proj: **XENON TPC**
Xenon Pressure Chamber
title: **Pressure Safety Note**

DRAFT, not complete

This Safety Note covers a pressure vessel recently acquired by LBNL, from LLNL, for a physics research experiment involving neutrinoless double beta decay. It also covers associated components attached to this pressure vessel. 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 Safety Note MESN99-020-OA (1999) contains the vessel design calculations, performed in accordance with ASME Pressure Vessel code Section VIII (1995), and is included here in the Appendix. It includes pressure testing procedures. The attached components consist of a 2" diameter 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, filters, valves, and pumps; it is similar to what was used at LLNL. This note is to assure that the Vessel meets LBNL Safety requirements of PUB-3000. It does not cover the associated gas handling system. The chamber is shown below:

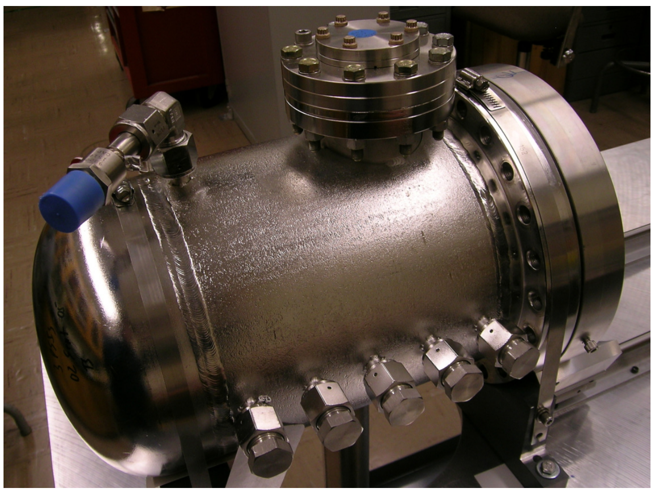


Fig. 1 Main pressure Vessel, 850 psig MOP

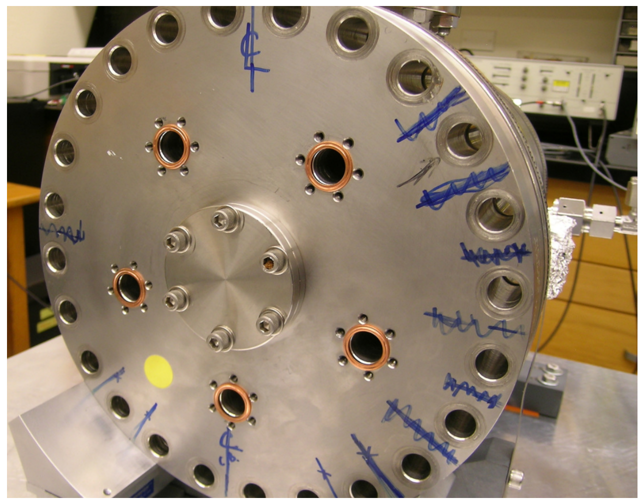


Fig 2. Flat Heat for 350 psig MOP (CF seals)

