" VCR male connector	8000
	SS-8-VCR-4-SC1		CR Male tube nut	-
	SS-8-VCR-1-SC1		CR female tube nut	-
3	SS-4-VCR-4-SC1		CR Male tube nut	-
	SS-4-VCR-1-SC1		CR female tube nut	-
	SS-8-VCR-3-SC1		CR socket weld	3000
	SS-6-VCR-3-SC1		CR socket weld 3/8 tube	8200
2	SS-FM4RF4RF4-		CR hose F fittings 36" Ig	3100
	SS-FM4RM4RF4		CR hose M/F fittings 48" Ig	3100
	SS-FM4RF4RF4-		CR hose F fittings 24" Ig	3100
	SS-6-RB-4-SC11		T to 1/4 NPT reducing bushing	3000
	6LV-8-VCR-3S-41		R to 1/4" tube reducing gland	5100
	-		x .035W 316SST Tubing	2936
	-		x .035W 316SST Tubing	4375
	SS-8-VCR-CS		CR cross	10900
	SS-4-WVCR-1-4		T male to 1/4 VCR female	10200
	SS-4-VCR-T	1/4" √0		14300
!	SS-4-VCR-CS		CR cross	14300
V13-V15,V18	SS-DSV51		CR diaphragm valve	2500
	SS-4-WVCR-7-4		m VCR to 1/4 fem NPT	6600
	SS-8-VCR-3-4TS		R to 1/4" tube reducing gland	13600
	SS-4-VCR-3	1/4 VC	R socket weld gland	5500
	SS-8-VCR-6-DM-		male VCR reducing union 1/2 to 1/4	10900
	SS-4-VCR-7-4		le VCR to 1/4" NPT female	6600
	SS-4-VCR-1-0003		le VCR to 9/16-18 adapter	14300
	SS-8-VCR-1-0108		le VCR to 9/16-18 adapter	15000
	SS-4-VCR-3-4TA	1/4 swa	age to 1/4 VCR gland	10200
	McMaster-Carr			
P1,P2	4066K418		osig dry gauge	600
P3	4005K48		sig dry gauge	400
P5	3852K24		psig dry gauge	2000
	Acme Cryogenics (for L			
C1	C1 C1		condensation cylinder	3000
3	Pump Works Inc.		-	

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	1				
60		SAE	S Pure Gas inc.		
61			HP190	inert gas purifier	1000
62			MC50	inert gas purifier	1000
63	V5-V9			valves supplied w/ above purifiers	1000
64		Carte	n		
65	V16		HF2000	2" straight thru valve	350
66		Math	eson		
67	R1-R3		3818-580	15-350 psi regulator with G type inlet	3500
68		Ome	ga		
69	FM1, FM2		FMA1818	flowmeter 5slpm	500
70	Р		MMG500V10P3C0T3A6	500 psig pressure transducer	500
71	TC		EI1202105/TC-K-NPT-U-72/3"	Pipe plug TC probe	2500
72		Cerar	mtec		
73			18088-01-CF	SHV-20 Coaxial feedthrough, 1.33" CF flange	250
74			8880-02-CF	SHV-5 Coaxial Feedthrough, 1.33" CF flange	1400
75			18898-01-CF	Multipin feedthrough 2.75" CF flange, 32 pin	375

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9. Test Procedures

9.1 Pressure Vessel and 350 MOP Head

These components have been tested at LLNL to higher pressures than used here. No retesting is needed, as there are no corrosive gasses or other materials used, and the vessel and lid have not been modified. Any minor modifications, such as rewelding a VCR fitting to the Vessel will require a retest. MESN-99-020-OA does not specify any retesting requirement. Since no cryogens are used, the vessel and head may be retested using a hydrostatic test in accordance with ASME Boiler and Pressure Vessel Code Section VIII, subsection UG-99 <u>Standard Hydrostatic Test</u>. Test pressure is 1.5x MAWP= 525 psig. Nevertheless, this component will be further tested, in its installed configuration, along with the gas system test at a test pressure of 1.25x MAWP = 438psig (313 initial).

9.2 Spool

This component will be hydrostatically tested by the manufacturer in accordance with ASME Boiler and Pressure Vessel Code Section VIII, subsection UG-99 <u>Standard Hydrostatic Test</u>, and tagged by the manufacturer, and may be used as received. Nevertheless, this component will be further tested, in its installed configuration, along with the gas system test at a test pressure of 1.25x MAWP = 438psig (313 initial).

9.3 Octagon

This component is not rated for pressure by the manufacturer, though the manufacturer does supply pressure rating recommendations. It shall be tested by either a certified pressure installer here at LBNL, or by an independent testing lab. It shall be tested using a hydrostatic test in accordance with ASME Boiler and Pressure Vessel Code Section VIII, subsection UG-99 <u>Standard Hydrostatic Test</u>. Test pressure is 1.5x MAWP= 525 psig. Nevertheless, this component will be further tested, in its installed configuration, along with the gas system test at a test pressure of 1.25x MAWP = 438psig (313 initial).

9.4 Source Insertion Tube

This component will be hydrostatically tested by the manufacturer in accordance with ASME Boiler and Pressure Vessel Code Section VIII, subsection UG-99 <u>Standard Hydrostatic Test</u>, and tagged by the manufacturer, and may be used as received. Nevertheless, this component will be further tested, in its installed configuration, along with the gas system test at a test pressure of 1.25x MAWP = 438psig (313 initial).

9.5 Gas system

All other attachments, fittings and components are pressure rated by the manufacturer as in the above table and may be used as installed up to MAWP. Nevertheless, this system will be tested, in its installed configuration, along with the gas system test at a test pressure of 1.25x MAWP = 438psig (313 initial), as described below:

cat. code: RP3030 serial:10506

dept.: Mech.Engineering

9.6 Final assembled system pressure check

Completed gas system, including pressure vessel, shall be pneumatically tested to 125% MAWP in place using a remote test system comprising a gas cyl., regulator, gauge, test valve, and vent valve. There are three sections of the complete gas system having different MAWP's; therefore the test is in three parts. Test pressures for the 3 sections are (125%MAWP):

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- a. 438 psig (313 initial) for the pressure vessel (MAWP=350 psig/250 psig initially),
- b. 563 psig for the gas purifier and supply section (MAWP=450 psig), and
- c. 1875 psig for the cryogenic reclamation section (MAWP=1500 psig).

The test shall be repeated for each section that is modified. The test system and operator shall be located a minimum of 8 ft. from the main pressure vessel, with no line of sight to system (behind a barrier; this can be a room wall or the existing wall of cabinets and workbenches presently in 70A-2263). Testing is to be performed by a Certified Pressure Installer, and witnessed by the M.E. Dept. Designee for Pressure Safety, at a minimum. Note that there is no V4 or V11; these valves were present in an earlier draft configuration and have been removed. Valves have not been renumbered to avoid confusion.

Prepare for test as follows (initial each step):

- 1. Procure:
- a. Two full gas cylinders, size 200 SCFM or more of clean Ar, N2, CO2, or dry air with supply pressure 2200 psig min.
- b. Calibrated test gauge(s) for reading 438 psig (313 initial), 563 psig, and 1875 psig to within 3% accuracy. Gauge maximum scale pressure should not be less that 1.2x or more than 4x the test pressure. Electronic gauges (calibrated) are permissible, and are not subject to the above range limitations.
 - c. Regulator(s), to provide above pressures in (b) to fit cyl. in (a).
- d. 30-35 ft. long high pressure clean gas service (e.g. McMaster P/N 5665K34 2-3 ea) or PTFE lined high pressure chemical hose (e.g McMaster P/N 5830K21, or similar), 2000 psig rated (min.), and fittings to connect to gas system at T1, T3.
- e. Pressure relief valves that fit exhaust ports of existing relief valves set to a minimum of 5% over test pressure (1.05x T.P. = 460 psig (329 initial), 591 psig, and 1968 psig), to fit exhaust ports of 350 psig (250 initial), 450 psig, and 1500 psig relief valves. These pressure relief valves should not be set higher than 33% of test pressure. See step 3 below for explanation.
 - f. Test pressure isolation valve, and fill vent valve, rated for test gas maximum pressure.
 - g. Test pressure release vent valve on Tee, both rated for test gas maximum pressure.
- 2. Assemble remote gas cylinder, regulator(RT), test gauge(GT) for 1875 psig test pressure, test isolation valve(TV), vent valve(VV), and fill vent valve (VF) as shown in fig. 17 below, and locate around corner from experiment, out of line sight, and behind wall of cabinets, or wall. Note that the pressure relief valve shown in fig. 17 is optional (see step 3 below for more explanation), since test feed ports T1 and T3 cannot be isolated from the system pressure relief valves.
- 3. Install 460 psig (329 initial), 591 psig, and 1968 psig relief valves into exhaust ports of 350 psig (250initial), 450 psig, and 1500 psig relief valves, respectively. Note that this is permissible only because the system pressure relief valves used, (Swagelok R3, R4 high pressure) are designed to be insensitive to back pressure; other types of pressure relief valves can be sensitive to back pressure and must be plugged while a separate test pressure relief valve installed as shown on fig. 17 (not optional).
- 4. Survey for, and remove any hazardous material (such as radioactive sources, flammable liquids, glassware, etc.) from line of sight to test area. Also remove as many other valuable or potentially hazardous materials such as glassware, dewars, electronic equipment as practical. Have fire extinguishers on hand.
- 5. Check that gas system is fully depressurized. Open V4 if closed, to connect T1 with P2 and open V14 and V18 if closed, to read pressure all the way to V13.
- 6. Barricade test area to prevent personnel ingress, notify building manager of impending test. Clear area of all people except for pressure test operator and witness(es).

Test 1500 psig MAWP subsystem (first) as follows (can be skipped if not needed for section retest):

7. Close V13, V15, if open. Open V14, V18 if closed. Screw in handle of R3 all the way. Check that C1 is fully depressurized.

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8. Unplug T3 and install test hose. Open VT, screw in RT handle; keep VV, test gas cyl valve closed.

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- 9. Start the backing pump and convectron gauge controller, Slowly open V15. When the convectron gauge reads < 1e-2 torr, close V15, and turn off backing pump and convectron gauge controller. Close V15.
- 10. Close V18. Back off R3 handle fully. Check that V14 is open. Check that V13 is closed. Leave V15 closed.
 - 11. Back off RT handle fully.
 - 12. Open test gas cyl. valve 1-2 turns.
- 13. Screw in RT handle slowly, in steps in steps of 33% MAWP (500 psi), each time closing VT, and watching GT to see that stable pressures are achieved. Watch GT for 5 minutes minimum, each time. If leaks occur, back off pressure to 300 psig (20% MAWP) max. and inspect to find leak. See note on possible methods below fig. 17. Once found, back off RT fully, open VV to depressurize fully, and fix leak. If no leaks occur, continue increasing pressure (stepwise, as above) until 1500 psig reads on test gauge. Watch GT closely while increasing pressure to note when 1500 psig relief valves open; pressure should drop slightly for each one. If this is not observed, 1500 psig relief valve(s) may be leaking, or not opening properly, and step 15 below must be performed. Record pressures on system gauges. Increase pressure to 1875 psig. Hold for 5 minutes, if stable then back off RT, close test gas cyl. valve and release system pressure; otherwise depressurize and fix leak as above.
 - 14. Remove 1968 psig relief valves from exhaust ports of 1500 psig relief valves.
- 15.(not necessary if both P.R valve openings observed in step 13). Close VV, and progressively repressurize system until relief valve exhausts, but not past 1600 psig. Depressurize and vent pressure. Adjust 1500 psig relief valve if needed and repeat this step.
- 16. Remove hose from T3, replace plug. Proceed to purge system as described in Gas System Operation.

Test 450 psig MAWP subsystem (next) as follows (skip steps 22-27 if not needed for section retest):

- 17. Check that entire system is depressurized.
- 18. Close valves V1-V9, V12, V15, V16, V17. Back off R1, R2.
- 19. Remove T1 plug and install hose end.
- 20. Start the backing pump and convectron gauge controller, Slowly open V3. When the convectron gauge reads < 1e-2 torr, close V3, and turn off backing pump and convectron gauge controller.
 - 21. Check that installed test gauge, GT, and regulator, RT, are for 563 psig test pressure.
 - 22. Open valves V6, V8 Check that valves V3, V5, V7, V9, V12, V15, V16, V17 are closed.
 - 23. Back off RT handle fully.
 - 24. Open test gas cyl. valve 1-2 turns.
- 25. Screw in RT handle slowly, in steps of 33% MAWP (150 psi), each time closing VT, and watching GT to see that stable pressures are achieved. Watch GT for 5 minutes minimum, each time. If leaks occur, back off pressure to 90 psig (20% MAWP) max. and inspect to find leak. See note on possible methods below fig. 17. Once found, back off RT fully, open test vent valve VV to depressurize fully, and fix leak. If no leaks occur, continue increasing pressure (stepwise, as above) until 450 psi reads on GT. Watch GT closely while increasing pressure to note when 450 psig relief valve opens; pressure should drop slightly. If this is not observed, 450 psig relief valve may be leaking, or not opening properly, and step 27 below must be performed. Record pressures on system gauges. Increase pressure to 563 psig. Hold for 5 minutes, if pressure is stable, then back off regulator fully, close test gas cyl. valve, and release system pressure through VV; otherwise depressurize and fix leak as above.
 - 26. Remove 591 psig relief valve from exhaust port of 450 psig relief valve.
- 27. (not necessary if P.R valve opening observed in step 25). Close VV, and progressively repressurize system until 450 psig relief valve exhausts, but not past 475 psig. Depressurize and vent pressure. Adjust relief valve if needed then repeat this step.

Test main pressure vessel (directly following 450 psig MAWP subsystem) as follows:

- 28. Open valves V5, V12, V13. Close valves V6, V8, V10, V14, V15, V18. Leave valves V3, V16, V17 closed. Back off R3 handle fully.
 - 29. Back off RT handle fully.

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30. Open test gas cyl. valve 1-2 turns.

31. Screw in test regulator slowly, in steps of 33% MAWP (115 psi, 85 psi initial), each time closing VT, and watching GT, to see that stable pressures are achieved. Watch GT for 5 minutes minimum, each time. If leaks occur, back off pressure to 50 psig (20% MAWP) max. and inspect to find leak. See note on possible methods below fig. 17. Once found, back off RT fully, open VV to depressurize fully, and fix leak. If no leaks occur, continue increasing pressure (stepwise, as above) until 350 psig (250 initial) reads on GT. Watch GT closely while increasing pressure to note when 350 (250 initial) psig relief valves open; pressure should drop slightly for each one. If this is not observed, 350 psig (250 initial) relief valve(s) may be leaking or not opening properly, and steps 33-35 below must be performed. Record pressures on system gauges. If gas system pressure gauge (P3) cannot read higher than 438 (313 initial) psi, then hold for 5 minutes, then back off regulator, close test gas cyl. valve, and release system pressure. Remove P3, plug, and repressurize to 438 psig (313 initial) as above. Hold for 5 minutes, if stable, then back off regulator, close test gas cyl. valve and release system pressure; otherwise depressurize and fix leak as above. Replace P3, if removed.

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- 32. Remove 460 psig (329 initial) psig relief valve from exhaust port of 350 (250 initial) psig relief valve located between V13 and V15.
- 33. (not necessary if both P.R valve openings observed in step 31). Close VV, and progressively repressurize system until 350 (250 initial) psig relief valve located between V13 and V15 exhausts, but not past 380 (275 initial) psig. Depressurize and vent pressure. Adjust relief valve if needed and repeat test.
- 34. Close V13, and remove 460 psig (329 initial) psig relief valve from exhaust port of 350 (250 initial) psig relief valve located on main pressure vessel.
- 35.Close VV, and progressively repressurize system until 350 (250 initial) psig relief valve located on main pressure vessel exhausts, but not past 380 (275 initial) psig. Depressurize and vent pressure. Adjust relief valve if needed and repeat test.
 - 36. Remove hose from T1, replace plug.
- 37. Start the backing pump and convectron gauge controller, Slowly open V3. When the convectron gauge reads < 1e-2 torr, close V3, and turn off backing pump and convectron gauge controller. Close V3.
- 38. Attach pressure test tags to pressure relief valves. These are found in Appendix D of PUB3000. File pressure test report (also in Appendix D) with Regulator Shop.

Leak checking may be performed at full MAWP after successful pressure testing. No tightening of flange bolts or other repair is allowable when under pressure.

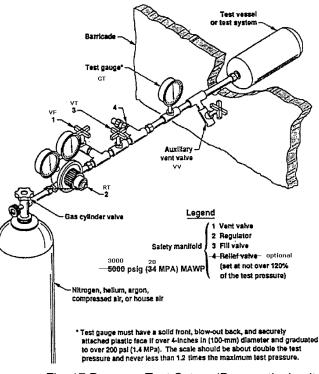


Fig. 17 Pressure Test Set up (Pneumatic, in-situ)

Engineering Note

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Leak Detection Methods for Pressure Leaks (not Vacuum):

Leak checking may be performed at full MAWP after successful pressure testing. Prior to pressure testing. leak checking may be performed up 20% MAWP

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Methods (not conclusive):

- 1. Hi resolution Pressure gauge. P4 has very high resolution and when used in conjuction with TC can indicate very slow leaks over time. Fully isolating any leakage is not possible, of course.
- 2. SNOOP this is essentially soapy water; NOT PREFERABLE, as it may be pulled into vacuum. If used, clean area throughly with DI water afterwards before pulling vacuum.
- 3. Helium Leak Testing (sniffer) DO NOT USE, glass in PMT's is very permeable to He, which will then ruin them.
- 4. Hydrogen Leak Testing (sniffer) PREFERABLE, uses 5% H2/95% N2 nonflammable mix test gas. Sniff as with He using appropriate equipment.
- 5. Gas Bag PREFERABLE, Wrap plastic bag material very loosely around suspect joint and seal tightly; watch for inflation.
- 6. LACO Technologies Gas Check 3000 (P/N LHHLD-G3), leak detector PREFERABLE, which can sniff for a variety of different gasses based on differential thermal conductivity (to air).

10. Appendix PDF page number

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Pressure Test Report for Gas System, Pressure vessel and Purification	281



TEST AND RETEST REQUEST **HIGH PRESSURE LAB** B343 • Ext. 3-2745

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RESULTS

Pressure tested #2 vessel ME-2285 to 604 psis 1.5 X MAWP (1.5 x 402 psis = 604 psis) Held for 15 minutes - NO leak noted, Dropped to 150 psig and SNoop Leak check. - No Leak noted, and SNoop leak check. - No Leak noted.

Conventional Vacuum Leak Check with leak detector

Using helicm as leak source, leak check - Oll

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Assign RD(s)

Save

Maintain Systems and Vessels General Information (Format - Dates: MM/DD/YYYY; Names: Last name, First name) ME Test No. 2286 RD No Temp 150 PSIG · · From 40 To 70 MAWP As of Date Status As per Person Oper Mode Config IN USE Manned Vessel Insp -Inspector - Cert FAIRCHILD, RICHARD F 002976 Please specify Trainee System Fluid Helium Device Owner 002678 Designer DOBIE D. 96 HEFFNER, MICHAEL D Ex: LASTNAME, FIRSTNAME P/R Please specify Inspection Date 12/13/2006 Test Date 12/13/2006 Inspection Freq 3 years Test Freq 6 years Expiration Date 12/13/2009 Safety Document Secondary Safety Document MESN · 01-091-0A Location Facility Room **२** 🗓 1131 LLNL 194A AD PAD Department Name not found Division Name not found SPRINGER. Assurance Manager THOMSON, STEPHEN B FPOC Alternate MICHAEL B Name Not **Facility Contact** LIND, SUSAN G **FPOC Exception** Found Description (also appears on label) Comments "Main pressure vessel #1 (AAA98-This system was retested on 104242, weld flange). Derated 12/13/2006 to 225 for helium only vessels on 8/31/01 to 150psig. at 130 PSIG .RF. Have tested an Vessel feed thrus will not have add on blast covers. Vessel will expire cone and flang it was tested at on original experation date of 343 by RF on 3/5/07. 6/01/02.Stored in place as per Bob Foerschler 8/12/03"

View Test Insp

New Test Insp

Copy

Print Labels

Tast Information (Dates should be in the format MM/DD/YYYY) ME Test No 2286 Date 12/13/2006 Test Request No TR-4191 Test Fluid Helium Test Pressure 225 PSIG Test Temp 70 F Size Measurements (pressure vessel tests ONLY) Test Comments Location Before Test (marked) (Inches) (Inches) Test Comments Location Before Test (marked) (Inches) (Inches) This system was tested to 225PSIG with Helium and will be used with Heliu	Maintain DTPS Tark and Increations
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Top Center Bottom Inspection Information Inspect the following and check the appropriate column, explaining as required, Status is OK or Not Applicable Question OK N/A Remarks Center Bottom OK N/A Polician Bottom OK N/A ON/A N/A N/A N/A N/A N/A N/A	Location Before Test After Test Difference This gueton was tested to 225 PSTG
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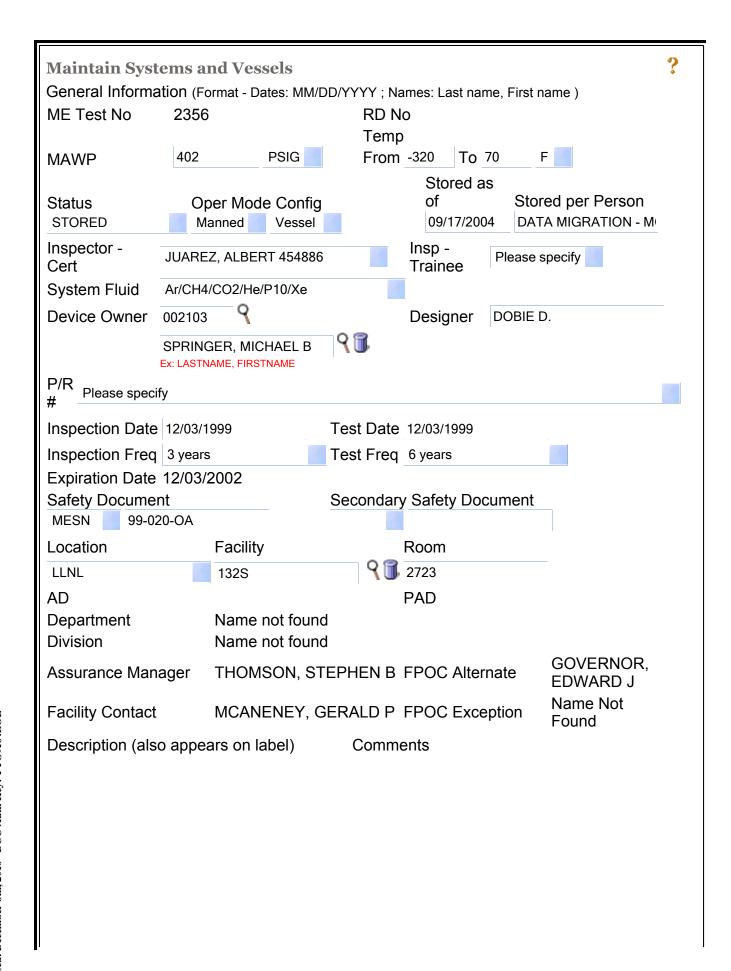
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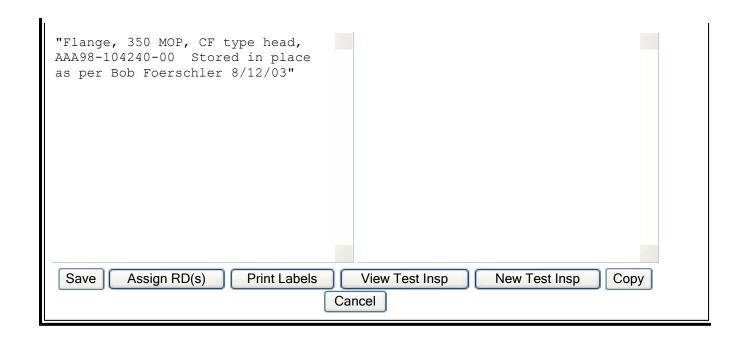
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Test Reques	st No	TR-2833			Test Flu	uid	Argon	
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2. Relief dev		التعالم مامير			• •			
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b) properly s					• •			
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_	and vessel s		_					
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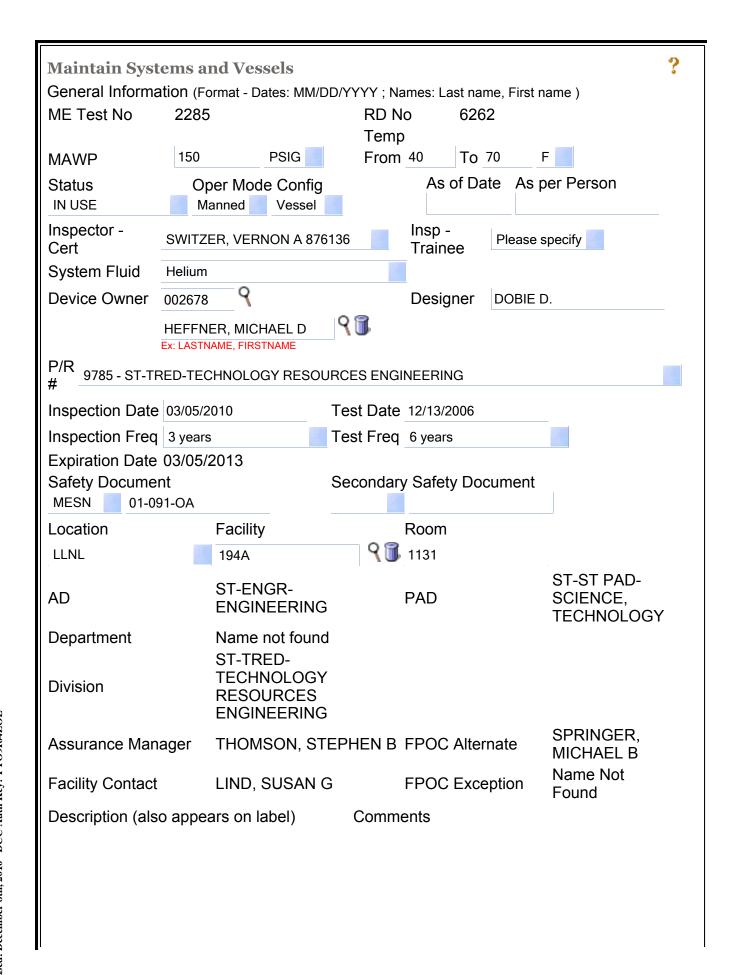


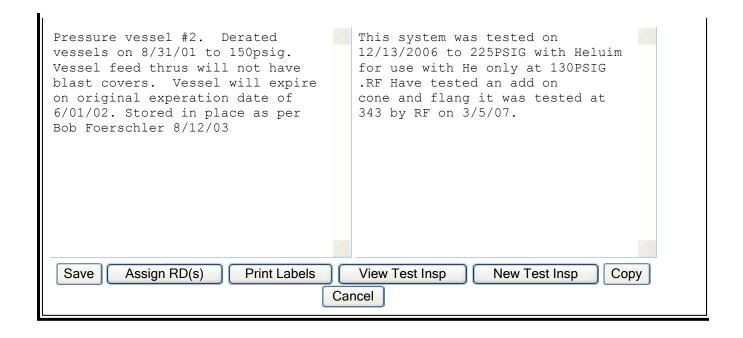


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c) pointed in safe direction	on or safely vent	ed	0				
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4. Replaced or added fitt piping*) are properly rate	ings, gauges, va		0				
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6. Valve packing nuts are type)	e tight and locke	ed (if locking		•	N/A		
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New Technologies Engineering Division

Mechanical Engineering Safety Note

Time Projection Chamber

MESN99-020-OA

April 26, 1999

Prepared By: Journal Volus

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D. Archer	L-188		

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A. Description

This safety note covers the design of time projection chambers (TPC) used in a full volume imaging detector. The chambers are used in building 132N, room 2723. There are three parts to the full volume imaging detector system. The first part is the gas purification subsystem that is used to purify and deliver electronegative free (99.999999%) gas. This part of the system is being built commercially by Insync Systems. The second part of the system, designed and built at LLNL, includes the time projection chambers (TPC) where the experiments will be performed. Gas, from the purification panel, feeds the TPC's that will nominally operate at 300 psig but are being designed for 350 psig maximum operating pressure (MOP). It will be necessary to work around the TPC's with radioactive sealed sources for testing and calibration; thus this is a manned operation. The third part of the system uses cylinders to reclaim the purified gas. These cylinders have been fabricated by ACME CRYOGENICS INC. and are rated by them at 3000 psig MAWP. Gas will be transferred in the TPC system by thermal cycles, using LN2 to create the temperature gradient inside the chamber via conduction through the walls of the cryogenic thimble. A certain percentage of alcohol may be used in the LN2 bath to move the temperature of the bath above 73K.

The TPC's are the experimental chambers designed at LLNL. These chambers are used for two purposes but were mechanically designed to be identical. The first chamber will be used as an ionization chamber where electron drift will be used as a measure of gas purity. The second chamber is the actual TPC itself, which is used for position sensitive readout of electron clouds and hence gamma ray imaging. Figure 1 depicts a TPC with its associated hardware. In the experimental setup, the chambers are connected together with high pressure tubing. The chambers have been designed to allow a 400 keV gamma ray to penetrate the chamber wall in well-defined places, specifically in the center of the 2 3/4 inch conflat flange and in a linear series of VCR blanks on the side of the chamber. It will be necessary to use radioactive sources in conjunction with these windows to probe the capabilities of the chamber. The 1 3/4 inch conflat flanges has been outfitted with a high voltage (20 kV) ceramic feedthrough from Ceramaseal. Many of the penetrations into the chamber and the internals of the chamber are attached to the conflat gasketed chamber head to allow easy removal from the chamber body. The chambers will be filled with a gas (Ar, Xe, along with at least one the following: CH4, CO2, and P10) using the 135psi gas purification system and then condensed by cooling the chamber using a cryogenic thimble. LN2 will envelope the outside of the thimble creating non-uniform thermal stresses along with membrane stress throughout the vessel.

This ME Safety Note is required because the TPC of the system contains compressed gas at pressures exceeding 150 psig or 100kJ of stored energy. This Safety Note covers the vessel depicted in Figure 1 up to and including the output connections. If required, a separate safety note will cover the remaining parts of full volume imaging detector system less the TCP's.

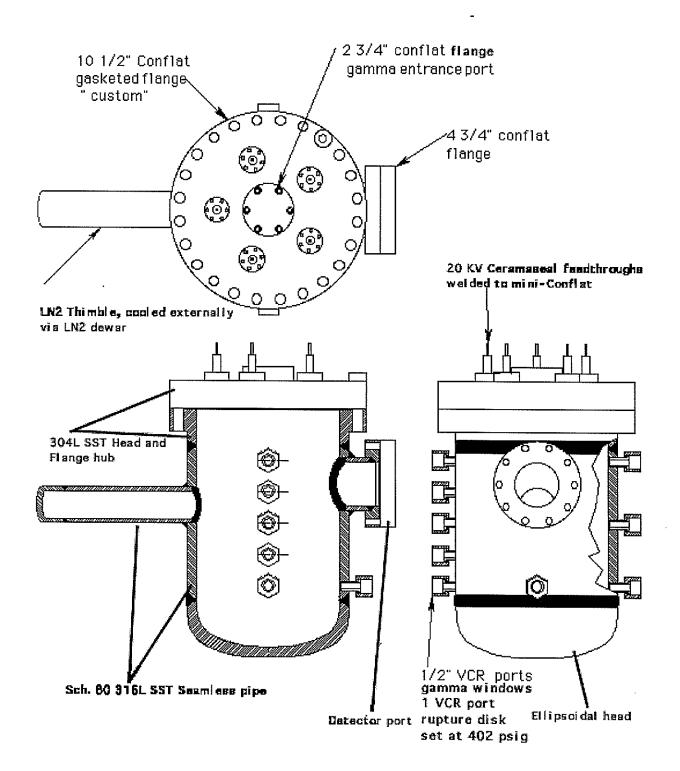


Figure 1 - Diagram of the Time Projection Chambers (TPC)

B. Operational Hazards

Associated hazards are those typical of any high pressure gas system. Failure of a vessel or component could result in either shrapnel or a blast overpressure to the body. Since the gases involved are not air, there is also the potential concern of asphyxiation. Other hazards include physical exposure to the radioactive sealed source and cold temperatures. The hazards other than those associated with the pressure vessel will be addressed by the FSP (if applicable) or separate OSP for this experiment.

C. Procedures

Design safety factors are robust for all intended pressures. The system is adequately protected by a pressure relief device at a VCR port so that components cannot be overpressurized. This document also specifies shielding requirements for personnel protection from shrapnel in the event of an accident. However, an OSP for this experiment will address associated interlocks and operational steps required during pressurization.

D. Calculations

The following will certify the TPC for this system:

[1] Hardware and Fabrication

The vessel is fabricated using commercially purchased metals. Fabrication and joining techniques are also standard technology. Welding was performed by LLNL ASME certified welders experienced in pressure systems.

[2] Engineered Design

The system design has relief devices at strategic locations (a VCR fitting) to insure that the MAWP's are never exceeded.

An evaluation of high risk pressure components indicated that a Ceramaseal feed-through may fail if improperly handled. Specifically, the weld joint at the Conflat is susceptible to bending and fracture. To minimize this risk, a fragment deflector/stop fixture was designed and will be mounted in front of the head where the Ceramaseal is mounted. A Kevlar drape will also be employed if this device fails to capture all fragments. This stop and Kevlar drape will be interlocked during pressure vessel operation.

[3] <u>Testing</u>

Detailed proof testing procedures at 1.5 times MAWP and at the working temperature, induced by LN2 cooling, have been developed and are enclosed as Appendix A. Successful completion of these procedures by a LLNL pressure inspector will complete the certification of the TPC's. Proof testing is the crux of pressure vessel qualification for fracture critical components and is best stated from literature⁵ as follows:

"The critical flaw size associated with proof test conditions can also be used for life expectance considerations. Specifically, if a pressure vessel survives a given proof test it can be concluded that the largest defect present in the structure is smaller than the critical flaw size at the proof test conditions. Therefore, in the absence of non-destructive inspection, this flaw size can be considered the existing flaw size at the beginning of life at the operating conditions and would, in turn, serve as the basis for further crack growth consideration" (also see fracture analysis below).

The vessel has been designed to meet ASME Boiler and Pressure Vessel Code design guidelines. Stresses are low enough to eliminate the need for impact testing of the material in the heat effected zones created by the butt welds, UHA-51 (g) (see misc.nb calculations in Appendix C). The ASME Code also exempt austenitic, chromium-nickel stainless steels from impact testing, UHA-51(d)(1)(a). Thus, the base materials 304L and 316L are exempt.

[4] Calculations

Most calculations were done using ASME Pressure Vessel Code, Section VIII, Division 1 guidelines. The TPC has a MAWP of 978 psig when using the C-Ring type head (no openings) and 402 psig for the Conflat type head(s) (with and without openings). A future addendum to this safety note will cover a head (with openings) to be used at 978 psig MAWP. The allowable stresses used in all calculations are based on values found in the ASME Pressure Vessel Code, Section II. For both 316L and 304L the allowable stress is 16,700 psi which provides a nominal Safety Factor of ~5 in all Pressure Vessel Code calculations (i.e., head thickness, maximum vessel pressure, minimum wall thickness, etc). The following tables are summaries of the detailed calculations found in Appendix A.

Vessel

The energy in each pressure vessel was calculated to be 55, 852 ft-lb. or 16.4 g TNT at the MAWP of 978 psig. The following table summarizes the analytical results for the main 8 inch schedule 80 pressure vessel, the detector pipe, the VCR "Cajon" fittings/ pipes, and the LN₂ pipe connected to the main vessel. All tubing is 316L. Calculations were made at a MAWP of 978 psig. The last column refers to the ratio of yield stress (37ksi) to Von Mises stress at the test pressure of 1.5 x MAWP. Values must be greater than 1.0 for a safe proof test.

	S1 (psi)	S2 (psi)	S3 (psi)	Von Mises (psi)	Required wall thickness (in)	Actual wall thickness (in)	If ≥ 1.0 stress less than yield for 1.5xMA WP
Main 8" vessel	3499	7976	-978	7755	0.336	0.500	3.2
Detector pipe 2.87 OD	1839	4657	-978	4880	0.102	0.275	5.1

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VCR pipe 0.5" OD	1739	4455	-978	4705	0.012	0.050	5.2
LN2 pipe 1.9" OD	1618	4214	-978	4496	0.066	0.200	5.5

Analytical results for welds, area reinforcement, and their related loads that attach the detector pipe, LN₂ pipe, and VCR pipe to the main vessel shell are detailed in the table below at a MAWP of 978 psig. Generally, if the nozzle and fillet weld load paths are greater than the total weld load, then the strengths are sufficient. The total weld load (W~(Area required – Area available)*Allowable stress)) for the VCR pipe is less than 0 because the vessel wall is 0.160" thicker than required creating much more area available than required. Thus, the area available is greater than the area removed and a negative number results.

	Area of mat'l. required (in^2)	Area of mat'l. avail. (in^2)	Total weld load (lb)	Nozzle wall load path (lb)	Fillet weld load path (lb)
Detector pipe	0.780	0.800	8172	13172	12749
LN ₂ pipe	0.504	0.508	5396	6243	6106
VCR pipe	0.134	0.194	< 0	413	402

The butt welds connecting the hub to the main vessel and the ellipsiodal head to the main vessel, the ellipsiodal head on liquid nitrogen pipe, and the hub to the detector pipe, reduced the allowable working pressure in the vessel they are connected to by 'E' (butt weld efficiency). An 'E' of 0.7 was used for these welds which reduced their associated allowable working pressures to 1421 psig, 6979 psig, and 6139 psig for the of the main vessel, LN pipe, and detector pipe respectively. Again, all of these calculated pressures use an allowable stress of 16,700 psi which has a nominal SF = 5.0 so an additional SF of 1.5 (1421 / 978) is obtained. Using a butt weld efficiency of 0.7 allows no radiography to be performed on the welds according to the ASME Boiler and Pressure Codes.

The VCR, LN₂, and detector port openings in the vessel shell are mounted 90° to each other. The radial distance between hole centers is approximately 6.0 inches. ASME Boiler Code requires that all openings be less than the sum of their respective diameters. The maximum sum of the diameters is 3.37 inches between LN₂ and the detector port.

Holes that do not penetrate the vessel shell may be required to horizontally mount the vessel. The depth of tapped 1/4-20 holes and 3/8-16 holes shall be ≤ 0.25 inches. Holes can not be placed near other openings or reinforcements.

Head / Flange Calculations

The following table summarizes the analytical results for the integral flange butt welded to the main access port and the small flange butt welded on the side of the

Flange	MOP	Longitudi nal hub stress (psi)	Radial flange stress (psi)	Tangential flange stress (psi)
Main 10.5" OD	850	16973	6327	4173
Main 10.5" OD	350	6388	2381	1571
Detector 4.625" OD	850	13998	2794	7367

The head for operating at 850 psig, uses a C-Ring type metal seal and is made from 304L stainless steel. The (24) required bolts for this flange are Unbrako KS 1216 1/2"-13 SHCS with a tensile strength of 160,000 psi (or 304 Stainless Steel with a 81 ksi tensile strength). The main flange for operating at 350 psig is a Conflat (CF) type (304L), sealed with a soft copper flat gasket to a knife edge. The (24) required bolts for this flange are Unbrako KS 1216 1/2"-13 SHCS with a tensile strength of 160,000 psi (or 304 Stainless Steel with a 81 ksi tensile strength). All other CF flanges (1 1/3 and 2 3/4 inch) shall be bolted to the 350 MOP head using Unbrako KS 1216 psi (or 304 Stainless Steel with a 81 ksi tensile strength), 8-32 or 1/4-28 SHCS as required.

The smaller 4 5/8" CF type flange for the detector port requires 10 bolts, Unbrako KS 1216 5/16"-24 SHCS with a tensile strength of 160,000 psi (or 304 Stainless Steel with a 81 ksi tensile strength) and is made from 304L stainless steel. The following table summarizes the fastener calculations.

Flange	MOP	No. of bolts	Bolt	Torqu e (in- lb)	Flange design bolt load, operating. (lb)	Flange design bolt load, gasket seal. (lb)	Max. allowable bolt load (SF 4 applied)
Main, C-ring 10.5" OD	850	24	1/2-13	1140	58850	96913	134976
Main, CF 10.5" OD	350	24	1/2-13	1140	24677	79827	134976
Detector 4.625" OD	850	10	5/16- 24	347	10144	15452	20760
1 1/3" CF	350	6	#8-32	51	231	230	2936
2 3/4" CF	350	6	1/4-28	152	1015	527	7937

Analytical results for the commercially purchased SA316 ellipsiodal head on main vessel, nominal wall thickness 0.5 inches and the SA316 ellipsiodal head on liquid nitrogen pipe, nominal wall thickness 0.2 inches follows. The head

thickness calculations were done at the MAWP of 978 psig and allow for strength reduction due to the butt weld connecting them to the vessel.

	MOP	Max. pressure (psig)	Required head thickness (in)	Actual head thickness (in)	If ≥ 1.0 stress less than yield for 1.5x MAWP
Main vessel	850	1513	0.320	0.500	1.03
LN ₂ pipe	850	3036	0.063	0.200	2.07

Results of the unstayed flat heads are presented in the table below. Two head types are planned for the main vessel, one CF type for low pressures at 350 MOP that has instrumentation ports, and one C-Ring type for high pressure (850 MOP) for vessel pressure testing and to be modified for a future head design (and subsequently proof tested along with a Safety Note Addendum). Stress concentration factors for the circular holes in a plate with internal pressure were used from empirical data in Wiley². Although not a perfectly matching model to Wiley, the concentration factors used are conservative. The stress concentration factor (2.278) reduced the allowable stress to 7,331 psi from 16,700 psi. Hole reinforcement requirements were also calculated using the ASME Codes. These results confirmed the thickness requirements using Wiley stress concentration factors.

Results of two types of Conflat feedthrough heads mounted to the 10.5 inch CF flange are also presented below. All head thickness calculations use the ASME head equation involving bending with the exception of the 2 3/4 inch CF where both bending and no bending cases were used. This flange was bored out to leave a head depth of 0.125" by 1.5" in diameter. The flange thickness around its mounting holes and under its knife edge remains at the nominal flange thickness of 0.5 inches. Thus, calculations were made for both and summarized below. A minimum thickness for the 1/2 inch VCR plug is calculated. The pressure side of a VCR plug is bored out 1/4 inch in diameter to this minimum thickness to be used as a gamma port.

Flange type	MOP	Required head thickness (in)	Actual head thickness (in)	Required hub thickness (in)	Actual hub thickness (in)
Conflat flange, Cu seal AAA99-104240	350	1.261	1.5	0.624	1.250
C-Ring type metal seal. AAA99-104243	850	1.247	1.980	0.661	1.250
Conflat flange, 4 5/8" Ø, x 0.750" thick. Commercial product	850	0.613	0.750	0.423	0.810

					MESN99-020-OA Page 10
1 1/3" CF	350	0.100	0.300	N/A	N/A
2 3/4" CF	350	0.178 / 0.092	0.5 / 0.125	N/A	N/A
VCR plug	850	0.052	0.052	N/A	N/A

Blind holes in the unstayed flat head were analyzed on the basis of area replacement. If the actual cross-sectional area available was greater than the cross-sectional area required, reinforcement was not required. The following table summarizes the results for the 350 MOP flat head. These calculations can also apply to blind mounting holes of the same dimension for mounting and handling the head with the caveat that hole can not be placed near other openings or reinforcements.

Hole type:	Area available (in^2)	Area required (in^2)
8-32 mini conflat holes	0.195	0.051
8-32 mounting bracket holes (internal)	0.205	0.041
1/4-28 medium conflat holes	0.250	0.125

Conflat (CF) flanges are used as connecting members and instrumentation feedthroughs in this pressure vessel design. Five 1 1/3 inch on a 5.5 inch bolt circle pattern and one 2 3/4 inch centrally located CF flanges are used on the 350 MOP head. A 4 5/8 inch CF flange is used on the detector port (850 MOP).

CF flanges were pressure tested in 1992 under the safety note END 92-072. The 1 1/3 inch nominally sized CF flanges with stainless steel bolts started leaking at ~15,000 psi. The 4 5/8 inch CF flange had no leakage with water as the pressure medium up to 1200 psi and minor (10⁻⁶ Torr-L/s) leaking with helium from 500 psi to 930 psi. All tests were done without catastrophic failure. Leakage occurred around the copper seal. A blank 2 3/4 inch was not proof tested.

For operation, the mating 1 1/3 inch CF flange to the CF port on the 350 MOP head has a high voltage feedthrough that is not rated by the manufacturer (Ceramaseal) because it is a special order. The manufacturer welded the high voltage feedthrough to an opening in the flange. LLNL has proof tested this component to burst (5850 psi). There is a concern for brittle fracture or weld failure due to cracking by mishandling that is addressed in the Fragment Hazard Mitigation paragraph below. The mating 2 3/4 inch CF flange will be proof tested at 604 psig along with the rest of the head. The mating 4 5/8 inch CF flange will be blanked off for pressure testing and initial operational tests. An addendum to this note will follow at a later date to address the attachment method of the detector to the mating flange. It will then be proof tested at 1467 psig.

Fracture Critical Components

This vessel is considered a Category IV risk according to MEDSS. Its failure has the potential for moderate injury and material testing is recommended.

The material used in this vessel is standard ASTM 304L and 316L stainless steel. Material testing was not done for the following reasons:

- (1) SA316L and SA304L are standard materials with strict manufacturing requirements.
- (2) ASME Boiler and Pressure Vessel Code does not require testing for austenitic stainless steels.
- (3) the large critical crack depths (a_{cr}) and lengths calculated using conservative stress intensity factors (K_{Ic}) from literature.
- (4) the number of cycles to failure were $> 10^5$; far larger than the $\le 10^2$ cycles expected using crack growth rates⁷ from literature.
- (5) The leak-before-break criterion is satisfied by a factor of ~10 or greater (136740 / 13824). Also, the CF type flanges used in the TPC design practically guarantee a leak before failure as demonstrated by earlier proof testing.
- (6) 316 and 304 stainless steel both have excellent toughness properties at cryogenic temperatures. Sharpy V-notch impact test data^{6,8} on 304 stainless steel indicates a slightly lowered toughness from room temperature to –196°C (150 to 124 ft-lb). For 316, the toughness lowered 13% from 141 to 122 ft-lb.

