Lawrence Berkeley Laboratory-
Univ. of California
Engineering Note

cat. code: RP3135
serial :10688
dept.: Mech.Engineering

date:3/2/2012

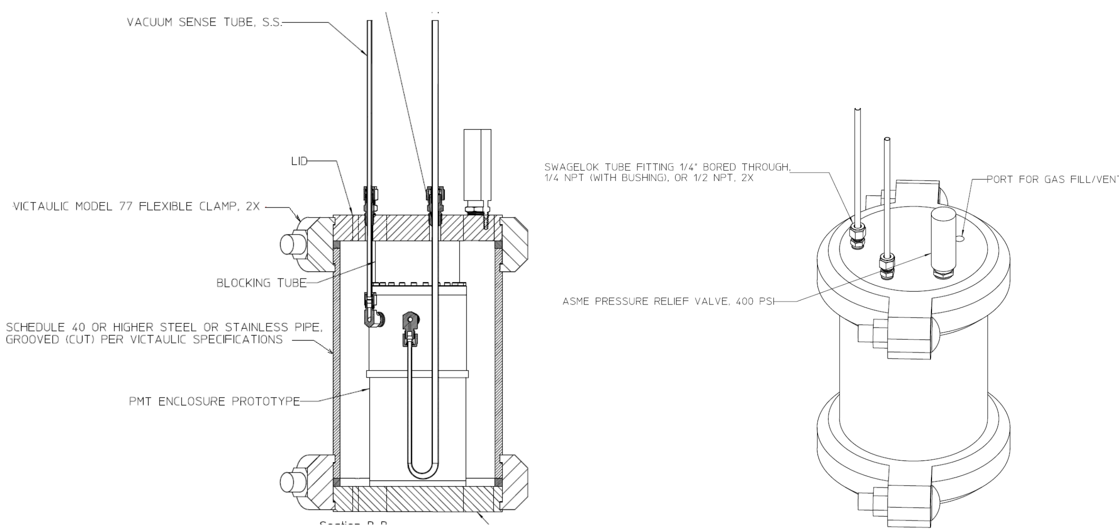
proj: **NEXT-100 XENON TPC**
Energy Plane, Tooling
title: **Pressure Safety Note, Pressure Test Chamber**

DRAFT

This is an Engineering Safety Note for a small pressure vessel to be used for gas pressure testing prototype photomultiplier tube (PMT) enclosures for the NEXT-100 Xenon Time Projection Chamber (TPC). The PMT enclosures operate under external xenon gas pressure of 15 bara.

The pressure vessel is a simple construction using Victaulic grooved pipe couplers with a section of 6" IPS schedule 40 pipe, 9 inch long, and two 1 inch thick caps. This results in a much lighter and easier assembling vessel than a similar one with ANSI flanges. One cap, the lid, is drilled and tapped for several 1/4NPT fitting to allow pressurization/vent, pressure relief and two service tubes from the PMT enclosure inside the vessel to be brought out.

The vessel will likely be used no more than 2 dozen times.



Background

NEXT is a collaboration between LBNL and other institutions to build a detector to observe neutrinoless double beta decay. This TPC will contain 100 kg of enriched Xenon gas at up to 15 bara pressure. The PMTs used inside this gas volume cannot withstand this pressure, so an enclosure has been designed to protect it.

Although not the subject of this Note, this PMT enclosure is designed in accordance with ASME PV code sec VIII div. 1, and sees external pressure only. It is fabricated from OFE (C10100) copper for high radiopurity, and is heavily built to provide shielding from background gamma rays. The enclosure incorporates a single crystal sapphire window for the PMT to view light produced in the xenon gas; this is the critical strength component of the enclosure due to its brittle failure mode. There will be a total of 60 of these windows inside the TPC, and they have been designed using the methodology of the Weibull distribution, in combination with linear elastic fracture mechanics to provide a quantitative estimate of reliability. These windows will be pressure tested hydrostatically in a separate test chamber (described in a separate note) before using.