Pressures for use at LBNL

Maximum Operating Pressure: $P_{MOP} := 300psi$

Maximum Allowable Working Pressure: $P_{MAWP} := 350psi$

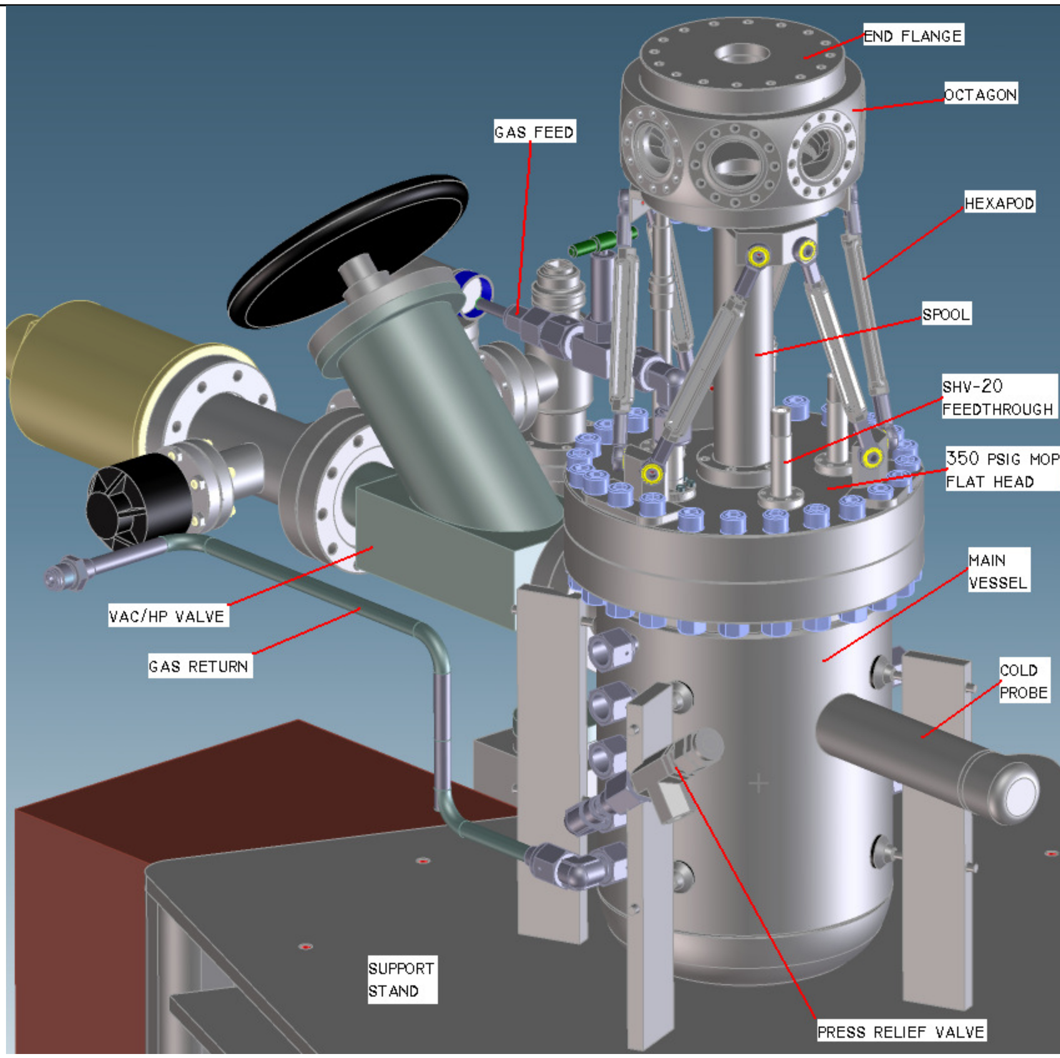


Fig. 3 LBNL configuration: pressure vessel with cabling extension spool and octagon vac. chamber

Description

The 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 scrub the Xenon gas to a high purity state, but also to eliminate any thermal convection currents from electronics. Argon may be used for initial flushing of air, H20, etc. when the vessel is first assembled. A 0.5-1L Xenon condensation bottle is used to condense/ freeze out Xenon in order to open up the vessel without venting the Xenon. It will be left open during operation and so is part of the vessel volume. This method eliminates accidental overpressurization. The stored energy is 40 kJ for either of these monatomic gasses @MAWP = 350 psig. A schematic is shown below:

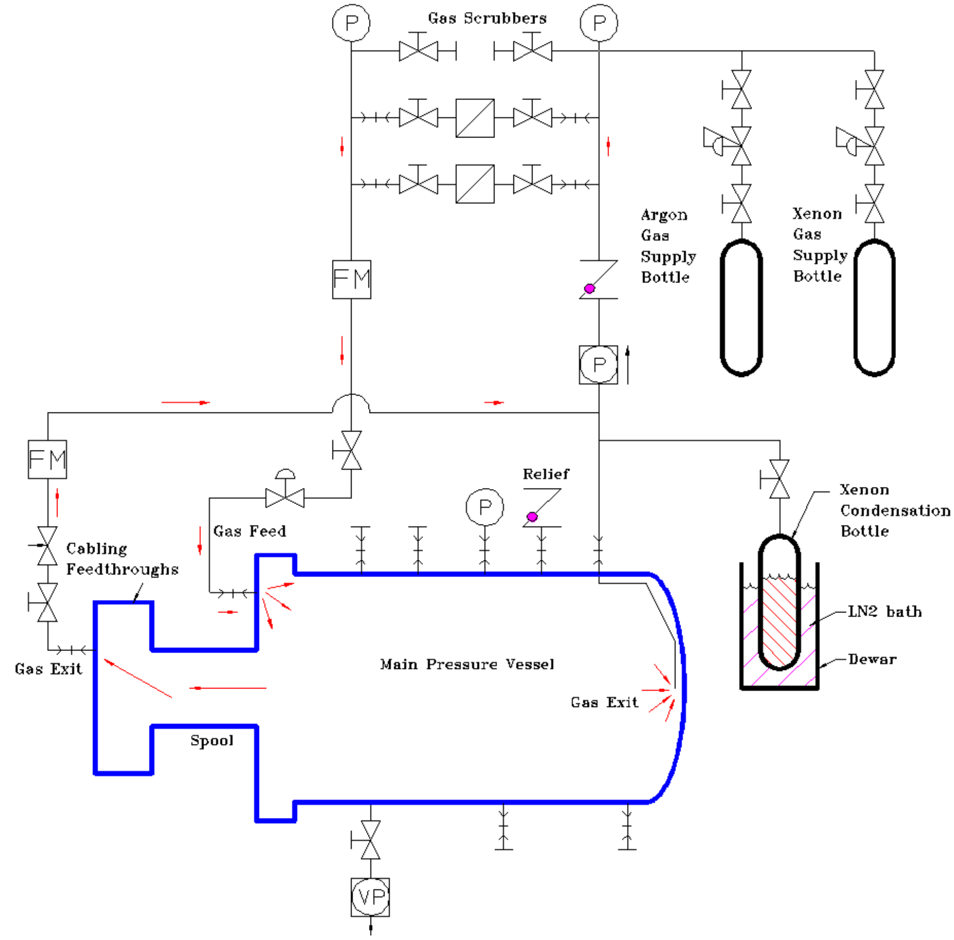


Fig. 4 Gas System Schematic

There are no toxic, flammable, biological, or radioactive gasses or materials inside the vessel with the exception of some small low intensity sealed gamma 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 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 pressure rated for use at 20 bar; they have the possibility of imploding under excessive pressure, but this is not expected to create an 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 125% MOP = 375 psig. There are no toxic or radioactive materials inside the PMT's. These PMTs are the limiting factor and set the MOP to 300psi. There are two SHV-20 high voltage feedthrus that are rated for use at 250 psi, however, the design is similar to ones that rate much higher; we will pressure test these at 1.5x MAWP hydrostatic to qualify for use at MOP.

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 pressured above 150 psig. An AHD is not required for the Xenon or Argon gases, but there may be pressure and process hazards, so an AHD will be formulated.

The chamber 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 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 only 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, and, if not, will be analyzed for presssure 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.

There are no toxic, flammable, biological, or radioactive gasses or materials 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. There is a cold probe welded to the main tank vessel which is used to condense Xenon, using a surrounding dewar of LN2, however, there are no plans at LBNL to use this feature.

There are new components which will be attached to the chamber, some of which 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 will be analyzed for sufficient strength and 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 experiment and additional calculations for the added components:

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:

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

Volume includes vessel, cabling octagon, connectiong spool, valve and gas sytem tubing:

$d_{ves} := 7.63in$	$l_{ves} := 13.5in$	main vessel inner dimensions
$d_{LNxt} := 2in$	$l_{LNxt} := 8in$	LN2 extension (cold probe)
$d_{oct} := 8in$	$l_{oct} := 3.0in$	Kimball octagon for cabling
$d_{spool} := 2in$	$l_{spool} := 10in$	connection spool, lid to octagon
$d_{tubing} := 0.5in$	$l_{tubing} := 20ft$	gas system tubing and filters
$d_{valve} := 2in$	$l_{valve} := 4in$	high pressure volume of closed valve and tank stub
$d_{rb} := 4.0in$	$l_{rb} := 36in$	recovery bottle (condensation bottle)

$$V_h := \frac{\pi}{4}\cdot\left(d_{ves}^{\ 2}\cdot l_{ves} + d_{LNxt}^{\ 2}\cdot l_{LNxt} + d_{spool}^{\ 2}\cdot l_{spool} + d_{oct}^{\ 2}\cdot l_{oct} + d_{tubing}^{\ 2}\cdot l_{tubing} + d_{valve}^{\ 2}\cdot l_{valve} + d_{rb}^{\ 2} l_{rb}\right)$$