The table below summarizes the fracture toughness calculations in Appendix C.

	K _{Ic} (psi in^1/2)	K ₁ (psi in^1/2)	a _{cr} surface flaw (in)	a _{cr} sub-surface flaw (in)	2c length of surface flaw (in)	2c length of sub-surface flaw (in)
Main vessel	136740	10115	77.3	93.6	309.3	374.2
Ellipsoidal head	136740	13824	42.2	51.1	168.9	204.4
Flat head	136740	6528	183.1	221.6	732.5	886.3

The Unbrako bolts recommended above in the Head / Flange Calculations section are rated at their maximum tensile strength at -400°F. The alternative, 304 stainless steel fasteners have the same safe fracture critical properties as the vessel. No fracture critical calculations were performed for fasteners.

A proof test at 1.5xMAWP and at the working cryogenic temperature is planned for this vessel. Proof testing is the crux of pressure vessel qualification and is best stated from literature⁵ as follows:

"The critical flaw size associated with proof test conditions can also be used for life expectance considerations. Specifically, if a pressure vessel survives a given proof test it can be concluded that the largest defect present in the structure is

Mechanical Engineering Safety Note

Time Projection Chamber

MESN99-020-OA

April 26, 1999

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A. Description

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The TPC's are the experimental chambers designed at LLNL. These chambers are used for two purposes but were mechanically designed to be identical. The first chamber will be used as an ionization chamber where electron drift will be used as a measure of gas purity. The second chamber is the actual TPC itself, which is used for position sensitive readout of electron clouds and hence gamma ray imaging. Figure 1 depicts a TPC with its associated hardware. In the experimental setup, the chambers are connected together with high pressure tubing. The chambers have been designed to allow a 400 keV gamma ray to penetrate the chamber wall in well-defined places, specifically in the center of the 2 3/4 inch conflat flange and in a linear series of VCR blanks on the side of the chamber. It will be necessary to use radioactive sources in conjunction with these windows to probe the capabilities of the chamber. The 1 3/4 inch conflat flanges has been outfitted with a high voltage (20 kV) ceramic feedthrough from Ceramaseal. Many of the penetrations into the chamber and the internals of the chamber are attached to the conflat gasketed chamber head to allow easy removal from the chamber body. The chambers will be filled with a gas (Ar, Xe, along with at least one the following: CH4, CO2, and P10) using the 135psi gas purification system and then condensed by cooling the chamber using a cryogenic thimble. LN2 will envelope the outside of the thimble creating non-uniform thermal stresses along with membrane stress throughout the vessel.

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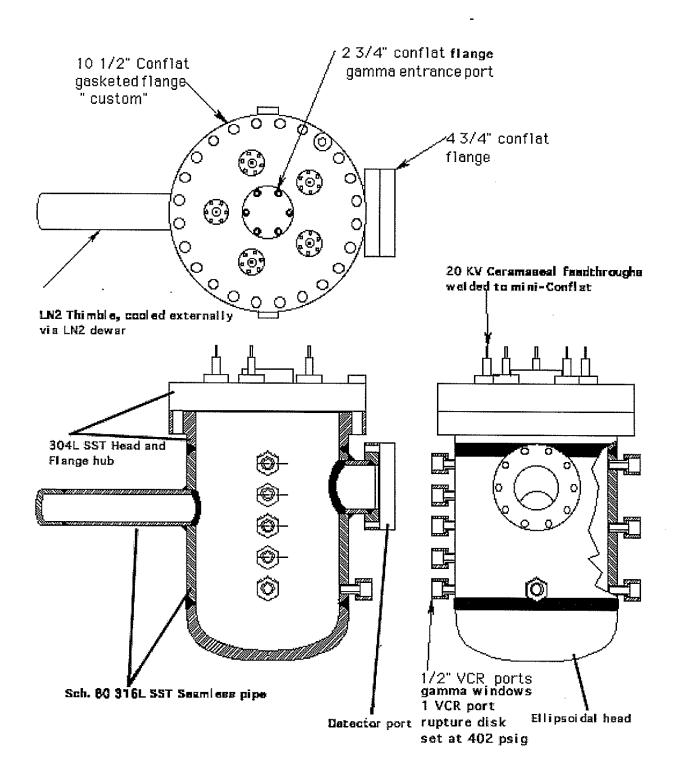


Figure 1 - Diagram of the Time Projection Chambers (TPC)

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Associated hazards are those typical of any high pressure gas system. Failure of a vessel or component could result in either shrapnel or a blast overpressure to the body. Since the gases involved are not air, there is also the potential concern of asphyxiation. Other hazards include physical exposure to the radioactive sealed source and cold temperatures. The hazards other than those associated with the pressure vessel will be addressed by the FSP (if applicable) or separate OSP for this experiment.

C. Procedures

Design safety factors are robust for all intended pressures. The system is adequately protected by a pressure relief device at a VCR port so that components cannot be overpressurized. This document also specifies shielding requirements for personnel protection from shrapnel in the event of an accident. However, an OSP for this experiment will address associated interlocks and operational steps required during pressurization.

D. Calculations

The following will certify the TPC for this system:

[1] <u>Hardware and Fabrication</u>

The vessel is fabricated using commercially purchased metals. Fabrication and joining techniques are also standard technology. Welding was performed by LLNL ASME certified welders experienced in pressure systems.

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Most calculations were done using ASME Pressure Vessel Code, Section VIII, Division 1 guidelines. The TPC has a MAWP of 978 psig when using the C-Ring type head (no openings) and 402 psig for the Conflat type head(s) (with and without openings). A future addendum to this safety note will cover a head (with openings) to be used at 978 psig MAWP. The allowable stresses used in all calculations are based on values found in the ASME Pressure Vessel Code, Section II. For both 316L and 304L the allowable stress is 16,700 psi which provides a nominal Safety Factor of ~5 in all Pressure Vessel Code calculations (i.e., head thickness, maximum vessel pressure, minimum wall thickness, etc). The following tables are summaries of the detailed calculations found in Appendix A.

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Detector pipe 2.87 OD	1839	4657	-978	4880	0.102	0.275	5.1

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LN ₂ pipe	0.504	0.508	5396	6243	6106
VCR pipe	0.134	0.194	< 0	413	402

The butt welds connecting the hub to the main vessel and the ellipsiodal head to the main vessel, the ellipsiodal head on liquid nitrogen pipe, and the hub to the detector pipe, reduced the allowable working pressure in the vessel they are connected to by 'E' (butt weld efficiency). An 'E' of 0.7 was used for these welds which reduced their associated allowable working pressures to 1421 psig, 6979 psig, and 6139 psig for the of the main vessel, LN pipe, and detector pipe respectively. Again, all of these calculated pressures use an allowable stress of 16,700 psi which has a nominal SF = 5.0 so an additional SF of 1.5 (1421 / 978) is obtained. Using a butt weld efficiency of 0.7 allows no radiography to be performed on the welds according to the ASME Boiler and Pressure Codes.

The VCR, LN₂, and detector port openings in the vessel shell are mounted 90° to each other. The radial distance between hole centers is approximately 6.0 inches. ASME Boiler Code requires that all openings be less than the sum of their respective diameters. The maximum sum of the diameters is 3.37 inches between LN₂ and the detector port.

Holes that do not penetrate the vessel shell may be required to horizontally mount the vessel. The depth of tapped 1/4-20 holes and 3/8-16 holes shall be ≤ 0.25 inches. Holes can not be placed near other openings or reinforcements.

Head / Flange Calculations

The following table summarizes the analytical results for the integral flange butt welded to the main access port and the small flange butt welded on the side of the

vessel (detector port). Again, the allowable stress in 16,700 psi for the base material. Also, the ASME allowable hub stress is 1.5 time the allowable stress.

Flange	MOP	Longitudi nal hub stress (psi)	Radial flange stress (psi)	Tangential flange stress (psi)
Main 10.5" OD	850	16973	6327	4173
Main 10.5" OD	350	6388	2381	1571
Detector 4.625" OD	850	13998	2794	7367

The head for operating at 850 psig, uses a C-Ring type metal seal and is made from 304L stainless steel. The (24) required bolts for this flange are Unbrako KS 1216 1/2"-13 SHCS with a tensile strength of 160,000 psi (or 304 Stainless Steel with a 81 ksi tensile strength). The main flange for operating at 350 psig is a Conflat (CF) type (304L), sealed with a soft copper flat gasket to a knife edge. The (24) required bolts for this flange are Unbrako KS 1216 1/2"-13 SHCS with a tensile strength of 160,000 psi (or 304 Stainless Steel with a 81 ksi tensile strength). All other CF flanges (1 1/3 and 2 3/4 inch) shall be bolted to the 350 MOP head using Unbrako KS 1216 psi (or 304 Stainless Steel with a 81 ksi tensile strength), 8-32 or 1/4-28 SHCS as required.

The smaller 4 5/8" CF type flange for the detector port requires 10 bolts, Unbrako KS 1216 5/16"-24 SHCS with a tensile strength of 160,000 psi (or 304 Stainless Steel with a 81 ksi tensile strength) and is made from 304L stainless steel. The following table summarizes the fastener calculations.

Flange	MOP	No. of bolts	Bolt	Torqu e (in- lb)	Flange design bolt load, operating. (lb)	Flange design bolt load, gasket seal. (lb)	Max. allowable bolt load (SF 4 applied)
Main, C-ring 10.5" OD	850	24	1/2-13	1140	58850	96913	134976
Main, CF 10.5" OD	350	24	1/2-13	1140	24677	79827	134976
Detector 4.625" OD	850	10	5/16- 24	347	10144	15452	20760
1 1/3" CF	350	6	#8-32	51	231	230	2936
2 3/4" CF	350	6	1/4-28	152	1015	527	7937

Analytical results for the commercially purchased SA316 ellipsiodal head on main vessel, nominal wall thickness 0.5 inches and the SA316 ellipsiodal head on liquid nitrogen pipe, nominal wall thickness 0.2 inches follows. The head

thickness calculations were done at the MAWP of 978 psig and allow for strength reduction due to the butt weld connecting them to the vessel.

	MOP	Max. pressure (psig)	Required head thickness (in)	Actual head thickness (in)	If ≥ 1.0 stress less than yield for 1.5x MAWP
Main vessel	850	1513	0.320	0.500	1.03
LN ₂ pipe	850	3036	0.063	0.200	2.07

Results of the unstayed flat heads are presented in the table below. Two head types are planned for the main vessel, one CF type for low pressures at 350 MOP that has instrumentation ports, and one C-Ring type for high pressure (850 MOP) for vessel pressure testing and to be modified for a future head design (and subsequently proof tested along with a Safety Note Addendum). Stress concentration factors for the circular holes in a plate with internal pressure were used from empirical data in Wiley². Although not a perfectly matching model to Wiley, the concentration factors used are conservative. The stress concentration factor (2.278) reduced the allowable stress to 7,331 psi from 16,700 psi. Hole reinforcement requirements were also calculated using the ASME Codes. These results confirmed the thickness requirements using Wiley stress concentration factors.

Results of two types of Conflat feedthrough heads mounted to the 10.5 inch CF flange are also presented below. All head thickness calculations use the ASME head equation involving bending with the exception of the 2 3/4 inch CF where both bending and no bending cases were used. This flange was bored out to leave a head depth of 0.125" by 1.5" in diameter. The flange thickness around its mounting holes and under its knife edge remains at the nominal flange thickness of 0.5 inches. Thus, calculations were made for both and summarized below. A minimum thickness for the 1/2 inch VCR plug is calculated. The pressure side of a VCR plug is bored out 1/4 inch in diameter to this minimum thickness to be used as a gamma port.

Flange type	MOP	Required head thickness (in)	Actual head thickness (in)	Required hub thickness (in)	Actual hub thickness (in)
Conflat flange, Cu seal AAA99-104240	350	1.261	1.5	0.624	1.250
C-Ring type metal seal. AAA99-104243	850	1.247	1.980	0.661	1.250
Conflat flange, 4 5/8" Ø, x 0.750" thick. Commercial product	850	0.613	0.750	0.423	0.810

					MESN99-020-OA
					Page 10
1 1/3" CF	350	0.100	0.300	N/A	N/A
2 3/4" CF	350	0.178 / 0.092	0.5 / 0.125	N/A	N/A
VCR plug	850	0.052	0.052	N/A	N/A

Blind holes in the unstayed flat head were analyzed on the basis of area replacement. If the actual cross-sectional area available was greater than the cross-sectional area required, reinforcement was not required. The following table summarizes the results for the 350 MOP flat head. These calculations can also apply to blind mounting holes of the same dimension for mounting and handling the head with the caveat that hole can not be placed near other openings or reinforcements.

Hole type:	Area available (in^2)	Area required (in^2)
8-32 mini conflat holes	0.195	0.051
8-32 mounting bracket holes (internal)	0.205	0.041
1/4-28 medium conflat holes	0.250	0.125

Conflat (CF) flanges are used as connecting members and instrumentation feedthroughs in this pressure vessel design. Five 1 1/3 inch on a 5.5 inch bolt circle pattern and one 2 3/4 inch centrally located CF flanges are used on the 350 MOP head. A 4 5/8 inch CF flange is used on the detector port (850 MOP).

CF flanges were pressure tested in 1992 under the safety note END 92-072. The 1 1/3 inch nominally sized CF flanges with stainless steel bolts started leaking at ~15,000 psi. The 4 5/8 inch CF flange had no leakage with water as the pressure medium up to 1200 psi and minor (10⁻⁶ Torr-L/s) leaking with helium from 500 psi to 930 psi. All tests were done without catastrophic failure. Leakage occurred around the copper seal. A blank 2 3/4 inch was not proof tested.

For operation, the mating 1 1/3 inch CF flange to the CF port on the 350 MOP head has a high voltage feedthrough that is not rated by the manufacturer (Ceramaseal) because it is a special order. The manufacturer welded the high voltage feedthrough to an opening in the flange. LLNL has proof tested this component to burst (5850 psi). There is a concern for brittle fracture or weld failure due to cracking by mishandling that is addressed in the Fragment Hazard Mitigation paragraph below. The mating 2 3/4 inch CF flange will be proof tested at 604 psig along with the rest of the head. The mating 4 5/8 inch CF flange will be blanked off for pressure testing and initial operational tests. An addendum to this note will follow at a later date to address the attachment method of the detector to the mating flange. It will then be proof tested at 1467 psig.

Fracture Critical Components

This vessel is considered a Category IV risk according to MEDSS. Its failure has the potential for moderate injury and material testing is recommended.

The material used in this vessel is standard ASTM 304L and 316L stainless steel. Material testing was not done for the following reasons:

- (1) SA316L and SA304L are standard materials with strict manufacturing requirements.
- (2) ASME Boiler and Pressure Vessel Code does not require testing for austenitic stainless steels.
- (3) the large critical crack depths (a_{cr}) and lengths calculated using conservative stress intensity factors (K_{lc}) from literature.
- (4) the number of cycles to failure were $> 10^5$; far larger than the $\le 10^2$ cycles expected using crack growth rates⁷ from literature.
- (5) The leak-before-break criterion is satisfied by a factor of ~10 or greater (136740 / 13824). Also, the CF type flanges used in the TPC design practically guarantee a leak before failure as demonstrated by earlier proof testing.
- (6) 316 and 304 stainless steel both have excellent toughness properties at cryogenic temperatures. Sharpy V-notch impact test data^{6,8} on 304 stainless steel indicates a slightly lowered toughness from room temperature to -196°C (150 to 124 ft-lb). For 316, the toughness lowered 13% from 141 to 122 ft-lb.

The table below summarizes the fracture toughness calculations in Appendix C.

	K _{Ic} (psi in^1/2)	K ₁ (psi in^1/2)	a _{cr} surface flaw (in)	a _{cr} sub-surface flaw (in)	2c length of surface flaw (in)	2c length of sub-surface flaw (in)
Main vessel	136740	10115	77.3	93.6	309.3	374.2
Ellipsoidal head	136740	13824	42.2	51.1	168.9	204.4
Flat head	136740	6528	183.1	221.6	732.5	886.3

The Unbrako bolts recommended abové in the Head / Flange Calculations section are rated at their maximum tensile strength at -400°F. The alternative, 304 stainless steel fasteners have the same safe fracture critical properties as the vessel. No fracture critical calculations were performed for fasteners.

A proof test at 1.5xMAWP and at the working cryogenic temperature is planned for this vessel. Proof testing is the crux of pressure vessel qualification and is best stated from literature⁵ as follows:

"The critical flaw size associated with proof test conditions can also be used for life expectance considerations. Specifically, if a pressure vessel survives a given proof test it can be concluded that the largest defect present in the structure is

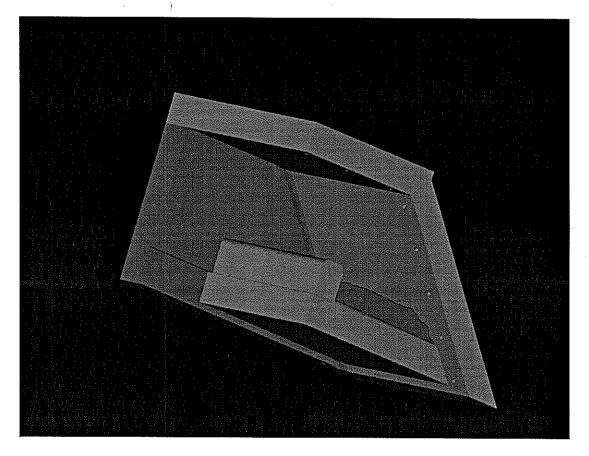
Page 12

smaller than the critical flaw size at the proof test conditions. Therefore, in the absence of non-destructive inspection, this flaw size can be considered the existing flaw size at the beginning of life at the operating conditions and would, in turn, serve as the basis for further crack growth consideration".

A physical inspection of the TPC for cracks is required between every experiment or experimental cycle. Careful handling of the head, vessel and its related hardware is important so that the welds attaching the various components (high voltage feedthroughs, VCR stubs) are not damaged. If any of these components are bent by mishandling, the suspect welds must be radiographicly inspected and re-proof tested.

Fragment Hazard Mitigation

A fragment deflector/stop was designed to deflect and capture a potential Ceramaseal feedthrough mishap if it were propelled from head of the vessel. It will be placed as close as practical to the TPC head and still allow operation of the vessel. The basic design is based on ballistic gun range technology where the fragment is deflected from a 45° wall into a sand trap (red arrow shows path in Figure below). All walls are made from 2.5" thick lexan that can stop the projectile if it were propelled normal into it. The opening in the stop (11" x 14") is sufficiently oversized to the Ceramaseal bolt circle diameter (5.5") and the sand trap baffle is made from 1/4" lexan to allow fragment passage. This stop will be interlocked during vessel operation. Calculation filename "fragmant.nb" in Appendix C details the shielding calculations obtained from MEDSS.



A Kevlar drape will also be employed to shield the operator from a potential stray fragment reflected back out of the catch.

The system pressure requirements are summarized as follows:

Component	Maximum Operating Pressure (psig)	Maximum Allowable Working Pressure (MAWP) (psig)	Pressure Relief Setting (psig)	Proof Test Pressure (psig)
Main Pressure Vessel	850	978	978	1467
(sketch)				
AAA99-104242 (weld				
flange)				
Flat Head, Metal C-Ring:	850	978	978	1467
AAA99-104243	0.50	0.70		
Conlfat flange, 4 5/8" Ø, x	850	978	978	1467
0.750" thick. commercial				
CF flange (blank)	050	070	070	1467
VCR Plug, 1/2" Ø, modified commercial	850	978	978	1467
Flat Head Conflat Type:	350	402	402	(04
AAA99-104240	330	402	402	604
Conlfat flange, 2 3/4" Ø, x	350	402	402	604
0.500" thick. modified	350	402	402	004
commercial CF flange				
Ceramaseal: 19543-04-CF;	350	402	402	604
1 1/3" Ø, x 0.300" thick.		-3-	""	
modified commercial CF				
flange				

E. Testing Requirements

Detailed testing procedures have been developed and are enclosed as Appendices B. The proof test criterion for each system is 150% of MAWP.

F. Labeling Requirements

Upon completion of the testing procedures, the LLNL pressure inspector will certify the inspection of this system by completion of an LLNL Pressure Test/Inspection Record, Form LL3586, and by attaching an LLNL Pressure Tested Label, properly filled out to the individual components identified below. Appropriate additional information will be inserted as required.

LLN	L PRESSURE FOR MANNED AR	
ASSY.	Pressure ve	ssel
SAFETY NO	MESN99	-020-0A
M.A.W.P	978	PSIG.
FLUID	le, Xe, Ar, CH4	, CO2, P10
TEMP.	3.20 to a	mbient 93
REMARKS	Halm Preveure Veskel (AAA92-104242, we	
TEST NO.		TATA MARKATAN
EXPIRATIO	NDATE	a de la composición
EV Lesses	DATE	Mark Street

L		RES!			STED	
ASSY.	ΔΑΑ	99-	10	424	13-	00
SAFETY	NOTE	ME:	SN9	9-02	20-C)Α
M.A.W.P		97	8		Ps	IG.
FLUID	He,	Хе, А	r, Cl	14, CC)2, P	10
TEMP.	-37	20	TO	amb	ient	D.F
REMAR		850 M				
TEST NO	2			T.R		
EXPIRA'	TION I	DATE				
ΒV	196 (Shrida)		DA	E	ALATAZ LINIY I	

	NL PRESS FOR MAN	NED AREA	SIED	
Assy.	AAA99-	104241-	00	
SAFETY I	NOTE MES	N99-0	20-0	A
.M.A.W.P	402		PS	G.
FLUID	He, Xe, Ar	, CH4, C	02, P1	0
TEMP.	-320	TO ami	pient	017
	350 MOI			
TEST NO		7.5		2017/101
EXPIRATI	ON DATE			
BY		DATE		

			1 agc 17
	LNL PRES	SURE TE	STED
ASSY.	AAA9	8-10424	0
SAFETY	NOTE ME	SN99-0	20-0A
M.A.W.P	40		PSIG.
FLUID	He, Xe, A	ι ε, CH4, C	02, P10
TEMP.	- 320	TO am	oient ºF
REMARI	(S 350 M	IOP CF ty	pe head
TEST NO		7.1	
EXPIRAT	TION DATE		
BY		DATE	

G. Associated Procedures

The concerns are asphyxiation, cold temperature and radiation exposure of personnel. Responsibility for an OSP resides with the user.

H. References and Notes

1. The defining drawings are as follows:

<u>Drawing Title</u>	<u>LLNL</u>
Pressure Chamber Lid Blank	AAA98-1104241
Pressure Chamber Lid	AAA98-1104240
Pressure Chamber Lid Blank C Ring 850 MOP	AAA98-1104243
Pressure Chamber Weld Flange 850 MOP	AAA98-1104242
Xenon Chamber Model 8" (sketch)	N/A
Xenon Chamber Model 8" associated sketches	N/A

- 2. 1995 ASME Boiler and Pressure Vessel Code, Section VIII, Division I.
- 3. Design of Piping Systems, John Wiley & Sons, Inc. 1974.
- 4. Degraded Piping Program - Phase II, Sixth Program Report, Oct. 1986 -September 1987, USNRC
- 5. Fracture 1969, Chapman and Hall Ltd. IBN 412094703
- 6. Handbook of Stainless Steels, D. Peckner, I. Bernstein, McGraw-Hill, 1977
- 7. Metal Fatigure in Engineering, H. Fuchs, R. Stephens, John Wiley & Sons, Inc. 1980.
- 8. Austenetic Steels at Low Temperatures, R.P. Reed, T Horiuchi, Plenum Press, 1982.

APPENDIX A: PROOF

TESTING PROCEDURE FOR

THE TPC

A.1 General

This procedure is for proof testing the TPC shown in Figure 1. Initial pressure and leak tests of the system will be conducted in Building 343 because it provides an adequate barricade for conducting the test and keeps personnel exposure to a minimum. Final leak testing of joints made up after installation and retest of the systems in the future will be conducted at the B132 facility.

A.2 Hazards

The Health and Safety Manual Supplement 32.05, Section 2 – "Standard Procedure for Pressure Testing with Gas" applies.

A.3 Pretest Procedure

Use the system indicated in Figure A1 as the test source. Support the chamber horizontally. Cool the chambers' LN2 pipe and surrounding metal with an LN2 filled dewar supplied by the experimenter to simulate the thermal stresses during actual operation. Let the metal 'soak' for 20-30 minutes before proof testing.

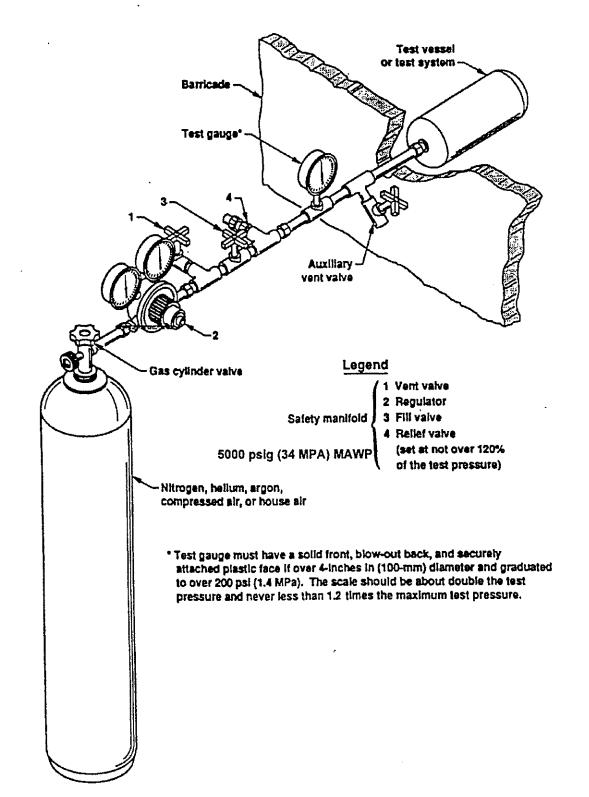


Figure A1 – Gas Test System

A.4 Test Procedure

Refer to Figure 1 and Appendix A for component designations.

A.4.1 High Pressure (1467 psig) Helium System Pressure Test

The two TPC's will first be tested to $1.5 \times MAWP$, or $1.5 \times 978 = 1467$ psig using the following components:

Vessel (2 ea., requires 2 separate proof tests) C-Ring type lid (AAA99-104243) 4 3/4" CF blank for the detector port Modified VCR plug(s) at the VCR ports

- 1. Install the hardware described above for the 1467psig proof test.
- 2. Apply 1467psig test pressure to one of the VCR ports.
- 3. Hold test pressure at 1467psig for 15 minutes.
- 4. Vent system down to 150 psig and leak check all joints under pressure with Snoop.
- 5. Vent helium to atmospheric pressure.

A.4.2 Moderate Pressure (604 psig) Helium System Pressure Test

A single TPC will also be tested to $1.5 \times MAWP$, or $1.5 \times 402 = 604$ psig using the following components. Two tests are required to qualify both heads.

Vessel

CF type lid (AAA99-104240, AAA99-104241)

2 3/4" CF modified blank for the x-ray port

1 1/3" CF flanges with high voltage feedthroughs

4 3/4" CF blank for the detector port Modified VCR plug at the VCR ports

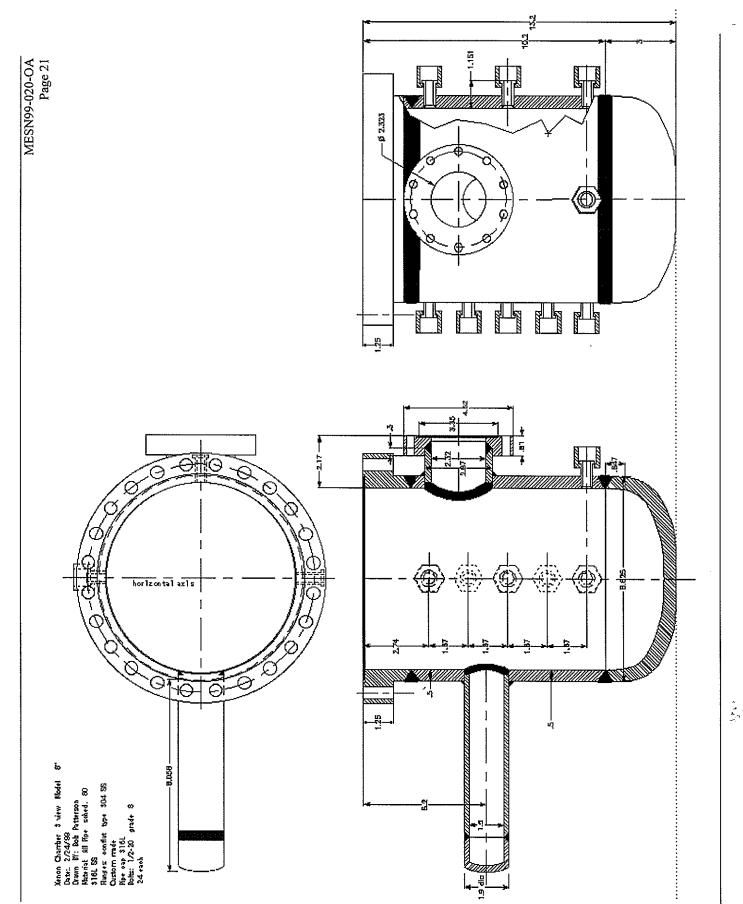
- 1. Install the hardware described above for the 604 psig proof test.
- 2. Apply 604 psig test pressure to one of the VCR ports.
- 3. Hold test pressure at 604 psig for 15 minutes.
- 4. Vent system down to 150 psig and leak check all joints under pressure with Snoop.
- 5. Vent helium to atmospheric pressure.

A.4.3 Documentation

Test records shall include an LLNL Pressure test/inspection record for the separate pieces of the vessel. The pressure inspector will send the original copies of the test reports to LLNL Pressure Safety (L-384).

APPENDIX B

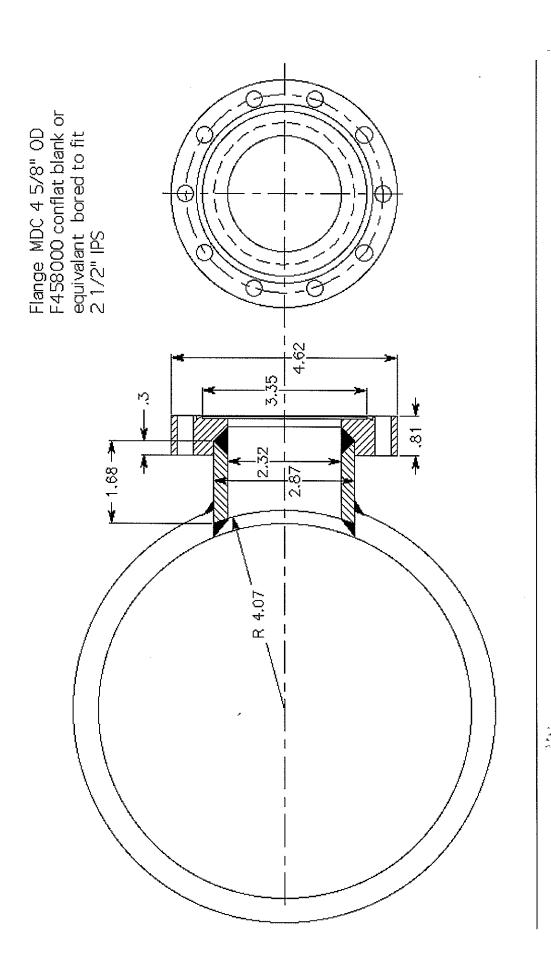
DRAWINGS

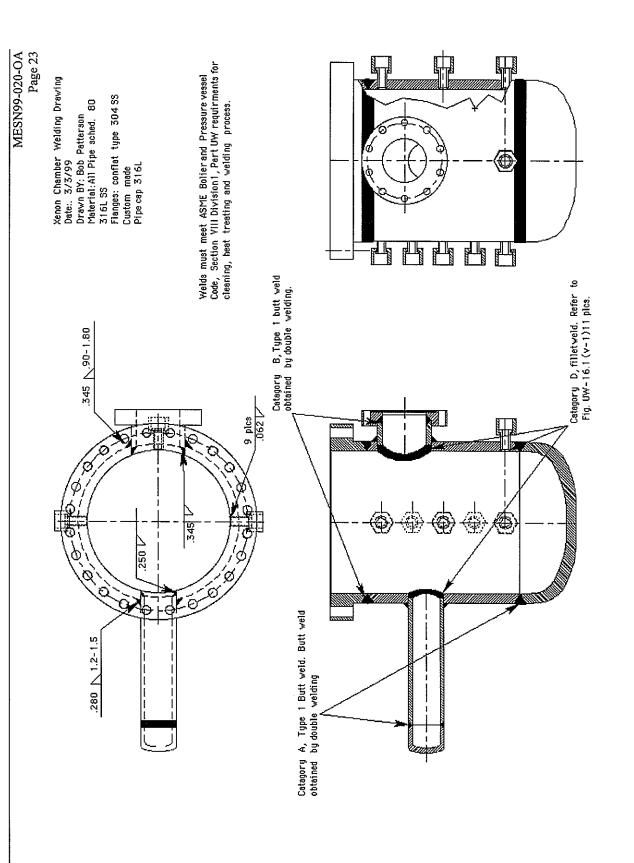


Detector Port

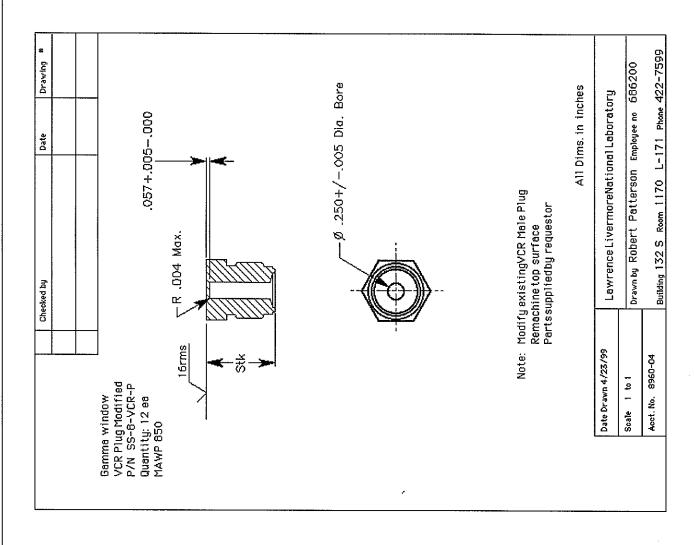
Date: 2/24/99 Drawn By: Bob Patterson

Material: Pipe 2 1/2 IPS sched. 80 316L SS 2 ea. required

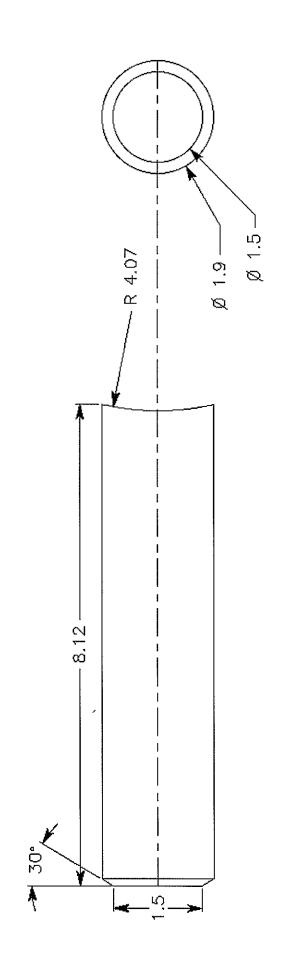


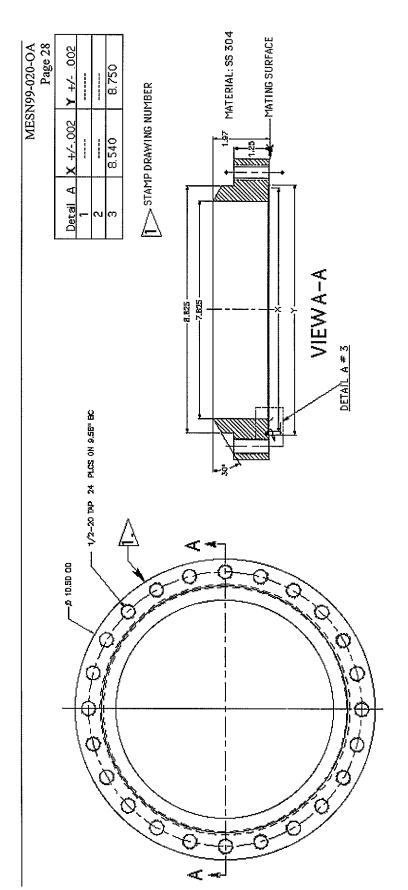


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PumpingTubulation
Date:. 2/25/99
Drawn By: Bob Patterson
Material: Pipe 1 1/2 IPS sched. 80
316L SS
2 ea. required





LEVEL 1 DRAWING

PressureChamber Weld Flange 850 M0P AAA99-104242-00 MESN99-020-OA Page 29

LEVEL 1 DRAWING

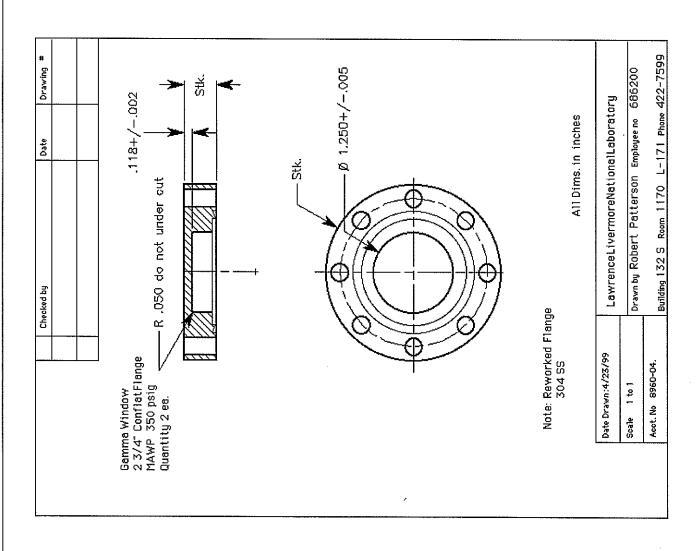
Pressure Chamber Lid Blank 350 MOP

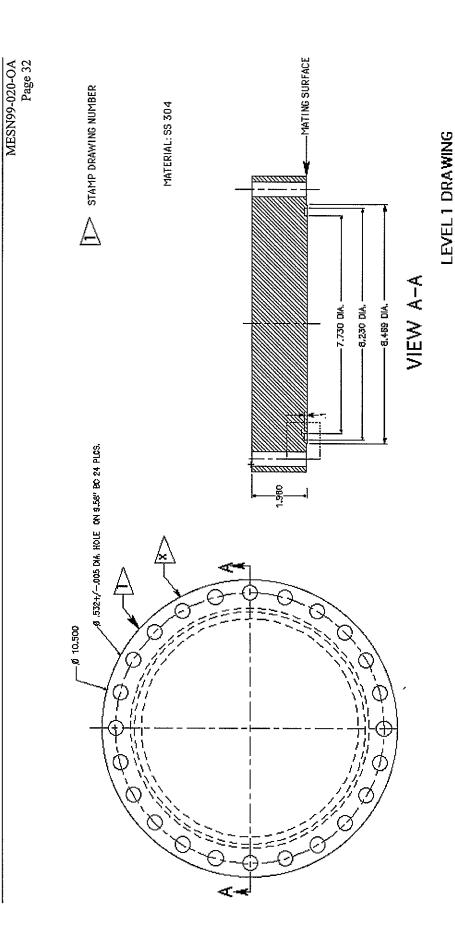
AAA99-104241-00

MESN99-020-0A

Pressure Chamber Lid C F Mini 350 MOP

AAA99-104240-00





PressureChamber Lid Blank C'Ring 850 M0P

AAA99-104243-00

APPENDIX C

CALCULATIONS

File name	Calculations performed
Energy_vessel.nb Vessel_stress2.nb	energy calculations, peak and static overpressure main vessel stress calculations, wall thickness, maximum pressure, proof test stress
Ellipsoidal_head_stress.nb Ellipsoidal_head_stress_LN2nb	main vessel head thickness, max. pressure, proof test stress LN2 head thickness, max. pressure, proof test stress
Flange stress_hub_978.nb Flange stress_hub_small_978.nb Flange stress_hub_403.nb	main vessel C-Ring head bolt load, moment, stresses detector port bolt load, moment, stresses main vessel CF head bolt load, moment, stresses
Xe_vessel_det.nb Detector_shell.nb Weld_load_stress.nb	detector pipe stress calculations, wall thickness, maximum pressure, proof test stress detector pipe weld reinforcement, area required, area available detector pipe weld load allowable, strength of connecting elements (welds)
Xe_vessel_VCR.nb VCR_shell.nb Weld_load_stress_VCR.nb VCR_gamma_port.nb	VCR pipe stress calculations, wall thickness, maximum pressure, proof test stress VCR pipe weld reinforcement, area required, area available VCR pipe weld load allowable, strength of connecting elements (welds) VCR minimum head thickness calculation
Xe_vessel_LN2.nb LN2_shell.nb Weld_load_stress_LN2.nb	LN2 pipe stress calculations, wall thickness, maximum pressure, proof test stress LN2 pipe weld reinforcement, area required, area available LN2 pipe weld load allowable, strength of connecting elements (welds)
Head_350_K_openings2.nb	main vessel CF type flat head: stress concentration factor, thickness, distance between hole centers
Head_850_no_openings2.nb Head_850_4.625_no_openings2 Bolt_load_1.33CF_350.nb Bolt_load_2.75CF_350.nb Misc.nb	1.33 CF flange bolt load, head thickness 2.75 CF flange bolt load, head thickness main vessel: distance between openings, blind mounting hole depth, reinforcement of blind holes on CF flanges mounted on 10.5" Ø CF flange, impact testing
Fracture_critical_mat'l.nb Fragmant.nb	K _{ic} , K _i , critical crack lengths, Life cycles shielding calculations

7

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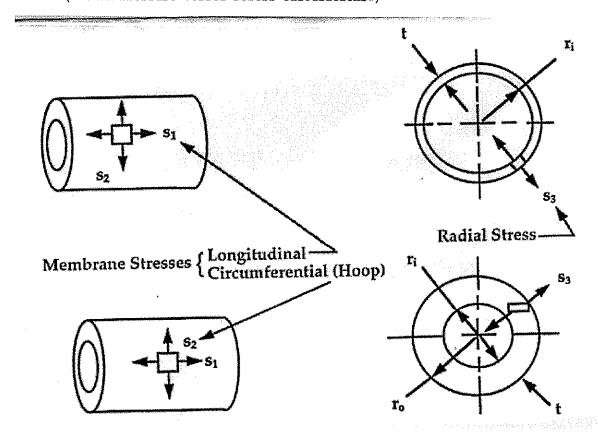
```
MAWP = 978
P_1 = MAWP
P_2 = 14.7
K = 1.66
R_i = 3.8125
D2 = 1.5
D3 = 2.32
V_{I} = \frac{\pi (2R_{I})^{2}}{4} (12.2 - 0.5) (* in^{3} *)
V_2 = \frac{\pi (D2)^2}{4} (8.058 - 0.2) (* in^3 *)
V_3 = \frac{\pi (D3)^2}{4} 2.17 (* in^3 *)
V_{T} = V_{1} + V_{2} + V_{3} (* in^{3} *)
Energy = \frac{P_1 V_T}{12 (K-1)} \left( 1 - \left( \frac{P_2}{P_1} \right)^{\frac{K-1}{K}} \right) (* ft-lb *)
Energy<sub>TNT</sub> = \frac{\text{Energy}}{3414.1} (* g TNT *)
Energy<sub>1b</sub> = Energy<sub>TNT</sub> * 0.002200 (* lb. TNT *)
978
978
14.7
                                                                                                                                       Ē
1.66
3.8125
                                                                                                                                       3
1.5
2.32
534.263
13.8862
9.1733
557.323
55852.
16.3592
0.0359903
```

(* From MEDSS, 30 psi is the threshold for fatalities. 0.2 to 15 psi cause physiological damage (ear, lung, etc.) However, the detailed calculation that follow (and proof tests of Conflat heads) show this vessel will leak before catastrophic failure. *)

(* The following is an analysis of the static overpressure in the confined room *)

$P_{\text{gov}} = 1.15 \times 10^4 \frac{\text{Energy}_{1b}}{20 \times 30 \times 10} $ (* psig *)	
0.0689813]
(* The peak overpressure is simply 6 X static *)	7
$P_{pov} = 6 \times P_{sov} $ (* psig *)]]
0.413888	E

(*Xenon Pressure Vessel Stress Calculations*)



Out[19]= medium wall

```
In[12]:=
          MAWP = 978
          \sigma_{\rm a} = 16700 (*allowable stress for 316 L SST*)
          \sigma_{\mathbf{y}} = 37000
          R_i = 3.8125
          R_o = 4.3125
          t = R_o - R_i
          If [1.1 < Ratio < 1.5, medium wall]</pre>
          If [Ratio < 1.1, thin wall]</pre>
          If [Ratio > 1.5, thick wall]
Out[12]= 978
Out[13]= 16700
Out[14]= 37000
Out[15] = 3.8125
Out[16] = 4.3125
Out[17] = 0.5
Out[18] = 1.13115
```

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TY09I64Z0E In[22]:= $(*Longitudinal Stress, S_1*)$ $S_1 = \frac{(MAWP R_1^2)}{(R_0^2 - R_1^2)}$

(*Circumferential Stress, S2*)

$$S_2 = \frac{\text{MAWP} (R_o^2 + R_i^2)}{(R_o^2 - R_i^2)}$$

(*Radial Stress, S3*)

 $S_3 = -MAWP$

(*Von Mises Stress*)

$$\sigma_{\rm m} = \sqrt{0.5 \left(\left({\rm S}_1 - {\rm S}_2 \right)^2 + \left({\rm S}_2 - {\rm S}_3 \right)^2 + \left({\rm S}_3 - {\rm S}_1 \right)^2 \right)}$$