This pressure test chamber is for the purpose of demonstrating proper PMT operation under high pressure conditions. We are primarily interested in measuring Xenon permeation through O-ring seals, and the achievable vacuum inside the enclosure under actual external pressure, using different conduit tubing diameters. We want to verify the collapse resistance of the different tubing diameters (after bending to shape). We plan to use an aluminum alloy substitute "window" here for most tests to avoid any brittle fracture possibility. We may run a pressure test with a pre-tested sapphire window installed; we will first do this without a PMT inside the enclosure, and with a high flow filter or muffler installed on the outside tubing (open to atmosphere) so as to capture any fragments of sapphire should it fracture.

The maximum pressure to be applied to the windows, for testing is 1.6 x 15 bara = 360 psia; therefore we set 350 psig as the MOP for the test vessel described below.

Assembly and Operation

The PMT enclosure prototype, (with cable conduit and vacuum sense tubes assembled) is placed inside the vessel, as shown above. The lid is placed over the tubes and the top clamp assembled. The through bored Swagelok tube fittings have plastic ferrules to avoid tube deformation that would disallow lid removal without cutting the tube.

The space between the vessel and the enclosure will then be pressurized with inert gas, thus applying an external pressure to the PMT enclosure. During this time, a vacuum will be applied through the cable conduit tube, and the vacuum inside the PMT enclosure will be measured with a vacuum gauge applied to the vacuum sense tube. In further testing the PMT will be assembled inside the enclosure, with electrical signals brought out through the cable conduit/vacuum tube; allowing the PMT operation to be verified. the PMT operates at a modestly high voltage 1.5 kV and we are concerned about flashover on the pins and resistor base

$$MOP := 350psi$$

ASME certified pressure relief valves are available in 400 psi (closest size)

$$MAWP := 400psi$$

Check , is MAWP > 110% MOP? (per PUB3000 recommendations)

$$MAWP > 1.1MOP = 1$$

The pressure vessel is simply a section of 6 inch schedule 40 stainless steel pipe, grooved on each end for Victaulic grooved pipe couplers (type 77, flexible). the ends are capped with stainless steel lids machined from plate.

All components except the lid and cap, are manufacturer rated for working pressures higher than MAWP above. The lid and cap are designed and made here at LBNL

Pipe Calcs

Pipe is a 6" schedule 40 IPS (6.625"OD x .28"thk) welded 304 stainless steel. It is likely ASME SA-312 (general purpose austenic stainless welded and seamless pipe), though provenance is unknown.

Maximum allowable stress, from **2009b ASME PV code sec II, part D - table 1A**,

$$S := 17000psi \qquad E := 1 \qquad R_{pipe} := 3.03in \qquad t_{pipe} := .28in$$

From **UG-27** pressure rating would be:

$$P_{pipe\_max} := \frac{S \cdot E \cdot t_{pipe}}{R_{pipe} + 0.6t_{pipe}} \qquad P_{pipe\_max} = 1.488 \times 10^{3}\,psi$$

However, pressure rating is conjunction with the Victaulic type 77 flanges is given in Victualic publication # 17.09 "Pressure Ratings and End Loads for Victaulic Ductile Iron Grooved couplings on stainless steel pipe" :