$V_h = 1.3 \times 10^3 \, in^3 \quad V_h = 21.9\,L$

Stored Energy @ 350 psig MAWP

$$U_v := \frac{P_h \cdot V_h}{\gamma - 1}\left[1 - \left(\frac{P_l}{P_h}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad U_v = 60\,kJ$$

Mass of Xenon in System at operating pressure

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

Number of moles:

$$n_{Xe} := \frac{P_{MOP} \cdot V_h}{R \cdot T_{amb}} \qquad n_{Xe} = 18.165\,mol$$

Weight:

$$W_{Xe} := M_{a\_Xe} \cdot n_{Xe} \qquad W_{Xe} = 2.39\,kg$$

Volume of LXe

density: $\rho_{LXe} := 3.05 \frac{gm}{mL}$ @ boiling, 1 bar, -101.8C

$$V_{LXe} := \frac{W_{Xe}}{\rho_{LXe}} \qquad V_{LXe} = 0.782\,L$$

Valve calcs

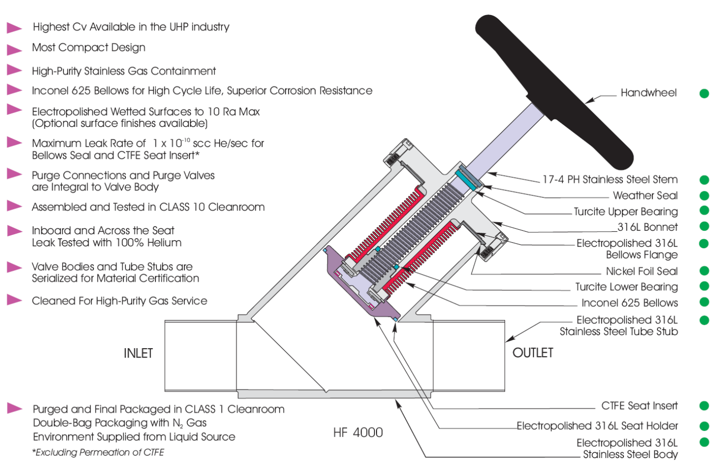
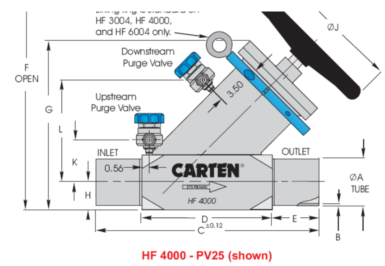


Fig. 4 Carten HF2000 process valve



Standard purge valve connection sizes are:
HF 500, HF 751, HF 1000, and HF 1501 = 1/4" purge connectors
HF 1502 and larger valves = 1/2" purge valves

CAT. NO.	A*	B*	C	D	E	F	G	H	J
HF 500	0.50	0.049	9.50 (241.1mm)	3.46 (87.9mm)	3.02 (76.7mm)	4.75 (120.7mm)	3.26 (82.8mm)	0.50 (12.7mm)	2.50 (63.5mm)
HF 751	0.75	0.065	12.86 (326.6mm)	4.8 (121.9mm)	4.03 (102.4mm)	7.97 (202.4mm)	5.86 (148.8mm)	0.75 (19.1mm)	3.94 (100.1mm)
HF 1000	1.00	0.065	10.84 (275.3mm)	4.8 (121.9mm)	2.98 (75.7mm)	7.97 (202.4mm)	5.86 (148.8mm)	0.75 (19.1mm)	3.94 (100.1mm)
HF 1501	1.50	0.065	14.76 (374.9mm)	4.8 (121.9mm)	4.98 (126.5mm)	7.97 (202.4mm)	5.86 (148.8mm)	0.75 (19.1mm)	3.94 (100.1mm)
HF 1502	1.50	0.065	17.16 (435.9mm)	6.98 (177.3mm)	5.09 (129.3mm)	13.15 (340.0mm)	8.86 (225.0mm)	1.31 (33.3mm)	7.87 (199.9mm)
HF 2000	2.00	0.065	15.24 (387.1mm)	6.98 (177.3mm)	4.13 (104.9mm)	13.15 (340.0mm)	8.86 (225.0mm)	1.31 (33.3mm)	7.87 (199.9mm)