Out[22]= 3499.17

Out[23]= 7976.34

Out[24]= -978

Out[25]= 7754.69

```
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```

```
(*wall thickness, in., max. pressure, psi*)
         (*Circumferential / Longitudinal Stress: wall thickness, in., max. pressure, psi*)
        E_f = 0.7
         (*butt weld efficiency based on no inspection, Table UW-12*)
         (*Circumferential butt welds connecting
           ellipsoidal head and hub to cylinder are Catagory A/B, Type 1 welds*)
        p = 1.67 (* in., longitudinal pitch of tube holes *)
        d = 0.5 (* in., diamnter of tube hole*)
        E_{flig} = \frac{p - d}{p} (* UG-53, Ligaments *)
         If [E_f < E_{flig}, E_f = E_f, E_f = E_{flig}]
        t_c = \frac{(\text{MAWP R}_1)}{(\sigma_a E_f - 0.6 \text{ MAWP})} \quad (*\text{UG27 c 1*})
        P_c = \frac{(\sigma_a E_f t)}{(R_1 + 0.6 t)} (*UG27 c 1*)
        SF_{uc} = \frac{P_c}{MAND} (* P<sub>c</sub> uses allowable stress so SF ~5 is also inlcluded*)
        t_1 = \frac{\text{(MAWP R}_1)}{\text{(2 } \sigma_a E_f + 0.4 MAWP)} (*UG27 c 2*)
        P_1 = \frac{(2 \sigma_a E_f t)}{(R_i - 0.4 t)} (*UG27 c 2*)
        SF_{u1} = \frac{P_1}{MAWP} (* P_1 uses allowable stress so SF \sim 5 is also included*)
         If [P_c < P_1, "circumferential stress applies", "longitudinal stress applies"]
         If [t_c > t_1, "circumferential stress applies", "longitudinal stress applies"]
Out[15] = 0.7
Out[16]= 1.67
Out[17] = 0.5
Out[18]= 0.700599
Out[19] = 0.7
Out[20]= 0.335815
Out[21]= 1421.28
Out[22] = 1.45325
Out[23]= 0.156855
```

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```
Out[189]= 3235.99
Out[190] = 13.2351
Out[191] = circumferential stress applies
Out[192] = circumferential stress applies
          (*Check of Von Mises stress at 1.5 \times MAWP for pressure test*)
          MAWP = 1.5 \times 978
          (*Longitudinal Stress, S1*)
          S_1 = \frac{(\text{MAWP } R_1^2)}{(R_0^2 - R_1^2)}
          (*Circumferential Stress, S2*)
          S_2 = \frac{\text{MAWP} (R_0^2 + R_i^2)}{(R_0^2 - R_i^2)}
          (*Radial Stress, S3*)
          S_3 = -MAWP
          (*Von Mises Stress*)
          \sigma_{\rm m} = \sqrt{0.5 \left( \left( S_1 - S_2 \right)^2 + \left( S_2 - S_3 \right)^2 + \left( S_3 - S_1 \right)^2 \right)}
          N_r = \frac{\sigma_y}{\sigma_m}
          If [N_r > 1, "vessel OK at 1.5 x MAWP during pressure test"]
          1467.
          5248.76
          11964.5
          -1467.
          11632.
          3.18087
```

vessel OK at $1.5 \times MAWP$ during pressure test

```
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```

```
(*Xenon Pressure Vessel Stress Calculations*)
         (*Ellipsoidal Head*)
In[704]:=
           MAWP = 978
           \sigma_a = 16700 (*allowable stress for 304 SST*)
            \sigma_y = 32000
           D_i = 7.625
           t_w = 0.5
            (*Circumferential butt welds connecting
              ellipsoidal head and hub to cylinder are Catagory A, Type 1 welds*)
           E_f = 0.7 (*butt weld efficiency based on no inspection, Table UW-12*)
Out[704]= 978
Out[705]= 16700
Out[706]= 32000
Out[707]= 7.625
Out[708] = 0.5
Out[709]= 0.7
In[710]:= (*Wall thickness, in., max. pressure, psi*)
            (*Circumferential Stress: wall thickness, in., max. pressure, psi*)
           t_h = \frac{(\text{MAWP D}_i)}{(2 \sigma_a E_f - 0.2 \text{ MAWP})} (*\text{UG32 } (d)*)
           P_{m} = \frac{(2 \sigma_{a} E_{f} t_{w})}{(D_{i} + 0.2 t_{w})} (*UG32 (d)*)
           SF_{uc} = \frac{P_m 4}{MAWP}
Out[710] = 0.321649
Out[711] = [1513.27]
```

Out[712] = 6.18924

In[713] :=(*Check of stress at 1.5 x MAWP for pressure test*) Solve $\left[\text{MAWP} == \frac{\left(2 \sigma E_f \ t_w\right)}{\left(D_i + 0.2 \ t_w\right)}, \ \sigma\right]$ Out[713]= 1467.

 $Out[714] = \{ \{ \sigma \rightarrow 16189.4 \} \}$

Out [715] = $\frac{32000}{\sigma}$ $\frac{16.700}{16/89.4}$ > 10



```
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```

```
(*Xenon Pressure Vessel Stress Calculations*)
         (*Ellipsoidal Head, LN2 Trap*)
In[716]:=
           MAWP = 978
           \sigma_a = 16700 (*allowable stress for 304 SST*)
           \sigma_{\rm y}=32000
           D_1 = 1.5
           t_w = 0.2
            (*Circumferential butt welds connecting
              ellipsoidal head and hub to cylinder are Catagory A, Type 1 welds*)
           E_f = 0.7 (*butt weld efficiency based on no inspection, Table UW-12*)
Out[716]= 978
Out[717]= 16700
Out[718]= 32000
Out[719] = 1.5
Out[720]= 0.2
Out[721] = 0.7
In[722]:= (*Wall thickness, in., max. pressure, psi*)
            (*Circumferential Stress: wall thickness, in., max. pressure, psi*)
           t_h = \frac{(\text{MAWP D}_i)}{(2 \sigma_a E_f - 0.2 \text{ MAWP})} (*\text{UG32} (d)*)
           P_{m} = \frac{(2 \sigma_{\alpha} E_{f} t_{w})}{(D_{i} + 0.2 t_{w})} (*UG32 (d)*)
           SF_{uc} = \frac{P_m 4}{MAWP}
Out[722] = 0.0632753
```

Out[723]= 3036.36

Out[724]= 12.4187

In[725]:= (*Check of stress at 1.5 \times MAWP for pressure test*) MAWP = 1.5 \times 978

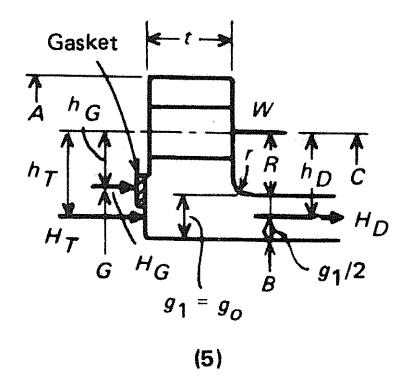
Solve [MAWP ==
$$\frac{(2 \sigma E_f t_w)}{(D_i + 0.2 t_w)}$$
, σ]
 $SF_y = \frac{\sigma_y}{\sigma}$

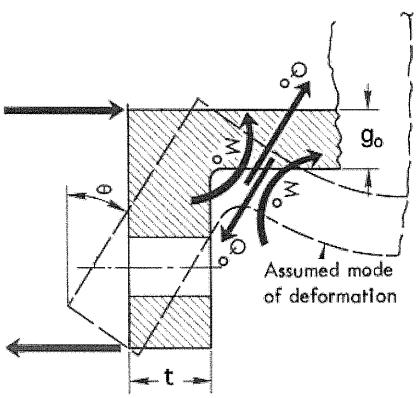
Out[725]= 1467.

 $Out[726] = \{ \{ \sigma \rightarrow 8068.5 \} \}$

$$Out[727] = \frac{32000}{\sigma}$$

16,700 7 1





- (* Bolted Flange Connections with Ring Type Joint *)
- (* Integral Flange Type, Appendix 2, Figure 2-4 (5) shown above *)
- (* 850 psia MOP, custom flange, ring type joint, metal seal *)

Out[11]= 20369.3

```
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```

```
In[1]:= (* Bolt Load at operating conditions *)
        G = 7.980 (* Diameter, in. at gasket load location *)
        P = 978 (* MAWP, internal design pressure *)
        m = 6.5 (* gasket factor ring joint, Table 2-4.1 *)
        N_g = 0.25 (* width of ring type gasket *)
       b_o = \frac{N_g}{8} (* Table 2-5.2 (6) *)
        If b_0 \le 0.25, b = b_0, b = .5 \sqrt{b_0}
        y = 26000 (* psi, design seating stress for metal seal, Table 2-5.1 *)
        H = 0.785 G^2 P (* 1b., Total hydrostatic end force *)
        H_p = 2b \times \pi GmP (* lb., Total joint-contact surface compression load *)
        W_{m1} = H + H_p (* Minimum required bolt load, for operating *)
        W_{m2} = \pi Gby (* Minimum required bolt load, for gasket seating *)
Out[1] = 7.98
Out[2] = 978
Out[3] = 6.5
Out[4] = 0.25
Out[5] = 0.03125
Out[6] = 0.03125
Out[7]= 26000
Out[8]= 48889.4
Out[9]= 9960.59
Out[10]= 58849.9
```

```
(* Flange Design Bolt Load*)
        A_b = 0.1406 \times 24 \text{ (*cross sectional area of 1/2-13 screw*)}
        SF = 4 (* MEDSS *)
        S_T = 81000
        (*Unbrako - KS 1216 1/2-13 SHCS, 160, ksi tensile strength; T = -400 °F to 1200 °F
         OR ASTM-A493-95 Grade S30430; 81 ksi tensile strength *)
        S_a = S_T + SF
        L_b = S_a \times A_b (* lb., Max allowable bolt load *)
        A_{m1} = W_{m1} / S_a (* in^2, cross-sectional area of bolts under operating condition *)
        A_{m2} = W_{m2} / S_a (* in^2, cross-sectional area of bolts for gasket seating *)
         If [A_{m1} > A_{m2}, A_m = A_{m1}, A_m = A_{m2}]
        (* in2, total required cross-sectional area of bolts *)
        W_o = W_{ml} (* lb., Flange design bolt load, for operating *)
        W_g = \frac{(A_m + A_b) S_a}{2} (* lb., Flange design bolt load, for gasket seating *)
Out[12]= 3.3744
Out[13]= 4
Out[14]= 81000
Out[15] = 20250
Out[16]= 68331.6
Out[17]= 2.90617
Out[18]= 1.00589
Out[19]= 2.90617
Out[20]= 58849.9
Out[21]= 63590.8
```

```
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```

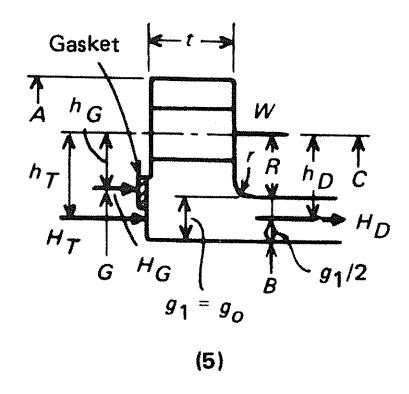
```
In[22]:=
           (* Flange Moment *)
           (* Table 2-6, integral flange *)
          C<sub>b</sub> = 9.58 (* in., bolt circle diameter *)
           g1 = 0.5 (* in., hub flange thickness *)
          B = 7.625 (*in., inside diameter of flange *)
          test = 20 g_1
          R = \frac{(C_b - B)}{2} - g_1
           R+0.5\,g_1 (* in., radial distance from bolt circle to the circle on which h_D acts *)
          h_G = \frac{(C_b - G)}{2}
          h_T = \frac{(R + g_1 + h_G)}{2}
          H_D = 0.785 \, B^2 \, P (* lb., total hydrostatic force on area inside of flange *)
           M_D = H_D h_D
          H_T = H - H_D
           (* lb., difference, total hydrostatic end force less H_D\ \star)
           M_T = H_T h_T
          H_G = W_o - H (* lb., gasket load *)
           M_G = H_G h_G
          M_{o} = M_{D} + M_{T} + M_{G} (* in-lb., total flange moment due to operating conditions *)
          M_g = W_0 - \frac{(C_b - G)}{2} (* in-1b., total flange moment due to gasket seating *)
           If [M_o > M_g, "operating conditions control", "gasket seating conditions control"]
           If [M_o > M_g, M_o = M_o, M_o = M_g]
Out[22] = 9.58
Out / 231 = 0.5
Out[24] = 7.625
Out [25] = 10.
Out[26]= 0.4775
Out[27]= 0.7275
Out[28] = 0.8
Out[29]= 0.88875
Out[30]= 44636.3
Out[31]= 32472.9
Out[32]= 4253.05
Out[33]= 3779.9
```

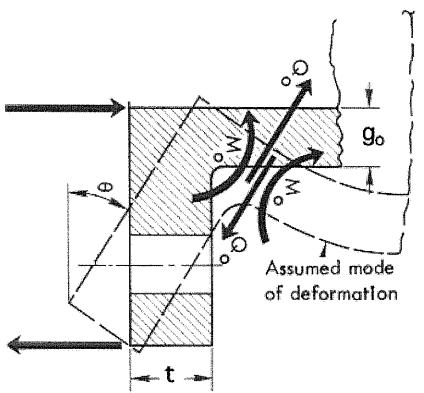
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```
Out[120]= 9960.59
Out[121] = 7968.47
Out[122] = 44221.3
Out[123]= 47080.
Out[124] = gasket seating conditions control
Out[125] = 47080.
In[126]:= (*Flange Stress *)
             \epsilon = 1 (*hub stress correction factor*)
             t = 1.25 (* in., flange thickness *)
             h = 0.125 (* in., hub length *)
             t_e = 2 g_1
             A = 10.5 (* in., OD of flange *)
             T = \frac{K^2 (1 + 8.55246 Log[10, K]) - 1}{(1.04720 + 1.9448 K^2) (K - 1)} (* factor, Fig. 2-7.1*)
            U = \frac{K^2 (1 + 8.55246 \log[10, K]) - 1}{1.36136 (K^2 - 1) (K - 1)} (* factor, Fig. 2-7.1*)
            Y = \frac{1}{K-1} \left( 0.66845 + 5.71690 \frac{K^2 \log[10, K]}{(K^2-1)} \right) (* factor, Fig. 2-7.1*)
            Z = \frac{K^2 + 1}{K^2 - 1} (* factor, Fig. 2-7.1*)
             g_0 = g_1
             h_o = \sqrt{B g_o}
            V = 0.550103 (* Fig. 2-7.3 Integral flange factor *)
            d_f = \frac{v}{v} h_o g_o^2
            L = \frac{t_e + 1}{T} + \frac{t^3}{d_e}
            S_{H} = \frac{\epsilon M_{o}}{L_{G_{1}}^{2} B} (* psi, Longitudinal hub stress *)
            S_{R} = \frac{(1.33 t_{e} + 1) M_{o}}{L t^{2} B} (* psi, Radial flange stress *)
             (* psi, Tangental flange stress *)
            S_{T} = \frac{Y M_{o}}{t^{2} B} - Z S_{R}
Out[126]= 1
Out[127]= 1.25
Out[128] = 0.125
Out[129] = 1.
Out[130]= 10.5
```

```
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```

```
Out[131]= 1.37705
Out[132] = 1.7642
Out[133] = 6.84641
Out[134]= 6.23025
Out[135]= 3.23148
Out[136] = 0.5
Out[137] = 1.
Out[138]= 1.95256
Out[139] = 0.0640184
Out[140] = 0.550103
Out[141]= 6.07525
Out[142]= 1.45515
Out[143]= 16972.6
Out[144]= 6327.39
Out[145]= 4172.77
In[146]:=
          (* Allowable Flange Stress *)
          S_f = 16700 (* allowable stress for 316 L -20 to 100 °F, Table 1A, Section II *)
           If[S_{\rm E} < 1.5 S_{\rm f}, "hub stress OK", "hub stress too large"]
           If[S_R < S_f, "radial stress OK", "radial stress too large"]
           If [S_T < S_f, "tangental stress OK", "tangental stress too large"]
           If \left[\frac{S_H + S_R}{2} < S_f, "average stress1 OK", "average stress1 too large"
           If \left[\frac{S_R + S_T}{2} < S_f, "average stress2 OK", "average stress2 too large"\right]
Out[146]= 16700
Out[147] = hub stress OK
Out[148] = radial stress OK
Out[149] = tangental stress OK
Out[150] = average stress1 OK
Out[151]= average stress2 OK
```





(* Bolted Flange Connections
 with flat metal Copper Gasket, Xe chamber Detector Port *)
(* Integral Flange Type, Appendix 2, Figure 2-4 (5) shown above *)
(* 850 psia MOP, conflat type head *)

```
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```

```
In[249]:= (* Bolt Load at operating conditions *)
          G = 3.35 (* Diameter, in. at gasket load location *)
          P = 978 (* MAWP, internal design pressure *)
          m = 4.75 (* gasket factor flat Cu gasket, Table 2-4.1 *)
          N_g = 0.5 (* width of Cu gasket *)
         b_o = \frac{N_g}{32} (* N/4 for multiple serrations Table 2-5.2 (5),
           assume N/32 given a single knife edge serration as used in Conflats *)
          If [b_o \le 0.25, b = b_o, b = .5 \sqrt{b_o}]
          y = 13000 (* psi, design seating stress for soft copper, Table 2-5.1 *)
          H = 0.785 G^2 P (* lb., Total hydrostatic end force *)
          H_p = 2b \times \pi GmP (* lb., Total joint-contact surface compression load *)
          W_{m1} = H + H_p (* Minimum required bolt load, for operating *)
          W_{m2} = \pi Gby (* Minimum required bolt load, for gasket seating *)
Out[249] = 3.35
Out[250]= 978
Out{251} = 4.75
Out[252] = 0.5
Out[253]= 0.015625
Out[254] = 0.015625
Out[255] = 13000
Out[256]= 8615.85
Out[257] = 1527.84
Out[258]= 10143.7
```

Out[259]= 2137.76

Out [21] = 10326.7

```
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```

```
In[12]:= (* Flange Design Bolt Load*)
         A_b = 0.0519 \times 10 \; (*cross sectional area of 5/16-24 screw*)
         SF = 4 (* MEDSS *)
         S_T = 81000
          (*Unbrako - KS 1216 5/16-24 SHCS, 160, ksi tensile strength; T = -400 °F to 1200 °F
          OR ASTM-A493-95 Grade S30430; 81 ksi tensile strength *)
         S_a = S_T \div SF
         L_b = S_a \times A_b (* lb., Max allowable bolt load *)
         A_{m1} = W_{m1} / S_a (* in<sup>2</sup>, cross-sectional area of bolts under operating condition *)
         A_{m2} = W_{m2} / S_a (* in<sup>2</sup>, cross-sectional area of bolts for gasket seating *)
          If [A_{m1} > A_{m2}, A_m = A_{m1}, A_m = A_{m2}]
          (* in2, total required cross-sectional area of bolts *)
         W_0 = W_{m1} (* lb., Flange design bolt load, for operating *)
         W_g = \frac{(A_m + A_b) S_a}{2} (* lb., Flange design bolt load, for gasket seating *)
Out[12] = 0.519
Out[13] = 4
Out[14]= 81000
Out[15]= 20250
Out[16]= 10509.7
Out[17]= 0.500923
Out[18]= 0.105568
Out[19]= 0.500923
Out[20]= 10143.7
```

```
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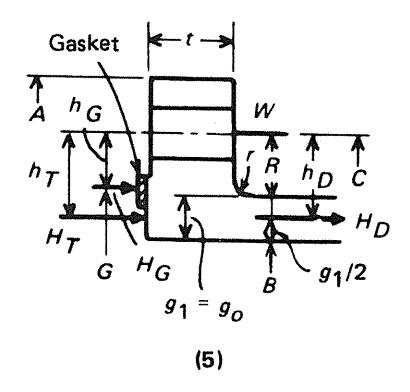
```
In[332]:=
           (* Flange Moment *)
           (* Table 2-6, integral flange *)
           C<sub>b</sub> = 4.030 (* in., bolt circle diameter *)
           g<sub>1</sub> = 0.275 (* in., hub flange thickness *)
           B = 2.32 (*in., inside diameter of flange *)
           test = 20 g<sub>1</sub> (* Refer to Appx 2, 2-3 notations, for design options *)
           R = \frac{(C_b - B)}{2} - g_1
            R + 0.5 g_1 (* in., radial distance from bolt circle to the circle on which h_D acts *)
           h_G = \frac{(C_b - G)}{2}
           \mathbf{h_T} = \frac{(\mathbf{R} + \mathbf{g_1} + \mathbf{h_G})}{2}
           H_D = 0.785 B^2 P (* lb., total hydrostatic force on area inside of flange *)
            M_D = H_D h_D
           H_T = H - H_D
           (* lb., difference, total hydrostatic end force less {\rm H}_{\rm D} *)
            M_T = H_T h_T
           H_G = W_O - H (* lb., gasket load *)
            M_G = H_G h_G
           M_o = M_D + M_T + M_G (* in-lb., total flange moment due to operating conditions *)
           M_g = W_0 \frac{(C_b - G)}{2} (* in-lb., total flange moment due to gasket seating *)
            If [M_o > M_g, "operating conditions control", "gasket seating conditions control"] \\
            If[M_o > M_g, M_o = M_o, M_o = M_g]
Out[332] = 4.03
Out[333] = 0.275
Out[334] = 2.32
Out[335] = 5.5
Out[336] = 0.58
Out[337] = 0.7175
Out[338] = 0.34
Out[339]= 0.5975
Out[340]= 4132.23
Out[341]= 2964.87
Out[342] = 4483.62
Out[343]= 2678.96
```

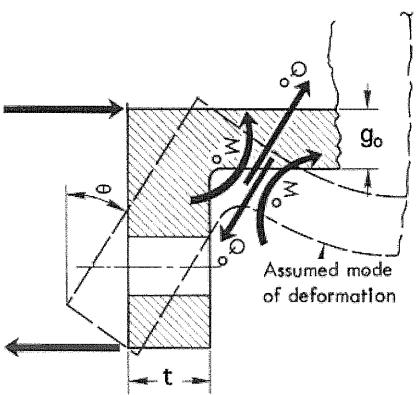
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```
Out[185] = 1527.84
Out[186]= 519.465
Out[187] = 6163.3
Out[188]= 3448.85
Out[189] = operating conditions control
Out[190] = 6163.3
In[191]:= (*Flange Stress *)
             ∈ = 1 (*hub stress correction factor*)
             t = 0.81 (* in., flange thickness *)
            h = 0.0 (* in., hub length *)
            t_e = 2 g_1
            A = 4.63 (* in., OD of flange *)
            T = \frac{K^2 (1 + 8.55246 \log[10, K]) - 1}{(1.04720 + 1.9448 K^2) (K - 1)} (* factor, Fig. 2-7.1*)
            U = \frac{K^2 (1 + 8.55246 \log[10, K]) - 1}{1.36136 (K^2 - 1) (K - 1)} (* factor, Fig. 2-7.1*)
            Y = \frac{1}{K-1} \left( 0.66845 + 5.71690 \frac{K^2 \log[10, K]}{(K^2-1)} \right) (* factor, Fig. 2-7.1*)
            Z = \frac{K^2 + 1}{K^2 - 1} (* factor, Fig. 2-7.1*)
            g_0 = g_1
            g_1/g_0
            h_o = \sqrt{B g_o}
            V = 0.550103 (* Fig. 2-7.3 Integral flange factor *)
            d_f = \frac{v}{v} h_o g_o^2
            L = \frac{t_e + 1}{T} + \frac{t^3}{d_f}
            S_B = \frac{\epsilon M_o}{L g_1^2 B} (* psi, Longitudinal hub stress *)
            S_{R} = \frac{(1.33 t_{o} + 1) M_{o}}{Lt^{2} B} (* psi, Radial flange stress *)
             (* psi, Tangental flange stress *)
            S_T = \frac{Y M_o}{t^2 B} - Z S_R
Out[191] = 1
Out[192]= 0.81
Out[193] = 0.
Out[194] = 0.55
Out[195] = 4.63
```

```
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```

```
Out[196]= 1.99569
Out[197]= 1.50825
Out[198] = 3.26596
Out[199] = 2.97203
Out[200] = 1.67052
Out[201] = 0.275
Out [202] = 1.
Out[203]= 0.798749
Out[204] = 0.
Out[205] = 0.550103
Out[206] = 0.358627
Out[207]= 2.50956
Out[208] = 13997.9
Out[209]= 2793.7
Out[210]= 7367.04
In[211]:=
           (* Allowable Flange Stress *)
          S_f = 16700 (* allowable stress for 304L -20 to 100 °F, Table 1A, Section II *)
           If [S_E < 1.5 S_f, "hub stress OK", "hub stress too large"]
           If [S_R < S_f, "radial stress OK", "radial stress too large"]
           If [S_T < S_f, "tangental stress OK", "tangental stress too large"]
           If\left[\frac{S_R + S_R}{2} < S_f, \text{ "average stress1 OK", "average stress1 too large"}\right]
           If\left[\frac{S_{R}+S_{T}}{2} < S_{f}, "average stress2 OK", "average stress2 too large"\right]
Out[211]= 16700
Out[212] = hub stress OK
Out[213] = radial stress OK
Out[214] = tangental stress OK
Out[215]= average stress1 OK
Out[216] = average stress2 OK
```





- (* Bolted Flange Connections with flat metal Copper Gasket *)
- (* Integral Flange Type, Appendix 2, Figure 2-4 (5) shown above *)
- (* 350 psia MOP, conflat type head *)

Out[194]= 5449.68

```
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```

```
In[184]:= (* Bolt Load at operating conditions *)
          G = 8.54 (* Diameter, in. at gasket load location *)
          P = 403 (* MAWP, internal design pressure *)
          m = 4.75 (* gasket factor flat Cu gasket, Table 2-4.1 *)
          N_g = 0.5 (* width of Cu gasket *)
          b_o = \frac{N_g}{32} (* N/4 for multiple serrations Table 2-5.2 (5),
           assume N/32 given a single knife edge serration as used in Conflats *)
          b = b_0
          y = 13000 (* psi, design seating stress for soft copper, Table 2-5.1 *)
          H = 0.785 G<sup>2</sup> P (* lb., Total hydrostatic end force *)
          H_p = 2 b \times \pi GmP (* 1b., Total joint-contact surface compression load *)
          W_{m1} = H + H_p (* Minimum required bolt load, for operating *)
          W_{m2} = \pi Gby (* Minimum required bolt load, for gasket seating *)
Out[184] = 8.54
Out[185] = 403
Out[186] = 4.75
Out[187] = 0.5
Out[188] = 0.015625
Out[189]= 0.015625
Out[190] = 13000
Out[191]= 23072.3
Out[192] = 1604.93
Out[193]= 24677.2
```

Out[42]= 46504.4

```
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```

```
In[33]:= (* Flange Design Bolt Load*)
          A_b = 0.1406 \times 24 \text{ (*cross sectional area of } 1/2-13 \text{ screw*)}
          SF = 4 (* MEDSS *)
          S_T = 81000
          (*Unbrako - KS 1216 1/2-13 SHCS, 160, ksi tensile strength; T = -400 °F to 1200 °F
          OR ASTM-A493-95 Grade S30430; 81 ksi tensile strength *)
          S_a = S_T \div SF
          L_b = S_a \times A_b (* 1b., Max allowable bolt load *)
          A_{m1} = W_{m1} / S_a (* in^2, cross-sectional area of bolts under operating condition *)
          A_{m2} = W_{m2} / S_a (* in^2, cross-sectional area of bolts for gasket seating *)
          If [A_{m1} > A_{m2}, A_m = A_{m1}, A_m = A_{m2}]
          (* in2, total required cross-sectional area of bolts *)
          W_o = W_{m1} (* lb., Flange design bolt load, for operating *)
         W_g = \frac{(A_m + A_b) S_a}{2} (* lb., Flange design bolt load, for gasket seating *)
Out[33]= 3.3744
Out[34] = 4
Out[35]= 81000
Out[36]= 20250
Out[37]= 68331.6
Out[38]= 1.21863
Out[39]= 0.26912
Out[40]= 1.21863
Out[41]= 24677.2
```

```
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```

```
In[205]:=
            (* Flange Moment *)
            (* Table 2-6, integral flange *)
           C<sub>b</sub> = 9.58 (* in., bolt circle diameter *)
           g<sub>1</sub> = 0.5 (* in., hub flange thickness *)
           B = 7.625 (*in., inside diameter of flange *)
           test = 20 g_1
           R = \frac{(C_b - B)}{2} - g_1
           h_D =
            R+0.5\,g_1 (* in., radial distance from bolt circle to the circle on which h_D acts *)
           h_T = \frac{(R + g_1 + h_G)}{2}
           H_D = 0.785 \, B^2 \, P \, (* \, lb., \, total \, hydrostatic force on area inside of flange *)
            M_D = H_D h_D
           H_T = H - H_D
           (* 1b., difference, total hydrostatic end force less H_D *)
            M_T = H_T h_T
           H_G = W_O - H (* lb., gasket load *)
            M_G = H_G h_G
           M_o = M_D + M_T + M_G (* in-1b., total flange moment due to operating conditions *)
           M_g = W_o - \frac{(C_b - G)}{2} (* in-lb., total flange moment due to gasket seating *)
            If [M_o > M_g, "operating conditions control", "gasket seating conditions control"]
            If[M_o > M_g, M_o = M_o, M_o = M_g]
Out[205] = 9.58
Out[206]= 0.5
Out[207] = 7.625
Out[208] = 10.
Out[209] = 0.4775
Out[210]= 0.7275
Out[211] = 0.52
Out[212]= 0.74875
Out[213]= 18393.1
Out[214] = 13381.
Out[215] = 4679.2
Out[216]= 3503.55
```

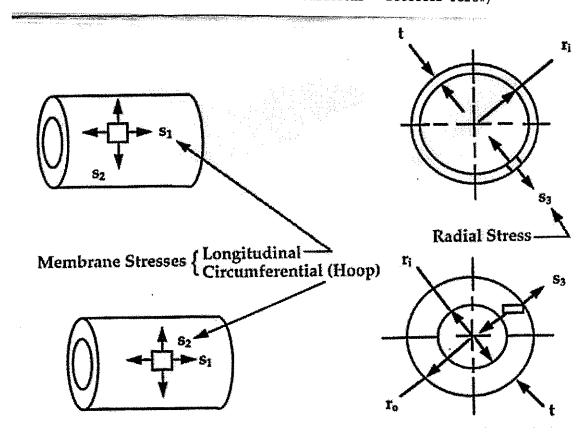
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```

```
Out[250] = 1604.93
Out[251]= 834.564
Out[252]= 17719.1
Out[253] = 12832.1
Out[254] = operating conditions control
Out[255] = 17719.1
In[256]:= (*Flange Stress *)
             \epsilon = 1 (*hub stress correction factor*)
             t = 1.25 (* in., flange thickness *)
             h = 0.125 (* in., hub length *)
             A = 10.5 (* in., OD of flange *)
             T = \frac{K^2 (1 + 8.55246 \log[10, K]) - 1}{(1.04720 + 1.9448 K^2) (K - 1)} (* factor, Fig. 2-7.1*)
             U = \frac{K^2 (1 + 8.55246 \log[10, K]) - 1}{1.36136 (K^2 - 1) (K - 1)} (* factor, Fig. 2-7.1*)
             Y = \frac{1}{K-1} \left( 0.66845 + 5.71690 \frac{K^2 \log[10, K]}{(K^2-1)} \right) (* factor, Fig. 2-7.1*)
             Z = \frac{K^2 + 1}{K^2 - 1} (* factor, Fig. 2-7.1*)
             go = g1
             g_1/g_o
             h_o = \sqrt{Bg_o}
             V = 0.550103 (* Fig. 2-7.3 Integral flange factor *)
             d_f = \frac{v}{v} h_o g_o^2
            L = \frac{t_a + 1}{T} + \frac{t^3}{d_s}
             S_{H} = \frac{\epsilon M_{o}}{L g_{1}^{2} B} (* psi, Longitudinal hub stress *)
             S_R = \frac{(1.33 t_e + 1) M_o}{L t^2 B} (* psi, Radial flange stress *)
             (* psi, Tangental flange stress *)
             S_{T} = \frac{Y M_{o}}{+^{2} R} - Z S_{R}
Out[256] = 1
Out[257] = 1.25
Out[258] = 0.125
Out[259]= 1.
Out[260]= 10.5
```

```
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```

```
Out[261]= 1.37705
   Out[262]= 1.7642
   Out[263]= 6.84641
   Out[264]= 6.23025
   Out[265] = 3.23148
  Out[266] = 0.5
  Out[267] = 1.
  Out[268]= 1.95256
  Out[269]= 0.0640184
  Out[270]= 0.550103
  Out[271]= 6.07525
  Out[272] = 1.45515
 Out[273]= 6387.84
 Out[274]= 2381.39
 Out[275]= 1570.47
 In[276]:=
                                   (* Allowable Flange Stress *)
                                  S_{\rm f} = 16700 (* allowable stress for 316 L -20 to 100 °F, Table 1A, Section II *)
                                     \label{eq:final_stress_stress_stress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_substress_ok_su
                                     If[S_R < S_f, "radial stress OK", "radial stress too large"] \\
                                     If [S_T < S_f, "tangental stress OK", "tangental stress too large"]
                                     If\left[\frac{S_{H}+S_{R}}{2} < S_{f}, "average stress1 OK", "average stress1 too large"\right]
                                    \text{If}\left[\frac{S_{\text{H}}+S_{\text{T}}}{2} < S_{\text{f}}, \text{ "average stress2 OK", "average stress2 too large"}\right]
 Out[276]= 16700
Out[277]= hub stress OK
Out[278] = radial stress OK
Out[279]= tangental stress OK
Out[280] = average stress1 OK
Out[281]= average stress2 OK
```

(*Xenon Pressure Vessel Stress Calculations - Detector Port*)



Out[383] = medium wall

```
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```
In[376]:=
          MAWP = 978
          \sigma_a = 16700 (*allowable stress for 316 L SST*)
          \sigma_{\rm y}=37000
          R_i = 1.1615
          R_o = 1.4375
          t = R_o - R_i
          If [1.1 < Ratio < 1.5, medium wall]
          If [Ratio < 1.1, thin wall]</pre>
          If [Ratio > 1.5, thick wall]
Out[376]= 978
Out[377]= 16700
Out[378]= 37000
Out[379]= 1.1615
Out[380]= 1.4375
Out[381]= 0.276
Out[382]= 1.23762
```

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TY09I64Z0E In[386]:= $(*Longitudinal Stress, S_1*)$ $S_1 = \frac{(MAWP R_1^2)}{(R_0^2 - R_1^2)}$

(*Circumferential Stress, S₂*)

$$S_2 = \frac{\text{MAWP} (R_0^2 + R_i^2)}{(R_0^2 - R_i^2)}$$

(*Radial Stress, S3*)

 $S_3 = -MAWP$

(*Von Mises Stress*)

$$\sigma_{\rm m} = \sqrt{0.5 \left(\left({\rm S}_1 - {\rm S}_2 \right)^2 + \left({\rm S}_2 - {\rm S}_3 \right)^2 + \left({\rm S}_3 - {\rm S}_1 \right)^2 \right)}$$

Out[386]= [1839.34

Out[387]= 4656.68

Out[388]= =978

Out[389]= 4879.78

```
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```

```
In[42]:=
          (*wall thickness, in., max. pressure, psi*)
          (*Circumferential Stress: wall thickness, in., max. pressure, psi*)
          E_f = 0.7 (*butt weld efficiency based on no inspection, Table UW-12*)
          t_c = \frac{(\text{MAWP R}_i)}{(\sigma_a E_f - 0.6 \text{ MAWP})} \quad (*\text{UG27 c 1*})
          P_c = \frac{(\sigma_a E_f t)}{(R_i + 0.6 t)} (*UG27 c 1*)
          SF_{uc} = \frac{P_c}{MAWD} (* P_c uses allowable stress so SF ~5 is also inlcluded*)
          (*Longitudinal Stress: wall thickness, in., max. pressure, psi*)
          (*Circumferential butt welds connecting
             ellipsoidal head and hub to cylinder are Catagory A, Type 1 welds*)
          E_f = 0.7 (*butt weld efficiency based on no inspection, Table UW-12*)
          t_1 = \frac{\text{(MAWP R}_i)}{(2 \sigma_a E_f + 0.4 \text{ MAWP})} (*UG27 c 2*)
          P_1 = \frac{(2 \sigma_a E_f t)}{(R_i - 0.4 t)} (*UG27 c 2*)
          SF_{ul} = \frac{P_1}{MaWp} (* P_1 uses allowable stress so SF ~5 is also inlcluded*)
          If [P_c < P_1, "circumferential stress applies", "longitudinal stress applies"]
          If [t<sub>c</sub> > t<sub>1</sub>, "circumferential stress applies", "longitudinal stress applies"]
Out[42]= 0.7
Out[43]= 0.102308
Out[44] = 2431.2
Out[45]= 2.48589
Out[46] = 0.7
Out[47]= 0.0477867
Out[48]= 6139.17
Out[49]= 6.27727
Out[50]= circumferential stress applies
Out[51] = circumferential stress applies
```

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```
In[400] := \\ (*Check of Von Mises stress at 1.5 \times MAWP for pressure test*) \\ MAWP = 1.5 \times 978 \\ (*Longitudinal Stress, S_1*) \\ S_1 = \frac{(\text{MAWP R}_1^2)}{(R_0^2 - R_1^2)}
```

(*Circumferential Stress, S2*)

$$S_2 = \frac{\text{MAWP} (R_o^2 + R_i^2)}{(R_o^2 - R_i^2)}$$

(*Radial Stress, S3*)

 $S_3 = -MAWP$

(*Von Mises Stress*)

$$\sigma_{\rm m} = \sqrt{0.5 \left(\left({\rm S}_1 - {\rm S}_2 \right)^2 + \left({\rm S}_2 - {\rm S}_3 \right)^2 + \left({\rm S}_3 - {\rm S}_1 \right)^2 \right)}$$

$$N_r = \frac{\sigma_y}{\sigma_m}$$
 If [N_r > 1, "vessel OK at 1.5 \times MAWP during pressure test"]

Out[400] = 1467.

Out[401]= 2759.01

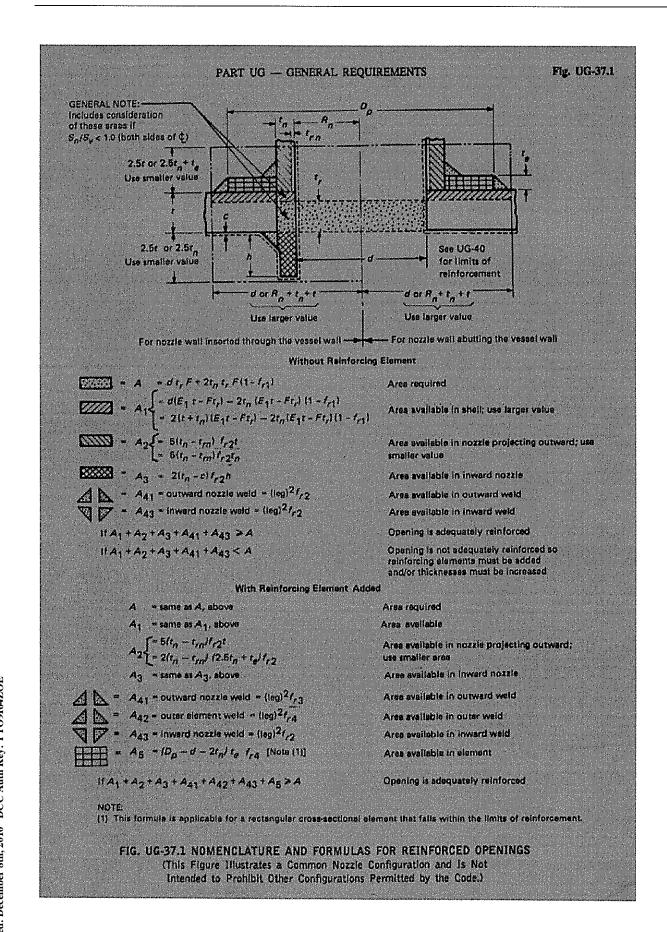
Out[402]= 6985.02

Out[403] = -1467.

Out[404]= 7319.66

Out[405]= 5.05488

Out[406] = vessel OK at 1.5 × MAWP during pressure test

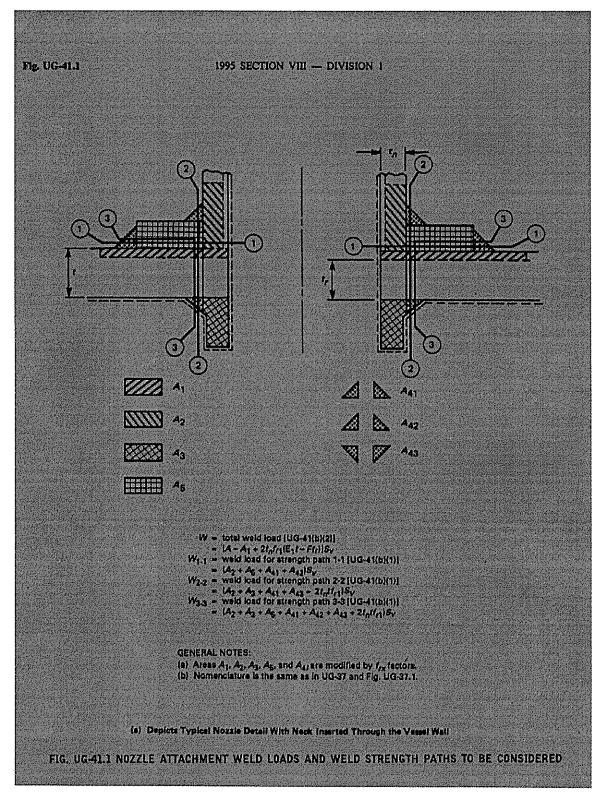


```
(*Opening reinforcement calculations*)
        (* Detector pipe to shell wall*)
        (* A3 = 0, A5 = 0, A42 = 0 *)
        (* Sch 80 Pipe, 3 " Ø *)
       Tx = 2.875 (*OD*)
       d = 2.323 (*ID min*)
       tn = (Tx - d) / 2 (*nozzel wall thickness*)
       te = 1.25 * tn (*weld leg height*)
Out[445]= 2.875
Out[446] = 2.323
Out[447] = 0.276
Out[448] = 0.345
In[473]:= F = 1 (*correction factor*)
          tr = 0.335815 (*minimum shell thickness, Vessel_stress2.nb*)
          fr1 = 1 (*strength reducton factor*)
          t = 0.5 (*shell wall thickness*)
         E1 = 1 (*joint efficiency*)
         A = dtr F + 2tntr F (1 - fr1)
          A1a = d (E1t - Ftr) - 2tn (E1t - Ftr) (1 - fr1)
          A1b = 2 (t + tn) (E1t - Ftr) - 2tn (E1t - Ftr) (1 - fr1)
            If [A1a > A1b, A1 = A1a, A1 = A1b]
Out[473] = 1
Out[474]= 0.335815
Out[475] = 1
Out[476] = 0.5
Out[477] = 1
Out[478] = 0.780098
Out[479]= 0.381402
Out[480] = 0.254815
Out[481]= 0.381402
```

Out[500]= True

```
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```
In[482]:= fr2 = 1 (*strength reducton factor*)
          trn = 0.10230807 (*requierd nozzel thickness, Xe_vessel_det.nb*)
          A2a = 5 (tn - trn) fr2 t
          A2b = 5 (tn - trn) fr2 tn
          If[A2a < A2b, A2 = A2a, A2 = A2b]
Out[482] = 1
Out[483] = 0.10230807
Out[484]= 0.43423
Out[485]= 0.239695
Out[486]= 0.239695
       fr3 = 1 (*strength reducton factor*)
       A43 = te^2 fr3
       A41 = \frac{te^2 fr3}{2} (* 1/2 the area, skip weld on outside*)
Out[492] = 1
Out[493]= 0.119025
Out[494]= 0.0595125
In[498] := (A1 + A2 + A43 + A41)
          (A1 + A2 + A43 + A41) >= A
          (*If actual area > area required, then no additional reinforcement required *)
Out [498] = 0.799634
Out[499]= 0.780098
```



(*must run "detector_shell.nb" file first to save variables defined below into memory*)

```
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```

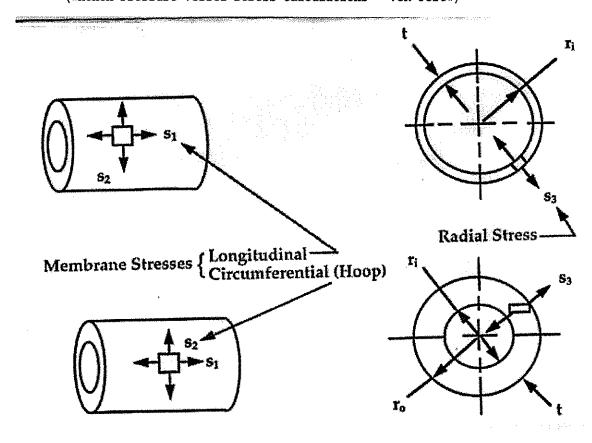
Out [539] = 8183.

```
In[523]:= (*Load / Stress Carried by Welds*)
          A1
          A2
          A3 = 0
          A5 = 0
          A41
          A42 = 0
          A43
Out[523]= 0.780098
Out[524]= 0.381402
Out[525]= 0.239695
Out[526]= 0
Out[527]= 0
Out[528] = 0.0595125
Out[529]= 0
Out[530]= 0.119025
In[533]:= Sv = 16700 (* allowable stress*)
          W = (A - A1 + 2 tn fr1 (E1t - Ftr)) Sv
Out[533]= 16700
Out[534]= 8171.75
In[535]:=
          W_{1-1} = (A2 + A5 + A41 + A42) Sv
Out[535]= 4996.76
In[536] := W_{2-2} = (A2 + A3 + A41 + A43 + 2 tn t fr1) Sv
Out[536]= 11593.7
In[537]:=
          W_{3-3} = (A2 + A3 + A5 + A41 + A42 + A43 + 2 tn t fr1) Sv
Out[537] = 11593.7
        (* W (total weld load) << W_{1-1}, W_{2-2}, W_{3-3}, (weld load available)*)
In[539]:= (*Allowable Unit Stresses*)
           (*Fillet Weld Shear, UW 15 c*)
          \sigma_{\text{fw}} = 0.49 \text{ (Sv)}
```

```
In[540]:= (*Nozzel Wall Shear, UG 45 c*)
            \sigma_{nw} = 0.7 \text{ (Sv)}
Out[540] = 11690.
In [541]:=
             (*Strength of Connection Elements*)
             (*Fillet Weld Shear*)
            W_{fw} = \frac{\pi}{2} \text{ Tx te } \sigma_{fw}
Out[541]= 12749.4
In[542]:=
             (*Strength of Connection Elements*)
             (*Nozzel Wall Shear*)
            W_{nw} = \frac{\pi}{2} \frac{(Tx + d)}{2} tn \sigma_{nw}
Out[542]= 13171.9
In[543]:=
            WS_{1-1} = W_{nw}
            WS_{2-2} = W_{fw}
Out[543]= 13171.9
Out[544]= 12749.4
```

(*All Paths WS_{1-1} , WS_{2-2} , are stronger than the required strength W*)

(*Xenon Pressure Vessel Stress Calculations - VCR Port*)



Out[552] = medium wall

```
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```

```
In[545]:=
           MAWP = 978
           \sigma_a = 16700 (*allowable stress for 316 L SST*)
           \sigma_{\rm y}=37000
           R_i = 0.40 / 2.
           R_o = 0.5 / 2.
           t = R_o - R_i
           If [1.1 < Ratio < 1.5, medium wall]</pre>
           If [Ratio < 1.1, thin wall]
           If [Ratio > 1.5, thick wall]
Out[545]= 978
Out[546]= 16700
Out[547]= 37000
Out[548] = 0.2
Out[549] = 0.25
Out[550] = 0.05
Out[551]= 1.25
```

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TY09I64Z0E In[555]:= $(*Longitudinal Stress, S_1*)$ $S_1 = \frac{(MAWP R_1^2)}{(R_0^2 - R_1^2)}$

(*Circumferential Stress, S_2*)

$$S_2 = \frac{\text{MAWP} (R_0^2 + R_1^2)}{(R_0^2 - R_1^2)}$$

(*Radial Stress, S3*)

 $S_3 = -MAWP$

(*Von Mises Stress*)

$$\sigma_{\rm m} = \sqrt{0.5 \left(\left(S_1 - S_2 \right)^2 + \left(S_2 - S_3 \right)^2 + \left(S_3 - S_1 \right)^2 \right)}$$

Out [555] = 1738.67

Out[556]= 4455.33

Out[557]= -978

Out[558]= 4705.4

```
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```

```
In[73]:=
           (*wall thickness, in., max. pressure, psi*)
          (*Circumferential Stress: wall thickness, in., max. pressure, psi*)
          Ef = 1.0 (*efficiency*)
          t_c = \frac{\text{(MAWP R}_i)}{\text{(}\sigma_a E_f - 0.6 MAWP)} \text{ (*UG27 c 1*)}
          P_c = \frac{(\sigma_a E_f t)}{(R_i + 0.6 t)} (*UG27 c 1*)
          SF_{uc} = \frac{P_c}{MainD} (* P_c uses allowable stress so SF \sim 5 is also inlcluded*)
          (*Longitudinal Stress: wall thickness, in., max. pressure, psi*)
          (*Circumferential butt welds connecting
             ellipsoidal head and hub to cylinder are Catagory A, Type 1 welds*)
          Ef = 1.0 (*efficincy*)
          t_1 = \frac{(\text{MAWP R}_1)}{(2 \sigma_a E_f + 0.4 \text{ MAWP})} (*\text{UG27 c } 2*)
          P_1 = \frac{(2 \sigma_a E_f t)}{(R_i - 0.4 t)} (*UG27 c 2*)
          SF_{ul} = \frac{P_1}{MaWP} (* P_1 uses allowable stress so SF ~5 is also inlcluded*)
          If [Pc < P1, "circumferential stress applies", "longitudinal stress applies"]
          If [tc > t1, "circumferential stress applies", "longitudinal stress applies"]
Out[73] = 1.
Out[74]= 0.0121391
Out[75]= 3630.43
Out[76]= 3.7121
Out[77] = 1.
Out[78]= 0.00578849
Out[79]= 9277.78
Out[80]= 9.48648
Out[81] = circumferential stress applies
```

Out[82] = circumferential stress applies

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```
In\{569\}:= \\ (*Check of Von Mises stress at 1.5 \times MAWF for pressure test*) \\ MAWP = 1.5 \times 978 \\ (*Longitudinal Stress, S_1*) \\ S_1 = \frac{(\text{MAWP R}_1^2)}{(\text{R}_0^2 - \text{R}_1^2)} \\ (*Circumferential Stress, S_2*) \\ S_2 = \frac{\text{MAWF }(\text{R}_0^2 + \text{R}_1^2)}{(\text{R}_0^2 - \text{R}_1^2)} \\ (*Radial Stress, S_3*) \\ S_3 = -\text{MAWF} \\ (*Von Mises Stress*) \\ \sigma_m = \sqrt{0.5 \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2\right)}
```

 $\sigma_{\rm m} = V_0 0.5 ((S_1 - S_2)^- + (S_2 - S_3)^- + (S_3 - S_3)^-)$

 $N_r = \frac{\sigma_y}{\sigma_m}$ If [N_r > 1, "vessel OK at 1.5 × MAWP during pressure test"]

Out[569] = 1467.

Out[570]= 2608.

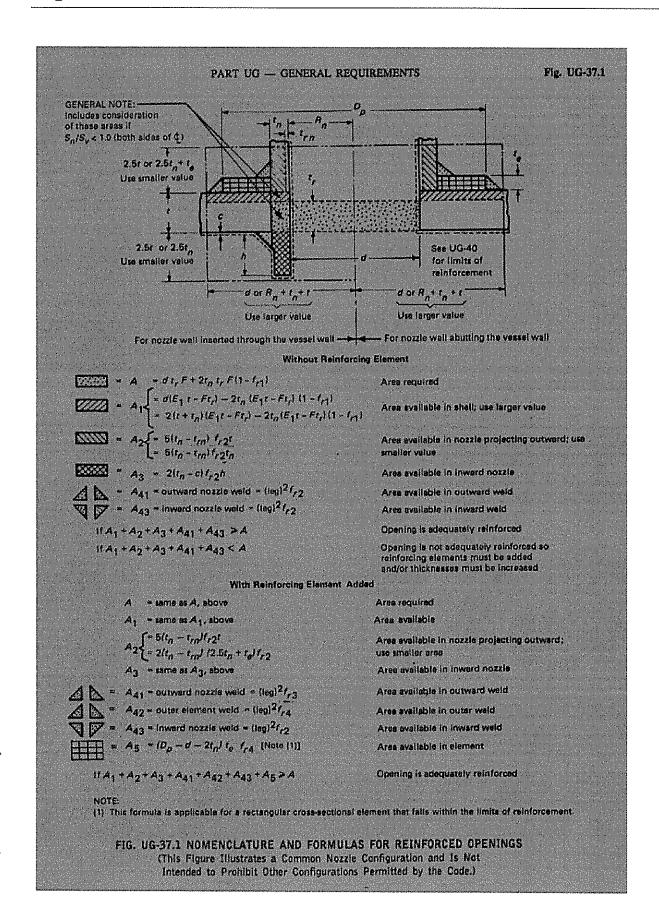
Out[571]= 6683.

Out[572] = -1467.

Out[573]= 7058.11

Out[574]= 5.2422

Out[575] = vessel OK at 1.5 × MAWP during pressure test

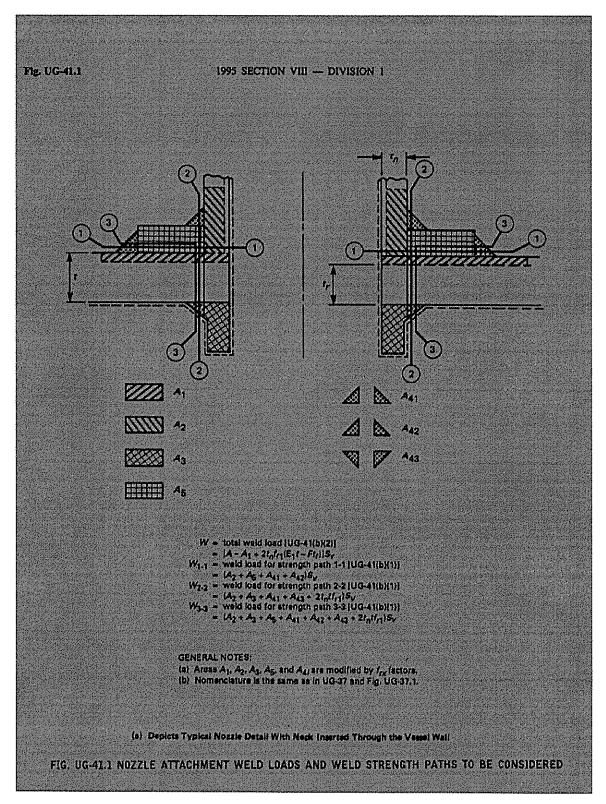


```
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```

```
In[576]:= (* Opening Reinforcement Calculations*)
          (* VCR Gland to shell wall*)
          (* A3 = 0, A5 = 0, A43 = 0, A42 = 0 *)
          (* VCR, 0.5 " Ø *)
          Tx = .5 (*OD*)
          d = 0.40 (*ID min*)
         tn = (Tx - d) / 2 (*nozzel wall thickness*)
          te = 1.25 * tn (*weld leg height*)
Out [576] = 0.5
Out[577] = 0.4
Out[578]= 0.05
Out[579]= 0.0625
In[580]:= F = 1 (*correction factor*)
         tr = 0.335815 (*minimum shell thickness, Vessel_stress2.nb*)
          fr1 = 1 (*strength reducton factor*)
         t = 0.5 (*shell wall thickness*)
         E1 = 1 (*joint efficiency*)
         A = dtr F + 2tntr F (1 - fr1)
          Ala = d(E1t - Ftr) - 2tn(E1t - Ftr)(1 - fr1)
          A1b = 2 (t + tn) (E1t - Ftr) - 2tn (E1t - Ftr) (1 - fr1)
            If [A1a > A1b, A1 = A1a, A1 = A1b]
Out[580] = 1
Out[581]= 0.335815
Out[582] = 1
Out[583] = 0.5
Out[584] = 1
Out[585]= 0.134326
Out[586]= 0.065674
Out[587] = 0.180604
Out[588] = 0.180604
```

```
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```

```
In[589]:= fr2 = 1 (*strength reducton factor*)
          trn = 0.0121391(*required nozzel thickness, Xe_vessel_VCR.nb*)
          A2a = 5 (tn - trn) fr2 t
          A2b = 5 (tn - trn) fr2 tn
          If [A2a < A2b, A2 = A2a, A2 = A2b]
Out[589]= 1
Out[590] = 0.0121391
Out[591]= 0.0946522
Out[592]= 0.00946522
Out[593] = 0.00946522
In[594]:= fr3 = 1 (*strength reducton factor*)
         A43 = te^2 fr3
Out[594] = 1
Out[595]= 0.00390625
In[596] := (A1 + A2 + A43)
          (A1 + A2 + A43) >= A
          (*If actual area > area required, then no additional reinforcement required *)
Out[596] = 0.193975
Out[597] = 0.134326
Out[598]= True
```



(*must run "VCR_shell.nb" file first to save variables defined below into memory*)

```
In[599]:= (*Load / Stress Carried by Welds*)
          Α
          A1
          A2
          A3 = 0
          A5 = 0
          \mathbf{A41} = \mathbf{0}
          A42 = 0
          A43
Out[599]= 0.134326
Out[600]= 0.180604
Out[601]= 0.00946522
Out[602] = 0
Out[603]= 0
Out[604]= 0
Out[605]= 0
Out[606]= 0.00390625
In[607] := Sv = 16700
          W = (A - A1 + 2 tn fr1 (E1t - Ftr)) Sv
Out[607]= 16700
Out[608] = -498.645
In[610]:=
          W_{1-1} = (A2 + A5 + A41 + A42) Sv
Out[610]= 158.069
In[611] := W_{2-2} = (A2 + A3 + A41 + A43 + 2 tn t fr1) Sv
Out[611]= 1058.3
In[612] := W_{3-3} = (A2 + A3 + A5 + A41 + A42 + A43 + 2 tn t fr1) Sv
Out[612]= 1058.3
        (* W (total weld load) << W_{1-1}, W_{2-2}, W_{3-3}, (weld load available)*)
In[613]:= (*Allowable Unit Stresses*)
           (*Fillet Weld Shear, UW 15 c*)
          \sigma_{\text{fw}} = 0.49 \text{ (Sv)}
Out[613]= 8183.
```

```
In[614]:= (*Nozzel Wall Shear, UG 45 c*)
            \sigma_{nw} = 0.7 \text{ (Sv)}
Out[614]= 11690.
In[615]:=
             (*Strength of Connection Elements*)
             (*Fillet Weld Shear*)
            W_{fw} = \frac{\pi}{2} \text{ Tx te } \sigma_{fw}
Out[615]= 401.682
In[616]:=
            (*Strength of Connection Elements*)
            (*Nozzel Wall Shear*)
            W_{nw} = \frac{\pi}{2} \frac{(Tx + d)}{2} tn \sigma_{nw}
Out[616]= 413.159
In[617]:=
            WS_{1-1} = W_{nw}
            WS_{2-2} = W_{fw}
Out[617]= 413.159
Out[618]= 401.682
```

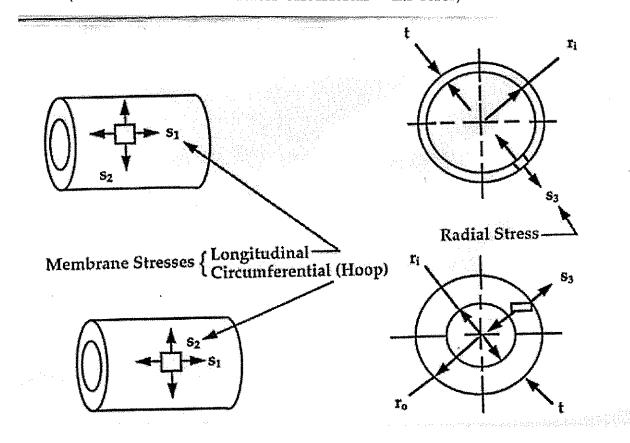
(*All Paths WS_{1-1} , WS_{2-2} , are stronger than the required strength $W\star$)

Out[32]= 0.0523806

```
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```

```
(* VCR Port Xe chamber gamma ray feedthru *)
        (* 850 psia MOP,
         stainless steel VCR plug with 0.250 " Ø counterbore. Determine head thickness: *)
In[24]:= (* Load at operating conditions *)
         G = 0.250 (* Diameter, in. at gasket load location *)
         P = 850 * 1.15 (* MAWP, internal design pressure *)
         H = 0.785 G^2 P (* lb., Total hydrostatic end force *)
Out[24] = 0.25
Out{25} = 977.5
Out[26]= 47.9586
In[27]:=
         C_0 = 0.75
                    (*Head attachment constant, UG-34 (r)*)
                    (*Efficiency Factor *)
         d_{ga} = G (*in. hole cross-sectional diameter*)
         \sigma_u = 77000.0 \; (*psi, 316 L \; ultimate \; strength*)
         \sigma_a = 16700 (*psi, 316 L allowable strength*)
         th = d_{ga} \sqrt{\frac{C_a \times P}{\sigma_a \times E_f}} (* in., required head thickness, no bending moment *)
Out[27] = 0.75
Out[28] = 1.
Out[29]= 0.25
Out[30]= 77000.
Out[31]= 16700
```

(*Xenon Pressure Vessel Stress Calculations - LN2 Port*)



Out[626] = medium wall

```
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```

```
In[619]:=
           MAWP = 978
           \sigma_{\rm a} = 16700 (*allowable stress for 316 L SST*)
           \sigma_{\rm y}=37000
           R_i = 1.5 / 2.
           R_0 = 1.9 / 2.
           t = R_o - R_i
           Ratio =
           If [1.1 < Ratio < 1.5, medium wall]</pre>
           If [Ratio < 1.1, thin wall]
           If [Ratio > 1.5, thick wall]
Out[619]= 978
Out[620]= 16700
Out[621]= 37000
Out[622] = 0.75
Out[623] = 0.95
Out[624] = 0.2
Out[625]= 1.26667
```

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TY09I64Z0E In[629]:= $(*Longitudinal Stress, S_1*)$ $S_1 = \frac{(MAWP R_1^2)}{(R_0^2 - R_1^2)}$

(*Circumferential Stress, S2*)

$$S_2 = \frac{\text{MAWP} (R_o^2 + R_i^2)}{(R_o^2 - R_i^2)}$$

(*Radial Stress, S3*)

 $S_3 = -MAWP$

(*Von Mises Stress*)

$$\sigma_{\rm m} = \sqrt{0.5 \left(\left(S_1 - S_2 \right)^2 + \left(S_2 - S_3 \right)^2 + \left(S_3 - S_1 \right)^2 \right)}$$

Out[629]= 1618.01

Out[630] = 4214.03

Out[631]= -978

Out[632] = 4496.43

```
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```

```
In[104]:=
            (*wall thickness, in., max. pressure, psi*)
            (*Circumferential Stress: wall thickness, in., max. pressure, psi*)
           E_f = 0.7 (*butt weld efficiency based on no inspection, Table UW-12*)
           t_c = \frac{(\text{MAWP R}_i)}{(\sigma_a E_f - 0.6 \text{ MAWP})} \quad (*\text{UG27 c 1*})
           P_c = \frac{(\sigma_a E_f t)}{(R_i + 0.6 t)} (*UG27 c 1*)
           SF_{uc} = \frac{P_c}{MaWD} (* P_c uses allowable stress so SF \sim 5 is also inlcluded*)
           (*Longitudinal Stress: wall thickness, in., max. pressure, psi*)
           (*Circumferential butt welds connecting
              ellipsoidal head and hub to cylinder are Catagory A, Type 1 welds*)
           E_f = 0.7 (*butt weld efficiency based on no inspection, Table UW-12*)
           t_1 = \frac{(\text{MAWP R}_1)}{(2 \sigma_a E_f + 0.4 \text{ MAWP})} (*\text{UG27 c } 2*)
           P_1 = \frac{(2 \sigma_a E_f t)}{(R_i - 0.4 t)} (*UG27 c 2*)
           SF_{ul} = \frac{P_1}{MaWP} (* P_1 uses allowable stress so SF ~5 is also inlcluded*)
           If [Pc < P1, "circumferential stress applies", "longitudinal stress applies"]
           If[t_c > t_1, "circumferential stress applies", "longitudinal stress applies"]
Out[104] = 0.7
Out[105]= 0.066062
Out[106]= 2687.36
Out[107]= 2.74781
Out[108] = 0.7
Out[109] = 0.0308567
Out[110] = 6979.1
Out[111]= 7.1361
Out[112] = circumferential stress applies
```

Out[113] = circumferential stress applies

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```
In \{643\} := \\ (*Check of Von Mises stress at 1.5 \times MAWF for pressure test*) \\ MAWF = 1.5 \times 978 \\ (*Longitudinal Stress, S_1*) \\ S_1 = \frac{(MAWP R_1^2)}{(R_0^2 - R_1^2)} \\ (*Circumferential Stress, S_2*) \\ S_2 = \frac{MAWP (R_0^2 + R_1^2)}{(R_0^2 - R_1^2)} \\ (*Radial Stress, S_3*) \\ S_3 = -MAWF \\ (*Von Mises Stress*) \\ \sigma_m = \sqrt{0.5 \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2\right)} \\ N_r = \frac{\sigma_y}{\sigma_n}
```

If $[N_r > 1$, "vessel OK at 1.5 x MAWP during pressure test"]

Out[643] = 1467.

Out[644]= 2427.02

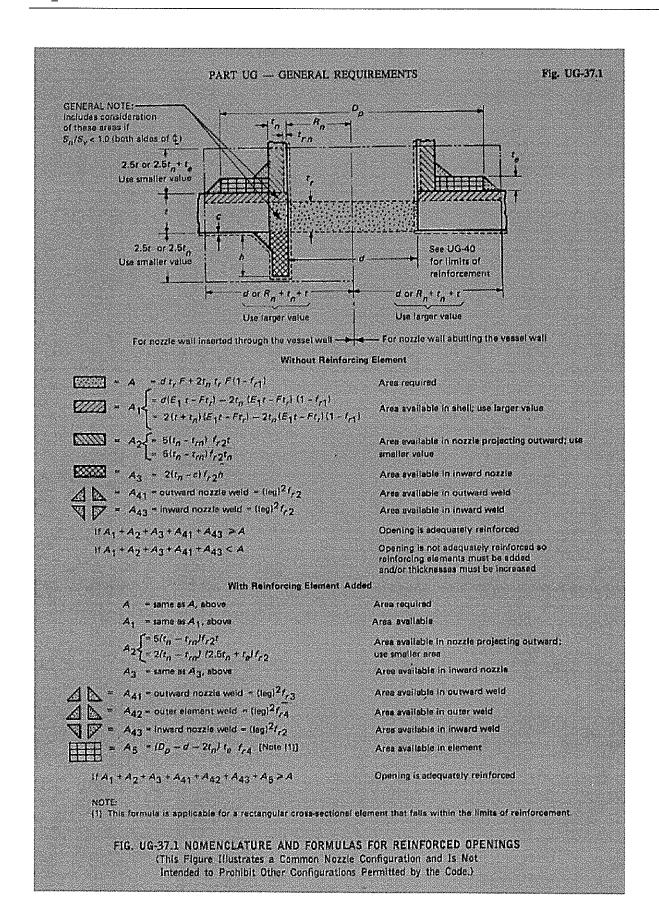
Out[645]= 6321.04

Out[646] = -1467.

Out[647]= 6744.64

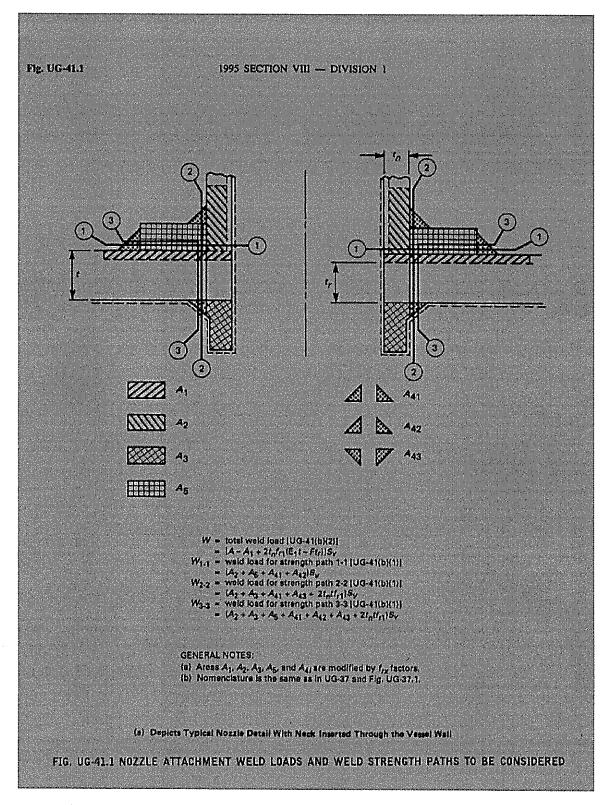
Out[648]= 5.48583

Out[649]= vessel OK at 1.5 × MAWP during pressure test



```
In[4]:= (* Opening Reinforcement Calculations*)
        (* LN2 Trap to shell wall*)
        (* A3 = 0, A5 = 0, A42 = 0 *)
        (* Pipe Sch. 80 1.5 " Ø *)
        Tx = 1.9 (*OD*)
        d = 1.5 (*ID min*)
        tn = (Tx - d) / 2 (*nozzel wall thickness*)
        te = 1.25 * tn (*weld leg height*)
Out[4] = 1.9
Out[5] = 1.5
Out[6] = 0.2
Out[7] = 0.25
In[8]:= F = 1 (*correction factor*)
        tr = 0.335815 (*minimum shell thickness, Vessel_stress2.nb*)
        fr1 = 1 (*strength reducton factor*)
        t = 0.5 (*shell wall thickness*)
        E1 = 1 (*joint efficiency*)
        A = dtr F + 2tn tr F (1 - fr1)
        Ala = d (Elt - Ftr) - 2tn (Elt - Ftr) (1 - fr1)
        A1b = 2 (t + tn) (E1t - Ftr) - 2tn (E1t - Ftr) (1 - fr1)
          If [A1a > A1b, A1 = A1a, A1 = A1b]
Out[8]=1
Out[9]= 0.335815
Out[10]= 1
Out[11] = 0.5
Out[12] = 1
Out[13]= 0.503722
Out[14]= 0.246278
Out[15]= 0.229859
Out[16]= 0.246278
```

```
In[17]:= fr2 = 1 (*strength reducton factor*)
         trn = 0.066062 (*required nozzel thickness, Xe_vessel_LN2.nb*)
         A2a = 5 (tn - trn) fr2 t
         A2b = 5 (tn - trn) fr2 tn
         If [A2a < A2b, A2 = A2a, A2 = A2b]
Out{17} = 1
Out[18]= 0.066062
Out[19]= 0.334845
Out[20]= 0.133938
Out[21]= 0.133938
In[72]:= fr3 = 1 (*strength reducton factor*)
         A43 = te^2 fr3
         te_o = 1.4 tn
         A41 = \frac{te_o^2 fr3}{1.2} (* 80\% the area, skip weld on outside*)
Out[72] = 1
Out[73] = 0.0625
Out[74] = 0.28
Out[75]= 0.0653333
In[76] := (A1 + A2 + A43 + A41)
         (A1 + A2 + A43 + A41) >= A
         (*If actual area > area required, then no additional reinforcement required *)
Out[76]= 0.508049
Out[77]= 0.503722
Out[78]= True
```



(*must run "LN2_shell.nb" file first to save variables defined below into memory*)

```
In[79]:= (*Load / Stress Carried by Welds*)
          A1
          A2
          A3 = 0
          A5 = 0
          A41
          A42 = 0
          A43
Out[79] = 0.503722
Out[80]= 0.246278
Out[81]= 0.133938
Out[82] = 0
Out[83] = 0
Out[84]= 0.0653333
Out[85] = 0
Out[86]= 0.0625
In[87] := Sv = 16700
          W = (A - A1 + 2 tn fr1 (E1t - Ftr)) Sv
Out[87]= 16700
Out[88]= 5396.09
In[89]:=
          W_{1-1} = (A2 + A5 + A41 + A42) Sv
Out[89]= 3327.83
In[90] := W_{2-2} = (A2 + A3 + A41 + A43 + 2 tn t fr1) Sv
Out[90]= 7711.58
        W_{3-3} = (A2 + A3 + A5 + A41 + A42 + A43 + 2 tn t fr1) Sv
        7664.26
        (* W (total weld load) << W<sub>1-1</sub>, W<sub>2-2</sub>, W<sub>3-3</sub>, (weld load available)*)
In[91]:= (*Allowable Unit Stresses*)
          (*Fillet Weld Shear, UW 15 c*)
          \sigma_{\text{fw}} = 0.49 \text{ (Sv)}
Out[91]= 8183.
```

```
In[92]:= (*Nozzel Wall Shear, UG 45 c*)
           \sigma_{nw} = 0.7 (Sv)
Out [92] = 11690.
In[93]:=
            (*Strength of Connection Elements*)
            (*Fillet Weld Shear*)
           W_{\text{fw}} = \frac{\pi}{2} \text{ Tx te } \sigma_{\text{fw}}
Out[93]= 6105.57
In[94]:=
            (*Strength of Connection Elements*)
            (*Nozzel Wall Shear*)
           W_{nw} = \frac{\pi}{2} \frac{(Tx + d)}{2} tn \sigma_{nw}
Out[94]= 6243.29
In[95]:=
           WS_{1-1} = W_{nw}
           WS_{2-2} = W_{fw}
Out[95]= 6243.29
Out[96]= 6105.57
```

(*All Paths WS_{1-1} , WS_{2-2} , are stronger than the required strength W*)

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(* Stress Concentration Factor for mini-conflat openings in head. Reference: Wiley *)

Stress Concentration Factors

	Pattern	Spacing	<u>Maximum</u> K,	Location	Reference
1	7 P	r/R = 0.5	`	See Fig. 126	223,228,229
2		$R/R_0 = 0.5$ $r/R_0 = 0.2$	See Fig. 127	See Fig. 127	230
3	A O RO	R/R ₀ = 0.5 r/R ₀ = 0.2	See Fig. 127	See Fig. 127	230
		$R/R_0 = 0.5$ $r/R_0 = 0.25$	2. 45	A	223
4	B O O	$R/R_0 = 0.6$ $r/R_0 = 0.2$	2. 278 Pressure in All Holes 1. 521	A	223
400000	30-1-30 ²		Pressure in Center Hole Only	В	

```
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```

```
In[1039]:= (*must run "Flange stress_hub_403.nb"
              file first to save variables defined below into memory*)
            (* Assumptions: Chamber head design has 5 mini-conflat holes, not 6,
            K_{t} will be conservative. Chamber head has 1.5 ^{\circ} diameter inner hole, #4 model has
              equal diameter holes throughout, K_t will not be conservative. Assume
              these 2 opposites have a cancelling effect and given K_t is valid. Actual BC hole
             radius is 0.3125 ". But, for this analysis assume all holes 0.75" radius *)
           Ro = 5.25 (*in.,Flange outside radius*)
           r_h = 0.750 (*in., BC hole radius*)
           Ri = 0.750 (*in.,inner hole radius*)
           R = 5.5/2 (* in., mini conflat bolt circle radius *)
           1 = \frac{Ri}{Ro} \ (*graph \ constant*)
           m = \frac{R}{Ro} (*graph constant*)
           o = \frac{r_h}{Ro} (*graph constant*)
Out(1039) = 5.25
Out[1040] = 0.75
Out[1041] = 0.75
Out[1042] = 2.75
Out[1043]= 0.142857
Out[1044] = 0.52381
Out[1045]= 0.142857
In[1256] := (* \frac{R}{Ro} \text{ and } \frac{r_h}{Ro} \text{ are slightly less than #4 model,}
            but K_t will be less (conservative) for chamber head design.*)
            K_t = 2.278
Out[1256]= 2.278
```

```
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```

```
In[1257]:=
            C_a = 0.3
                        (*flange attachment constant*)
            p = 350 \times 1.15 (*psi, MAWP*)
            E_f = 1.0
                       (*Efficiency Factor *)
            d<sub>ga</sub> = 8.54 (*in. gasket diameter*)
            (* lb., Must run "Flange stress_hub_403.nb" to
               define this variable. Minimum required bolt load, for operating *)
            h_G = 0.520 (* in., Must run
               "Flange stress_hub_403.nb" to define this variable.Bending moment length *)
            \sigma_{\rm u} = 77000.0 (*psi, 316 L ultimate strength*)

    (*psi, 316 L allowable strength*)

Out[1257] = 0.3
Out[1258]= 402.5
Out[1259]= 1.
Out[1260]= 8.54
Out[1261]= 24677.2
Out[1262]= 0.52
Out[1263]= 77000.
Out[1264]= 7330.99
In[1265] := t_h = d_{ga} \sqrt{\frac{(C_e * p)}{(\sigma_a * E_f)} + \frac{(1.9 * W_{m1} * h_g)}{(\sigma_a * E_f * d_{ga}^3)}}  (* in., required flange thickness *)
Out[1265]= [1.26123]
In[1266]:= If[th < 1.5, "flange thickness is OK", "flange thickness is NOT OK"]</pre>
```

Out[1266]= flange thickness is OK

```
In[1565]:= (* Maximum distance between
                hole centers for a cluster of holes in head, UG-36 (3) (d)*)
              (* No two unreinforced openings shall have their centers closer than: *)
              d_{\text{betweenholes1}} = Sin[36 \times \frac{\pi}{180}] \times R \times 2
              d_2 = 0.625
              d_1 = d_2 (* diameter of holes *)
              C_d = 2.5 (d_1 + d_2)
              If[dbetweenholes1 > Cd,
               "distance between 5.5 BC holes OK", "distance between 5.5 BC holes NOT OK"]
              d_{\text{betweenholes2}} = R - .75 - .3125
              d_2 = 0.625
              d_1 = 1.500
              C_d = 2.5 (d_1 + d_2)
              If [dbatweenholes2 > Cd, "distance between center hole and 5.5 BC holes OK", "distance
                  between center hole and 5.5 BC holes NOT OK,,,,, use alternative UG-39(d)"]
              d_{\text{betweenholes2}} < 2 \left( \frac{(d_1 + d_2)}{2} \right)
              d_{\text{betweenholes2}} > 1.25 \left( \frac{(d_1 + d_2)}{2} \right)
              (* in., required flange thickness,
               UG-39 (e) (1) (2), using alternative to Area reinforcment of UG39 (b) (1) \star)
              \sigma_a = 16700
              ef = \frac{R - (\frac{(d_1 + d_2)}{2})}{R} (* UG39 (e) (2) *)
              fs = \sqrt{0.5/ef}
             t_{h} = d_{ga} \sqrt{fs \times 2 \left( \frac{(C_{a} * p)}{(\sigma_{a} * E_{f})} + \frac{(1.9 * W_{m1} * h_{G})}{(\sigma_{a} * E_{f} * d_{ga}^{3})} \right)}
```

```
Out[1566]= 3.23282

Out[1567]= 0.625

Out[1568]= 0.625

Out[1569]= 3.125

Out[1570]= distance between 5.5 BC holes OK
```

Out[1565] = 2.75

Out[1571]= 1.6875

```
Out[1572] = 0.625
```

Out (1573] = 1.5

Out[1574]= 5.3125

Out[1575]= distance between center hole and 5.5 BC holes NOT OK,,,,, use alternative UG-39(d)

Out[1576]= True

Out[1577]= True

Out[1578]= 16700

Out[1579]= 0.613636

Out[1580] = 0.902671

Out[1581] = 1.12279

Out[1598]= 1.24385

```
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```

```
Out[1589]= 0.625
Out[1590]= 1.5
Out[1591]= 5.3125
Out[1592]= distance between center hole and 5.5 BC holes NOT OK,,,, use alternative UG-39(d)
Out[1593]= True
Out[1594]= True
Out[1595]= 16700
Out[1596]= 0.613636
Out[1597]= 0.902671
```

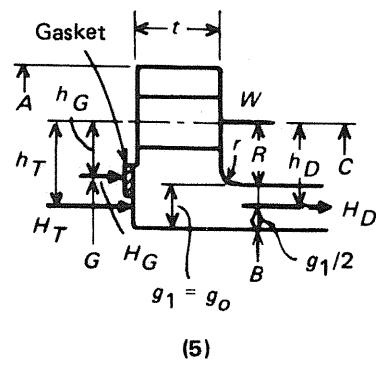
```
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```

```
(*must run "Flange stress_hub_978.nb"
  file first to save variables defined below into memory*)
(* Assumptions: Chamber head design has has no holes *)
Ro = 5.25 (*in.,Flange outside radius*)
C_0 = 0.3
           (*flange attachment constant*)
p = 850 \times 1.15 (*psi, MAWP*)
E_f = 1.0
          (*Efficiency Factor *)
dga = G (*in. gasket diameter*)
(* lb., Must run "Flange stress_hub_978.nb
  " to define this variable. Minimum required bolt load, for operating \star)
h_G = 0.520 (* in.,)
Must run "Flange stress_hub_978.nb" to define this variable.Bending moment length *)
\sigma_{\rm u} = 77000.0 (*psi, 316 L ultimate strength*)
\sigma_a = 16700 (*psi, 316 L allowable strength*)
0.3
977.5
7.98
58849.9
0.52
77000.
16700
t_h = d_{ga} \sqrt{\frac{(C_e * p)}{(\sigma_a * E_f)} + \frac{(1.9 * W_{m1} * h_G)}{(\sigma_a * E_f * d_{ga}^3)}} \quad (* in., required flange thickness *)
1.2468
If[t_h < 1.980, "flange thickness is OK", "flange thickness is NOT OK"]
flange thickness is OK
(* Minimum thickness of plate under gasket (hub) *)
tg = d_{ga} \sqrt{(1.9 * W_{m1} * h_{g}) / (\sigma_{a} * d_{ga}^{3})} (* UG34, sketch (k) *)
If[tg < 1.980, "flange hub thickness is OK", "flange hub thickness is NOT OK"]
0.660529
```

flange hub thickness is OK

```
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```

```
(*must run "Flange stress_hub_small_978.nb"
  file first to save variables defined below into memory*)
(* Assumptions: Head design has has no holes *)
Ro = 4.63/2 (*in.,Flange outside radius*)
C_{e} = 0.3
           (*flange attachment constant*)
p = 850 \times 1.15 (*psi, MAWP*)
\mathbf{E_f} = \mathbf{1.0}
           (*Efficiency Factor *)
d<sub>ga</sub> = G (*in. gasket diameter*)
(* lb., Must run "Flange stress_hub_small_978.nb
  " to define this variable. Minimum required bolt load, for operating *)
h_G = 0.520 (* in., Must run
  "Flange stress_hub_small_978.nb" to define this variable.Bending moment length *)
\sigma_a = 16700 (*psi, 304 L allowable strength*)
0.3
977.5
3.35
10143.7
0.52
16700
t_h = d_{ga} \sqrt{\frac{(C_o * p)}{(\sigma_a * E_f)} + \frac{(1.9 * W_{m1} * h_g)}{(\sigma_a * E_f * d_{ga}^3)}} \quad (* in., required flange thickness *)
0.613356
If[t_h < 0.750, "flange thickness is OK", "flange thickness is NOT OK"]
flange thickness is OK
(* Minimum thickness of plate under gasket (hub) *)
tg = d_{ga} \sqrt{(1.9 * W_{m1} * h_{g}) / (\sigma_{a} * d_{ga}^{3})} (* UG34, sketch (k) *)
If[tg<0.81, "flange hub thickness is OK", "flange hub thickness is NOT OK"]
0.423249
flange hub thickness is OK
```



(* Bolted Flange Connections with flat metal Copper Gasket,
Xe chamber high voltage feedthru *)
(* 350 psia MOP, conflat type head *)

```
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```

```
(* Bolt Load at operating conditions *)
G = 0.72 (* Diameter, in. at gasket load location *)
P = 350 * 1.15 (* MAWP, internal design pressure *)
m = 4.75 (* gasket factor flat Cu gasket, Table 2-4.1 *)
N_g = 0.25 (* width of Cu gasket *)
b_o = \frac{N_g}{32} (* N/4 for multiple serrations Table 2-5.2 (5),
 assume N/32 given a single knife edge serration as used in Conflats *)
If [b_o \le 0.25, b = b_o, b = .5 \sqrt{b_o}]
y = 13000 (* psi, design seating stress for soft copper, Table 2-5.1 *)
H = 0.785 G^2 P (* 1b., Total hydrostatic end force *)
H_p = 2b \times \pi GmP (* lb., Total joint-contact surface compression load *)
W_{m1} = H + H<sub>p</sub> (* Minimum required bolt load, for operating *)
W_{m2} = \pi Gby (* Minimum required bolt load, for gasket seating *)
0.72
402.5
4.75
0.25
0.0078125
0.0078125
13000
163.795
67.5712
231.366
229.729
```

```
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```

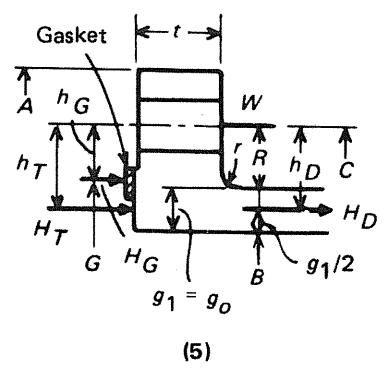
Out[64]= 6.92239

```
In[54]:= (* Design Bolt Load*)
         A_b = \frac{\pi \times 0.1248^2}{4} \times 6 \text{ (*cross sectional area of $\#8-32 screw*)}
          SF = 4 (* MEDSS *)
          S_T = 81000
          (*Unbrako - KS 1216 8-32 SHCS, 160, ksi tensile strength; T = -400 °F to 1200 °F
          OR ASTM-A493-95 Grade S30430; 81 ksi tensile strength *)
          S_a = S_T \div SF
         L_b = S_a \times A_b (* lb., Max allowable bolt load *)
         A_{m1} = W_{m1} / S_a (* in^2, cross-sectional area of bolts under operating condition *)
         A_{m2} = W_{m2} / S_a (* in^2, cross-sectional area of bolts for gasket seating *)
          If [A_{m1} > A_{m2}, A_m = A_{m1}, A_m = A_{m2}]
          (* in2, total required cross-sectional area of bolts *)
         W_o = W_{m1} (* lb., Flange design bolt load, for operating *)
         W_{\sigma} = \frac{(A_m + A_b) S_a}{2} (* lb., Flange design bolt load, for gasket seating *)
          SF_u = L_b SF / W_g
Out[54]= 0.0733956
Out[55] = 4
Out[56]= 81000
Out[57]= 20250
Out[58]= 1486.26
Out[59]= 0.0114255
Out[60]= 0.0113446
Out[61]= 0.0114255
Out[62]= 231.366
Out[63]= 858.814
```

0.1

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```
(*flange attachment constant*)
p = 350 \times 1.15 (*psi, MAWP*)
Ef = 1.0 (*Efficiency Factor *)
d<sub>ga</sub> = G (*in. gasket diameter*)
(* lb., Minimum required bolt load, for operating *)
h<sub>G</sub> = 0.171 (* in., Bending moment length *)
\sigma_{\rm u} = 77000.0 (*psi, 304 L ultimate strength*)
\sigma_a = 16700 (*psi, 304 L allowable strength*)
t_h = d_{ga} \sqrt{\frac{(C_o * p)}{(\sigma_a * E_f)}} + \frac{(1.9 * W_{m1} * h_G)}{(\sigma_a * E_f * d_{ga}^3)} \quad (* in., required flange thickness *)
0.3
402.5
1.
0.72
231.366
0.171
77000.
16700
```



(* Bolted Flange Connections with flat metal Copper Gasket,
Xe chamber gamma ray feedthru *)
(* 350 psia MOP, conflat type head *)

```
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```

```
(* Bolt Load at operating conditions *)
G = 1.650 (* Diameter, in. at gasket load location *)
P = 350 * 1.15 (* MAWP, internal design pressure *)
m = 4.75 (* gasket factor flat Cu gasket, Table 2-4.1 *)
N_g = 0.25 (* width of Cu gasket *)
b_o = \frac{N_g}{32} (* N/4 for multiple serrations Table 2-5.2 (5),
 assume N/32 given a single knife edge serration as used in Conflats *)
If [b_0 \le 0.25, b = b_0, b = .5 \sqrt{b_0}]
y = 13000 (* psi, design seating stress for soft copper, Table 2-5.1 *)
H = 0.785 G^2 P (* 1b., Total hydrostatic end force *)
H_p = 2b \times \pi GmP (* 1b., Total joint-contact surface compression load *)
W_{m1} = H + H_p (* Minimum required bolt load, for operating *)
W_{m2} = \pi \, G \, b \, y \, (\star \, Minimum \, required \, bolt \, load, for gasket seating <math>\star)
1.65
402.5
4.75
0.25
0.0078125
0.0078125
13000
860.208
154.851
1015.06
526.462
```

```
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```

Out[86]= 6.38661

```
In[76]:= (* Design Bolt Load*)
         A_b = \frac{\pi \times 0.2052^2}{4} \times 6 \text{ (*cross sectional area of 1/4-28 screw*)}
         SF = 4 (* MEDSS *)
         S_T = 81000
          (*Unbrako - KS 1216 1/4-28 SHCS, 160, ksi tensile strength; T = -400 °F to 1200 °F
          OR ASTM-A493-95 Grade S30430; 81 ksi tensile strength *)
         S_a = S_T \div SF
         L_b = S_a \times A_b (* lb., Max allowable bolt load *)
         A_{m1} = W_{m1} / S_a (* in^2, cross-sectional area of bolts under operating condition *)
         A_{m2} = W_{m2} / S_a (* in^2, cross-sectional area of bolts for gasket seating *)
          If [A_{m1} > A_{m2}, A_m = A_{m1}, A_m = A_{m2}]
          (* in2, total required cross-sectional area of bolts *)
         W_o = W_{m1} (* lb., Flange design bolt load, for operating *)
         W_g = \frac{(A_m + A_b) S_a}{2} (* 1b., Flange design bolt load, for gasket seating *)
         SF_u = L_b SF / W_a
Out[76]= 0.198425
Out[77]= 4
Out[78]= 81000
Out[79]= 20250
Out[80]= 4018.1
Out[81]= 0.0501264
Out[82]= 0.0259981
Out[83]= 0.0501264
Out[84]= 1015.06
Out[85]= 2516.58
```

```
C_0 = 0.13
               (*flange attachment constant*)
p = 350 \times 1.15 (*psi, MAWP*)
             (*Efficiency Factor *)
 dga = G (*in. gasket diameter*)
 (* lb., Minimum required bolt load, for operating *)
h<sub>G</sub> = 0.331 (* in., Bending moment length *)
 \sigma_u = 77000.0 (*psi, 304 L ultimate strength*)
 \sigma_a = 16700 (*psi, 304 L allowable strength*)
th = d_{ga} \sqrt{\frac{C_e \times p}{\sigma_a \times E_f}} (* in., required flange thickness, no bending moment *)
t_{ho} = d_{ga} \sqrt{\frac{(C_a * p)}{(\sigma_a * E_f)} + \frac{(1.9 * W_{m1} * h_g)}{(\sigma_a * E_f * d_{ga}^3)}} \quad (* \text{ in., required flange thickness } *)
p = 0 (*psi, MAWP*)
 (* lb., Minimum required bolt load, for gasket seating *)
t_{hg} = d_{ga} \sqrt{\frac{(C_a * p)}{(\sigma_a * E_f)} + \frac{(1.9 * W_{m2} * h_g)}{(\sigma_a * E_f * d_{ga}^3)}} \quad (* \text{ in., required flange thickness *})
 0.13
 402.5
 1.65
 1015.06
 0.331
 77000.
16700
0.0923592
0.1780383
 526.462
```

0.109616