Fig. 5 Carten HF2000 process valve dimensions

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:

(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:

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

(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:

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

MAWP | Maximum allowable stress | Weld efficiency

$P_{MAWP} = 350\,psi$ $\qquad S_{304SS} := 16500psi$ $\qquad E_w := 0.7$

wall thickness | inner radius

$t_{neck} := .065in$ $\qquad R_{i\_neck} := 1.0in$

$$t_{neck\_min\_circ} := \frac{P_{MAWP} \cdot R_{i\_neck}}{S_{304SS} \cdot E_w - 0.6 \cdot P_{MAWP}} \qquad t_{neck\_min\_circ} = 0.031\,in \qquad \text{OK}$$

$$t_{neck\_min\_long} := \frac{P_{MAWP} \cdot R_{i\_neck}}{2S_{304SS} \cdot E_w + 0.4P_{MAWP}} \qquad t_{neck\_min\_long} = 0.015\,in \qquad \text{OK}$$

Note: manufacturer has agreed to weld valve to a 4 5/8" CF flange and pressure certify to 350 psig MOP.

Spool tube calcs

A 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 fanout manifold (Kimball Physics Octagon). The spool has a 2.75" CF flange on one end and a 6" CF flange on the other end. To prevent external loading of the tube from the manifold or attached cabling there will be an adjustable hexapod strut system rigidly connecting the 6" flange periphery to the 350 psi MOP head periphery. See fig 3. The hexapod struts will attach to tabs which are captured by the flange bolts. There will be provision for locking the strut lengths once assembled to prevent inadvertent length adjustment after attachment. Tube to flange welds will be full penetration.

tube thickness, inner radius, weld efficiency :

$t_{spool} := .125in$ $\qquad R_{i\_spool} := 0.75in$ $\qquad E_w = 0.7$

As above, from UG-27:

$$t_{spool\_min\_circ} := \frac{P_{MAWP} \cdot R_{i\_spool}}{S_{304SS} \cdot E_w - 0.6 \cdot P_{MAWP}} \qquad t_{spool\_min\_circ} = 0.023\,in \qquad \text{OK}$$

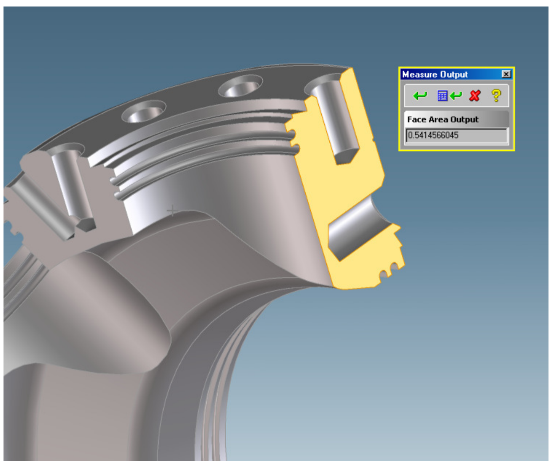
$$t_{spool\_min\_long} := \frac{P_{MAWP} \cdot R_{i\_spool}}{2S_{304SS} \cdot E_w + 0.4P_{MAWP}} \qquad t_{spool\_min\_long} = 0.011\,in \qquad \text{OK}$$