```
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```

```
(* Miscellaneous Calculations *)
 (* UG-36 Openings in Pressure vessels*)
 (* UG-36 (c) (3) (d), No two unreinforced openings shall have their centers
   closer than the sum of their diameters: *)
 (* This applies to all holes in the shell of the vessel. Actual holes have
   reinforcement built into the design so this is concervative. *)
 d_1 = 2.87
 d_2 = 0.5
 \mathbf{l}_{\mathbf{s}} = \mathbf{d}_{\mathbf{1}} + \mathbf{d}_{\mathbf{2}}
 1 = \frac{\pi \times 7.625}{4} \quad (* \text{ distance between holes*})
 2.87
 0.5
 3.37
5.98866
 True
 (* Drilled holes not penetrating shell *)
 (* holes must be less than 2 " dia. & not less than 0.25 "*)
 D_i = 7.625
 t = 0.5
 D_1 / t
 D_{i} / t >= 10
 7.625
 0.5
 15.25
 True
 d_h = 0.375 (* UNF 3/8-16, major dia. *)
 d_h / D_i
 0.375
 0.0491803
```

```
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```

```
Rt = 0.375 (* from graph *)
 If [d_h/D_i < 0.03, Rt = .25, Rt = Rt]
 tmn = t (Rt) (* Appx. 30 Fig. 30-1, remaining wall thickness*)
 0.375
 0.375
               0.5-,1475 = 0.313 in.
 0.1875
d_h = 0.250 \ (*\ UNF\ 1/4-20,\ major\ dia.\ *)
 d_h/D_i
 0.25
 0.0327869
Rt = 0.256 (* from graph *)
If [d_h/D_i < 0.03, Rt = .25, Rt = Rt ]
tmn = t (Rt) (* Appx. 30 Fig. 30-1, remaining wall thickness*)
 0.256
 0.256
              6.5-0.128 = 6.372 W.
 0.128
 (* Drilled / tapped holes in unstayed flat head *)
 (* reinforcement required, replacement of area *)
 (* 8-32 for mini conflats *)
 tr = 1.26123 (* in., minimum required flange thickness *)
ta = 1.5 (* in., actual flange thickness *)
d_h = 0.164 (* in., hole diameter *)
 d_d = 0.312 (* in., depth of hole *)
Ar = d_h \times d_d (* in.^2, area required *)
Aa = d_h (ta - d_d) (* in.^2, area available *)
 If [ Aa > Ar, "Reinforcement OK for mini-conflat blind holes",
 "Reinforcement NOT OK for mini-conflat blind holes" ]
1.26123
1.5
 0.164
 0.312
0.051168
0.194832
Reinforcement OK for mini-conflat blind holes
```

```
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```

```
(* Drilled / tapped holes in unstayed flat head *)
 (* reinforcement required, replacement of area *)
 (* 8-32 for mounting brackets inside vessel *)
 tr = 1.26123 (* in., minimum required flange thickness *)
 ta = 1.5 (* in., actual flange thickness *)
 d_h = 0.164 (* in., hole diameter *)
 d_d = 0.25 (* in., depth of hole *)
 Ar = d_h \times d_d \ (* in.^2, area required *)
 Aa = d_h (ta - d_d) (* in.^2, area available *)
 If [ Aa > Ar, "Reinforcement OK for mounting bracket blind holes",
  "Reinforcement NOT OK for mounting bracket blind holes" ]
 1.26123
 1.5
 0.164
 0.25
0.041
0.205
 Reinforcement OK for mounting bracket blind holes
 (* Drilled / tapped holes in unstayed flat head *)
 (* reinforcement required, replacement of area *)
 (* 1/4-28 for medium conflat, center hole *)
 tr = 1.26123 (* in., minimum required flange thickness *)
 ta = 1.5 (* in., actual flange thickness *)
 d_h = 0.250 (* in., hole diameter *)
 d_d = 0.5 (* in., depth of hole *)
 Ar = d_h \times d_d \ (* in.^2, area required *)
 Aa = d_h (ta - d_d) (* in.^2, area available *)
 If [ Aa > Ar, "Reinforcement OK for medium conflat blind holes",
  "Reinforcement NOT OK for medium conflat blind holes" ]
 1.26123
 1.5
 0.25
 0.5
 0.125
 0.25
 Reinforcement OK for medium conflat blind holes
```

316, 316 L.

```
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```

```
(* Weld impact testing exemption calculation *)
(* UHA-51 (g) *)
Sa = 16700
S1 = 3499.17
S<sub>vm</sub> = 7754.6879
If [S1/Sa < 0.4, "Impact testing NOT required for weld",
  "Impact testing REQUIRED required for weld"]
16700
3499.17
7754.6879
Impact testing NOT required for weld
(* Base material Impact testing exemption *)
(* UHA-51 (d) (1) (a) austenitic chromium-nickel stainless steels: 304, 304 L,</pre>
```

```
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```

```
(* Fracture Critical Components *)
In[91]:= (* The applied stress is: *)
         R_i = 3.8125
         R_o = 4.3125
         MAWP = 978
         \sigma_a = 16700 (*allowable stress for 316 L SST*)
         \sigma_{y} = 37000
         R_i = 3.8125
         R_0 = 4.3125
         t = R_o - R_i
         Ratio = \frac{R_o}{R_i}
         If [1.1 < Ratio < 1.5, medium wall]
         If [Ratio < 1.1, thin wall]
         If [Ratio > 1.5, thick wall]
         (*Circumferential Stress, S2*)
         S_2 = \frac{\text{MAWP} (R_0^2 + R_1^2)}{(R_0^2 - R_1^2)}
Out[91]= 3.8125
Out[92] = 4.3125
Out[93]= 978
Out[94]= 16700
Out[95]= 37000
Out[96] = 3.8125
Out[97] = 4.3125
Out[98] = 0.5
Out[99]= 1.13115
Out[100] = medium wall
Out[103] = 7976.34
        (* First consider actual stress intensity factors from literature (testing). Then
           apply this K_{IC} = K_{I} value to the Xe vessel at its MAWP/stress *)
        (* Degraded Piping Program Phase II, 4/99 *)
        (* Material 304 and 316 stainless steel, range: 561 to 13,400 in-lb/in^2,
         Ji used is the lowest measurable value in all tests, parent or welded material *)
```

In[14]:=
Ji = 561 (* in-1b/in^2 *)

v = 0.33 (* Poisson's ratio *)

$$E_{y} = \frac{29.7 \times 10^{6}}{(1 - v^{2})} (* psi *)$$

$$K_{Ic} = \sqrt{Ji \times E_{y}} (* psi \sqrt{in} *)$$

$$a_{crs} = \frac{1}{1.21 \pi} \left(\frac{K_{Ic}}{S_2} \right)^2$$
 (* in., crack critical length, surface flaw *)

$$a_{cri} = \frac{1}{\pi} \left(\frac{K_{Ic}}{S_2} \right)^2$$
 (* in., crack critical length, imbedded flaw *)

 $lengthc_{crs} = 4 \times a_{crs}$

 $lengthc_{cri} = 4 \times a_{cri}$

(* considering leak before break criteria,

leak occurs occurs before catastrophic failure in a pressure vessel when *)

$$\sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{\sigma_y}\right)^2}}$$
 (* Fracture and Fatigue Control in Structures,

Rolfe and Barsom, Prentice-Hall, 1977, pg. 394*)

$$K_{Ic} >= \sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{\sigma_v}\right)^2}}$$
 (* Hoop stress applies, S_2 *)

$$If\left[K_{Ic}>=\sqrt{\frac{\pi\,t\,S_2^{\,2}}{1-\frac{1}{2}\,\left(\frac{S_2}{\sigma_c}\right)^2}}\right],$$

"Leaking should occur before failure", "failure may occur before leaking"

(* LIFE Expectancy Cycles *)

 $a_0 = 0.125$ (* in., initial flaw size *)

A = 3.0×10^{-10} (* Metal Fatigue in Engineering, 1980, John Wiley & Sons, pg 86 *) n = 3.25 (* Metal Fatigue in Engineering, 1980, John Wiley & Sons, pg 86 *)

$$N_{f} = \frac{2}{2-n} \left(\frac{1}{A \left(1.12 \frac{s_{2}}{1000} \sqrt{\pi} \right)^{n}} \right) \left(a_{crs} \left(\frac{2-n}{2} \right) - a_{c} \left(\frac{2-n}{2} \right) \right)^{2}$$

(* Damage Tolerant Design Handbook " V.2, 1983 *)

$$N_{f} = \frac{2}{2-n} \left(\frac{1}{A \left(1.12 \frac{S_{2}}{1000} \sqrt{\pi} \right)^{n}} \right) \left(a_{cri} \left(\frac{2-n}{2} \right) - a_{o} \left(\frac{2-n}{2} \right) \right)$$

(* Damage Tolerant Design Handbook " V.2, 1983 *)

Out[14] = 561

Out[15]= 0.33

```
Out[16] = 3.33296 \times 10^7
```

Out[17]= 136740.

Out[18]= 77.3126

Out[19]= 93.5482

Out[20]= 309.25

Out[21]= 374.193

Out[22]= 10115.1

Out[23]= True

Out[24]= Leaking should occur before failure

Out[25] = 0.125

 $Out[26] = 3. \times 10^{-10}$

Out[27]= 3.25

 $Out[28] = 2.42577 \times 10^6$

Out $[29] = 2.43076 \times 10^6$

In[60]:= (* For the ellipsoidal head *)

 $D_i = 7.625$

 $t_w = 0.5$

 $E_{\rm f} = 0.7$ (*butt weld efficiency based on no inspection, Table UW-12*)

$$\sigma = \frac{\text{MAWP } (D_i + 0.2 t_w)}{(2 E_f t_w)}$$

 $S_2 = \sigma$

$$a_{crs} = \frac{1}{1.21\pi} \left(\frac{K_{rc}}{S_2} \right)^2$$
 (* in., crack critical length, surface flaw *)

$$a_{cri} = \frac{1}{\pi} \left(\frac{K_{Ic}}{S_2} \right)^2$$
 (* in., crack critical length, imbedded flaw *)

 $lengthc_{crs} = 4 \times a_{crs}$

lengthc_{cri} = 4 × a_{cri}

(* considering leak before break criteria,

leak occurs occurs before catastrophic failure in a pressure vessel when *)

$$\sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{\sigma_y}\right)^2}}$$
 (* Fracture and Fatigue Control in Structures,

Rolfe and Barsom, Prentice-Hall, 1977, pg. 394*)

$$K_{Ic} >= \sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{\sigma_y}\right)^2}}$$
 (* Hoop stress applies, S_2 *)

$$If\left[K_{Ic} > = \sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{c_y}\right)^2}},\right]$$

"Leaking should occur before failure", "failure may occur before leaking"

(* LIFE Expectancy Cycles *)

a_o = 0.125 (* in., initial flaw size *)

A = 3.0×10^{-10} (* Metal Fatigue in Engineering, 1980, John Wiley & Sons, pg 86 *) n = 3.25 (* Metal Fatigue in Engineering, 1980, John Wiley & Sons, pg 86 *)

$$N_{f} = \frac{2}{2-n} \left(\frac{1}{A \left(1.12 \frac{s_{2}}{1000} \sqrt{\pi} \right)^{n}} \right) \left(a_{crs} \left(\frac{2-n}{2} \right) - a_{o} \left(\frac{2-n}{2} \right) \right)$$

(* Damage Tolerant Design Handbook " V.2, 1983 *)

$$N_{f} = \frac{2}{2-n} \left(\frac{1}{A \left(1.12 \frac{s_{2}}{2} \sqrt{\pi} \right)^{n}} \right) \left(a_{\text{cri}} \left(\frac{2-n}{2} \right) - a_{0} \left(\frac{2-n}{2} \right) \right)$$

(* Damage Tolerant Design Handbook " V.2, 1983 *)

Out[60] = 7.625

Out[61] = 0.5

Out[62]= 0.7

```
Out[63]= 10792.9
```

Out[71]= Leaking should occur before failure

Out[72]= 0.125

 $Out[73] = 3. \times 10^{-10}$

Out[74]= 3.25

Out[75]= 900192.

Out[76]= 902921.

```
In[104]:= (* For the flat head *)
```

$$S_2 = 0$$

$$a_{crs} = \frac{1}{1.21 \pi} \left(\frac{K_{Ic}}{S_2} \right)^2$$
 (* in., crack critical length, surface flaw *)

$$a_{cri} = \frac{1}{\pi} \left(\frac{K_{Ic}}{S_2} \right)^2$$
 (* in., crack critical length, imbedded flaw *)

 $lengthc_{crs} = 4 \times a_{crs}$

 $lengthc_{cri} = 4 \times a_{cri}$

(* considering leak before break criteria,

leak occurs occurs before catastrophic failure in a pressure vessel when *)

$$\sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{\sigma_y}\right)^2}}$$
 (* Fracture and Fatigue Control in Structures,

Rolfe and Barsom, Prentice-Hall, 1977, pg. 394*)

$$K_{Ic} >= \sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{\sigma_y}\right)^2}}$$
 (* Hoop stress applies, S_2 *)

$$\mathrm{If}\left[K_{\mathrm{Ic}} > = \sqrt{\frac{\pi t S_2^2}{1 - \frac{1}{2} \left(\frac{S_2}{\sigma_c}\right)^2}}\right],$$

"Leaking should occur before failure", "failure may occur before leaking"]

(* LIFE Expectancy Cycles *)

 $a_o = 0.125$ (* in., initial flaw size *)

A = 3.0×10^{-10} (* Metal Fatigue in Engineering, 1980, John Wiley & Sons, pg 86 *) n = 3.25 (* Metal Fatigue in Engineering, 1980, John Wiley & Sons, pg 86 *)

$$N_{f} = \frac{2}{2 - n} \left(\frac{1}{A \left(1.12 \frac{s_{2}}{1000} \sqrt{\pi} \right)^{n}} \right) \left(a_{org} \left(\frac{2 - n}{2} \right) - a_{o} \left(\frac{2 - n}{2} \right) \right)$$

(* Damage Tolerant Design Handbook " V.2, 1983 *)

$$N_{f} = \frac{2}{2-n} \left(\frac{1}{A \left(1.12 \frac{s_{2}}{1000} \sqrt{\pi} \right)^{n}} \right) \left(a_{cri} \left(\frac{2-n}{2} \right) - a_{o} \left(\frac{2-n}{2} \right) \right)$$

(* Damage Tolerant Design Handbook " V.2, 1983 *)

Out[104]= 5182.85

Out[105]= 5182.85

Out[106] = 183.113

Out[107] = 221.567

Out[108]= 732.454

Out[109]= 886.269

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```
Out[110] = 6527.84
```

Out[111] = True

Out[112] = Leaking should occur before failure

Out[113]= 0.125

Out[114] = $3. \times 10^{-10}$

Out[115] = 3.25

 $Out[116] = 9.92359 \times 10^6$

 $Out[117] = 9.93542 \times 10^6$

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- (* Fragment Evaluation *)
- (* It is assumed that the most vulnerable point in this vessel is the Ceramaseal high voltage feedthroughs mounted to the mini-Conflats which are mounted to the 350 MOP head. These could easily be bumped or damaged by mishandling resulting in a fragment / projectile. The following will estimate the shielding thickness required for personnel protection near the vessel head. Also assume all of the energy is transferred to a single fragment. *)

In[22]:=
$$m_{fg} = 37.7$$
 (* g; actual measurment *)
 $m_{fs} = m_{fg} * 6.852 \times 10^{-5}$ (* lb.s^2/ft; slugs *)
 $v_f = \sqrt{\frac{2 \text{ Energy}}{m_{fs}}}$ (* ft/s *)

Out[22] = 37.7

Out[23]= 0.0025832

Out[24]= 6575.9

```
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```

```
P_{\text{ratio}} = \frac{P_1}{P_2} (* *)
         g = 32.2 (* ft/s^2 *)
         T = 528 (* {}^{\circ}R *)
         k = 1.4
         R = 53.3 (* ft-lb/lb-{}^{\circ}R *)
         a = \sqrt{kgRT}
         v_{f1} = a \times 2.55 (* ft/s Figure 12 Zero Mass velocity *)
         v_{f12} = v_{f1} \cos \left[ \frac{0.785398}{2} \right] (* MEDSS eqn. 38 *)
         v_{flm} = v_{fl} \times 0.3048 (* m/s *)
         v_{flm2} = v_{rf} \times 0.3048 (* m/s *)
         m_1 = \frac{2 \text{ Energy}}{{V_{el}}^2} 32.2 (* 1b<sub>m</sub>; largest fragment that can achieve this velocity *)
Out[94]= 66.5306
Out[95]= 32.2
Out[96]= 528
Out[97]= 1.4
Out[98]= 53.3
Out[99]= 1126.35
Out[100] = 2872.19
Out[101]= 2653.55
Out[102]= 875.443
Out[103] = 808.804
Out[104] = 0.436013
         (* The Ceramaseal feedthrough mass is <
              m<sub>1</sub> so it can only achive this maximum velocity.
```

Fragment shielding evaluation..... *)

```
\begin{split} & In \text{$[105]$} := \ T_m = \ 6 \times 10^{-5} \ \bigg( \frac{m_{\text{fg}}}{1000} \bigg)^{0.33} \ v_{\text{flm}} \ \ (* \ \text{UK formula *}) \\ & T_m = \ T_m \times 12 \times 3.28084 \ \ (* \ \text{in *}) \\ & (* \ \text{Thor formula: Lexan *}) \\ & \alpha = 1.814 \\ & \beta = -1.652 \\ & c_1 = 7.329 \\ & A_f = \frac{\pi \ 0.5^2}{4} \\ & T_{\text{in}} = \frac{1}{A_f} \left( \frac{v_{\text{fl}}}{10^{c_1} \ (7000 \ \frac{m_1}{32.2})^{\beta}} \right)^{\frac{1}{\alpha}} \end{split}
```

Out[105]= 0.0178062

Out[106] = 0.701032

Out[107]= 1.814

Out[108] = -1.652

Out[109]= 7.329

Out[110]= 0.19635

Out[111] = 2.36231

(* After ricochet the shielding thickness needs to be:*)

$$\begin{split} &T_{m}=6\times10^{-5}\left(\frac{m_{fg}}{1000}\right)^{0.33}v_{flm2}\ (*\ m;\ UK\ formula\ *)\\ &T_{m}=T_{m}\times12\times3.28084\ (*\ in\ *)\\ &(*\ Thor\ formula:\ Lexan\ *)\\ &\alpha=1.814\\ &\beta=-1.652\\ &c_{1}=7.329\\ &A_{f}=\frac{\pi\ 0.5^{2}}{4}\\ &T_{in}=\frac{1}{A_{f}}\left(\frac{v_{fl2}}{10^{c_{1}}\ (7000\ \frac{m_{1}}{32.2})^{\beta}}\right)^{\frac{1}{\alpha}} \end{split}$$

Out[112]= 0.0164508

Out[113] = 0.647669

Out[114]= 1.814

Out[115]= -1.652

Out[116]= 7.329

Out[117] = 0.19635

Out[118]= 2.26142



File No. MESN99-038-0A July 2, 1999

MECHANICAL ENGINEERING SAFETY NOTE

Gas Delivery System and Reclamation Cylinders for Gamma Ray Imager

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Description of the System:

This safety note covers the gas delivery system and the gas reclamation cylinders used in a full volume gamma ray imager located in Building 132S, Room 2723. There are three parts to the imager. The first part is the gas delivery system built commercially by Insync Systems. It is used to purify and deliver electronegative free (99.999999%) gas at an MOP of 135 psig. The second part of the system consists of two time projection chambers (TPC) where the experiments will be performed. The TPCs will nominally operate at 300psig but one has been designed for 400 and the other for 980 psig MAWP. They are covered by a separate safety note titled Time Projection Chamber, MESN99-020-0A. The third part of the system uses cryogenic reclamation cylinders to reclaim the purified gas. These cylinders have been fabricated by Acme Cryogenics and are rated by Acme to 2200 psig MAWP. The system layout is seen in Fig. 1. Gas will be transferred in the system by thermal cycles, using LN2 to create the temperature gradient via conduction through the walls of the reclamation cylinders. A certain percentage of alcohol may be used in the LN2 bath to raise the temperature of the bath above 77K. The asphyxiation hazard associated with the evaporation of LN2 and alcohol is dealt with in OSP 132S.31.

Note that there are four MAWPs in this system. They are MAWP0 for the input to the Supply Panel, MAWP1 for the Gas Delivery portion, MAWP2 for TPCs and MAWP3 for the Gas Reclamation portion.

The Gas Delivery System purifies research grade gas to an ultraclean gas that is free of electronegative materials. It consists of a Control Panel plus 4 secondary panels and connecting plumbing . A schematic is shown in Fig. 2. All of the process valves on the secondary panels are all metal, bellows sealed valves actuated with 50 psig house air with manual switches controlling the air. The switches are on the Control Panel. The secondary panels are designated as: Supply, Fig. 3, Purification, Fig. 4, Chamber, Fig. 5 and Reclamation, Fig. 6.

The Supply Panel has connections for three gas cylinders of research grade (99.999%) gas. The gas cylinders will contain Ar, Xe and CO2. (There may be interest in using combustible gases in later stages of this research. A revision of this note would be written to cover such work.) The pressure output of the cylinders is limited by a regulator to 135 psig MOP and protected by a 157 psig rupture disc. It is connected to the Purification and Reclamation panels as shown in Fig.2.

The Purification Panel includes a room temperature getter (Oxisorb Model S511-HV) followed by a hot getter (SAES Phase 1 MonoTorr). The Oxisorb and the MonoTorr

both have a manufacturer's MOP of 150 psig. The material in the getters can be returned to the manufacturer, after being saturated, for regeneration or disposal. There is a mass flow controller and a 157 psig rupture disk following the MonoTorr. The output of the Purification Panel flows to 3 places: 1) the Chamber Panel which leads to the TPC's, 2) the recirculation pump (which is currently replaced by a jumper) and 3) the Reclamation Panel, again as shown in Fig. 2.

The Chamber Panel provides gas flow to the TPCs, the turbomolecular pump (TMP) and system vent. The gas flow/pressure from the chamber into the rest of the system is restricted operationally by pressure regulators at the outlet of the chambers. Intermediate pressure gas is prevented from pressuring the purification panel above the MOP of 135 psig by both purification system operating procedures and a 157 psig rupture disk.

The rupture disc reliability is closely regulated by the manufacturer to the requirement that 2 discs from the involved lot rupture at the lot pressure plus or minus 5%. The lot pressure is the average of the two test disc rupture pressures and it must fall into the manufacturing range of -4 / +7 % of the pressure that is ordered by the customer. The lot pressure is stamped on a tag attached to the disc body. It is 157 psig. This means that MAWP1 could be as high as 168 psig for the low pressure portion of the the system. We designate MAWP1 at the lot pressure of 157 psig.

Overpressuring the TPCs will be prevented in final operations by: 1- monitoring and controlling gas flow into the chamber with the Mass Flow Controller, 2- using a load cell with 50 gm resolution interlocked to the valve allowing flow into the chamber, 3- having 402 psig rupture disks on the chambers. In preliminary operations the mass flow controller will be used under 2-man operator control to limit the amounts of Xe to 840 gm and Ar to 250 gm as measured by a Data Instruments load cell with a resolution of 200 gm. This would limit the TPC pressure to <3/8 the MAWP2 or ~150 psig as shown in Tables 1 and 2 respectively. The operators will have pressure readings on the TPCs to confirm the control and can revert to LN2 cooling and venting to limit the pressure. There is inherent safety in gas transfer from a TPC to a reclamation cylinder in that the volume ratio, TPC to RC, is ~3 but the MAWP ratio is 400/2200 or ~1/5.

The Reclamation Panel allows for gas to be transferred into or out of the reclamation cylinders. These cylinders attach to the reclamation panel with a VCR fitting (for cleanliness) immediately followed by a rupture disc set at 2230 psig and a pressure transducer. They each have a volume of 5.36 liter. Gas is drawn into a reclamation cylinder by dipping it in a surrounding cryogenic bath of LN2 or LN2/alcohol mix. In preliminary operations the mass of Xe in a reclamation cylinder will be limited by 2-man operator control to 8 kg and Ar in a separate cylinder to 650 gm as measured by a Data Instruments load cell with a resolution of 200 gm. This will limit the pressure to <1/2 of MAWP3 or ~1000 psig as shown in Tables 1 and 2 respectively. The associated pressure transducer reading will confirm the 2-man operator control. Above these masses the

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cylinder will be weighed with a load cell from Data Instruments to measure the amount of gas in the cylinder. As above, in final configuration the load cell will be interlocked to the inlet flow valve,

The characteristics of the gases of interest are given in the following table:

Table 1. Process Gas Characteristics

Gas	Mol.Wt. grams	Melting Point °C	Boiling Point °C	Critical Temp °C	Critical Pressure psia	Critical Density g/ml
Ar	39.95	-189.4	-185.9	-122.4	705.4	0.531
Xe	131.1	-111.9	-108.1	16.6	846.7	1.155
CO_2	44.01	-56.6	-78.4*	16.6	1070.6	0.460

* Sublimation Temperature

Tables 2 and 3 respectively show that <10.6 kg of Xe and <1.3 kg of Ar will limit the cylinder pressures to less than the 2200psig MAWP3. The reclamation cylinders themselves weigh about 75 lbs. The present load cells have a 300 lb capacity, a 0.5 lb resolution and a tare weight removal feature on the readout.

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Table 2. Pressure vs Mass of Argon in a Reclamation Cylinder or a TPC

reclaim cyl	(liters)=	5.4				
T=294K			Reclaim		TPC	
p(atm)	p(psi)	moles/liter	V Ar@1atr	mass(kg)	V Ar@1atr	mass(kg)
.1	14.7	0.0	5.4	0.01	15.04	0.02
1.5	22.05	0.1	8.1	0.01	22.57	0.04
2	29.4	0.1	10.8	0.02	30.10	0.05
3	. 44.1	0.1	16.2	0.03	45.34	0.08
4	58.8	0.2	21.5	0.04	60.28	0.10
5	73.5	0.2	26.9	0.04	75.40	0.12
6	88.2	0.2	32.4	0.05	90.55	0.15
7	102.9	0.3	37.8	0.06	105.71	0.18
8	117.6	0.3	43.2	0.07	120.89	0.20
9	132.3	0.4	48.6	0.08	136.09	0.23
10	147	0.4	54.1	0.09	151.31	0.25
15	220.5	0.6	81.4	0.13	227.70	0.38
20	294	0.8	108.8	0.18	304.56	0.50
25	367.5	1.1	136.5	0.23	381.89	0.63
30		1.3	164.3		459.66	0.76
35	514.5	1.5	192.2	0.32	537.87	0.89
40	588	1.7	220.3	0.37	616.50	1.02
45	661.5	1.9	248.5	0.41	695.52	1.15
50	735	2.1	276.9	0.46	774.91	1.28
60	882	2.6	334.0	0.55	934.73	1.55
70	1029	3.0	391.6	0.65	1095.77	
80	1176	3.5	449.5			
90	1323	3.9	507.6			
100	1470	4.4	566.0	0.94	1583.82	
120	1764	5.3	682.7			
140	2058	6.2	799.0	1.32	2235.95	
160		7.1		1.51	2557.34	
180	2646	7.9	1026.5	1.70	2872.59	4.76
200		8.8		1.88	3179.75	
220		9.6	1242.5	2.06	3477.20	
240		10.4	1344.9	2.23	3763.74	6.24
260		11.1		2.39	4038.63	6.69
280		11.9			4301.43	7.13
300				2.70	4551.99	7.54
from Theri	nodynamic	Properties	od Argon fr	om the Trip	le Point to	300 K At
	to 1000 Atn		QD 162	G1 1969B	A.L.Gosmar	ו

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Table3. Pressure vs Mass of Xenon in a Reclamation Cylinder or a TPC

	reclaim cyl	(liters)=	5.36				
	T=295K	·		Reclaim (L	iters)	TPC (Liter	s)
m^3/kg	p(atm)	p(psi)	moles/liter	V Xe@1at	mass(kg)	V Xe@1at	mass(kg)
185.80	1.0	14.5	0.0	5.3	0.03	14.91	0.08
36.33	4.9	72.4	0.2	27.3	0.15	76.27	0.41
17.63	9.9	144.9	0.4	56.2	0.30	157.17	0.85
11.38	14.8	217.3	0.7	87.0	0.47	243.50	1.31
8.24	19.7	289.8	0.9	120.2	0.65	336.36	1.81
6.34	24.7	362.2	1.2	156.1	0.84	436.92	2.35
5.07	29.6	434.7	1.5	195.5	1.05	547.08	2.94
4.14	34.5	507.1	1.8	239.3	1.29	. 669.64	
3.43	39.5	579.6	2.2	289.0		808.81	4.35
2.85	44.4	652.0	2.7	347.1		971.25	5.23
2.37	49.3	724.5	3.2	418.1		1170.17	
1.93	54.3	796.9	3.9	512.2		1433.51	7.72
1.50	59.2	869.4	5.1	662.3		1853.49	9.98
0.86	64.2	941.8	8.8	1147.7	6.18	3211.98	
0.67	69.1	1014.3	11.4	1483.2		4150.65	22.34
0.62	74.0	1086.7	12.3	1594.5		4462.12	24.02
0.60	79.0	1159.2	12.8	1664.1		4657.10	
0.58	83.9	1231.6	13.2	1715.5		4800.72	
0.56	88.8	1304.1	13.5	1756.9		4916.56	
0.55	93.8	1376.5	13.8	1791.5		5013.52	
0.54	98.7		14.0	1821.5		5097.45	
0.53	· 108.6	1593.9	14.4	1871.8		5238.14	
0.52	118.4	1738.8	14.7	1913.0		5353.50	
0.51	128.3	1883.7	15.0			5454.67	
0.50				1980.3		5541.95	
0.49			15.5	2008.8		5621.78	
0.49		2318.4	15.7	2034.9		5694.56	
0.48			15.8	2058.5	11.08	5760.86	
0.48		2608.2	16.0	2081.0		5823.82	
0.47				2100.5		5878.18	
0.47		2897.9	16.3	2119.8		5932.29	
0.46						6027.79	
0.45		3477.5				6116.94	
7.19			3.5	452.6	0.75	<- Ar for co	mparison

Once the gas has been condensed in the bottom of the reclamation cylinders, pressure is built in the reclamation cylinders by removing the cryogenic bath. Gas is introduced into the low pressure loop of the system through a regulator as shown in Fig. 2. The pressure of the gas is monitored with a pressure transducer and is physically limited by a 157 psig rupture disk. Normal gas flow is into the Gas Purification System from the reclamation cylinders.

InSync Systems certifies the tubing, fittings and weldments as shown in Appendices D-G. Copies of all Insync certification documents are attached in AppendixD.

Hazards:

The LLNL safety guidance is to calculate the isentropic energy release associated with the expansion of the contained gas from MAWP3 to the local atmospheric pressure. The pertinent equation is

$$E = kRT/(k-1)((p_2/p_1)exp((k-1)/k)-1),$$
 ftlb/lb

Using values as follows

k = 1.67 for Ar and Xe, 1.3 for CO2, T = 530R, $p_1 = 2244.3$ psia, $p_2 = 14.3$ psia, R = 1545/MW ft lb / lb F, MW for Ar = 39.9, for Xe = 131.3, for CO2 = 44, storage masses for Ar and Xe from Tables 1 and 2 and for CO2 from 5.36 liter and perfect gas density

gives the greatest total delta energy for Xe of 3.26E5 ft lb / cylinder equivalent to 97.8 gm of TNT. The total is over the 7.5E4 ft lb level prescribed as the lower limit for requiring a safety note for manned area equipment. A lower total delta energy value results for CO2 because its three atom molecule lowers k from 1.67 to 1.30 and for Ar because of its greater departure from a perfect gas.

The operational pressure hazards are tempered by the use of rupture discs to limit the service pressures to the MAWPs. These discs are closely controlled by their manufacturers as discussed earlier.

Two-man operator judgment is required to limit the fill gas weights in initial runs to give pressures of ~ half MAWP3. There will be interlocks on the TPC and reclamation cylinder fill levels to prevent over charging before going on to higher fill weights and pressures.

There is a slight potential for asphyxiation associated with the free evaporation of LN2 and for excessive noise associated with valve venting. These hazards are discussed in OSP 132S.31.

Pressure Safety Assessment:

Acme designed the reclamation cylinders in accordance with ASME Boiler and Pressure Vessel Code, Section 8, Division 1, 1998. These calculations are shown in Appendix B. They did not Code stamp the vessels for reasons that are not clear at this juncture. The fabrication drawing is shown in Appendix C. As shown the cylindrical portion is 4-in. Schedule 160 pipe with an OD of 4.50 in. and an ID of 3.44 in. The heads are 4-in Schedule 160 welding pipe caps with the same inner and outer diameter as the pipe as

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shown also in Appendix C. The welds are full penetration with a standard 37.5 degree bevel on each part. The cylinder material is Type 316L stainless steel. The minimum thickness of the wall of the vessel nozzle is 0.035 in. as shown in Appendix C. The ID of the nozzle is 0.180 so that the nominal stress at MAWP3 is pr/t= 2200*0.090/.035= 5700 psi.

Thick wall pressure vessel calculations for the main body in accordance with Timoshenko (2) show a von Mises stress (Timoshenko (3)) of 5.7 ksi which gives a factor of safety of 32 on the 316L steel at ~70K and 17 (Aerospace Materials ...(4)) at room temperature. All welding at Acme was done by ASME Code certified welders. Acme tested all four cylinders at 3300 psig.

InSync Systems fabricated all of the panel plumbing in their shop under SEMI (Semiconductor Equipment and Materials International) rules. All pressure boundaries are Type 316 stainless. All welding is automatic Orbital. Fabrication conditions are clean to meet the SEMI standards. Table 4 and Appendix D show the properties of the components in the InSync assemblies. The pressure ratings for the components are seen to be a minimum of 200 psig for the low pressure system, 1000 psig for the 980 psig system and 2200 psig for the 2200 psig system. SEMI standards do not require a pressure check of plumbing in order to maintain the cleanliness of the internal surfaces. InSync did a vacuum leak test of the plumbing in each panel with the satisfactory results shown in Appendix E. InSync did the panel connecting plumbing at Livermore. The table shows the tubing and fittings to be well above the 157 psig MAWP1.

This note provides for (1) pressure proof testing at 1.27 X MAWP1 of all of the branches which are rated at an MAWP1 of 157 psig, (2) leak testing at 0.5 X MAWP2 of the TPC circuit and (3) pressure proof testing of the high pressure portion of the Reclamation Panel and Cylinder circuits at 0.85 X MAWP3. The 157 psig branches test pressure level is limited by the 200 psig limit of the Supply Panel regulator output pressure gages. The TPC circuit test pressure is limited for operational convenience noting that the chambers have been tested to 1.5 X MAWP2 separately and that the valves and hoses are rated well above MAWP2. The Reclamation Panel and Cylinder test pressure level is limited by the need to preserve the high pressure rupture discs. Here it is noted that the chambers have been pressure tested separately to 1.5 X MAWP3 plus the valves and Swagelok flex tubing are rated well above MAWP3.

Table 4. Component Pressure Ratings

Component	Pressure Rating	Remarks
Valves, Supply and Reclaim Panel	3500 psig	Nupro SS-HBVCR4-P-C
Valves, Chamber Panel	1000 psig	Nupro SS-8BG-VCR-3C
Valves, Chamber discharge	1000 psig	Nupro SS-8BG-VCR-3C
Reclamation Cylinders	2200 psig	Acme Cryogenics
Pressure regulators, S.& R.Panels	3500 psig	Tescom 64-2663KRA10
Pressure regulators, Chmbr Disch	3500 psig	Tescom 64-2663KRH19
Rupture disc, low pressure	157 psig,+/-5%	Zook 306546
Rupture disc, high pressure	2230 psig,+/-5%	Zook 306953
Pressure transducer, low pressure	5000 psig	Bendix C2143000C-834655
Pressure transducer, high pressure	10000 psig	Bendix C214250C-834655
Pressure gage, low pressure	200 psig	Tescom 4802-0200M
Pressure gage, high pressure	3000 psig	Tescom 4802-3000M
Oxygen getter	150 psig	Oxisorb S511-HV
SAES Getter	150 psig	Monotorr Phase 1
Mass flow controller	1500 psig	Brooks 5964C4MAP35KA
VCR plugs, 1/4 in.	5100 psig	Cajon SS-4-VCR-P
VCR caps, 1/4 in.	5100 psig	Cajon SS-4-VCR-CP
VCR caps, 1/2 in.	5100 psig	Cajon SS-8-VCR-CP
VCR gaskets, 1/4 in., unplated, nickel	NA	Cajon NI-4-VCR-2-GR-VS
Welding fittings	5100 psig	Swagelok Microfit
Tubing, 1/4 in.	4140 MSWP	316L, ASTM A269
Tubing, 3/8 in.	2770 MSWP	316L, ASTM A269
Tubing, 1/2 in.	2910 MSWP	316L, ASTM A269

Pressure Testing Preparation

The purpose of the pressure testing is to demonstrate that the overall system is leak tight as assembled and that all panel and interconnect plumbing is pressure safe. The low pressure rupture disc bodies are massive and difficult to open without jeopardizing the integrity of the panel plumbing and the discs themselves so that a buffer array as shown in Fig. 7 will be used to remove any pressure difference on the discs during pressure testing.

Prior to testing it is necessary it is necessary to carry out the following procedures. Please refer to Figs. 2 and 7 for component identification.

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First introduction of gas into the system:

The gas should be introduced into the system in stages. The gas handling system is under a slight pressure, a few psi, from when the system was assembled at InSync.

- 1. The Dirty Gas Bottle should be installed and attached to the supply gas panel with a regulator and CGA flex tube connector
- 2. Perform a cycle purge on the section of tubing where the bottle was connected. Use the Ar cylinder as a purge gas.
 - b) Hook up Ar cylinder with a regulator and CGA hose
 - c) Open Valve 11
 - d) Crack Ar Cyl and regulator
 - e) Cycle Valve 11 a few times ending with Valve 11 open
 - f) Close then Crack Ar cyl a few times
 - g) Allow Ar to flow for a few minutes
 - h) With Ar bleeding off, close Valve 11
 - i) Open Ar Cylinder completely
 - j) Make sure Regulator is closed
 - k) Open Valve 10

The other dirty supply lines should be purged in a similar manner. This will require opening the valves corresponding to V11 which are V21 and V31, closing them as above and opening the V10 equivalents, V20 and V30. When the Ar purge is complete, purge for a few seconds with the gas that is going to be used in the system on that line to clean out any Ar.

- 3. Proceed to introduce the gas into the rest of the system opening only one valve at a time until you reach the Mass Flow Controller.
- 4. Make sure the Mass Flow Controller is in the closed position before gas is introduced on the inlet side of the controller. Once gas pressure is built on the inlet side of the Mass Flow Controller, crack the controller open and allow a little gas to flow through, then open the controller slowly until it is full open.
- 5. Flow gas through the remainder of the system making sure to go thru both the chamber section of tubing and the reclaim sections.
- 6. Gas should be collected in the reclaim cylinders starting with Reclaim 4 and working back to Reclaim 1. Cryo (LN2) will have to be used to collect the gas in the reclaim cylinders.
- 7. If necessary, gas can be vented through Valve 95.

Adding a new cylinder of Dirty Gas (at least Research Grade):

- 1. Ensure all valves (V10-V11-V12, V20-V21-V22, V30-V31-V32) are closed near the cylinder, including the main valve on the cylinder.
- 2. Remove the old cylinder.
- 3. Place the new cylinder in the rack and attach the CGA fitting leading to the Gas Handling system.

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- 4. Cycle purge the lines with the following prescription that shows Xe as an example. There should be a bottle of Ar on the system. If you are replacing the Ar cylinder, use the new cylinder of Ar for the cycle purge.
 - d) Hook up Xe cylinder with a check valve in the discharge line to prevent inflow
 - e) Open Valve 22 (Ar for Cycle Purge)
 - f) Ar Cyl should be open. If not, follow cycle purge above to ensure that opening the Ar cyl does not introduce dirt into the system.
 - g) Open Valve 22 to introduce gas into the purge line
 - h) Open Valve 11
 - i) Open Valve 12
 - j) Allow Ar to flow and blow the line out
 - k) Close Valve 11
 - 1) Close Valve 12
 - m) Close Ar Cyl Valve
 - n) Cycle Valve 21
 - o) Close Valve 22
 - p) Open Valve 11
 - q) Crack Xe Cyl open
 - r) Close Valve 11
 - s) Work Xe Cyl valve open and closed to get dirt out ending in Closed position
 - t) Cycle Valve 11 ending in closed position
 - u) Open Xe Cyl Valve
 - v) Make sure Regulator is Closed
 - w) Open valve 10
 - x) Now use the regulator to introduce gas into the system

Pressure Testing

The following testing is to be carried out by a Pressure Inspector, a Pressure Installer, a mechanical engineer and the chief experimenter.

Clear the area and put up the signs and barricades.

1. Overall system low pressure test.

Having swept the plumbing in accordance with the previous procedure connect a research grade gas bottle to the Ar supply connection with a regulator and CGA flex hose.

Check that a rupture disc buffer array has been installed which connects the supply panel vent line to the four 157 psig rupture disc discharge connections as shown in Fig. 7. Check that the source bottle supply and regulator valves are closed.

Check that all valve positions on the control boards show closed.

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Check that the four reclamation cylinders are connected to their respective pigtails as shown on the Insync schematic (Fig. 2).

Check that TPC1 is connected between V91 and V96 and that jumpers are connected between V93 and V97 and between V88 and V98.

Check that 3 supply, 2 TPC and 4 reclaim regulators are closed (adjusting handle fully CCW).

Open the source bottle stop valve and set the regulator to 200 psig.

Verify that PT1 and PT2 read zero psig.

Reduce the source pressure to ~20 psig.

Open all valves one at a time except V83, V86 and V95.

This involves a total of 43 numbered valves as follows,

V10, V11, V12, V13, V20, V21, V22, V23, V30, V31, V32, V33, V40, V41, V42, V43, V50, V51, V52, V53, V60, V61, V62, V63, V70, V71, V72, V80, V81, V82, V84, V85, V87, V88, V89, V90, V91, V92, V93, V94, V96, V97, V98,

plus 3 Supply Panel, 4 Reclaim Panel and 2 TPC pressure regulators for an overall total of 52 items.

Raise the source pressure to 50 psig, verify that PT1 and PT2 read 50 psig.

Shut off the source pressure and show that PT1 and PT2 hold 50 psig for 5 minutes.

If there is a leak, leak hunt with an audio leak detector, repair the leak and retest.

Repeat this pressurize, shut off, hold procedure at 100, and 150 psig.

Raise the source pressure to 200 psig, verify that PT1 and PT2 read 200 psig.

Shut off the source pressure and show that PT1 and PT2 hold >195 psig for a period of one hour.

If the pressure falls below 195 psig, shut off the source pressure and vent the system by simultaneously cracking V-Test 1 and V-Test 2 and adjusting them for a pressure drop rate of ~15 psi/ min with the pressure at V-Test 1 kept ~5 to 10 psig below that at V-Test 2, repair the leak and return directly to the 200 psig test level for verification. When the 200 psig test results are satisfactory vent the system in the same way. Close the 43 numbered valves and the 9 pressure regulators.

Remove the buffer array.

2. Supply Panel Input High Pressure Test

Since the Supply Panel input manifold will be pressurized directly to a bottle pressure MOP of up to 2000 psig in normal operation and since it is not pressure relieved it is necessary to test it to 3300 psig to provide for a MAWPO of 2200 psig following the 200 psig testing.

Connect a regulated high pressure clean gas source to a Source Panel input station.

Verify that the other two input stations are closed.

Open valves V10, V12, V20, V22, V30 and V32.

Raise the source pressure to 1100 psig and note that the Supply Panel regulator input pressure gages all read 1100 psig.

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Shut off the source pressure and show that the input pressure gages hold 1100 psig for 5 minutes.

If there is a leak, leak hunt with an audio leak detector, repair the leak and retest.

Raise the source pressure to 2200 psig

Shut off the source pressure and show that the input pressure gages hold 2200 psig for 5 minutes.

If there is a leak, leak hunt with an audio leak detector, repair the leak and retest.

Raise the source pressure to 3300 psig.

Shut off the source pressure and show that the pressure gages hold >3300 psig for 30 minutes.

Repeat the leak hunt, repair, retest procedure as necessary.

When the 3900 psig test results are satisfactory vent the system by opening V31. Close V10, V12, V20, V22, V30, V31 and V32.

3. Reclamation Panel High Pressure Test

There is need to check the integrity of the high pressure portion of the Reclamation Panel. The cylinders have been tested to 3300 psig as required for an MAWP3 of 2200 psig. The flex hoses which connect the four cylinders to the panel are rated at 3100 psig. The tubing, pressure transducers and pressure regulators are rated higher than the 3300 psig as is seen in Table 4. The burst discs will fail at MAWP3 within their tolerance band.

Verify that all valves and pressure regulators on the Reclamation Panel are closed. Fill Reclaim 1 thru the MFC with enough Ar to give 1800 psig plus 0, minus 200 psig when liquefied and equilibrated to room temperature.

The fill sequence is to supply the gas from the Ar Supply connection on the Source Panel, thru the getters and MFC, thru V94, V89, V63, V53, V43, V41, V40 to Reclaim 1. Close V41 and show that the initial pressure is held within 30 psig over a 30 minute period.

If there is a leak, vent the cylinder at <140 psig thru the V42, V43, V53, V63, V89, V97, V93, V95 path, repair it and retest.

Transfer the gas thru the Reclaim 1 regulator at <140 psig and V42, V43, V51, V50 to Reclaim 2 and repeat the 1800 psig nominal pressure test as above, make up for any residue in Reclaim 1 using the initial fill sequence shown above except replace V43, V41, V40 with V51, V50.

Close V51 and show that the initial pressure is held within 30 psig over a 30 minute period.

If there is a leak, vent as above from Reclaim 2 and retest.

Transfer the gas thru the Reclaim 2 regulator at <140 psig and V52, V53, V61, V60 to Reclaim 3 and repeat the 1800 psig nominal pressure test as above, make up for any residue in Reclaim 2 using the initial fill sequence shown above.

Close V61 and show that the initial pressure is held within 30 psig over a 30 minute period.

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If there is a leak, vent as above from Reclaim 3 and retest.

Transfer the gas thru the Reclaim 3 regulator at <140 psig and V62, V63, V71, V70 to Reclaim 4 and repeat the 1800 psig nominal pressure test as above, make up for any residue in Reclaim 3 using the initial fill sequence shown above except replace V63, V53, V43, V41, V40 with V71, V70.

Close V71 and show that the initial pressure is held within 30 psig over a 30 minute period.

If there is a leak, vent as above from Reclaim4 and retest.

If not, vent as above from Reclaim 4.

This concludes the testing._

Close all valves.

Leave the Ar bottle in place.

Remove the signs and barricades.

Labeling

Attach a standard LLNL pressure test label to the Gas Supply Valve Control Panel as follows,

ASSY Gamma Ray Imager

SAFETY NOTE MESN99-038-0A

MAWP Varies, see labels

FLUID Ar, Xe, CO2

TEMP varies, see labels

REMARKS

Restricted use

TEST NO.

(Supplied by tester)

BY

DATE

Attach standard LLNL pressure test labels to each of the four reclamation cylinders and to each of the four valve panels as follows,

ASSY Reclamation Cylinder No. 1, 2, 3, 4

SAFETY NOTE MESN99-038-0A

MAWP3 2200 psig

FLUID Ar, Xe, CO2

TEMP 77 K to 50 C

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REMARKS

Restricted use

TEST NO.

(Supplied by tester)

BY

DATE

ASSY Gas Supply Panel Input, PN 10E0804-01

SAFETY NOTE MESN99-038-0A

MAWPO 2200 psig

FLUID Ar, Xe, CO2

TEMP 10

10 C to 50C

REMARKS

Restricted use

TEST NO.

(Supplied by tester)

BY

DATE

ASSY Gas Supply Panel Output, PN 10E0804-01

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP 10 C to 50C

REMARKS

Restricted use

TEST NO.

(Supplied by tester)

BY

DATE

ASSY Gas Reclamation Panel Input, PN 10E0804-02

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP 10 C to 50C

REMARKS

Restricted use

TEST NO.

(Supplied by tester)

BY DATE

ASSY Gas Processing Panel, PN 10E0804-03

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP 10C to 50 C

REMARKS

Restricted use

TEST NO.

(Supplied by tester)

BY

DATE

ASSY Detector Chambers Fill Panel, PN 10E0804-04

SAFETY NOTE MESN99-038-0A

MAWP1 150 psig

FLUID Ar, Xe, CO2

TEMP -20C to 50 C

REMARKS

Restricted use

TEST NO.

(Supplied by tester)

BY

DATE

Associated Procedures

1. OSP 132S.31

References

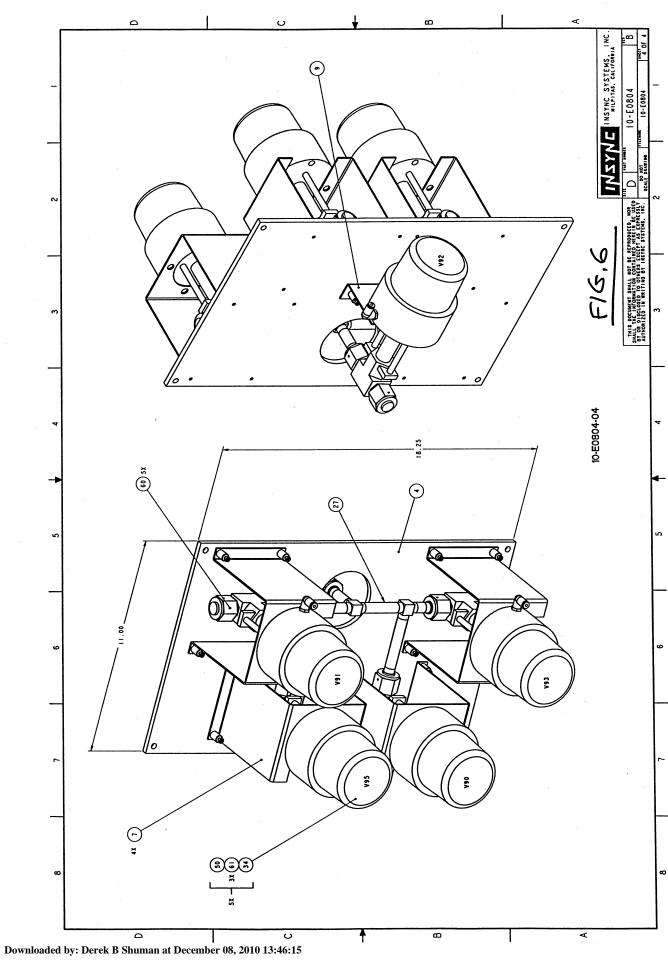
- Chapter 32 Pressure, Supplements 32.03 Pressure Vessel and System Design and 32.05 - Pressure Testing, LLNL Health & Safety Manual
- 2. S. Timoshenko, Strength of Materials, Part 2, D. Van Nostrand, 1941, 239
- 3. S. Timoshenko, Strength of Materials, Part 2, Krieger, 1976, 454
- 4. Aerospace Structural Metals Handbook, Volume 2, DOD/Battelle, 1995

- 5. B-132S Facility Safety Procedure (FSP-132S)
- 6. LLNL Environmental Compliance Manual
- 7. LLNL Training Program Manual
- 8. Design Safety Standards Manual, ME Department, LLNL

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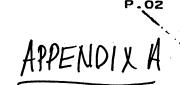
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FINAL INSPECTION AND TEST REPORT

ITEM NO. 225-819633 DESCRIPTION LIVER MORE LABS PRE	STURE VESSEL
SHOP ORDER NO	
PRESSURE TEST	
TYPE TEST: PNEUMATIC CIRCUIT: CIRCUIT:	
▲	
PROOF TESTED AT FULL TEST PRESSURE OF 3300 PSIG WITH WAR	
AND HELD FOR <u>/O</u> MINUTES/HOURS; PRESSURE THEN REDUCE FOR EXAMINATION FOR LEAKS.	ED TOPSIG
SAFETY RELIEF VALVE SET AT N/A PSIG; PRESSURE SWITCH SET AT	AIA
TEST PROCEDURE NO, TESTED BY TEST DA	TE 3/8/99
FINAL INSPECTION	INSP. STAMP
ALL PROCESS & INSTRUMENT LINES STRAIGHT, LEVEL & PLUMB	(3) gr. 4C.
ALL REQUIRED COMPONENTS INSTALLED, IN PROPER LOCATION, AND FLOW DIRECTIONS IS CORRECT	THE STATE OF THE S
ALL WELDS MEET QUALITY STDS. OF Q-113	OND ES
ALL BRAZED JOINTS-EVIDENCE OF COMPLETE BOND AROUND ENTIRE JOINT (360•)	NIA
PAINTED SURFACES SMOOTH & UNIFORM, FULL COVERAGE, NO RUNS OR SAGS, TOUCHED-UP WHERE REQUIRED	NIA
ALL REQUIRED TAGS & NAMEPLATES IN PLACE & CORRECT PER DRAWING	(Search SE)
FUNCTIONAL TEST PERFORMED	(T. 12)
PREPARATION FOR SHIPMENT	INSP. STAMP
ALL OPEN PORTS CLOSED/SEALED TO PREVENT CONTAMINATION	AVOL. STAUL
ALL TEMPORARY & FLO-PEN MARKINGS HAVE BEEN REMOVED	
ALL GROSS STAINS & DISCOLORATION REMOVED FROM PIPING & FRAMES	prain.
EQUIPMENT CLEANED FOR SHIPMENT (WIPED DOWN)	
SYSTEM PRESSURIZED TO PSIG FOR SHIPMENT (SHOW EXACT PRESSURIZED TO PSIG FOR SHIPMENT (SHOW EXACT PRESSURIZED TO EQUIPMENT).	RE, TEMP
THIS EQUIPMENT MEETS ALL ABOVE REQUIREMENTS AND IS APPROVED FOR	R SHIPMENT
QUALITY CONTROL TECHNICIAN DATE	

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TABLE 1A SECTION I; SECTION III, CLASS 2 AND 3; AND SECTION VIII, DIVISION 1 MAXIMUM ALLOWABLE STRESS VALUES S FOR FERROUS MATERIALS ("See Maximum Temperature Limits for Restrictions on Class)

8 1 70 25 arts Only) NP NP NP 850 HA-4	500 600 650 700 750 800 850 900	10.9 10.4 10.2 10.0 9.8 9.6 9.4	1250 1300 1350 1400 1450 1500 1550 1600 1650	
ets Only) NP NP	600 650 700 750 800 860	10.4 10.2 10.0 9.8 9.6 9.4	1300 1350 1400 1450 1500 1550 1600	
arts Only)	600 650 700 750 800 860	10.4 10.2 10.0 9.8 9.6 9.4	1300 1350 1400 1450 1500	
arts Only)	60 0 650 700 750 800	10.4 10.2 10.0 9.8 9.6	1300 1350 1400 1460 1500	\
25	60 0 650 700 750	10.4 10.2 10.0 9.8	1300 1350 1400 1450	
25	60 0 650 700	10.4 10.2 10.0	1300 1350 1400	\\ \
	60 0 650	10.4 10.2	1300 1350	<i>]</i>
	600	10.4	1300	\
1				\
8	500	10.9	1250	•••
_				
***	400	11.7	•	•••
•···	300	12.7	•	•••
S31603	250		1100 .	•••
TP316L	200	14.1	1050	•••
SA-312	150		1000	•••
Smis, pipe	-20 to 100 (16.7	950	***
16Cr - 12Ni - 2Mo	pall, for Meta	Temperature, *F,	Not Exceedi	ng
	 16Cr • 12Ni • 2Mo Smle. pipe SA-312 TP316L S31603	Maximum All 16Cr - 12Ni - 2Mo Smis. pipe -20 to 100 (SA-312 180 TP316L 200 S31603 250 300	Maximum Allowable Stress, kg/ 16Cr - 12Ni - 2Mo Path, for Metal Temperature, °F,	Maximum Allowable Stress, kxl (Multiply by 16Cr - 12Ni - 2Mo 16Cr - 2Ni - 1000 16Cr 16Cr - 2Ni - 1000 16Cr - 2Ni

- (a) The following are the abbreviations used for Product Forme: (a) Wid. Welded; (b) Smis. Seamless.
- (b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.
- (c) When used for Section III Class MC design, the stress values listed herein shall be multiplied by a factor of 1.1 (NE-3112.4); these values shall be considered as design stress intensities or alloyable stress values as required by NE-3200 or NE-3300, respectively.
- (d) For Section VIII applications, stress values in restricted shear such as down bolts or similar construction in which the shearing member is so restricted that the section under consideration would fall without reduction of area shall be 0.80 times the values in the above Table.
- (c) For Section VIII applications, stress values in bearing shall be 1.60 times the values in the above Table.
- (f) Stress values for -20 to 100°F are applicable for colder temperatures when toughness requirements of Section III or Section VIII are met.

Min Allowable Tensile Stess

70 > 4 Safety Factor

Allowable Stress used in ASME BPV Code Section VIII Div. 1 Calculations

This report derived from 1996 ASME Boiler & Pressure Vessel Code Stress Tables, Q1998 ASME International. It is for this record only.

APPENDIX B

ACME Cryogenics, Inc. Pressure Vessel Calculations for:

Lawrence Livermore Labs Pressure Vessel S/O: M058560, qty (4) ea

Vessel Description: 4" dia. x 36 OAL vessel w/(1) nozzle

Design Code: ASME Boiler & Pressure Vessel Code Sect. VIII, Div. 1 1998 Edition

Special Notes: Vessel designed w/ SF=4 as is standard with code.

Design Engineer: A. Halsey Date: 1/15/99

ENGINGER REVIEW: MATIL, DE Date: 1/20/99

NOTE: ASME Sut 8, Div 1 uses Met 1 Albert 16

Stresses = Min. tensile stress/4: 4:1 S.F. is MET.

May 12, 1999

ACME CRYOGENICS ID-61079 C:\COMPRESS\DATA\QUOTES\PATERSON.VSL

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Pressure Summary

Pressure summary for pressure chamber 1

- (
	Identifier	design	design	MAWP	MAP	Pe external	UG-99	UC\$-66	Corresion
	TOP HEAD	(psi)	(deg F)	(psi)	{psi}	(psi)	Ratio	MOMT Exemption or (deg F) Stress Reduction	Allowance
	SHELL BOTTOM HEAD	3000.0 3000.0 3000.0	158.0 158.0 158.0	3869.3 3095.6 3869.3	4253.4 3402.9 4253.4	0.0 0.0 0.0	1.099	Not applicable Not applicable	0.000
	N1	3000.0	158.0	3000.0	3000.0	0.0	1.089	Not applicable Not applicable	0.000
	Veccel Marin I		_ '						

Vessel MAWP hot & corroded is 3000 psi @ 158 degrees F.

Vessel MAP new & cold is 3000 psi @ 70 degrees F.

Vessel is not designed for external pressure.

Hydrotest pressure calculation based on MAWP

= 1.5*MAWP*1 = 4500 PSI OR PNEUMATIC = 1.25 × MAWP X 1 = 3750 PSI

Vessel hydrotest pressure, horizontal position is 4500 psi.

Design notes:

Minimum thickness is 1/16 inch per UG-16(b). Corrosion weight loss is 100% of theoretical loss. UG-23 stress increase is 1.2. Test liquid specific gravity is 1. Minimum nozzle outside projection 1 inches. Maximum stress allowed during field hydrotest is 90% of yield. Butt weld thickness transitions made by removing material. P-No 1 material >1.25 to 1.5 in. thick is preheated (UCS-56). Interpretation VIII-1-83-66 has been applied.

P.05

Component	Dia	Length	Nom t	Req t	Joint	Load	Governing		Deflect
Identifier	(in)	(in)	(in)	(in)	E		Status	Stress	(in)
Top head Shell Bottom head	4.50 od 4.50 od 4.50 od	30.00	0.5310* 0.5825 0.5310*	0.4323 0.4783 0.4323	0.85 0.85 0.85	intern intern intern	āj		

Nom t Req t

vessel wall thickness
 required vessel thickness due to governing loading + corrosion
 longitudinal seam joint efficiency
 head minimum thickness

Load:

internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

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May 12, 1999

TOP HEAD

ASME Section VIII Division 1, 1998 Edition

Component:

2:1 head

Material specification:

SA 182 F316L LOW <=5"

Internal design pressure:

P = 3000

psi @ 158

deg F

Corrosion allowance: Inner C = 0

Outer= 0

in

PWHT is not performed

Radiography:

Category A joints -Head to shell seam -

Seamless NO X-Ray None UW-11(c) type 1

Estimated weight:

capacity:

new = 8.7new = .1

corr = 8.7corr = .1

US ga

OD = 4.5

t = .531 (min)

flange= 1.5

forming= 0

in (new)

Design thickness: (At 158 deg F) Appendix 1-4(c)

t = P*Do*K/(2*S*E + 2*P*(K-0.1)) + Corrosion + fa= 3000*4.5*1/(2*15192*0.85 + 2*3000*(1-0.1)) + 0 + 0

MAP: (New & at 70 deg F)

Appendix 1-4(c)

P = 2*S*E*t/(K*Do - 2*t*(K-0.1)) - Ps = 2*16700*0.85*0.531/(1*4.5 - 2*0.531*(1-0.1)) - 0 = 4253.454 psi

MAWP: (Corroded & at 158 deg F)

Appendix 1-4(c)

P = 2*S*E*t/(K*Do - 2*t*(K-0.1)) - Ps = 2*15192*0.85*0.531/(1*4.5 - 2*0.531*(1-0.1)) - 0

= 3869.369 psi

UG-32(1) Minimum Straight Flange Thickness

Design thickness: (At 158 deg F)

Appendix 1-1(a)

t = P*Ro/(S*E + 0.4*P) + Corrosion = 3869.369*2.25/(15192*0.85 + 0.4*3869.369) + 0 = 0.602 in

C:\COMPRESS\DATA\QUOTES\PATERSON.VSL

May 12, 1999

SHELL

ASME Section VIII Division 1, 1998 Edition

Component:

Material specification:

Cylinder SA 312 TP316L SMLS LOW (pipe)

Internal design pressure:

capacity:

P = 3000

psi @ 158

deg F

Corrosion allowance: Inner C = 0

Outer= 0

in

PWHT is not performed

Radiography:

Category A joints - Category B joints -

Seamless NO X-Ray None UW-11(c) type 1

Estimated weight:

new = 60.5new = 1.162

corr = 60.5 corr = 1.162

US ga

OD = 4.5

length Lc= 30

t = 0.5625

in (nominal, new)

Design thickness: (At 158 deg F)

t = P*Ro/(S*E + 0.4*P) + Corrosion = 3000*2.25/(15192*0.85 + 0.4*3000) + 0 = 0.4783 in

MAP: (New & at 70 deg F)

Appendix 1-1(a)

Appendix 1-1(a)

P = S*E*t/(Ro - 0.4*t) - Ps = 16700*0.85*0.4921875/(2.25 - 0.4*0.4921875) - 0 = 3402.911 psi

MAWP:

(Corroded & at 158 deg F)

Appendix 1-1(a)

P = S*E*t/(Ro - 0.4*t) - Ps= 15192*0.85*0.4921875/(2.25 - 0.4*0.4921875) - 0 = 3095.63 psi

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BOTTOM HEAD

ASME Section VIII Division 1, 1998 Edition

Component;

Material specification:

2:1 head SA 182 F316L LOW <=5"

Internal design pressure:

P = 3000

psi @ 158

deg F

May 12, 1999

Corrosion allowance: Inner C = 0

Outer= 0

in

PWHT is not performed

Radiography:

Category A joints -Head to shell seam -

Seamless NO X-Ray None UW-11(c) type 1

Estimated weight: capacity:

new = 8.7 new = .1

corr = 8.7corr = .1

US ga

OD = 4.5

t = .531 (min)

flange= 1.5

forming≈ 0

in (new)

Design thickness: (At 158 deg F)

Appendix 1-4(c)

t = P*Do*K/(2*S*E + 2*P*(K-0.1)) + Corrosion + fa = 3000*4.5*1/(2*15192*0.85 + 2*3000*(1-0.1)) + 0 + 0 = 0.4323 in

MAP: (New & at 70 deg F)

Appendix 1-4(c)

P = 2*S*E*t/(K*Do - 2*t*(K-0.1)) - Ps = 2*16700*0.85*0.531/(1*4.5 - 2*0.531*(1-0.1)) - 0 = 4253.454 psi

MAWP: (Corroded & at 158 deg F)

Appendix 1-4(c)

P = 2*S*E*t/(K*Do - 2*t*(K-0.1)) - Ps = 2*15192*0.85*0.531/(1*4.5 - 2*0.531*(1-0.1)) - 0 = 3869.369 psi

UG-32(1) Minimum Straight Flange Thickness

Design thickness: (At 158 deg F) Appendix 1-1(a)

t = P*Ro/(S*E + 0.4*P) + Corrosion = 3869.369*2.25/(15192*0.85 + 0.4*3869.369) + 0 = 0.602 in

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May 12, 1999

Opening N1 Reinforcement Calculations Per UG-37

Located on: Local vessel thickness:

Liquid static head included:

TOP HEAD 0 bai

Flange description: Not installed

Nozzle material specification:

SA 479 316L HIGH

Nozzle orientation: End of nozzle to datum line: Nozzle calculated as hillside: Projection outside vessel Lpr:

0 degrees -4.5 in

no 1.884711 in

tn →1 |<-

----- R -----> |

corrosion allow = 0 in noz thick new tn= .191 in nozzle id. new d= .18 in fillet weld tw1 = .25 in

To head center R= 0 in

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall (Rn + tn + t) = .812 in Normal to the vessel wall outside 2.5*(tn-Cn) + te = .4775 in Normal to the vessel wall inside 2.5*(tn-Cn-C) = .4775 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P) = 3000*0.09/(16700*1 - 0.6*3000) = 0.0181 in

Required thickness tr from UG-37(a)(3)

tr= P*K1*D/(2*S*E - 0.2*P) = 3000*0.9*3.438/(2*15192*1 - 0.2*3000) = 0.3117 in

Opening does not require reinforcement per UG-36(c)(3)(a)

Check the welds - From UW-16(c):

Fillet weld: tmin = lesser of 0.75 or tn or t, tmin = 0.191 in tc(min) = lesser of 0.25 or 0.7*tmin, tc(min) = 0.1337 in tc(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (a).

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):
Wall thickness per UG-45(b)(1):
Wall thickness per UG-16(b):
Std pipe wall per UG-45(b)(4):
The greater of tr2 or tr3:
The lesser of tr4 or tr5: tr1 = 0.0181 in (E = 1) tr2 = 0.3463 in tr3 = 0.0625 in tr4 = 0.079625 in tr5 = 0.3463 in tr6 = 0.079625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.079625 in

May 12, 1999

Available nozzle wall thickness new, tn = 0.191 in The nozzle neck thickness is adequate for MAWP. Exempt from weld strength calculations per UW-15(b)(2)

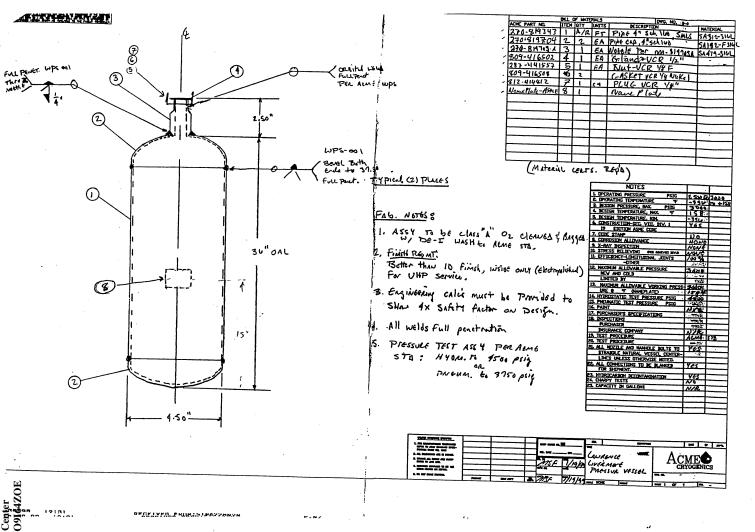
VCR FITTING:

Notale CiRC. STRESS;

S1479-316L 5= 14700 psi e 158°F E = 1 t= .035" Ti= . 18/2= .09

= 5266 psi > 3000 psi : de

APPENDIX C



The all to digital

				AREAS and WEIGHTS				RADIUS				PRESSUI	RE/STRE	SS		
SCHEDULE	WALL THICK-	INSIDE DIAM-	FIFTH POWER	SURFA	CE AREA	Cross-	Sectional	WEI	GHT of	of	MOMENT of	TION	BOILER CODE	OIL	GAS	& AIR
and/or	NESS	ETER	of ID	OUT- SIDE	IN- SIDE	METAL		PIPE	WATER	GYRA- TION	INERTIA	MOD-	POWER DISTR.	PIPING (based		PING
WEIGHT*	inches	inches	In.5	sq ft	sq ft	AREA	AREA	Ιb	IЬ				HEAT'G. & REFR.	on LAMÉ	DIV. 1	DIV. 2
1	t	d	d ⁵	per ft	per ft Ai	sq in,	sq in. Āf	per fi W	per ft Ww	inches Ig	in. ⁴ I	in ³	PIPING	FORM.)		
			•	3″ :	NOMIN	IAL SI	·	nt'd) ((C ₁	c ₂	c ₃	C ₄
	.241	3.018	250	.916	.790	2.467	7.15	8.39	3.10	1.155	3.29	1.883	.0862	.0961	.0948	1 0000
	.254	2.992	240	.916	.783	2.590	7.03	8.81	3.04	1.151	3.43	1.962	.0932	.1032	.1013	.1045
80 XS 80S	.289 .300	2.922 2.900	213 205	.916 .916	.765	2.915 3.016	6.71	9.91	2.90 2.86	1.140	3.79 3.90	2.165 2.226	.1122	.1226	.1188	.1189
	.312	2.875	196	.916	.753	3.129	6.49	10.64	2.81	1.132	4.01	2.294	.1248	.1287	.1243	.1234
160	.406 .437	2.687 2.626	140 125	.916 .916	.703	3.950 4.205	5.67 5.42	13.43 14.30	2.46 2.35	1.103 1.094	4.81 5.03	2.748 2.876	.1776	.1894	.1773	.1670
XX	.600	2.300	64	.916	.602	5.466	4.15	18.58	1.80	1.047	5.99	3.425	.2937	.2076	.1928	.1798
				31	½″ NO	MINA	SIZE	(OUTS	IDE D					1.5500		.4400
108	.120 .128	3.760	752	1.047	.984	1.463	11.10	4.97	4.81	1.372	2.76	1.378	.0202	.0279	.0300	.0432
	.134	3.744 3.732	736 724	1.047 1.047	.980	1.557 1.628	11.01	5.29 5.53	4.77 4.74	1.370 1.368	2.92 3.04	1.461 1.522	.0237 .0264	.0315	.0335	.0461
	.148	3.704	697	1.047	.970	1.791	10.78	6.09	4.67	1.363	3.33	1.664	.0327	.0342	.0361	.0482
40 ST 40S	.188 .226	3.624 3.548	625 562	1.047 1.047	.949 .929	2.251 2.680	10.31	7.65 9.11	4.47 4.28	1.349 1.337	4.10 4.79	2.050 2.394	.0508 .0682	.0589	.0598	.0677
80 XS 80S	.281	3.438	480	1.047	.900	3.283	9.28	11.16	4.02	1.319	5.71	2.855	.0938	.1027	.0764	.1012
00 AS 00S	.318 .344	3.364 3.312	431 399	1.047 1.047	.881 .867	3.678 3.951	8.89 8.62	12.51 13.43	3.85 3.73	1.307 1.298	6.28 6.66	3.141 3.331	.1114	.1206	.1166	.1145
xx	.469 .636	3.062 2.728	269	1.047	.802	5.203	7.36	17.69	3.19	1.259	8.25	4.127	.1855	.1333	.1280	.1238
	.030	4.148	151	1.047	.714	6.721	5.84	22.85		1.210	9.85	4.925	.2725	.2840	.2558	.2290
108	.120	4.260	1403	1.178	1.115	1.651		OUTSI		<u>1</u>						
	.128	4.244	1377	1.178	1.111	1.758	14.25 14.15	5.61 5.98		1.549 1.546		1.762	.0179	.0247	.0267	.0384 .0410
	.134	4.232 4.216	1358 1332	1.178	1.108	1.838	14.07	6.25	1	1.544	į.	1.949	.0234	.0303	.0321	.0429
	.165	4.170	1261	1.178	1.092	1.944 2.247	13.96 13.66	6.61 7.64	6.04 5.91	1.542		2.054 2.350	.0266	.0335	.0352	.0454 .0528
	.188	4.124	1193 1144	1.178	1.080	2.55	13.36	8.66	i	1.526	5.93	2.64	.0450	.0522	.0531	.0602
40 ST 40S	.237	4.026	1058	1.178		2.77 3.17	13.14 12.73	9.40 10.79		1.520	6.39 7.23	2.84 3.22	.0519	.0592	.0597 .0722	.0656 .0758
	.250	4.000 3.958	971	1.178	1.047	3.34	12.57	11.35	1	1.505	7.56	3.36	.0702	.0778	.0772	.0800
	.281	3.938	947	1.178	1.036	3.60 3.74	12.30 12.18	12.24 12.72		1.498	8.08 8.33	3.59 3.70	.0789	.0866	.0854	.0867 .0899
	.300	3.900 3.876	902 875	1.178	1.021	3.96	11.95	13.46	5.17	1.489	8.78	3.90	.0910	.0989	.0867	.0960
80 XS 80S	.337	3.826	820	1.178	1.015	4.10	11.80	13.96 14.99	4.98	1.485	9.05	4.02 4.27	.0960	.1040	.1013	.0998
120	.437	3.750 3.626	742 627	1.178	.982	4.86 5.58	11.04	16.52	la la		10.42	4.63	.1227	.1312	.1258	.1200
160	.500	3.500 3.438	525	1.178	.916	6.28	9.62	18.96 21.36	4.17	1.425	11.65 12.77	5.18 5.67	.1495	.1585	.1499	.1398 .1600
xx	5 M. A.	3.152	480 311	1.178	.900	6.62 8.10	9.28 7.80	22.51	13	1.416	13.27	5.90	.1912	.2009	.1865	.1699
								27.54		394 74 3	15.29	6.79	.2573	.2676	.2421	.2157
108	.134	5.295	4162	1.456	1.386	2.29	22.02	OUTSII		12.7					т	
40 ST 40S		5.047 4.859	3275 2708	1.456	1.321	4.30	20.01	7.77 14.62	8.66		8.43 15.17	5.45		.0245 .0652	.0260	.0347 .0688
80 XS 80S	.378	4.813	2583	1.456	1.272	5.76 6.11	18.54	19.59	18	1.847	19,65	7.07	.0905	.0970	.0946	.0911
120	.437 .500	4.688 4.563	2264	1.456	1.227	7.04	18.19	20.78	7.47	1,819	20.68 23.31			.1050 .1266	.1018 .1213	.0971
160	.625	4.313	1492	1.456	1.194	7.95 9.70	16.35	27.04 32.97	133	T 200 1	25.74	9,25	.1415	.1489	.1411	.1294
XX	.750	4.063			1.064	11.40	12.97	38.77	6.33 5.61	1722		10.80 12.10			.1804	.1618

CAPS Schedule 160†



Part No. 84

Seamless Steel TUBE-TURN Welding Fittings

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NOMINAL PIPE SIZE	OUTSIDE DIAMETER O.D.	INSIDE DIAMETER I.D.	WALL THICKNESS T	LENGTH E	TANGENT S	DISH RADIUS R‡	KNUCKLE RADIUS r‡	APPROXIMATE WEIGHT IN POUNDS	LIST PRICE
1	1.315	.815	.250	1½	1.05	.71	.14	.39	\$ 8.50
11/4	1.660	1.160	.250	1½	.96	1.00	.20	.54	8.50
1½	1.900	1.338	.281	1½	.88	1.17	.22	.68	8.50
2	2.375	1.689	.343	13/4	.98	1.47	.28	1.19	18.00
2½	2.875	2.125	.375	2	1.09	1.90	.35	1.96	24.20
3	3.500	2.626	.437	21/2	1.41	2.29	.44	3.52	24.20
4	4.500	3.438	.531	3	1.61	3.02	.57	6.54	28.00
5	5.563	4.313	.625	3½	1.80	3.77	.72	11.0	39.70
6	6.625	5.189	.718	4	1.98	4.54	.86	17.5	50.00
8	8.625	6.813	.906 ⁽¹⁾	5	2.39	5.96	1.14	32.0	60.00
10	10.750	8.500	1.125 ⁽¹⁾	5½	2.25	7.43	1.42	54.1	105.00
12	12.750	10.126	1.312(1)	6½	2.66	8.85	1.69	88.7	147.00

kinetics.

fluid systems 1463 centre pointe drive milpitas, ca 95035

telephone 408.946.3100 facsimile 408.934.6301

Mr. Daniel Archer, Ph.D. Nuclear Physicist Lawrence Livermore National Laboratory 7000 East Avenue Livermore, CA 94551

APPENDIX D

Dear Dan,

Per your request, this letter outlines the manufacturing techniques and industry standards Kinetics Fluid Systems (formerly Insync) used to fabricate the Xenon Delivery System specified and purchased by Lawrence Livermore National Laboratory.

Insync Job # U0898 (1/8/99)

Insync Item # 870LLL-0001-U0898

Description: 10-E0804 REV. X1, Xenon Delivery System

LLNL PO # B502632

Ship Date: 3/23/98

Overview:

The design rules, materials of construction, welding methods and assembly techniques used on the Xenon delivery system are consistent with the standards used in low pressure (<250psig) and high pressure (250-3000psig) ultra high purity gas delivery systems for the semiconductor manufacturing industry. These industry standards are extremely rigorous due to the susceptibility to microcontamination and the highly toxic, flammable and corrosive gases used in semiconductor manufacturing.

Below, please find the material specifications and industry standards used for this project. Note that the SEMI (Semiconductor Equipment and Materials International) standards each reference other standards including ASME, ASTM, FED-STD, IES, ISO, SEMI, etc. The texts of the specific documents are available from each of the respective organizations.

Panel design and construction:

The following standards were used as general design rules for the Xenon delivery system.

System Design:

SEMI E49.9 'Guide for ultra-high purity gas distribution systems in semiconductor manufacturing equipment'

Materials:

SEMI F20

Assembly/Test:

SEMI E49.6 'Guide for subsystem assembly and testing procedures-stainless steel systems'

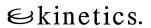
Leak Testing:

SEMI F1 'Specification of for leak integrity of toxic gas piping systems'

Tubing:

All tubing used in this system is manufactured by Valex and conforms to the following standards:

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TYO9I64ZOE



	Tubing specifications											
Component	Materials	Application Specifications										
1/4" O.D. Tubing P/N T40-VS25-035A5	T316L Stainless Steel	ASTM A 269, ASTM A632 MSWP 4,142 psi, TBP 17,355psi										
3/8" O.D. Tubing P/N T40-VS375-035A5	T316L Stainless Steel	ASTM A 269, ASTM A632 MSWP 2,776 psi, TBP 11,631psi										
1/2" O.D. Tubing T40-VS5-049A5	T316L Stainless Steel	ASTM A 269, ASTM A632 MSWP 2,917 psi, TBP 12,222psi										

MSWP=maximum safe working pressure

TBP=theoretical burst pressure

Fittings, glands and gaskets:

The fittings, glands and gaskets used in this system are manufactured by Swagelok or Parker and conform to the following standards:

Fitting, gland and gasket standards										
Materials	Component	Application Specifications								
316SS	Bodies, Nuts Gaskets, Forged Shapes	ASME SA479, ASTM A276 ASME A240, ASTM A167 ASME SA182, ASTM A314								
316L VAR	TB Glands	ASME SA479, ASTM A276								
200 Nickel	Gaskets	ASTM B162								

Gasket seal integrity specifications											
Leak rate, std cm ³ /s											
	Inboard	Outboard									
Gasket	At 10 ⁻⁵ torr	At 5000 psig	Extrapolated to vacuum								
(Nickle) VS unplated	<4 x 10 ⁻¹¹	<5.5 x 10 ⁻¹⁰	<4 x 10 ⁻¹⁵								

Please call if you have any additional questions or require further clarifications. Thank you again for the opportunity.

Sincerely,

Kinetics Fluid Systems Ed Poe

INSYNC Systems, Inc. 1463 Centre Pointe Drive Milpitas, CA 95035 408-946-3100 Fax 408-934-6301

APPENDIX E

SYSTEM LEAK CHECK AND CONFORMANCE CERTIFICATION

Ser. # 003707, 003708, 003709,	003710						
System Number: 10-E0804			Rev.: _	_B	_Qty: _	_1 set_	_
INSYNC System Job Number:	U0898						
Description:_Xenon Delivery Sy	stem						
Technician: _Sid Cropper		Date:_	3/22/1999	9			

We certify this panel was Helium leak checked and is certified with a Helium Mass Spectrometer with a leak rate sensitivity of less than 1 x 10⁻⁹ atm.cc He/sec. with the following:

(X) Alcatel 181 td

And passed with the following exceptions:

Four 2" rupture disc assemblies passed at; 1.0 x 10 -8 atm, 2.4 x 10 -8 atm, 5.0×10^{-7} atm, 3.0×10^{-5} atm Four 1/2" rupture disc assemblies passed at 1.0×10^{-8} atm

Signature:

Released: December 8th, 2010 DCC Auth Key: TYO9I64ZOE

																				At	PE	<u> </u>	lD	/}	(t	_
REV: X1 REV DESC: Initial Release ENG: GPM DATE: 12/22/98	CUSTOMER/ D REV Max psi	9	Elle	000-170-42/2	10/1 1/0 000															10-113150-00 X1			3500		3500	-
	MFR PART #			30-E1875, Rev B 30-E1876, Rev ∆			Re<		30-E1881, Rev A		30-E1883, Rev B				30-E1889, Rev A	30-E1890, Rev A	30-E1891, Rev A	30-E1895, Rev A	30-E1896, Rev A				SS-HBVCR4-P-C SS-8BG-VCR-3C		64-2663KRA10	
	QTY MFR		3 Insync v 1 Insync	1 Insync	1 Insync	1 Insync	2 Insync	4 Insync	1 Insync	4 Insync	1 Insync	2 Insync	3 Insync	1 Insync	1 Insync	1 Insync	1 Insync	1 Insync	1 Insync	4 Insync	`	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	39 Nupro		6 Tescom	
INSYNC PARENT #: 10-E0804 DESCRIPTION: Xenon Delivery System WELD COUNT: 74	ITEM # DESCRIPTION	Weldments	14 Tube Assy, Supply, Inlet 15 Tube Assy, Reclaim, Divert	16 Tube Assy, Main Outlet	18 Tube Assy, Supply, Purge Manifold	19 Tube Assy, Supply Outlet	•	•	22 Tube Assy, Reclaim Inlet, Rt	23 Tube Assy, Reclaim Diver Outlet		25 Tube Assy, Reclaim Divert Manifold	26 Tube Assy, Supply, Spool	27 Tube Assy, Chamber Manifold	28 Tube Assy, Main Divert Manifold	29 Tube Assy, Main, Getter Divert	30 Tube Assy, Main, Inlet Manifold	31 Tube Assy, Getter Inlet Line	32 Tube Assy, Getter Line	55 Tube Assy, Adapter, F/F	Purchased Components	Clean Valves	33 Valve, High-Pressure Bellows, M/M	Decilotors	regulator, Adjustable, M/M	

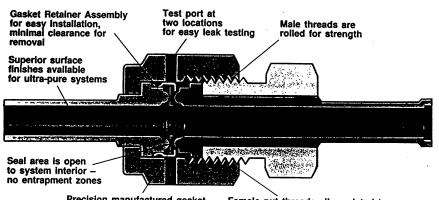
		•			
3500 n/a n/a	10000 burst n/a 5000 burst n/a	150 150 1500 n/a	n/a n/a n/a n/a n/a		157 2230
64-2663KRH19 4802-3000M 4802-0200M	C2143000C-834-655 3301C4CLC C214250C-834-655 3301C7CLC	S511-HV Monotorr Phase 1 5964C4MAP35KA 0151AAD2A11A	1C-013-10 KJL01-34S 20-E0804 MTV-3P IND-3	SS-4-VCR-P NI-4-VCR-2-GR-VS SS-4-VCR-CP SS-8-VCR-CP	6U 1/2 UNION HOLDER
3 Tescom 3 Tescom 3 Tescom	4 Setra / 4 Setra 2 Setra 2 Setra	1 Oxisorb V 1 Saes V 1 Brooks V 1 Brooks	34 Bay Pneum 46 SMC 4 Pro-Fastener 76 Pro-Fastener 0 Insync 46 Clippard	14 Cajon 183 Cajon 3 Cajon 5 Cajon	7 InSync 3 Zook 4 Zook BS&B BS&B BS&B BS&B
36 Regulator, Adjustable, 4 port F/F 37 Gauge, Pressure 38 Gauge, Pressure	Pressure Monitoring 39 Transducer, Pressure, FVCR, Bendix 40 Display, Pressure, Bendix 62 Transducer, Pressure, FVCR, Bendix 63 Display, Pressure, Bendix Getter Materials	Flow Controller 43 MFC, 20 SLM Ar, D-sub 44 MFC, Controller	45 Tubing, Poly, 1/8 × 1/16 50 Fitting, male 1/8 npt, 1/8t elbow 46 Screw, 8-32 × 3/8, SS, Button Hd 47 Screw, 10-32 × 3/8, SS, Button Hd 52 Schematic, Gas Box 53 Toggle, Pneum Valve 54 Indicator, Pressure	VCK Components 48 Plug, 1/4" VCR 49 Gasket, 1/4" VCR, Unplated Nickel 51 Cap, 1/4" VCR 60 Cap, 1/2" VCR Rupture Disks	Union Holder, 1/2 Tube Stub Rupture Disk, #306546 Rupture Disk, #306953 Rupture Disk Rupture Disk

n/a = pressure rating not needed



GENERAL INFORMATION

APPENDIX G



Precision manufactured gasket for maximum performance

Female nut threads silver-plated to assure easy assembly and consistent make-up

VCR® Components offer the high purity of a metal-to-metal seal, providing leak-free service from critical vacuum to positive pressure.

The seal on a VCR® assembly is made when the gasket is compressed by two highly polished beads during the engagement of a male nut or body hex and a female nut.



PRESSURE RATINGS

- Calculations based on allowable stress value of 20,000 psi for stainless steel at ambient temperature, per ANSI Code for Pressure Piping B31.3.
- To determine pressure ratings in accordance with ANSI B31.1, multiply psig rating by 0.94.

TEMPERATURE RATINGS

Components	Material	Tempe	erature
Components	Material	°F	°C
ZOE	316 Stainless Steel	1000	538
Center (Oath	316L Stainless Steel	1000	538
rol TY	316LV Stainless Steel	1000	538
t Cont	316 Stainless Steel	1000	538
Document DCC Gaskets See See See See See See See See See See	Nickel	600	316
DCC	Copper	400	204
BNI 010	Aluminum®	400	204

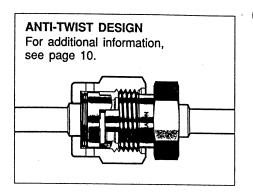
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assembly and consistent make-up MATERIALS (designators)

Bodies, Glands and Nuts: 316 stainless steel (SS) 316L stainless steel (316L) 316L VAR – Vacuum Arc Remelt stainless steel (6LV)

HIGH PURITY

A variety of VCR Face Seal Fittings are available with controlled surface finishes, electropolished and specially cleaned to meet Ultra-Pure system requirements. (For more information refer to SWAGELOK Specification SC-01.)



TESTING

The VCR® assembly with a standard gasket design has been helium leak tested to a rate of 4x10⁻⁹ std cm³/s and the VS gasket design to a rate of 5x10⁻¹¹ std cm³/s without leakage.

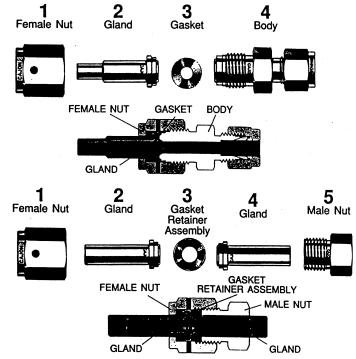
DIMENSIONS

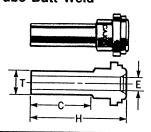
- Dimensions are in inches, for reference only, subject to change
- E dimension references the smallest nominal inside diameter of the part

CAUTION: Do not mix or interchange parts with those of other manufacturers

TYPICAL VCR® ASSEMBLY

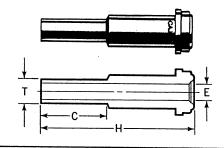
VCR® Assemblies are made up of four or five basic components.





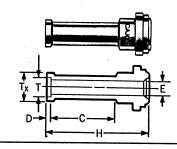
T Tube O.D.	ORDERING NUMBER	С	E	н	Nominal Wall Thickness	Work Press psig	
1/8	316L-2-VCR-3S-2TB7	.75	.06®	1.08	.028	8500	585
1/4	6LV-4-VCR-3S-4TB2®	.25	.18	.60	.035	5100	351
1/4	316L-4-VCR-3S-4TB3	.38	.18	.72	.035	5100	351
1/4	6LV-4-VCR-3S-4TB7®	.75	.18	1.10	.035	5100	351
1/4	6LV-8-VCR-3S-4TB7	.75	.18	1.12	.035	5100	351
3/8	6LV-8-VCR-3S-6TB2	.25	.31	.62	.035	3309	227
3/8	6LV-8-VCR-3S-6TB7®	.75	.31	1.12	.035	3300	227
1/2	6LV-8-VCR-3S-8TB2	.25	.40	.62	.049	3500	241
1/2	316L-8-VCR-3S-8TB3	.38	.40	.74	.049	3500	241
1/2	6LV-8-VCR-3S-8TB7®	.75	.40	1.12	.049	3500	241

Long Tube Butt Weld



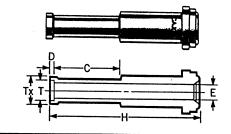
Tube	ORDERING	ORDERING NUMBER C E H			Nominal Wall	Work Press	cing sure
O.D.	NUMBER	C	<u> </u>	Н	Thickness	psig	bar
1/8	316L-2-VCR-3-2TB7	.75	.06º	1.42	.028	8500	585
1/4	6LV-4-VCR-3-4TB2	.25	.18	1.20	.035	8100	351
1/4	316L-4-VCR-3-02205	.36	.18	1.31	.035	5100	351
1/4	6LV-4-VCR-3-4TB3	.38	.18	1.32	.035	5100	351
1/4	6LV-4-VCR-3-4TB7®	.75	.18	1.70	.035	5100	351
1/4	6LV-8-VCR-3-4TB7	.75	.18	1.80	.035	5100	351
3/8	6LV-8-VCR-3-6TB2	.25	.31	1.29	.035	3300	227
3/8	6LV-8-VCR-3-6TB7	.75	.31	1.79	.035	3300	227
1/2	316L-8-VCR-3-8TB2	.25	.40	1.29	.049	3500	241
1/2	316L-8-VCR-3-8TB3	.38	.40	1.41	.049	3500	241
1/2	6LV-8-VCR-3-8TB7	.75	.40	1.79	.049	3500	241
3/4	316L-12-VCR-3-12TB7	.75	.65	2.03	.049	2400	165
1	316L-16-VCR-3-16TB7	.75	.87	2.32	.065	2400	165

Short Automatic Tube Weld



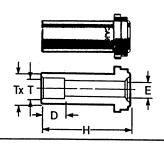
T Tube Size	ORDERING NUMBER	C	D	E	н	Tx	Nominal Wall Thickness	Worl Press	
1/4	316L-4-VCR-3AS	.75	.02	.18	1.12	.29	.035	5100)	351
1/2	316L-8-VCR-3AS	.75	.04	.40	1.16	.55	.049	3500	241
3/8	316L-8-VCR-3AS6	.75	.03	.31	1.15	.41	.035	3300	227

Long Automatic Tube Weld



T Tube	ORDERING	•	_	_			Nominal Wall	Worl Pres	sure
Size	NUMBER	С	D	E	н	Tx	Thickness	peig	bar
1/4	316L-4-VCR-3A	.75	.02	.18	1.72	.29	.035	5100	351
1/4	316L-8-VCR-3A4	.75	.02	.18	1.82	.29	.035	5100	351
3/8	316L-8-VCR-3A6	.75	.03	.31	1.82	.41	.035	3300	227
1/2	316L-8-VCR-3A	.75	.04	.40	1.83	.55	.049	3500	241
3/4	316L-12-VCR-3A	.75	.04	.65	2.07	.80	.049	2400	165
, 1	316L-16-VCR-3A	.96	.04	. 87	2.57	1.06	.065	2400	165

Short Socket Weld



T Tube Socket	ORDERING NUMBER	D	E	н	Tx	Working Pressure
1/4	SS-4-VCR-350LG	.28	.18	.50	.35	5200 358
1/4	SS-4-VCR-375LG	.28	.18	.75	.35	5500 378

[®]Also available in Alloy C-22 (HC22) material.