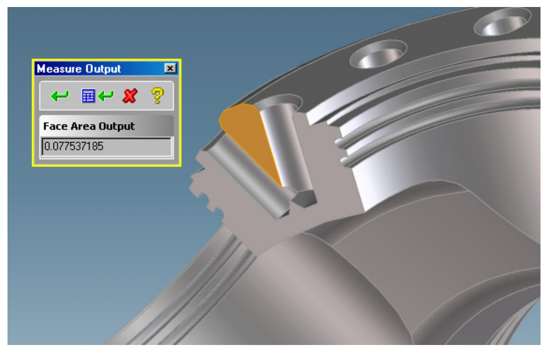
Kimball octagon calcs

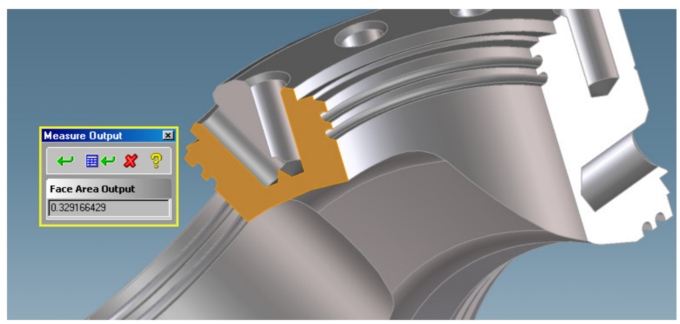
This is a 304 stainless steel machined octagonal vacuum chamber. It has eight 2.75 in CF ports, which will be used for feedthroughs and As above, we use subsection UG-27:

Areas, minimum of half cross sections:

$$A_{circ} := 2 \cdot 0.5415in^2 \qquad A_{circ} = 1.083\,in^2 \qquad A_{long} := 4 \cdot (0.329 + 0.0775)\,in^2 \qquad A_{long} = 1.626\,in^2$$







Radii: $R_{i\_oct} := 3.5in$ note: this is largest radius (at the 2.75 in CF flanges)

Equivalent thicknesses (by dividing out radius)

$$t_{oct\_circ} := \frac{A_{circ}}{R_{i\_oct}} \qquad t_{oct\_circ} = 0.309\,in$$

$$t_{oct\_long} := \frac{A_{long}}{R_{i\_oct}} \qquad t_{oct\_long} = 0.465\,in$$

Minimum equivalent thicknesses:

$E_{w.} := 1$ machined, not welded

$$t_{oct\_min\_circ} := \frac{P_{MAWP} \cdot R_{i\_oct}}{S_{304SS} \cdot E_{w.} - 0.6 \cdot P_{MAWP}} \quad t_{oct\_min\_circ} = 0.075\,in$$ compare --> $t_{oct\_circ} = 0.309\,in$ OK

$$t_{oct\_min\_long} := \frac{P_{MAWP} \cdot R_{i\_oct}}{2S_{304SS} \cdot E_{w.} + 0.4P_{MAWP}} \quad t_{oct\_min\_long} = 0.037\,in$$ compare --> $t_{oct\_long} = 0.465\,in$ OK

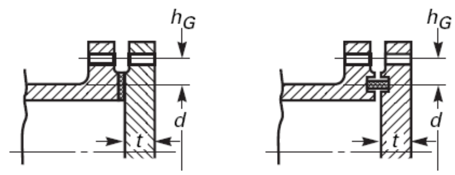
CF flange calcs

(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

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



$C = 0.3$
[Use Eq. (2) or (5)]
(j)

$C = 0.3$
[Use Eq. (2) or (5)]
(k)

The following calculations are parallel calculations (not matrix or vector calcs). Read straight across from desired flange size, OD_{CF} :

Flange size Number of bolts Knife edge diameter Torque, bolt

$$OD_{CF} := \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \quad N_{CF} := \begin{pmatrix} 6 \\ 4 \\ 6 \\ 8 \\ 8 \\ 10 \\ 16 \\ 20 \\ 24 \\ 30 \end{pmatrix} \quad d_{ke} := \begin{pmatrix} .72 \\ 1.15 \\ 1.65 \\ 2.25 \\ 2.75 \\ 3.25 \\ 4.54 \\ 6.25 \\ 8.54 \\ 11.5 \end{pmatrix} in \quad T_{CF} := \begin{pmatrix} 40 \\ 163 \\ 163 \\ 197 \\ 217 \\ 190 \\ 217 \\ 246 \\ 260 \\ 330 \end{pmatrix} lbf \cdot in$$