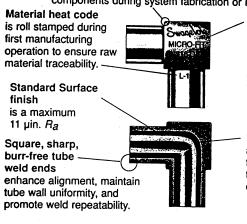
OVCR Face Seal end of the gland may be back-drilled to a larger I.D.

Features

Compact design

- accommodates tubing systems requiring miniaturization.
- allows close component spacing.
- provides flow and service ratings equal to larger weld fittings designed for the same size tubing.

Rounded body block prevents injury or damage to other components during system fabrication or maintenance.



Laser etch marking identifies manufacturer, material, and when applicable, the appropriate process designator according to Swagelok Specification SC-01.

Radius junction allows for a smooth flow transition and is designed to eliminate pockets and entrapment zones.

Material

Reducing

Union

- 316L VAR (vacuum arc remelt) or 316L stainless steel
- some configurations are available in Alloy C-22

Ultra-High-Purity

A variety of Micro-Fit weld fittings are available with controlled surface finishes, electropolished and specially cleaned to meet Ultra-High-Purity system requirements. For more information refer to Swagelok Specification SC-01.

Ordering Information

To order fittings manufactured according to Swagelok Specification SC-01 use the following Designator codes as a suffix to the Ordering Number.

Example: 6LV-4MW-9P

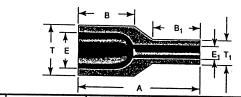
·	Surface Finish (Ra)						
Designator	Average	Maximum					
Р	5 μin (0.13 μm)	10 μin (0.25 μm)					
PX	4 μin (0.10 μm)	7 μin (0.18 μm)					

Technical Data

	Pressure l	Rating [©]	
Size	psig	bar	Nominal Wall Thickness
1/8 in.	8500	580	0.028 in,
1/4 in.	5100	350	0.035 in.
3/8 in.	3300	220	0.035 in.
1/2 in.	3500	240	0.049 in.
6 mm	6600	460	1 mm

[®] Pressure ratings are calculated in accordance with ANSI B31.3, based on equivalent wall ASTM A269 tubing and an allowable stress value of 20 000 psi.

Dimensions/Ordering Information



T Tube	T ₁	Ordering		lı	iches (mi	n)	
OD	OD	Number	A	В	B ₁	E	E ₁
1/4	1/8	6LV-4MW-6-2	0.75 (19.1)	0.41 (10.4)	0.25 (6.4)	0.18 (4.6)	0.06 (1.5)
3/8	1/4	6LV-6MW-6-4	0.75 (19.1)	0.41 (10.4)	0.25 (6.4)	0.31 (7.9)	0.18 (4.6)
1/2	1/4	6LV-8MW-6-4®	0.75 (19.1)	0.41 (10.4)	0.25 (6.4)	0.40 (10.2)	0.18 (4.6)
1/2	3/8	6LV-8MW-6-6®	0.75 (19.1)	0.41 (10.4)	0.25 (6.4)	0.40 (10.2)	0.31 (7.9)

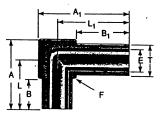
(15.1) (10.4) (0.4)	ı
F T E	

Co Key			Inches (mm)						
ument Osath	Ordering Number	A	В	E	F Body Cube	L			
) ភ្នំ ជ)00.7	6LV-2MW-9	0.56 (14.2)	0.25 (6.4)	0.06 (1.5)	5/16	0.41 (10.4)			
the LBN	6LV-4MW-9®	0.56 (14.2)	0.25 (6.4)	0.18 (4.6)	5/16	0.41 (10.4)			
0.8	6LV-6MW-9®	0.69 (17.5)	0.25 (6.4)	0.31 (7.9)	7/16	0.47 (11.9)			
Released Becenthe	6LV-8MW-9	0.81 (20.6)	0.25 (6.4)	0.40 (10.2)	9/16	0.53 (13.5)			
5.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00	6LV-6MMW-9	0.56 (14.2)	0.25 (6.4)	0.16 (4.0)	5/16	0.41 (10.4)			

Reducing Elbow

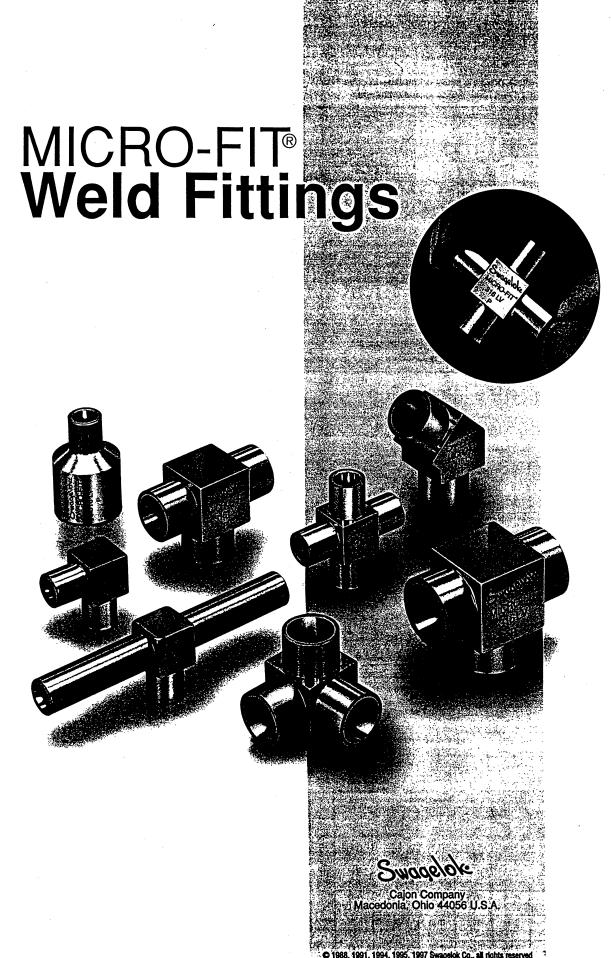
	1,	87.45. 1 f. 1 f.	Francisco Inches (mm)										
T Tube OD	T ₁ Tube OD	Ordering Number	A	A ₁	В	B ₁	Ε	E ₁	F Body Cube	L	L ₁		
3/8	1/4	6LV-6MW-9-4	0.69 (17.5)	0.69 (17.5)	0.25 (6.4)	0.25 (6.4)	0.31 (7.9)	0.18 (4.6)	7/16	0.47 (11.9)	0.47 (11.9)		
1/2	1/4	6LV-8MW-9-4	0.81 (20.6)	0.81 (20.6)	0.25 (6.4)	0.25 (6.4)	0.40 (10.2)	0.18 (4.6)	9/16	0.53 (13.5)	0.53 (13.5)		
1/2	3/8	6LV-8MW-9-6	0.81 (20.6)	081 (20.6)	0.25 (6.4)	0.25 (6.4)	0.40 (10.2)	0.31 (7.9)	9/16	0.53 (13.5)	0.53 (13.5)		

Extended Leg 90° Union Elbow

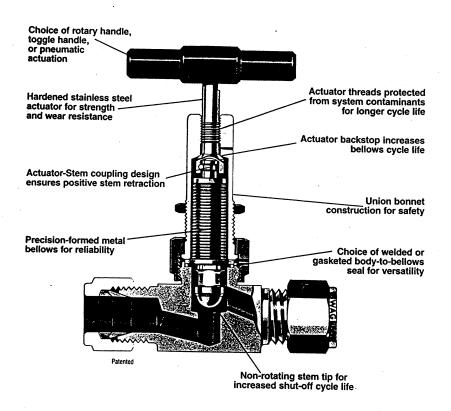


		Inches (mm)									
T Tube OD	Ordering Number	A	A ₁	В	B ₁	E	F Body Cube	L	L ₁		
1/4	6LV-4MW-9-03442	0.56 (14.2)	0.76 (19.3)	0.25 (6.4)	0.45 (11.4)	0.18 (4.6)	5/16	0.41 (10.4)	0.61		
1/4	6LV-4MW-9-03443	0.56 (14.2)	0.81 (20.6)	0.25 (6.4)	0.50 (12.7)	0.18 (4.6)	5/16	0.41 (10.4)	0.66		
1/4	6LV-4MW-9-03444	0.76 (19.3)	0.76 (19.3)	0.45 (11.4)	0.45 (11.4)	0.18 (4.6)	5/16	0.61 (15.5)	0.61		
1/4	6LV-4MW-9-03445	0.81 (20.6)	0.81 (20.6)	0.50 (12.7)	0.50 (12.7)	0.18 (4.6)	5/16	0.66 (16.8)	0.66		

Also available in alloy C-22 (HC22) material Dimensions are for reference only, subject to change.



FEATURES/BENEFITS



- Pressures to 1000 psig (68 bar)
- Temperatures to 900°F (482°C)
- Choice of materials: brass, 316 stainless steel, and alloy 400
- Flow Coefficients (C_V) from 0.36 to 1.2
- Gageable SWAGELOK® Tube Fitting ends 1/4" to 1/2" and 6mm to 12mm
- Tube socket weld ends: 1/4" to 1/2"
- Tube butt weld ends: 3/8" to 3/4"
- Tube extensions: 1/4" to 3/4" O.D. x 3" long
- CAJON® Male VCR® Metal Gasket Face Seal Fitting ends: 1/4" and 1/2"
- Choice of stem insert materials for shut-off and regulating service
- Panel mounting and bottom mounting
- Every valve is factory tested

TECHNICAL DATA

VALVE: SIZE/SERIES	STEM	FLOW: COEFFICIENTS	MAXIMUM BRASS®	PRESSURE PAT	ING	MAXIM	UM) VEMPERATURE	#IATING
		(G)	1	emmo		37 7. \$\$	अहर	A VIVOYAMO
-4BG-	Metal	0.39	1000 psig	1000 psig	700 psig	400°F (204°C)	600°F (315°C)	500°F (260°C)
-4BK-	Kel-F	0.05	(68 bar)	(68 bar)	(48 bar)	200°F	200°F.	
-4BKT-	Kel-F	0.36	100	psig (6.8 bar)	<u> </u>	(93°C)	(93°C)	200°F (93°C)
-4BW-	Metal	0.39	· N/A	, , , , , , , , , , , , , , , , , , ,		N/A	900°F (482°C)	(60 0)
-4BRG-	Regulating	0.00	450 psig (31 bar)			400°F (204°C)	0001 (402 0)	50005
-4BRW-	Regulating	0.26	N/A			N/A	600°F	500°F (260°C)
-6BG-	Metal		1000 psia			400°F (204°C)	(315°C)	(200 0)
-6BK-	Kel-F	1.0	(68 bar)	/ 1000 psig \:	700 psig	200°F (93°C)	200°F (93°C)	20095 (0290)
-6BW-	Metal	·	N/A	(68 bar)	(48 bar)	N/A	(/	200°F (93°C)
-8BG-	Metal						900°F (482°C)	500°F
S	Kel-F	1.2	1000 psig (68 bar)			400°F (204°C)	600°F (315°C)	(260°C)
± ₹BW-	Metal	1.2				200°F (93°C)	200°F (93°C)	200°F (93°C)
		he cycle life of hones yet	N/A			N/A	900°F (482°C)	500°F (260°C)

cycle life of brass valves will be limited when operated frequently at pressures above 450 psig (31 bar). Released December 8th, 2010 DCC Auth Key: TYO

Internal Volume

SERIES SE	NITERNAL VOLUME (Approx.)
4B	0.10 in.3 (1.6 cm3)
4BKT	.0.11 in.3 (1.8 cm3)
4BR	0.16 in.3 (2.6 cm3)
6B	0.24 in.3 (3.9 cm3)
8BKT	0.26 in.3 (4.3 cm3)

Temperature Gradient 316 Stainless Steel Valves

WHE NAMES ALLES	WAVE HANDLE IS:
600°F (315°C)	195°F (91°C)
900°F (482°C)	275°F (135°C)

mined using SWAGELOK ended valves.

Officially Released to the LBNL Document Control C

HB Series Air Actuated High Pressure Bellows Valve

VALVE FEATURES

- Choice of Normally Closed and Normally Open Modes
- Low actuation pressure of 75 psig (5 bar)
- Full pressure rating in either flow direction
- Positive stem retraction
- Easily purged
- Specially cleaned to SWAGELOK Specification SC-11
- Optional high-purity processing to SWAGELOK Specification SC-01 available
- 100% helium leak-tested
- Optional bonnet Sniffer Tube available

Bonnet Sniffer Tube (Optional)

Unique
Stepped
Seal Design



under the second and management

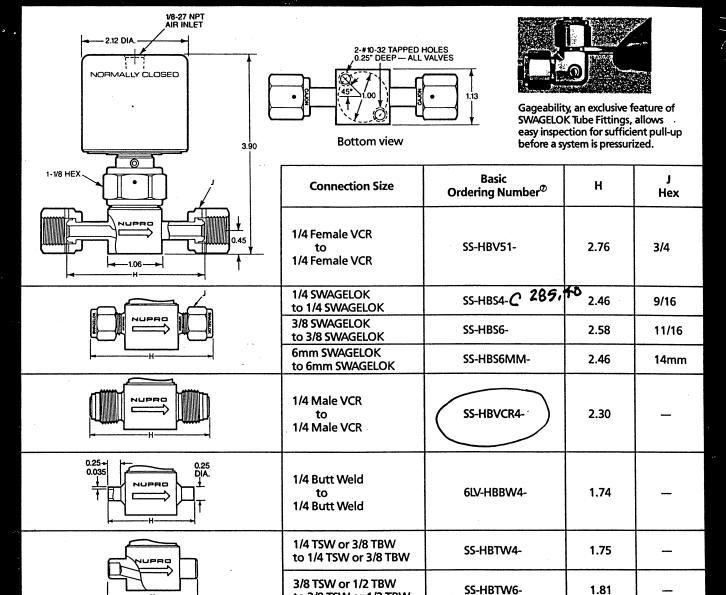
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regilited DETE

୍ତି Orifice Size		Flow ^③ Coefficient	Internal [®] Volume		Ratings (20°C)®	Back Pressure	Temperature Ratings ^①	
in.	mm	C _V	(approx.)	for Valve	for Air Actuator	Rating	for Valve	for Air Actuator
cember 8th, 2010 DC	3.8	0.30	0.27 in.³ (4.4 cm³)	3500 psig ⁱ (240 bar) Maximum	30 to 110 psig [®] (2 to 8 bar) See Air Actuator Pressure at System Pressure graph.	3500 psig (240 bar)	with Kel-F Stem Insert: -40°F to 150°F (-40°C to 65°C) with Vespel Stem Insert: -40°F to 400°F (-40°C to 200°C)	-10°F to 400°F (-20°C to 200°C)

क्षेत्रकारताता गुगार हो जाता है। जाता है कि लाग है। जाता है। जाता



নিয়া ব্যৱসাধার প্রাথমিকার সামানিকার করি । আন্তর্মীয় প্রতিক্রমানিকার সামীয়ে এক বর্তিকার সির্বাচনত বিশ্ববর্তিক বিজিল বিশ্ববাহাটী বিশ্ববহন করে সামীয়ে এ কি উল্লেখ্য ব্যবসাধার বিশ্ববাহা উল্লেখ্য উল্লেখ্য বিশ্ববাহা

दि कार्यस्य जनमा ११४६ विकास कार्यस्य स्थान । १४४६ म. इ. १८६६ - देश्य प्रमाणकार अस्तावार । स्थान हर अस्तिका स्थानकार । १८५४मा । अस्तिकार । १९५६ - स्थानकार । स्थानकारीकार । १९५९ - इ.स. अस्तिकार १९५५ ।

ly angle more mili sepape apa mayo, kan T nder Mich die Terende Ander. Benann: Zeilfehren

to 3/8 TSW or 1/2 TBW

de system westfam delen dette delen O allien and de Soudering Alemani Danistere (Kolliffam)

টালেল্ডারকেল ব্রুক্তিটা ক্রিটি ইপ্সিল্টেরটি লাভ Tegerr-Teges, vilver andikaber. A Teorgeon

লাইটার ক্রিম্মতার ক্রিপ্রেটা করে। ব ব্যবসাধ্যার । ক্রিপ্রতালাকে করেও স্বাধিকর ১৮ টেলাকর

शास्त्र अवस्थातः विभागात् भेटन्यात्रातः



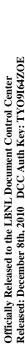
VCR-TM SWAGELOK Co. / Kel-F--TM 3M Company / Viton, Vespol --TM Dupont / 17-4PH, 17-7PH --TM Armoo Steel

Printed in U.S.A. SP April, 1997

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16809 PARK CIRCLE DRIVE P.O. BOX 419 CHAGRIN FALLS, OHIO 44022

TOLL FREE:

800.543.1043 440.543.1010 440.543.4930

FAX: E-MAIL: WEB URL:

zook@zookdisk.com http://www.zookdisk.com

FAX TRANSMISSION SHEET

DATE: JUNE 25, 1999

TO: BOB PATTERESON

COMPANY:

LAWERNCE-LIVERMORE NATIONAL LAB.

FROM: ALAN KOHTA

SUBJECT:

1/2" - 2250 PSIG & 2" 150 PSIG RUPTURE DISKS

THE RUPTURE DISKS YOU RECEIVED ARE TESTED UNDER THE SAME GUIDE LINES AS ASME RUPTURE DISKS.

DISK

SIZE:

1/2"

2" \mathbf{z}

TYPE: S/N:

Z 44786.010

44786.030 STAINLESS STEEL

MATERIAL: RATING

STAINLESS STEEL 2250 PSIG 72 DEG. F

150 PSIG 72 DEG. F

TEMPERATURE: MFG RANGE:

-3/+6%

-4/+7%

BURST TOL:

+/-5%

+/-5%

HOLDER

SIZE:

1/2"

2"

TYPE: S/N:

UNION 6U 44786.020

UNION 6U

MATERIAL:

STAINLESS STEEL

44786.040 STAINLESS STEEL ZOOK Series Z
Forward Acting
Metal Rupture Disks

Features:

- Forward acting tension type design without score lines
- Operates to 70% of the disk's rated burst pressure
- Sizes available from 1/4" thru 36" diameters
- Burst pressures range from 3 to 80,000 psig
- Temperature ratings up to 1000°F (538°C)
- Excels in liquid or gas applications

Options

Seating Configurations ZOOK's Series Z Rupture Disks come in two basic seating designs:

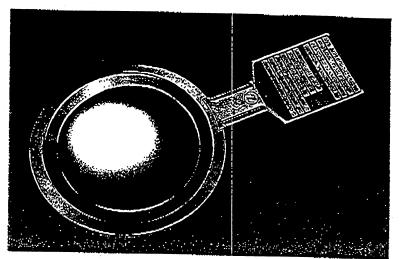
- 1. 30° angular *light-lip design* for normal operating pressures
- 2. 30° heavy-lip design for higher pressures.

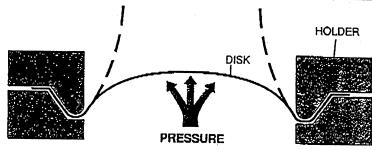
Vacuum Supports Due to thinness of some disk materials, a vacuum support may be required. Vacuum supports are attached to a disk and allow the disk to support a full system vacuum. Consult ZOOK if back pressures are expected.

Liners/Coatings Provide additional protection from the effect corrosives might have on disk performance. Liners are made of TEFLON®. Teflon coatings also are used to protect the disk from atmospheric or corrosive media. Refer to *Table 2* for maximum temperature ratings for various disk, liner and coating materials.

Protective Rings Can be used with Series Z Disks made of thin materials or when delicate liners are used. These rings protect the rupture disk from foreign material in the sealing area where holders may be pitted or corroded from extended use.

Gaskets Can be used to provide additional sealing and prevent leakage through the seating area of a scratched or pitted holder. They are located on the process side of the disk and are usually made from Teflon. Other materials are available upon request.





Series Z Disks mount with the concave surface toward the process media. As pressure increases above the recommended operating pressure, the disk will bulge until it reaches the maximum tensile strength of the material. When the Series Z Disk bursts, it folds back against the holder. This results in a full-opening for optimal flow conditions.

Forward Acting Rupture Disk Cross-Reference

	ZOOK	ÓSECO	BS & B	CDC	FIKE
Forward Acting	Z	STD	В	STD	Р
W/Vacuum Support	ZV	\$TDV	BV	STD-V	PV
W/Top Ring	RZ	RSTD	₿R	R-STD	СР
W/Top & Bottom Ring	RZR:	RSTOR	BRR	R-STD-R	CPC
W/Ring & Vacuum Support	RZV	RDTDV	BRV	R-STD-V	CPV



ZOOK® ENTERPRISES

16809 Park Circle Drive Box 419 Chagrin Falls, OH 44022 Phone: (216) 543-1010 I-800-543-1043 FAX: (216) 543-4930

Table 1 - Minimum and Maximum Burst Pressures for Series Z Rupture Disks

	Alun	ninum	Si	lver		kel		72°F		_				k Minimum Bu	1
Size	min.	imax.	min.	inous.						onel		6SS	Inlet	Outlet	Both
1100					min.	meet	min.	mack	min.	4	min.	amen's	Only	Only	Sides
1/4"	160	30	450		600		700	42	1120			SEC.	<u> </u>	1 ^	A
1/2"	65	5500	220	21500	300	26000	350	20000	560	10.000	760	10.000	150	150	300
^	29	\$1000E	120	\$100G	150	3000	180	XX100	250	\$2000	420	#500U	50	50	100
-1/2"	22	700	80	X	100	2000	116	22000E	160	EX	275	38 34 DOC	35	35	70
٠٢	13	25008	48	新200 歳	60	\$1300B	70	\$1300	110	1000	150	## (BOO	25	25	50
3"	10	SEA OUT	35	*************************************	45	表 500数	50	*	80	1500	117	4 (000)	15	15	30
.	7	5325	26	第325%	35	22.650E	40	6.650	70	atrock.		20100	11	11	22
*	5	\$248	20	A 250%	25	48 20 CE	30		47	388800	62	##X00CF	8	8	16
7	4	3888	15	200	20	1000	23	被	34		51	200	6	6	12
Š	4	* C55		A	16	300	17		30	22500	43	\$ 500	5	5	10
2"	3	Setion.		A	13	数23次	15	22.5	25	W. 100	36	Section,	4	4	8
4"	3			4	11	**************************************	13	W	21		31		4	4	8
6″	3	教士会		A	10	MAKE	12		19		28		3	3	6
8"	3	1		<u> </u>	9		11	SEC. 18.	17		24		3	3	6
20"	3			A	8		9	30 M	16		22		3	. 3	6
4"	3	数		A		A		A		4		A	2	2	4
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-	l	I	-	_	. –	
X.		Entective Bit	ngs strould be use the pressures st	dwhen/Burst/Pro	ssure /	
1/4"		A	A	A	A	A
1/2*	520	1300	2290	3000	3600	3700
1"	260	650	1145	1500	1800	1830
1-1/2"	180	450	790	1030	1240	1255
2*	110	280	485	635	760	775
3"	75	200	340	445	535	545
4"	60	150	270	350	420	430
6"	45	115	200	260	315	320
8"	35	85	155	200	240	245
10"	28	A	125	160	195	200
12"	24	A	105	135	160	165
14"	20	A	90	115	140	140
16"	18		80	100	120	125
18"	16	A	70	90	110	110
20"	14	A	62	80	100	100
24"	12	A	52	68	80	85
30°	A	A		A .	A	A
36"	A	1		1		

Table 1 – notes

- Maximum burst pressures depend on disk size and application temperature. Pressures to 80,000 psig are available.
- Other material and sizes are available upon request.
- Other liner materials are available upon request. Minimum burst pressures will change with change in liner material.
- For larger sizes or sizes not shown, contact ZOOK.

(A) = Consult ZOOK

Table 2

Maximum Temperature Ratings for Disk Materials
Aluminum 260°F Silver 260°F Nickel 800°F Monel 800°F Inconel 1000°F 316 Stainless Steel 900°F
Maximum Temperature Ratings for Liners and Coatings
Teflon

Table 3

Maximum Temperature Hatings:		decturing:		
Aluminum 260°F Silver 260°F Nickel 800°F Monel 800°F Inconel 1000°F	Specified Burst Pressure Rating psig	Manufi Ra Under	***	Burst Tolerance
316 Stainless Steel 900°F	2-5	-4 0	+40	
Maximum Temperature Flatings	6-8	-40	+40	
for Liners and Coatings	9-12	-30	+30	42 ocio
Teflon	13-14	-10	+20	±2 psig
TFE or PFA 500°F	15-19	−10	+20	
	20-39	-4	+14	
	40-50	-4	+14	
	51-100	-4	+10	1 450/
	101-500	-4	+7	± 5%
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Table 3 - notes

- Special reduced manufacturing design ranges for the Series Z forward acting metal disk. 25%, 50% and 75% ranges are available upon request. Please consult ZOOK for additional information.
- Burst tolerances are the maximum expected variation from the disk's rated (stamped) burst pressure.
- ZOOK Series Z rupture disks can be manufactured to comply with ASME code requirements.

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TYO9164ZOE

Union Holder for Standard or Composite Type Rupture Discs

2-3308-2



Assembly #1U Free Oudet Threaded Inlet



Assembly #4U Free Outlet Welded Inlet



Assembly #2U Threaded Outlet Threaded Inlet



Assembly #5U Threaded Outlet Welded Inlet



Assembly #3U
Welded Outlet
Threaded Inlet



Assembly #6U Welded Outlet Welded Inlet

Union type SAFETY CROWNS are provided in 1/4", 1", 11/4" and 2" pipe sizes. Standard bore for welded connections in Assemblies 3U, 4U, 5U and 6U are as follows:

%'', 1" and 1%" (either 3000 or 6000 psig. rating) - Schedule 80 2" (1200 psig. Maximum rating) - Schedule 40

These units are normally furnished constructed of carbon steel. However, all parts can be supplied from 300 series stainless steel or other machinable metal. Free outlets are sometimes supplied with threaded or welded connections at no additional charge.

All units are designed with 30 degree angular seating. When ordering standard or composite discs, please state that the disc is for a (UT) union type holder. By doing so, 200K will NOT attach the tags to the disc, and we will trim the disc OD to assure a perfect fit in the holder. The tags will ship with discs as a separate item. Holes have been punched in the corner of the tag, so they can be wired to the union during installation for positive disc identification.



Union assemblies #2U and #5U can be supplied with a muffled outlet. This prevents any fragments or product from dispersing direct from nozzle. Also, there is a reduction in the noise (db) level at burst of the disc.

Dimensions and maximum pressure ratings are listed on Page 2.

DIMENSIONS

PIPE SIZE	MAX		OVERALL HEIGHT (Inches)					
	RATING PSIG	HEX SIZE	1U	2U	3U	4U	бU	6U
1/2" 1/2"	3000 6000	1-3/4" 2"	1-5/8" 1-7/8"	2-3/8" 2-5/8"	2-1/4" 2-3/4"	1-3/4" 2-3/16"	2-3/8" 2-11/16"	2-1/4"
1"5 1"	3000 6000	2-1/2" 3"	2-1/8" 2-7/16"	3-1/4" 3-3/8"	3-1/4" 3-1/4"	2-1/4" 2-5/8"	3-1/4" 3-1/2"	3-1/4" 3-3/8"
1-1/2"	3000	3-1/2"	2-7/16"	2-7/16"	3-6/16"	2-7/16"	3-7/16"	3-1/2"
2"	1200	4-1/2"	2-5/8"	4"	4"	2-5/8"	4"	4"

PRESSURE/TEMPERATURE RATINGS FOR UNION TYPE SAFETY CROWN FITTINGS

	MAXIMUM RATING								
SERVICE TEMP.	1	assembly Erial		SSEMBLY ERIAL	6000 psi ASSEMBLY MATERIAL				
°F .	C. Sti	300 Ser. Stainless	C. St	300 Ser. Stainless	C. St	300 Ser. Stainless			
100	1200	1200	3000	3000	6000	6000			
200	1165	1165	2915	2915	5830	5830			
300	1135	1135	2845	2845	5690	5690			
400	1110	1110	2775	2775	5550	5550			
500	1040	1040	2605	2605	5210	5210			
600	925	925	2310	2310	4620	4620			
700	785	825	1960	2055	3920	4110			
800	610	750	1525	1865	3050	3730			
900	370	670	925	1675	1855	3350			
1000	140	695	355	1485	715	2976			

To change inches to millimeters multiply inches by 25.40.

To change inches to centimeters multiply inches by 2.540.

To change PSIG to Kg-cms squared multiply PSIG by 0.3417.



ASME Seche Den I VG/27 or so ZIG-600

16809 PARK CIRCLE DRIVE • CHAGRIN FALLS, OHIO 44022 •

RUPTURE DISKS (440) 543-1010 • FAX (440) 543-4930

SERIES 'Z' INSTALLATION GUIDE
IN ZA TYPE 30° SEAT, FULL BOLTED & UNION TYPE HOLDER

USER SHOULD READ AND THOROUGHLY UNDERSTAND THESE INSTRUCTIONS BEFORE INSTALLING RUPTURE DISK. THESE INSTRUCTIONS DO NOT PURPORT TO ADDRESS ALL OF THE SAFETY FACTORS ASSOCIATED WITH THE RUPTURE DISK'S USE IN SERVICE. IT IS THE RESPONSIBILITY OF THE USER TO ESTABLISH APPROPRIATE SAFETY, HEALTH, AND TRAINING MEASURES FOR THEIR PERSONNEL INSTALLING, SERVICING, OR WORKING IN AN AREA WHERE RUPTURE DISK ASSEMBLIES ARE IN USE.

IT IS THE USER'S RESPONSIBILITY FOR DESIGN OF ADEQUATE VENTING AND INSTALLATION OF ADEQUATE VENT PIPING OR DIRECTIONAL FLOW AFTER RUPTURE OCCURS WITH THE RUPTURE DISK AS INTENDED. WHEN SIZE IS SPECIFIED, ZOOK ENTERPRISES ASSUMES THAT ADEQUATE PROVISIONS HAVE BEEN MADE BY PURCHASER FOR PROPER VENTING OF A SYSTEM TO RELIEVE THE SPECIFIC PRESSURE. LOCATE RUPTURE DISK WHERE PEOPLE OR PROPERTY WILL NOT BE EXPOSED TO THE SYSTEM DISCHARGE IN CASE OF RUPTURE. VENT TOXIC OR FLAMMABLE FUMES OR LIQUIDS TO A SAFE LOCATION TO PREVENT PERSONAL INJURY OR PROPERTY DAMAGE.

IT IS THE USER'S RESPONSIBILITY TO SPECIFY THE BURST PRESSURE RATING OF A RUPTURE DISK AT A COINCIDENT TEMPERATURE AT WHICH THE RUPTURE DISK IS TO BE USED. A RUPTURE DISK IS A TEMPERATURE SENSITIVE DEVICE. THE BURST PRESSURE OF THE RUPTURE DISK IS DIRECTLY AFFECTED BY ITS EXPOSURE TO THE COINCIDENT TEMPERATURE. GENERALLY, AS THE TEMPERATURE AT THE RUPTURE DISK INCREASES, THE BURST PRESSURE DECREASES; INVERSELY, AS THE TEMPERATURE AT THE RUPTURE DISK DECREASES, THE BURST PRESSURE MAY INCREASE. FAILURE TO PROPERLY UTILIZE A RUPTURE DISK AT THE SPECIFIED COINCIDENT TEMPERATURE COULD CAUSE PREMATURE FAILURE OR OVERPRESSURIZATION OF A SYSTEM.

THE INSTANTANEOUS RELEASE OF PRESSURE FROM THE RUPTURE DISK CAN CREATE VIOLENT NOISES DUE TO THE DISCHARGE AT SONIC VELOCITY. IT IS THE USER'S RESPONSIBILITY TO PROTECT AGAINST HEARING DAMAGE TO ANY BYSTANDERS.

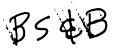
PARTICLES MAY BE DISCHARGED WHEN THE RUPTURE DISK RUPTURES. THESE PARTICLES MAY BE PART OF THE RUPTURE DISK ITSELF, OR OTHER ENVIRONMENTAL MATTER IN THE SYSTEM. IT IS THE USER'S RESPONSIBILITY TO ASSURE THAT THESE PARTICLES ARE DIRECTED TO A SAFE AREA TO PREVENT PERSONAL INJURY OR PROPERTY DAMAGE.

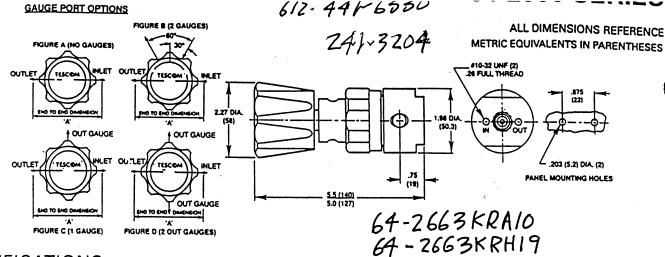
THERE IS NO GUARANTEE OF RUPTURE DISK LIFE. SUCH LIFE SPAN IS AFFECTED BY CORROSION, CREEP AND FATIGUE, AND PHYSICAL DAMAGE. THESE CONDITIONS WILL DERATE THE RUPTURE DISK TO A LOWER SET PRESSURE. THE CUSTOMER AND/OR USER SHOULD BE PREPARED TO HANDLE A PREMATURE FAILURE OF THE RUPTURE DISK. THE MEDIA OR OTHER ENVIRONMENTAL CONDITIONS SHOULD NOT ALLOW ANY BUILD-UP OR SOLIDIFICATION OF MEDIA TO OCCUR ON A RUPTURE DISK. THIS MAY INCREASE THE PRESSURE SETTING OF THE RUPTURE DISK.

CUSTOMER AND/OR ITS INSTALLER SHALL BE RESPONSIBLE FOR THE PROPER INSTALLATION OF SELLER'S HOLDERS AND RUPTURE DISKS INTO A SYSTEM. CUSTOMER AND/OR ITS INSTALLER SHALL BE RESPONSIBLE FOR IMPROPER INSTALLATION AND PHYSICAL DAMAGE RESULTING THEREFROM, INCLUDING, BUT NOT LIMITED TO, DAMAGE RESULTING FROM LEAKAGE, IMPROPER TORQUING, AND FAILURE TO FOLLOW INSTALLATION INSTRUCTIONS.

Safety Precautions Before Installation

- 1. The SERIES "Z" Type Rupture Disk is a precision instrument and must be handled with extreme care. Rupture disks should be installed only by qualified personnel familiar with rupture disks and proper piping practices.
- 2. Do not install rupture disk if there is any damage in the dome area. A damaged rupture disk is any rupture disk with visible nicks or dents in the dome.
- 3. Zook Enterprises does not recommend reinstalling a rupture disk that has been removed from the holder as reinstallation may adversely affect the joint sealing capabilities and/or performance of the rupture disk.





SPECIFICATIONS

 All gases corrosive or non-corrosive or those requiring high 3500 PSIG (238 bar) 600 PSIG (41 bar) 1-30, 1-60, 1-100 and 1-250 PSIG (.1-2, .1-4, .1-7 and .1-17 bar) 150% of maximum rated pressure Design proof pressure. 400% of maximum operating pressure Design burst pressure Materials Body Diaphragm Valve stem 316 Stainless Steel Spring 316 Stainless Steel 316L Stainless Steel Valve guide 316L Stainless Steel

Cv= .06 (3500 PSIG model)

Cv= .15 (600 PSIG model)

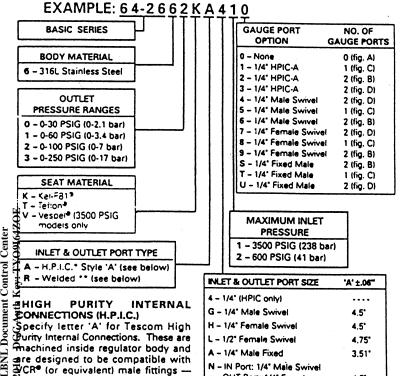
Four High Purity Internal Connections (Style'A')

Kel-F 81* -40*F to +140*F (-40*C to +60*C)

Teflon*: -40*F to +165*F (-40*C to +71*C)

Vespel*: -40*F to +165*F (-40*C to +74*C) Flow capacity Porting Operating temperature Weight Iw/o gauges). .. 2.0 lbs. (.9 kg.)

ORDERING INFORMATION



CLEANING: Tescom ES 500 DI water cleaning is performed on all 64-2600 models.

ADJUSTABLE STOP: This regulator incorporates an adjustable stop which allows the maximum outlet pressure to be limited to any value between the maximum rated value and 50% of the maximum rated value.

LEAK RATE CERTIFICATIONTo 1 x 10 $^{\rm 9}$ atm cc/sec He available at extra cost. Consult factory.

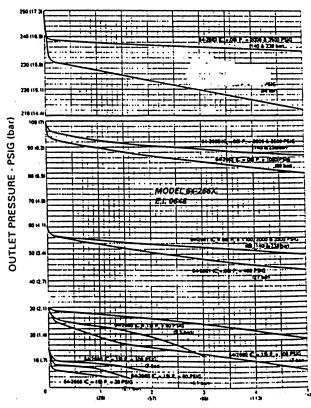
ACCESSORIES (additional cost)

REPAIR	KITS:
--------	-------

Model	Standard Repair Kit	Soft Goods Kit
64-266XKXX1X	P/N 389-3575	P/N 389-3572
64-266XKXX2X	P/N 389-3576	P/N 389-3573
64-266XTXX1X	P/N 389-3577	P/N 389-3574
64-266XTXX2X	P/N 389-3607	P/N 389-3606
64-266XVXX1X	P/N 389-3739	P/N 389-3738
64-266XVXX2X	P/N 389-3741	P/N 389-3740

Gauges: Consult GAUGES, section of catalog.

FLOW CHART (Metric units are in parenthesis) REGULATOR DISCHARGE CHARACTERISTIC CURVES



FLOW RATE - SCFM (LPM) Air

FORM NO 1732 10-94 NW 20M

₹• WELDED FITTINGS — Optional

含taight tubing or VCR® (or equivalent

compatible) fittings welded to the reguator body. Consult factory for specific

wivel only.

gart number.

Officially

at Additional Cost

Printed in U.S.A.

OUT Port: 1/4° Female

OUT Port: 1/4° Male Swivel

R - IN Port: 1/4" Female

K - 1/2° Male Swivel

4.5

4.5

4.75

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File No. MESN99-038-0B January 31, 2000

MECHANICAL ENGINEERING SAFETY NOTE

Gas Delivery System and Reclamation Cylinders for Gamma Ray Imager, B Revision

Prepared by:

Blake Mers

Mechanical Engineer

New Technologies Engineering Division

Reviewed by:

Tim Ross

Pressure Inspector

Laser Science Engineering Division

Chuck Borzileri

Pressure Consultant

Applied Research Engineering Division

Dan Archer

Experimental Physicist

C&MS Directorate / NAI Program

Approved by:

Satish Kulkarni

Division Leader

New Technologies Engineering Division

Distribution:

Dan Archer, L-186 Chuck Borzileri, L-384 Neil Frank, L-113 Satish Kulkarni, L-113 Blake Myers, L-174 Tim Ross, L-474 Kathlyn Snyder, L-172 Klaus Ziock, L-43 Engineering Records Center, L-118

Purpose:

This revision has the purpose of permitting the addition of components to the time projection chambers (TPCs) in the Gamma Ray Imager.

Situation:

There are two time projection chambers which have been installed on the Gamma Ray Imager. They are covered by MESN99-020-0A which includes the following referenced drawings and which sanctions the use at an MAWP of 978 psig when used with the metal C-ring type blind flange (called a flat head in the safety note), as shown on AAA99-104243, on the main chamber flange, plus the conflat blind flange 4-5/8 D x 0.75 thick on the top chamber flange, plus the 1/2 D VCR plugs modified to give a 0.057 thick window in 5 of the 9 VCR chamber outlets and stock 1/2 D VCR plugs in the remaining outlets. The east chamber in this configuration has been pressure tested at 1470 psig and is tagged for 978 psig for reference and has a 978 psig rupture disc installed to protect this sanction.

The sanctioned MAWP for routine operations is 402 psig when used with the six-hole conflat type flange as shown on AAA99-104240 on the main chamber flange, plus the same conflat blind flange on the top chamber flange, plus the 5 and 4 VCR plugs in the 9 side outlets as above, plus a 2 3/4 D conflat blind flange, modified to give a 0.118 thick x 1.25 D gamma ray window, in the central hole of the six-holer and the five Ceramaseal part no. 19543-04-CF electrical feed thrus or the 1.33 D conflat blind flanges in the remaining five holes. The west chamber in this configuration has been pressure tested to 604 psig

and is tagged for 402 psig for reference and has a 402 psig rupture disc installed to protect this sanction.

The two chambers are connected to the gas handling system via V91, V93, V96 and V97 with Swagelok H016 flex hose rated at 1200 psig. The valves are NUPRO, p/n SS-8BGVCR3-C, rated at 1000 psig. The hoses connect from the valves to two VCRs on the 3 VCR side of the chambers.

The chambers are pressurized by filling with the appropriate measured mass of input gas at the chamber cryo leg temperature and then warming as required.

There is interest on the part of the experimenters in having flexibility in configuring the connections on the TPCs in various ways apart from the basic flex hose connection to the gas handling system. Examples include adding pressure gages and transducers, adding a quartz window, changing the Ceramaseal feedthrus and changing the rupture discs to match the pressure rating of these new components.

Plan:

The plan is very simple. Any departure from the sanctioned configurations shall be signed off by a pressure inspector and involve an independent pressure test of the proposed component(s) at 1.5X the desired MAWP and installation of a rupture disc within the subject circuit set at that MAWP. The proposed components must be used at an MAWP at or below their nameplate pressure rating as well as at or below the basic chamber MAWP. This pressure at the present time for routine operaions is 402 psig.

All departures shall be entered in the TPC log in detail on each occasion and referenced on the following summary sheet in the TPC log.

Summary of Departures from Sanctioned Configuration:

Brief Description

Page No.

New MAWP

Signed By

Date

Mail Station L-

373

Ext:

4-4688

AAN93-100021-0A

High Pressure Systems Group Nuclear Test Engineering Division

September 8, 1993

TO:

Distribution

FROM:

Matt Traini, Pressure Inspector

SUBJECT:

END92-072, REVISION A, PRESSURE TESTING OF VACUUM

"CONFLAT" FLANGES

Please replace your existing copy of END92-072 with the current one enclosed. The only difference is the addition of information regarding the pressure testing of 8 inch diameter flanges with viewports. Tests were conducted by Roger Carnahan, Pressure Inspector, High Pressure Laboratory. This information is summarized on page 14.

Distribution:

C. Borzileri, L-384

J. Brentjes, L-373

R. Carnahan, L-373

O. Parker, L-373

T. Ross, L-373

P. Smuda, L-373

H/C File 3-ME Safety Notes

Standards/Specification, L-129

ME Library, L-127

HPL Library, L-373

NTED Division File

University of California



Mechanical Engineering Note

PRESSURE TESTING OF VACUUM "CONFLAT" FLANGES



Ву

Matthew W. Traini

November 1992 Revision A, September 1993

Distribution:

C. Borzileri, L-384

J. Brentjes, L-373

R. Carnahan, L-373

O. Parker, L-373

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H/C File 3-ME Safety Notes

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NTED Division File

The purpose of this Engineering Note is to summarize pressure tests that were performed on a variety of vacuum "conflat" flanges. Since manufacturers offer no pressure ratings on vacuum components, it was necessary to perform tests at the Lawrence Livermore National Lab (LLNL), High Pressure Laboratory (HPL), Bldg. 343. This would assist designers in determining working pressures and establishing safety guidelines when using.

All the test results are presented in memo format as was originally issued.

The first series of tests involved testing a $1\frac{1}{3}$ " diameter flange that was welded to a valve and connected to a gas sample cylinder (Refer to memo dated January 27, 1988 to C. Borzileri). Building 343 Test Request (T.R.) #6226 required the testing of both $1\frac{1}{3}$ " and $2\frac{3}{4}$ " blank flanges.

The second series of tests are referenced to T.R. 6408 (Refer to memo dated March 31, 1988 to J. Stapleton). These tests involved 4.5/8" flanges that were connected to a 2 liter volume.

The final series of test involved pressure testing of 2 $^{3}/_{4}$ " vacuum flanges with viewports (Refer to the 3 memos to Brad Maker dated January 23, February 6 and February 23, 1989) on several Bldg. 343 Test Requests.

The mode of failure for the blank flanges, regardless of size, is the assembly bolts would stretch causing gas to vent through the gasket. On several tests, a linear displacement tranducer was used to detect any growth of the flange at test pressure, which proved minimal.

The flanges with Pyrex viewport of course failed at much lower pressures than the blank leaked. It should be emphasized that the failure pressure was very much dependent on the condition of the glass (i.e. scratches or blemishes). Further recommendation for their use are detailed in Engineering Safety Note ENW 89-901.



Mail Station L- 373

Ext: 2-9596

January 27, 1988

TO:

Chuck Borzileri

FROM:

Matt Traini

SUBJECT:

PRESSURE TESTING OF "CONFLAT" VACUUM FLANGES

The purpose of this memo is to document information on test results pertaining to knife-edge type vacuum ("conflat") flanges when used in positive pressure situations.

These components are known to be used in pressure systems throughout the laboratory and because commercial manufacturers offer no pressure (only vacuum) data, it became necessary to perform a series of tests in order to establish guidelines to be followed when using vacuum flanges for pressure requirements.

The nature of these tests evolved as a result of Building 343 Test Request No. 6196. The customer requested us to pressure test a gas sample bottle that consisted of a 1-1/3" Ø vacuum flange welded to a valve. This assembly was then threaded to the sample bottle. The area of concern was the weld integrity between the flange and valve and the pressure at which the flange would leak or fail. Therefore, test requests were generated internally in order to obtain this information. These results will be explained later in this report.

The results summarized in this document were comprised of three separate Building 343 Test Requests: T.R. #6202 tested the weld integrity between the conflat flange and valve. T.R. #6226 determined at what pressure a conflat flange will begin to leak. The purpose of T.R. #6196 was to proof-test the gas sample bottle assembly. Figures 1, 2 and 3 illustrates each of these arrangements.

All tests were performed using kmife-edge "conflat" flanges and copper gaskets. Tests performed on 1-1/3" Ø flanges used #8-32 bolts and were torqued to 70 in-lbs. (5.8 ft-lbs.). The 2-3/4" Ø flanges used 1/4-28 bolts and were torqued to 192 in-lbs. (16 ft-lbs.). An anti-seize lubricant ("Silver Goop") was used on all threads.

University of California

Lawrence Livermore
National Laboratory
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Each test was performed using helium. New gaskets and bolts were used for each run. Results are summarized below.

T.R. #6202

The purpose of T.R. #6202 was to test the weld joint between the valve and flange and to determine the weakest point in the assembly. The flange tested was an MDC Model No. F133000 (1-1/3" Ø blank flange). The valve that was threaded and then welded to the flange was a Whitey "DK" series shut-off valve, Model No. SS-14DKM4 rated for 3,000 psi.

Testing procedure included pressurizing flange/valve assembly and then isolating the flange from the valve and checking leak pressure across the valve stem.

Five assemblies were tested. In all cases except one, the vacuum flange was the first to fail. The average pressure where leakage occurs for the tests performed was at 10,970 psi, with a range of 10,150 to 12,700 psi. With the flange isolated from pressure, leakage at the valve stem occurred at an average of 12,200 psi, with a range of 9,700 to 13,400 psi. This valve confirmed an industry standard of a 4 to 1 safety factor on valves.



It should be noted that failure in all cases were not catastrophic, but took the form of small leaks. No failure concerning the welds were noted. The stainless steel bolts used to assemble the flanges stretched 0.010 - 0.020 inches in length under pressure allowing the flanges to separate from each other resulting in leakage at the gasket.

T.R. #6226

The purpose of T.R. #6226 was somewhat similar to T.R. #6202. However, both 1-1/3" Ø and 2-3/4" Ø flanges were tested. Also, tests were made for flanges with stainless steel and Grade 8 alloy bolts in order to make comparisons. In addition, a linear variable differential transformer (LVDT) was used to measure flange movement when subjected to a pressure load. Three tests were performed for each size flange and bolt material in order to obtain an average value.

The 1-1/3" \emptyset flanges assembled with stainless steel bolts leaked at an average of 15,170 psi. The same size flange assembled with alloy bolts leaked at an average of 14,170 psi.

The 2-3/4" Ø flanges (MDC Model No. F 275000) assembled with stainlyss steel bolts leaked at an average of 5,050 psi; at 4,860 psi with those assembled with alloy bolts.

The LVDT measured movement in the center of the test flange and ranged from 0.0005 to 0.001 inch at full pressure. It should be noted that a new flange was used for each test to eliminate any cumulative fatigue that may have occurred.

T.R. #6196

The final portion in this series involved proof-testing the gas sample bottles with the valves and flanges in position. The cylinders were a Whitey Part No. 304L-HDF4-500. Their volume was 0.5 liter and a 1800 psi maximum operating pressure. Testing pressure was 2,700 psi. A total of 9 vessels and 5 valve/flange assemblies were tested. An Engineering Safety Note should have accompanied this test request in order to certify these vessels. An identifying T.R. number was etched on each vessel and released to the customer. However, it was made clear that an Engineering Safety Note needed to be provided in order to use the valve/flange assembly with the Whitey vessel for their intended purpose.

Conclusion:

It should be noted that the intention of these tests were to provide guidelines for usage of "conflat" flanges. Any modifications to hardware may alter test results and would require additional engineering and testing. Therefore, it is necessary to understand under what conditions results were derived from and decisions can be made accordingly. It should be further emphasized that failure was not catostraphic, but rather took the form of a small leak resulting from flange bolts stretching and allowing gas to pass between the gasket and "kmife-edge" seal.

If there are any questions regarding these tests, please contact me at (415) 422-9596.

Matt Traini

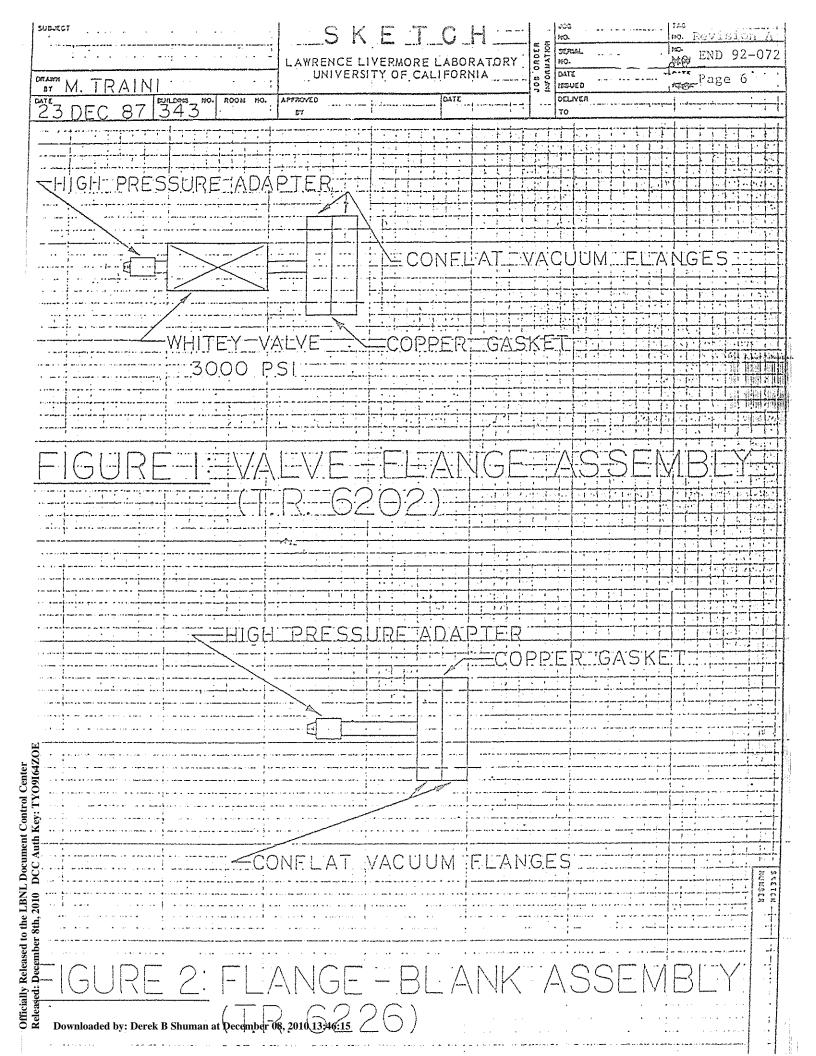
High Pressure Laboratory

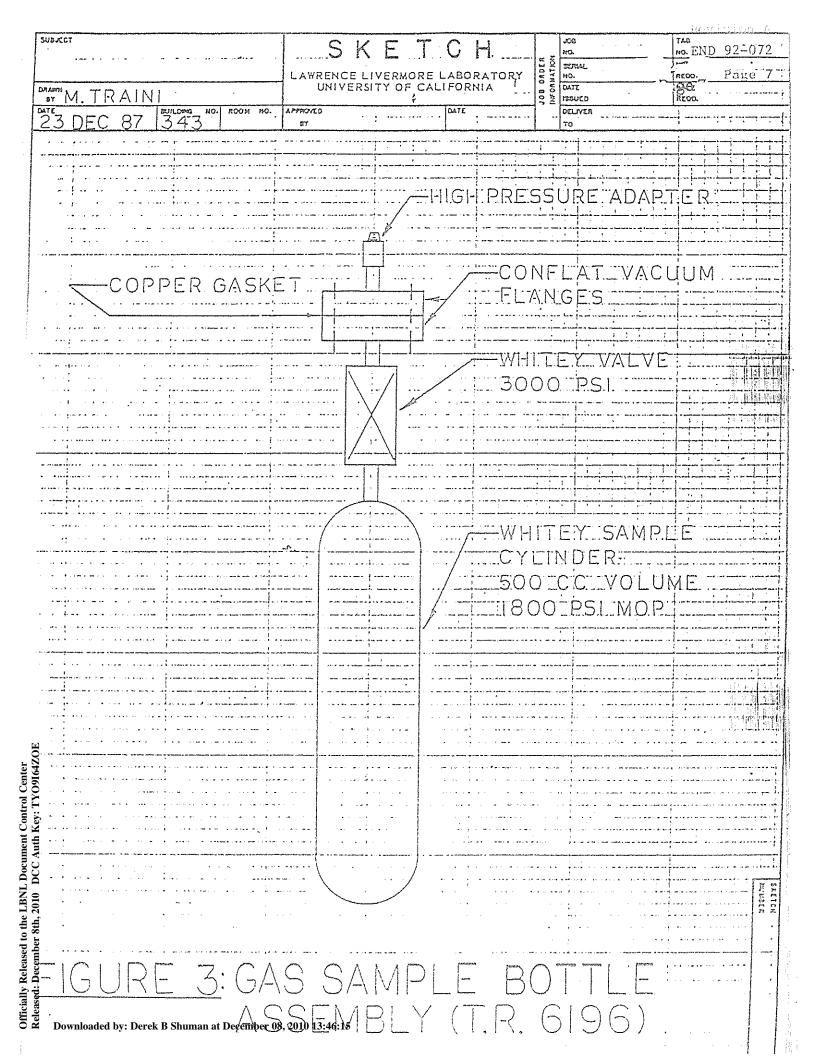
Building 343

0264mt

Distribution:

D.	Frischknecht	L-373
T.	Gates	L-236
D.	Holten	L-122
0.	Parker	L-373
В.	Schleicher	L-122





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Mail Station L-373 Ext: 2-9595

March 31, 1988

TO:

Jerry Stapleton

FROM:

Matt Traini - High Pressure Laboratory

PRESSURE TESTING OF 4 5/8" Ø "CONFLAT" VACUUM FLANGES SUBJECT:

The following is an explanation of pressure tests performed on 4 5/8" Ø "Conflat" vacuum flanges. These tests are referenced to Bldg. 343 Test Request No. 6468.

Two test assemblies were provided and the flanges were bolted together using 12 point stainless steel capscrews. Each of the vessels were initially hydro tested to 1200 psi and no leaks were present. The purpose for the initial hydro testing was to minimize any catastrophic failure that may have occurred due to the relatively large volume (approximately 2 liter) of the assemblies. In addition, 300 psi NPT fittings were welded into the assemblies (for testing purposes only) and this was also an area of concern. Each assembly was tested separately and initially pressurized to approximately 500 psi. Pressure increased in 50 to 100 psi increments to a maximum test pressure of 1200 psi. These tests are referenced to T.R. 6408B and 6408C.

Following hydro testing the vessels were disassembled and cleaned. They were reassembled using new stainless steel hardware and gaskets and tightened to a specified torque of 9 ft-lbs. Next, they were pressurized with helium in 100 psi increments until a helium mass spectrometer could detect any leaks. Following the series of tests using stainless steel hardware, the vessels were reassembled using grade 8 alloy steel cap screws. They were tightened to a specified torque of 30 ft-lbs. These results are referenced to T.R. 6408D thru 6408H and are detailed at the end of this memo.

It should be noted that no significant conclusions could be drawn accomparing alloy bolts to stainless steel hardware. Past similar tests boindicate there is no pressure advantage using one over the other.

New hardware was used for each too! It should be noted that no significant conclusions could be drawn when

New hardware was used for each test and the bolt lengths were measured New hardware was used for each test and the bolt lengths were measured to the portion of the adapter where the cap was welded on was measured before and safter testing. No growth was evident. Refer to the attached data for the pressure/time plots for each test.

University of California

Lawrence Livermore

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Test No.	Assembly No.	Fluid	<u> Hardware</u>	Leakage / Range
6408B	# 1	Water	SST	No leaks @ 1200 psi
6408C	# 2	Water	SST	No leaks @ 1200 psi
6408D	<i>#</i> 1	Helium	SST	930 psi / 10 ⁻⁶ Torr
6408E	#2	Helium	SST	500 psi / 10 ⁻⁶ Torr
6408F	#2	Helium	SST	525 psi / 10 ⁻⁶ Torr
6408G .	<i>#</i> 1	Helium [.]	Alloy	550 psi / 10 ⁻⁶ Torr
6408H	<i>-</i> #2	Helium	Alloy	900 psi / 10 ⁻⁶ Torr

If there are any questions regarding these tests, please contact me at Ext. 2-9596.



High Pressure Laboratory

Mail Station L- 373

Ext: 2-9596

January 23, 1989

TO:

Brad Maker

FROM:

Matt Traini

High Pressure Laboratory

SUBJECT: PRESSURE TESTING OF CONFLAT FLANGES WITH PYREX VIEWPORTS

The purpose of this memo is to summarize work performed under Bldg. 343 Test Request No. 6709.

Five VARIAN conflat flanges, 2 3/4" diameter, with Pyrex windows were to be pressurized with helium gas to failure. Pressure was increased in 10 psi increments with a one minute hold at each pressure. The flanges were assembled using copper gaskets. Following manufacturer's specifications, the bolts were tightened to 16 ft-lbs. New bolts and gaskets were used for each flange.

The test results are summarized in the table below.

Flange Number	Failure Pressure, psig	Nature of Glass
6709 A	108 psig	Normal.
6709 B	39	2 Scratches
6709 C	140	Normal
6709 D	116	Normal
6709 E	54	1 Scratch

If there are any questions regarding these tests, please contact me at Ext. 2-9596.

High Pressure Laboratory

0358mt

Distribution:

D. Holton

O. Parker

University of California



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Interdepartmental letterhead

Mail Station L- 373

Ext: 2-9596

February 6, 1989

TO:

Brad Maker, L-125

FROM:

Matt Traini

SUBJECT:

Testing of MDC flanges with Pyrex viewports

The purpose of this memo is to summarize work performed under Bldg. 343 Test Request No. 6726.

Three MDC "conflat" flanges, part number VP-150 (2 3/4" diameter), were pressurized with helium gas to failure. Pressure was increased in 10 psi increments with a 30 second hold at each pressure. The flanges were assembled using copper gaskets and bolts were tightened to 16 ft-lbs. New hardware was used on each of the flanges and threads were lubricated with "Silver Goop". Tests were similar to those performed previously under Test Request No. 6709 where VARIAN flanges were used.

Mention should be made regarding the types of failure. With the VARIAN flanges (TR 6709), the viewports fractured into small pieces. With the MDC flanges (TR 6726), the viewport actually separated intact from the seam of the flange.

Test results for the MDC flanges are summarized in the table below:

FLANGE NUMBER	FAILURE PRESSURE
6726A	190 psig
6726B	110 psig
6726C	141 psig

If there are any questions regarding these tests, please contact me at ext.2-9596.

Matt Traini

High Pressure Laboratory

Distribution:

D. Holten

L-122

O. Parker

L-373

University of California



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Mail Station L- 373

Ext: 2-9596

February 23, 1989

TO:

Brad Maker

FROM:

Matt Traini

SUBJECT: PRESSURE TESTING OF CONFLAT FLANGES WITH PYREX VIEWPORTS

The purpose of this memo is to summarize work performed under Bldg. 343 Test Request No. 6741.

It was requested that three VARIAN flanges were pressurized with helium gas to failure. The flanges were 2-3/4" diameter. These tests were similar to those previously performed under Test Requests 6709 and 6726. The purpose for testing this set of flanges was to determine if there had been any degradation caused by cleaning the flanges in a caustic solution. The flanges were assembled using copper gaskets and the hardware used for assembly were lubricated with "Silver Goop". The bolts were tightened to 16 ft-lbs. All three viewports fractured into small pieces upon failure.

Results for this series of tests as well as previous ones are summarized in the table below.

FLANGE NUMBER	NATURE OF GLASS	FAILURE PRESSURE, PSIG
6741 A B C	Normal Normal Normal	180 psig 250 150
6726 A B C	Normal Normal Normal	190 psig 110 114
6709 A B C D E	Normal 2 Scratches Normal Normal 1 Scratch	108 psig 39 140 116 54

Matt Traini

High Pressure Facility

0359mt

Distribution:

D. Holten L-122

O. Parker L-373

University of California Downloaded be befel & Styling 1 Dee hbj 1/8 2pp 0 14015 National Laboratory

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This additional information regarding the proof and burst testing of new 8" O.D. vacuum "conflat" flanges with viewports is being added to the existing engineering note. These series of tests were performed under Bldg. 343 Test Request number 1489 by Roger Carnahan.

Viewports from 2 manufacturers' were supplied for the tests and results are summarized below:

Flange Mfg. Proof Pressure/Hold Time Burst Pressure

MDC 15 psig/15 minutes Varian 15 psig/15 minutes

MDC 54 psig

Two of the flanges were taken to proof test pressure with no leaks and the third to burst. Upon burst, the entire viewport remained intact and separated from the seam of the flange. This is the same type of failure that had occurred on the smaller 2 ³/₄" diameter flanges (MDC) with viewports (see pg. 12).

It should also be stated that as an added safety precaution, a lexan shield should be installed over the viewport in the event of a failure.

ASME Code Qualification of ConFlat Flanges

Overview

ConFlat (CF) flanges or their equivalent are available from a number of vacuum supply companies (i.e. MDC Vacuum, Kurt J. Lesker Co., NorCal, etc.). They have been designed for vacuum service only. It has been standard practice at a number of facilities, Jefferson Lab being one, however, to use these fittings as pressure fittings where high purity and extremely cold (<4.5K) (non permanent or semi permanent) connections are required. Figure 1 gives a cutaway view of a typical CF connection. The all metal leak tight seal is achieved by extruding the gasket between the opposing conical sealing (knife) edges. This causes the gasket material to flow against the capture rings. The extruded gasket material fills small imperfections in the sealing surfaces and provides a reliable leak tight seal. It is commonly thought that the actual sealing surfaces are the knife edges. We will assume, however, that they are the outer capture rings.

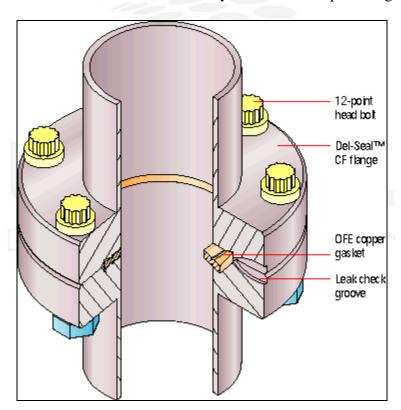


Figure 1: Cutaway view of CF assembly. From MDC Vacuum Catalog.

The purpose of this technical note is to qualify as much as possible the CF flange connection for use in ASME (B31.3 and Section VIII Div. 1) coded pressure systems and components. Pressure design of flanges and blanks is covered in Appendix 2 of the ASME Boiler and Pressure Vessel Code Section VIII Div. 1. Other necessary

information is contained in Appendix S of the same code. The B31.3 code, for process piping, (Section 304.5) refers to this section of the B&PV code for flange design.

UG-34 Eq (2) of Section VIII gives the required minimum thickness for a blank flange or flat cover as

$$t = d\sqrt{CP/SE + 1.9Wh_g/SEd}$$
 (1)

where

C is a constant determined by flange geometry. Using sketch (k) it is 0.3

d is the mean gasket diameter

P is the pressure loads

W is the gasket seating bolt load

E is a casting factor

 h_o is the

A slight modification of this equation should be used. The pressure seal should be taken as the gasket OD. The gasket seating moment arm h_g is determined as the radial distance from the bolt circle to the knife edge. The first term in the radical considers on the pressure load. The second term considers only the moment from the bolt load. Thus, the minimum thickness of the CF flange is given by

$$t = \sqrt{CPd_g^2 / SE + 1.9Wh_g d_k / SE}$$
 (2)

where

 d_k is the knife edge diameter

 d_{o} is the gasket ring diameter

An expression for stress can easily be derived from the above equation for a given thickness. The standard CF flange available from MDC can be supplied with a certificate of conformance. This states that the material is SST 304. From Table 1A in Section II of the ASME B&PV code, the maximum allowable stress for SST 304 plate is 20 ksi.

Test Procedure

Materials

The following is a list of the tools and materials used to assemble the CF test joints.

- 1. Torque wrenches
 - 1.1. Kobalt 3/8 drive (Ser#1001500784)
 - 1.2. KD ¼ drive (Ser#991135747)
- 2. Snap-On torque tester (Ser # 0699800012) calibrated.
- 3. Transducer Techniques load cell Model THC-7.5K-S Serial # 114657
- 4. Test flanges were supplied by MDC vacuum
- 5. Gaskets (both OFHC copper and aluminum) were supplied by Kurt J. Lesker Co.
- 6. Loctite 51609 anti-seize
- 7. Bolting hardware (18-8 SST nuts and bolts no washers were used)
 - 7.1. 1.33" nominal flange hardware from Kurt J. Lesker Co.

- 7.2. 2.75" and 2.125" flange hardware from Kurt J. Lesker Co. (1/4-28 x 1.25 12pt)
- 7.3. 13.25" flange hardware from York Bolt (3/8-24 x 3.5 HHCS)
- 7.4. All other flanges (5/16-24 x 3.5 12pt) from Kurt J. Lesker Co.

Torque wrench calibration

It is recognized that there will be significant error in the actual bolt torque for an individual technician using a given torque wrench. In an effort to minimize this error and quantify it, the technician performing all assembly work and torque wrench calibration/force measurements was kept constant. Both torque wrenches are "snap" type. The assembly technician and torque wrenches were checked for consistency using the Snap-On torque tester at multiple torque settings. Table A1 in Appendix A summarizes the measurements made to check the consistency of the small ¼ inch drive KD torque wrench and technician. Measurements were made at 10, 20, 30, 40, and 68 inch pounds. Similar measurements were also taken with the Kobalt 3/8 in drive torque wrench at larger values of torque. These data are shown in Table A2.

While it is necessary to understand the consistency of the actual torque, it is most important to know the actual force (bolt load) relative to a given torque setting. The total bolt load will be required in the analysis of the flange and fastener stress. It is common practice to determine the force on a bolt assembly using the standard equation for fastener torque τ

$$\tau = kFD$$
 (3)

Where

k is a coefficient determined by friction geometry etc.

F is the bolt load force

D is the nominal outer diameter of the fastener

The coefficient k is nominally taken as 0.2 in many conditions and Machinery's Handbook suggests 0.18 for lubricated assemblies. For our case, however, it is proper to measure the value of k where possible. Indeed it is even better to measure the absolute force applied by the fastener for a given torque setting. The load cell was used to determine the actual force applied by a given fastener for a given toque setting. Figure xxx shows the technique. Measurements were performed with both torque wrenches at several torque settings. These data are summarized in Table A3. Accounting for torque consistency and load cell error, the data indicate that a conservative error for absolute force applied is 10%.

CF test assemblies

The test assemblies were made by assembling two blank CF flanges with a copper gasket (from Lesker) and, when available, aluminum gaskets (from Lesker). The flanges were tightened using the cross flange pattern recommended in the MDC catalog until the flanges were visibly close to "metal to metal". At this point, the fasteners were torqued in a clockwise pattern until the flange faces were visibly "metal to metal". This is the

standard practice of many of the technicians at Jefferson Lab. No washers were used on any assembly. In all cases, a backing wrench was applied to the nut and the torque wrench was applied to the bolt head (see Figure xxx).

The torque was incrementally increased in 5 inch lb steps when using the smaller KD wrench and in 1 ft lb steps when using the Kobalt wrench. The fasteners were tightened at a given torque setting in repeated patterns until no rotation was felt. If needed the torque setting was increased and the tightening pattern repeated. The final torque setting was recorded. In the case of the smaller flange sizes, many assemblies were measured. In all cases (with the exception of the aluminum seals), at least 2 assemblies were measured. No measurable deviation in torque required to complete the assembly was found at any flange size, thus it is felt that more test assemblies are unnecessary. Assemblies using "plate nuts" (Ref 1) were also tested.

After the initial gasket crushing assembly, the bolts were loosened to less than finger tight and retightened following the same procedure above so that the flanges were again "metal to metal". This was done to determine the gasket sealing torque. This is the final gasket seating torque required to maintain a leak tight connection. The final gasket seating torque values were also recorded.

Results

The torque values required to make each CF connection are summarized in Table xxx. The 1.33 and 2.75 (aluminum gasket only) inch CF joints were assembled using the KD torque wrench. All other assemblies were performed with the Kobalt torque wrench.

	Nominal Flange Size	Torque Cu	Torque Al
	(in)	(in lb)	(in lb)
	1.33	40	31
	2.125	163.2	n/a
	2.75	163.2	67
	3.375	197.5	142
J	4.5	217.7	142
	4.625	190.4	n/a
	6	217.7	163.2
	8	246.8	146.8
	10	260	163.2
	13.25	330	n/a

Table 1: Torque values required to make CF assemblies "metal to metal"

Analysis

Flanges

The actual force required to make the CF seal was determined from the final torque wrench setting and the data in Table A3. It is clear from equation (2) that an expression

for stress in the flange may easily be derived. Table xxx shows the final bolt loads for copper gasket assemblies.

Fasteners



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Appendix A

This appendix contains the torque wrench consistency and calibration data.

Table A2: Torque consistency data for 1/4 inch drive KD torque wrench all data are in inch pounds

Torque Setting (in-lb)	10	20	30	40	68
Data	12.7	24	32	40.1	66.1
	12.7	22	29.4	39.9	66.9
	13.9	19.2	29.1	39.6	66
	13.9	20.8	28.4	38.5	67
	11.1	19.3	29.4	40.4	67.7
	11.6	20.3			66.9
	12.1				
	11.1				
	12.6				
	11.1				
	10.6				
Average	12.12727	20.93333	29.66	39.7	66.76667
Std dev	1.137621	1.823915	1.370401	0.731437	0.631401

Table A3: Torque consistency data for 3/8 inch drive Kobalt torque wrench all data are in inch pounds

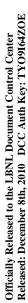
Torque Setting (ft-lb)	10	11	12	13	15	16	17	18	19	20
			N 4							
Data (in-lb)	117	131	142	168	182	191	219	236	243	250
	121	131	144	162	182	196	215		247	256
	115.2	138	146	162	189	195	217		247	260
	117.2	140	138	159	178.3	198	212		247	252
Пааспа	117.2	142	146.6	161.7	194	196	212		243	245
DUUUII	CII	140	ا لیا ت	150	179	195	209	JU.	243	241
				151	188				243	252
				148						
				150						
				156						
				157						
Average	117.5	137	143.3	156.8	184.6	195	214	236	245	251
Std deviation	2.119	4.8	3.48	6.423	5.829	2.3	3.7		2.1	6.4

Table A3: Torque wrench setting to absolute force calibration data

Torque wrench setting to force calibration Excitation voltage is 10V 2mV per V full scale (7500 lb)

Kobalt wrench

KODAIT Wrench									
Torque setting	Torque Setting	Actual torque	Error	Load Cell readout	Fastener OD	Force	Coefficient	Error	Error
Torque setting (ft lb) 10 11 12 13 14 15 16 17 18 19 20 21 22 25 27 27 KD wrench	(in-lb)	(in-lb)	Torque (in-lb)	(mV)	(in)	(lb)	K	K	Force (lb)
10	120	118	2	5.35	0.313	2006.25	0.19	0.01	112.0501604
11	132	137	5	5.81	0.313	2178.75	0.20	0.01	134.479561
12	144	143	3	6.34	0.313	2377.5	0.19	0.01	133.3982048
13	156	157	6	6.77	0.313	2538.75	0.20	0.01	161.0098237
14	168	168	0	7.57	0.313	2838.75	0.19	0.01	150.1375589
15	180	185	6	7.95	0.313	2981.25	0.20	0.01	178.7758102
16	192	195	2	8.76	0.313	3285	0.19	0.01	176.4593824
17	204	214	4	9.75	0.313	3656.25	0.19	0.01	207.1244576
18	216	236	0	10.45	0.313	3918.75	0.19	0.01	203.6701817
19	228	245	2	10.86	0.313	4072.5	0.19	0.01	214.4773258
20	240	251	6	11.77	0.313	4413.75	0.18	0.01	264.8551591
21	252	252	0	12.28	0.313	4605	0.17	0.01	263.3922946
22	264	264	0	12.74	0.313	4777.5	0.18	0.01	270.6087294
25	300	300	0	13.66	0.313	5122.5	0.19	0.01	273.7707319
27	324	324	0	14.36	0.313	5385	0.19	0.01	280.1371736
27	324	324	0	9.16	0.375	3435	0.25	0.01	136.5651042
KD wrench									
	20	21	2	0.87	0.313	326.25	0.21	0.02	44.40902721
	30	30	1	1.41	0.313	528.75		0.01	34.08049604
	40	40	1	1.91	0.313	716.25	0.18	0.01	43.95591393
	50	50	0	2.47	0.313	926.25	0.17	0.01	53.70698531
	68	67	1	3.41	0.313	1278.75	0.17	0.01	78.73891481







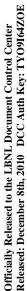
HYDROSTATIC TEST CERTIFICATION

DATE: 5-27-2010
The following reference pressure vessel(s) were successfully hydrostatically tested in accordance with the ASME Code Section VIII, Section 1.
JOHANSING JOB #: 6528
CUSTOMER: Lawrence Bereley National Labs
PURCHASE ORDER #: 6922618
NATIONAL BOARD #: N/A
VESSEL SERIAL #: 6528
GAUGE #: 3259
GAUGE RANGE: 0-ZOOO
GAUGE CALIBRATION DATE: 5-6-2010
HYDROSTATIC TEST PRESSURE: 550 PSI
VESSEL DESCRIPTION: 1/2" OD 304 S/S Pipe Spool x 10.0"
OTHER:
CERTIFIED BY:
Quality Control Manager, Johansing Iron Works, Inc. Devek Shuman WITNESS BY: Name:
signature milker
TITLE:

2955 Ford St.

(510) 261-1800 FAX (510) 261-1870

Oakland, CA 94601





LAWRENCE LABORATORY BERKELEY

Mr. Derek Shuman Mail Stop 46R0125 1 Cyclotron Road Berkeley, CA. 94720 06/23/2010 Laboratory No: B427 Client No.: New

PO No.: 450824 Page 1 of 1

Mr. Shuman:

SUBJECT: Hydrostatic test on a stainless steel octagon chamber.

TEST: At your request Testing Engineers Inc. has conducted Hydrostatic Pressure Test on one (1) MFC6DO-S0200 800 Octagon Chamber. Utilizing a Richard Dudgeon Test Pump (Model 7-TSS.1 6000 PSI capacity s/n 5453), and a calibrated pressure gage (s/n 7624 0 to 600 PSI).

PROCEDURE: The chamber was placed on a table attached to the hydrostatic pump. The chamber was then filled with water and pressurized until a pressure of 525 PSI was obtained. The test pressure was held for a minimum of five (5) minutes.

RESULTS: No leaks or loss of pressure were observed during the test. The chamber was then visually examined for sign of distress, none were apparent.

NOTE: Testing was witnessed by Mr. Derek Shuman and Mr. Tom Miller of Advanced Light Sources, Lawrence Laboratory Berkeley.

If you should have any questions concerning this test or if we may assist you in any other way please call at 1-510-835-3142 ext. 106.

TESTING ENGINEERS, INC

By

Jack A. Snow

Materials Testing Technician

Attachments:

The results presented in this report relate only to the items(s) tested. This report can be reproduced only in its entirety unless written permission from TEI is obtained

Released: December 8th, 2010 DCC Auth Key: TYO9I64ZOE Officially Released to the LBNL Document Control Center

TECHNICAL SERVICES

2900 Main St Alameda CA 94501 Phone (510)522-8326 Fax (510)522-3136

Certificate of Calibration

Rated Accuracy

Pass/Fail as Found

Pass/Fail as Left

Ist (Mfg) S/N

TESTING ENGINEER, INC. 2811 TEAGARDEN ST SAN LEANDRO

CALIFORNIA 94577

Customer ID # 2103

File #

321

Instrument Type

PRESSURE GAUGE

0-600

CPI

Units **PSIG**

Resolution 20

Mfg.

Range

Model 2.5-600

Cal By

R.K. STRAHL

Notes

2nd S/N

Cal Date

1%

PASS

PASS

7624

N/A

6/21/2010 6/21/2011

Cal Due

Curent Cal Cycle (Months)

Previous Cal Cycle

12

Standards Used

AMETEK PK-654WC S/N 73272 DUE 1/28/2012 NIST#

35817.001

TECHNICAL SERVICES GROUP CERTIFIES THAT THIS INSTRUMENT HAS BEEN CALIBRATED TRACEABLE TO THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY AND CONFORMS TO ISO 10012 AND ANSI / NCSL Z-540. UNLESS OTHERWISE SPECIFIED MEASURMENT UNCERTAINTIES ARE LESS THAN 1/4 OF TOLERANCE OR 1 MINOR DIVISION.



HYDROSTATIC TEST CERTIFICATION

DATE: 6/30/2010
The following reference pressure vessel(s) were successfully hydrostatically tested in accordance with the ASME Code Section VIII, Section 1.
JOHANSING JOB #: 6528
CUSTOMER: UC Lawrence Berkeley National Lab.
PURCHASE ORDER #: 6926046
NATIONAL BOARD #: N/A
VESSEL SERIAL #: N/A
GAUGE #: 409C
GAUGE RANGE: 0-1000 P51
GAUGE CALIBRATION DATE: 5/8/10
HYDROSTATIC TEST PRESSURE: 550 psi
VESSEL DESCRIPTION: 1/2" S/S x 15" Long
OTHER:
CERTIFIED BY: Quality Control Manager Johansing Iron Works, Inc.
WITNESS BY: Jon Min Name: Tom Miller
signature print name
TITLE:

2955 Ford St.

(510) 261-1800 FAX (510) 261-1870

Oakland, CA 94601

						PICK LIST				
Location	n Group:	MDCP	Description:	MDC PICKIN	G					
Pos	Del Warehou Lot/Batcl		Bay	Eng Revision Row Pallet Id	Tier	Description Bin Serial No	Package Part Wanted Delivery EC	Ďelivery Date Quantity	Expiration Dat	te Ity p
1	1	110008		C .		REF# F275000				
	Buildir	ng 3	Main	С	09	AE	06/10/2010	06/24/2010 12.0		
	*			*		*	1	1.00	EACH	

End of Report:

Return Policy:

- Unused standard catalog items may be returned within 60 days of the date the item was shipped, provided the item is properly packaged and shipping charges are pre-paid.
- Special order items may not be returned without specific, pre-approval from MDC.
- All returns must have a RMA number assigned by Customer Service.
- Returned items will not be accepted if the revision has changed or the material is now obsolete. Please check with Customer Service prior to returning items.
- Installed, used or damaged items are not eligible for reprocessing and will be returned with no credit applied.
- A minimum of 25% restocking fee applies.
- Items should be returned freight prepaid as collect shipments will not be accepted.

NOTE:

There will be up to a \$500.00 evaluation charge for non-warranty repairs. This evaluation fee will be credited to the repair cost if the repair is ordered.

The evaluation fee plus applicable return shipping charges will be assessed for any returned item you elect not to repair.

A \$50 fee will be applied to any returned item requested to be scrapped.

ORDER INFORMATION

Delivery Address:

JOHANSING IRON WORKS

2955 FORD ST

OAKLAND, CA 94601 UNITED STATES

Delivery Site:

MDC VACUUM PRODUCTS

Terms of Delivery:

SHIPPING POINT

Ship Via:

FED EX GROUND

PO Number:

011349

Route Id:

Forward Agent:

Label Note:

Our Reference:

CUSTOMER SERVICE

TELEPHONE: 2611800 FAX: 261 1870

Certificate of Conformance

This is to certify that the material referenced on the above PO and listed on the attached pick list were manufactured to the customer's requirements or to MDC's internal drawing and specifications.

Materials used in the production of this order are certified as new and not counterfeit. Any deviation to specifications has been authorized by the customer.

MDC Vacuum Products is an ISO 9001:2008 registered company. Key elements of our fully implemented Quality Management System include our Quality Manual, Quality Policy, Product Objectives, Process Measurements, Design Capability and Validation, detailed production Process Travelers, Corrective / Preventive Action System, Nonconforming Material System, Calibration, First Article / First Piece / CNC Program Qualification Process, Internal Audits, and Sub-Supplier Program.

Quality Management Contacts:

MDC, VPD, Hayward, CA (510) 265-3500 MDC, ISI, Sarasota, FL (941) 751-2880 MDC, SSD, San Jose, CA (408) 350-0244

Report:

Pick List for Customer Order

Created: 06/15/2010 7:21:5



MILL TEST REPORT

RM ID NUMBER 103309 SALES ORDER / RLS 004752 / 2 CERT ID / REV 00030402 / 01

SOLD TO

SOUTHWEST STAINLESS 8505 MONROE RD HOUSTON, TX 77061 USA

CUSTOMER P.C 199262	cụ	STOMER PA	RT				HEAT 975 6			
DESCRIPTION3 .5" WELDED			04/TP304	L (UNS# S	30400/S30 ₄	403) A312	2			
CERTIFICATION	REQUIREME	NTS								
ENGINEERING ASTM A312-0	08a ASME S	SA312-07,	08 ADD.		es Te	4				1 40.
HYDRO PRESSU 2,500 PSI	JRE									
HEAT TREAT Annealed at1	900 Deg F	. and wate	r quenche	d to belov	v 800 Deg.	F. in less	than 3 m	ninutes.		
				CI	nemical					
C .013	Cr 18.2	Mn 1.5	Ni 8.07	.06	р .033	Si .44	.013			
TEST Tensile PSI		PS		RES 9	chanical SULTS 1500				3	E 2
Yield PSI Elong %		PS	81	4	0400 55					
Hardness RB81	v									
TEST Flattening			SULT							
This test re in full comp Certification	port represent bliance with ap n is in accorda	s the actual a plicable speci	ttributes of th	e items furnis your purchas	hed and all ite e order.	ems were m	anufactured	, sampled, insp	ected, and tes	ted

Certification is in accordance with EN10204:2004 type 3.1.
Chemical content is % by weight. Mechanical test results are in English units (inches and pounds).
No weld repairs have been performed on the base material.
Hardness in accordance with NACE MR0175 and MR0103 and material is free of cold work to enhance mechanical properties.
Pipe is Pickled and Passivated in accordance with ASTM A380.
Bristol Metals has a Quality Management System in place that is in compliance with ISO 9001:2000.
Bristol Metals does not add mercury during any manufacturing process.
NAFTA country of orgin: USA
Raw Material Mat Source 1154

Raw Material Melt Source USA

FAR BAA - Complies, DFARS BAA - Complies, FAR TAA - Complies

This MTR contains 1 page (Page: 1)

SO#: LAA825 CHEN INTERNATIONAL CORPORATION PO#: 042S-6777435 148763A MTR#: TCFB02590 Customer#: ESC900 Item#: G6L00120116 Bundle#: HG0256-069 Heat#:

Released: December 8th, 2010 DCC Auth Key: TYO9164ZOE

Officially Released to the EBNL Document Control Center

: STAINLESS STEEL PLATE CUT STRIP

Mill Test Report

Shipper

EN 10204-3.1 / DIN 50049-3.1B

Customer

: TA CHEN INTERNATIONAL, INC.

TA CHEN STAINLESS PIPE CO., LTD.

NO. 125 HSIN-TIEN 2ND ST...

: TA CHEN STAINLESS PIPE CO., LTD.

JENG-TEH, TAINAN, TAIWAN TEL:(06)2793254 FAX:(06)2701382

Specification

Commodity

TCFB02590

: ASTM A240/A480-01 ASME SA240/SA480-95

Destination

: LOS ANGELES

COUNTRY ORIGIN: TAIWAN

ASTM A479-01/ASME SA479-95 Chem/Mech.only

ASTM A484-01 Chem/Mech.only

ASTM A276-01 Chem/Mech.only

Customer's PO# : L21603

Certificate NO : HG0256002

QQS-763-F Chem only

Factory O/N

QA02HA059

Date : 2007/10/11

INVOICE NO : QAO2HG0256

Item	Case No.	Heat		Size	, ,	Quantity	Weight	8		Chen	nical C	omposit	ion in 9	6		-
No.	(Crate No.)	No.	Supplier			Pcs	Kqs	С	Si	Mn	Р	S	Ni	Cr	Мо	N_
	(0.0.0)	INO.				1 65	1.90									
01	068,069,070,071	148763A	YUSCO	.187 X 1.250 X 144 316/316L			923	0.017	0.540	1.040	0.030	0.004	10.09	16.74	2.070	0.023
02	023,024,025,026	147462D	YUSCO	.250 X 4.000 X 144 316/316L			961	0.017	0.530	1.080	0.029	0.005	10.17	16.78	2.160	0.021
03	063	147462D	YUSCO	.250 X 6.000 X 144 316/316L			249	0.017	0.530	1.080	0.029	0.005	10.17	16.78	2.160	0.021
04	003,004,005,006,007,058,059,060	A2701669	TISCO	.500 X 6.000 X 144 316/316L			2311	0.021	0.441	1.257	0.030	0.002	10.26	16.88	2.007	0.039
						r										
				,	Total	n	1111									7

		Tensile Te	st .		Hardness		Heat	Dimension
ltem	0.2%Yield	Tensile	Elongation	Reduction	Test	Bend	Treatment	And
No.	Strength	Strength	%	of Area	HRB	Test	TEMP.	Surface
140.	PSI	PSI	70	%	חאם		٥F	Condition
01	44800	84200	52.00	62.00	78.00	OK	1960	OK
02	43600	85800	50.00	60.00	83.00	OK	1960	OK
03	43600	85800	50.00	60.00	83.00	OK	1960	OK
04	42000	84100	59.00	65.00	83.00	OK	1960	OK
			"					

We hereby certify the above statement to be true and correct every detail

TA CHEN has established a QMS according to ISO 9001, which is certified by LRQA (cert. no.TWN0936925)

Remarks 1. NO WELD REPAIR PERFOMED 2. FREE OF MERCURY CONTAMINATION 3. ASTM A262-01 PRAC, E OK 4. MECHANICAL PROPERTIES ARE MEASURED FROM SHEET COIL BEFORE CUTTING. 5. NACE MR0175-03

Large Yang

Manager of Inspection Section/George Yang

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TYO9I64ZOE

LAWRENCE BERKELEY NATIONAL LABORATORY PRESSURE-TEST RECORD Date: 8/17/10 Locatior of vessel (or system): Build. 70 Rm. 2263 Reclamation Subsystem (1 of 3 subsystems to test) Pressure Vessel 🗔 Pressure System 降 (check box) "Pressure-Tested" Label attached 🗌 TEST INFORMATION: (MAVP)1. Test pressure 1500 psig x 1.25y = pa(1.875) kpsi) TEST INFORMATION: 2. Testing Fluid (oil, He, etc.) _ A V _ _ _ _ G _ G S _ ____ 3. Test Temperature Voon temp 4. Design Temperature Voom temp 6. Responsible Designer Tom Willer Name: 7. Responsible User Helmath Spieler Name: Dept. D. Shuman 8/17/10 Location (marked) Before testing After testing Difference (+ or •) miller M&O, Mach, Shop CERTIFICATION: The vessel identified above has been pressure tested and is approved for operation within these test Certified by: Parsel, Will 8/17/10

Officially Released to the LBNL Document Control Center Released: December 8th, 2010 DCC Auth Key: TYO9I64ZOE

LAY	WRENCE BERKELEY NAT	TONAL LABORATORY	
	PRESSURE-TES		• t 1
		1	Date: 8/25/20
Locatior of vessel (or system)	: Build. <u>10A</u> Rm. <u>22</u> 63	LBL PRESSURE	TESTED
	PC Presque Ve	SAFETY NOTE	Psi
and Gas Sys	iten check (1.25	× WAWI) WORKING FLUID	eivip . °
Subsections 2+	3 (0) 3)	r e m a u Test number	
Pressure Vessel 🗹 Pressure (System 🗹 (check box)	DV .	D RE
Pressure-Tested" Label attac	hed 🗆		
rest information: 5	10/320		
. Test pressure		Pa (kpsi)
	Argon gas		
	-		- /1
3. Test Temperature		& ¢ (/ // •F)
3. Test Temperature 4. Design Temperature			<u>74</u> •F) •F
4. Design Temperature	roon ter		
I. Design Temperature 5. Safetv Case	roon ter		
I. Design Temperature 5. Safetv Case 6. Responsible Designer	m Miller Name:	P. *c(
i. Design Temperature i. Safetv Case i. Responsible Designer _To v. Responsible User _H=\w	m Miller Name: th Spieler Name:	P. *c(
Design Temperature i. Safetv Case i. Responsible Designer _To c. Responsible User _H_e\w DeptDeve k	m Willer Name: th Spieler Name: Shuman	P. *c(
i. Design Temperature i. Safetv Case i. Responsible Designer _To v. Responsible User _Helm DeptDevekS Divn:KehC	m Willer Name: th Spieler Name: Shuman how	P. *c(
J. Design Temperature J. Safetv Case J. Responsible Designer J. Responsible User J. Devek Divn: Kell C. Diameter measurements ifo	m Miller Name: th Spieler Name: Shuman how r pressure-vessel tests only)	ρ. •c(
4. Design Temperature 5. Safetv Case 5. Responsible Designer 7. Responsible User Dept Dept Deve k Divn: Keh C 3. Diameter measurements [fo	m Miller Name: The Spieler Name	ρ. •c (
1. Design Temperature 5. Safetv Case 6. Responsible Designer To 7. Responsible User Helm 8. Devek Colvn: Keh Colvn: Keh Colvn: Location (marked) Be	m Miller Name: The Spieler Name: Shuman How Tressure-vessel tests only) If ore testing After testing Diff	ρ. •c (
1. Design Temperature 5. Safetv Case 6. Responsible Designer To 7. Responsible User Helm 8. Devek Colvn: Keh Colvn: Keh Colvn: Location (marked) Be	m Miller Name: The Spieler Name: Shuman How Tressure-vessel tests only) If ore testing After testing Diff	ρ. •c (
4. Design Temperature 5. Safetv Case 5. Responsible Designer 7. Responsible User Dept Dept Deve k Divn: Keh C 3. Diameter measurements [fo	m Miller Name: The Spieler Name: Shuman How Tressure-vessel tests only) If ore testing After testing Diff	ρ. •c (