<- checked (.72)
<- checked (1.65)
<- checked (4.54)
<- checked (8.54)

from ref. 3, ANL CF pressure capacity document, torque to pull CF flanges fully together

Flange size Bolt circle dia. Flange thickness Bolt dia. Height of bolt flange

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \quad d_{bc} := \begin{pmatrix} 1.062 \\ 1.625 \\ 2.312 \\ 2.85 \\ 3.628 \\ 4.03 \\ 5.128 \\ 7.128 \\ 9.128 \\ 12.06 \end{pmatrix} in \quad t_{nomCF} := \begin{pmatrix} .285 \\ .47 \\ .5 \\ .62 \\ .68 \\ .75 \\ .78 \\ .88 \\ .97 \\ 1.12 \end{pmatrix} in \quad d_{bolt} := \begin{pmatrix} .16 \\ .25 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .3125 \\ .375 \end{pmatrix} in \quad h_{fl} := \begin{pmatrix} .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \\ .05 \end{pmatrix} in$$

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

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad W_{CF} = \begin{pmatrix} 7500 \\ 13040 \\ 15648 \\ 25216 \\ 27776 \\ 30400 \\ 55552 \\ 78720 \\ 99840 \\ 1 \times 10^{5} \end{pmatrix} lbf$$

$$t_{CF} := \overrightarrow{\left(t_{nomCF} - h_{fl}\right)}$$

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad t_{CF} = \begin{pmatrix} 0.235 \\ 0.42 \\ 0.45 \\ 0.57 \\ 0.63 \\ 0.7 \\ 0.73 \\ 0.83 \\ 0.92 \\ 1.07 \end{pmatrix} in$$

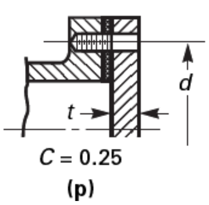
$$h_g := \overrightarrow{0.5\left(d_{bc} - d_{ke}\right)} \qquad OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} in \qquad h_g = \begin{pmatrix} 0.171 \\ 0.238 \\ 0.331 \\ 0.3 \\ 0.439 \\ 0.39 \\ 0.294 \\ 0.439 \\ 0.294 \\ 0.28 \end{pmatrix} in$$

$S := 20000psi \qquad E := 1 \qquad C_j := 0.3$

Solving for pressure in eq (2) above:

$$p_j := \overrightarrow{\frac{S \cdot E}{C_j}\left(\frac{t_{CF}^{\ 2}}{d_{ke}^{\ 2}} - \frac{1.9 \cdot W_{CF} \cdot h_g}{S \cdot E \cdot d_{ke}^{\ 3}}\right)} \qquad p_j = \begin{pmatrix} -14660 \\ -4004 \\ -2344 \\ 72 \\ -215 \\ 905 \\ 618 \\ 279 \\ 475 \\ 423 \end{pmatrix} psi$$

It can be seen that the maximum bolt torque obtainable results in plate stresses that are higher than allowable. However this is misleading in that this maximum torque occurs as the flange faces start to mate which changes the joint type to type (p) (from fig. UG-34):



for this joint type we can use eq (1), and p is then:

$C_p := 0.25$

$$p_p := \frac{S \cdot E}{C_p} \cdot \overrightarrow{\left(\frac{t_{CF}^{\ 2}}{d_{ke}^{\ 2}}\right)} \qquad p_p = \begin{pmatrix} 8522 \\ 10671 \\ 5950 \\ 5134 \\ 4199 \\ 3711 \\ 2068 \\ 1411 \\ 928 \\ 693 \end{pmatrix} psi$$

This calculation is conservative (only) if full flange contact is achieved for the combination of the following two conditions:

1. The edge slope is zero which means that a reverse edge moment has been applied which cancels the edge moment from the gasket. The gasket now only applies a shear load to the periphery of the pressure loaded portion of the plate. The pressure bearing portion of the plate now has a negligible initial stress before pressurization, especially at the center, where the stress from pressure is highest (see plate bending formula below).

2. The plate now has fixed edge with zero slope. Maximum stress under pressure load with this end condition is substantially lss than for simpe supports. This is reflected in the lower value of C in the above formula, which is conservative when compared to

A. .001" thick feeler gauge can be used to find the first point point of flange contact. Bolts must be further tightened until maximum bolt torque is achieved. Since it is not assured that full flange contact is achieved, th e most conservative calculationbest What is needed is a torque value which corresponds to the maximum gasket load just before flange to flange contact is made. Any further tightening will then act to reduce the edge moment

$M(r) := M_C + LT_M$ $\quad LT_M := -q \cdot r^2 G_{17}$ $\quad G_{17} := \frac{3+\nu}{16}$ $\quad \nu \equiv 0.3$ $\quad G_{17} = 0.206$

$M_c := K_m \cdot q \cdot a^2$ $\quad K_m := G_{17}$ for full pressure load

$a := r_o$

from"Roark's Formulas for Stress and Strain", 6th ed. table 24, case 10a, simple supports

$$M(r) := G_{17} \cdot q \cdot r_o^2 \left[1 - \left(\frac{r}{r_o} \right)^2 \right]$$

which is a maximum for r = 0 and zero for r = edge radius

For fixed edge condition and full pressure load

$G_{17fe} := \frac{1+\nu}{16}$ $\quad G_{17fe} = 0.081$

as before:

$M_{c\_fe} := K_m \cdot q \cdot a^2$ $\quad K_m := G_{17}$ for full pressure load

so stress reduction ratio (from simple to fixed edge condition) is:

$R_{sf} := \frac{G_{17fe}}{G_{17}}$ $\quad R_{sf} = 0.394$

maximum bending stress from pressure is 40% of that for a simple support

with central opening

For the small 2.75 inch flange on the spool we consider this as a loose flange, per mandatory Appendix 2 of Section VIII- Div. 1

gasket calculations

From Appendix 2 Section VIII-Div. 1 Rules for Bolted Flange Connections with Ring type Gaskets:

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

$$\begin{aligned} W_{m1} &= H + H_p \\ &= 0.785G^2P + (2b \times 3.14GmP) \end{aligned} \qquad (1)$$

(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).

$$W_{m2} = 3.14bGy \qquad (2)$$

where G is the gasket diameter

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

$m_{Cu\_flat} := 4.75$ $\qquad y_{Cu\_flat} := 13000psi$

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):

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

$b_{ke} = 0.031\,in$

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

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

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

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

and eq(2):

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

$$OD_{CF} = \begin{pmatrix} 1.33 \\ 2.125 \\ 2.75 \\ 3.375 \\ 4.5 \\ 4.625 \\ 6 \\ 8 \\ 10 \\ 13.25 \end{pmatrix} \text{in} \quad P_{m1} = \begin{pmatrix} 6272 \\ 5763 \\ 4045 \\ 3994 \\ 3163 \\ 2611 \\ 2666 \\ 2124 \\ 1514 \\ 1143 \end{pmatrix} \text{psi} \quad W_{m2} = \begin{pmatrix} 980 \\ 1519 \\ 2146 \\ 2899 \\ 3526 \\ 4153 \\ 5770 \\ 7914 \\ 10786 \\ 14498 \end{pmatrix} \text{lbf} \quad \text{compare-->} \quad W_{CF} = \begin{pmatrix} 7500 \\ 13040 \\ 15648 \\ 25216 \\ 27776 \\ 30400 \\ 55552 \\ 78720 \\ 99840 \\ 1 \times 10^5 \end{pmatrix} \text{lbf}$$

We see that the gasket preloading requirement is easily met, and that the gaskets can hold far higher pressure than necessary (350 psi). Flange strength will thus be the determinant of pressure capability.

Pressure Relief Valve Capacity

References:

1. ASME Pressure Vessel Code Section VIII div 1 (2007)
2.
3.

Xenon gas volume:

$w_b := 2000\text{kg}$

$MPa := 10^6 Pa$

$1.5 \cdot 406 = 609$

$bar := .103MPa$

$bar = 1.03 \times 10^5 Pa$

$kJ := 10^3 J$

$d_{gr} := 4in$

$l_{gr} := 36in$

$v_{gr} := .7854 \cdot d_{gr}^{2} \cdot l_{gr}$

$v_{gr} = 7.413\,L$