Style 07 Zero-Flex Rigid Coupling


Style 77 Flexible Coupling


Style 75 Standard Coupling


Style 741 Vic-Flange® Adapter

Pipe Size		Pipe Inches/millimeters			Style 07		Style 77		Style 75		Style 741	
					Maximum		Maximum		Maximum		Maximum	
Nominal Dia. In./mm	Actual Out. Dia. In./mm	Wall Thickness	Sched. #	R = Roll C = Cut	Work. Press.* PSI/kPa	End Load* Lbs./N	Work. Press.* PSI/kPa	End Load* Lbs./N	Work. Press.* PSI/kPa	End Load* Lbs./N	Work. Press.* PSI/kPa	End Load* Lbs./N
165,1 mm	6.500 165,1	0.280 7,11	–	C	700 4825	23230 103375	750 5175	24900 110805	450 3100	14930 66440	250 1725	8300 36935
		0.280 7,11	–	R	450 3100	14930 66440	500 3450	14930 66440	300 2065	9955 44300	150 1034	4975 22140
		0.134 3,40	–	R	200 1375	6635 29525	200 1375	6635 29525	125 862	4150 18470	125 862	4150 18470
		0.109 2,77	–	R	125 862	4150 18470	125 862	4150 18470	75 517	2490 11080	75 517	2490 11080
6 150	6.625 168,3	0.280 7,11	40S	C	700 4825	24130 107380	750 5175	25850 115030	450 3100	15525 69085	250 1725	8625 38380
		0.280 7,11	40S	R	450 3100	15515 69040	500 3450	17235 76695	300 2065	10340 46015	150 1034	5170 23005
		0.134 3,40	10S	R	200 1375	6895 30685	200 1375	6895 30685	125 862	4310 19180	125 862	4310 19180
		0.109 2,77	5S	R	125 862	4310 19180	125 862	4310 19180	75 517	2585 11505	75 517	2585 11505

Therefore:

$Pmax\_SSpipe\_Vic77 := 750psi$ pipe has a cut groove

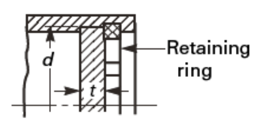
This publication also states that a one time only overpressure of 1.5x the max. working pressure is acceptable for a field test. We will not exceed the working pressure for the hydraulic presure test

Lid and Cap Calculations

From **UG-34 Unstayed Flat Heads and Covers**

diameter: $d := 6.625in$

attachment factor: $C := 0.3$ from fig. UG-34:



C = 0.30
(m)

$P := MAWP$ $P = 27.225\,bar$

material : steel SA--283 carbon steel or better (plate is SA-240 304L stainless steel (UNS30403)

$S_{283} := 15700psi$ $S_{304} := 16700psi$ from table 1A ASME PV code,sec II part D

$E = 1$ (weld efficiency) from Table UW12

$S_{plate} := S_{283}$

Minimum head thickness is then:

$$t_{min} := d \cdot \sqrt{\frac{C \cdot P}{S_{plate} \cdot E}} \qquad t_{min} = 0.579\,in \tag{1}$$

$$t := 1.0 \cdot in \qquad t > t_{min} = 1$$

This completes the calculation for the (bottom) cap. The lid has four 1/4-NPT tapped holes in it:

UG39 Reinforcement Required for Openings in Flat heads

UG-39(a) General, rules in this section are exempted for openings that do not exceed size and spacing limits of UG-36(c)(3)

UG-36 (c) (3) Strength and Design of finished Openings:

(3) Openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:

<--no rapid fluctuations

(a) welded, brazed, and flued connections meeting the applicable rules and with a finished opening not larger than:

$3\frac{1}{2}$ in. (89 mm) diameter — in vessel shells or heads with a required minimum thickness of $\frac{3}{8}$ in. (10 mm) or less;

<-- not applicable

$2\frac{3}{8}$ in. (60 mm) diameter — in vessel shells or heads over a required minimum thickness of $\frac{3}{8}$ in. (10 mm);

(b) threaded, studded, or expanded connections in which the hole cut in the shell or head is not greater than $2\frac{3}{8}$ in. (60 mm) diameter;

<--holes <60mm dia

(c) no two isolated unreinforced openings, in accordance with (a) or (b) above, shall have their centers closer to each other than the sum of their diameters;

<-- check this below

(d) no two unreinforced openings, in a cluster of three or more unreinforced openings in accordance with (a) or (b) above, shall have their centers closer to each other than the following: for cylindrical or conical shells,

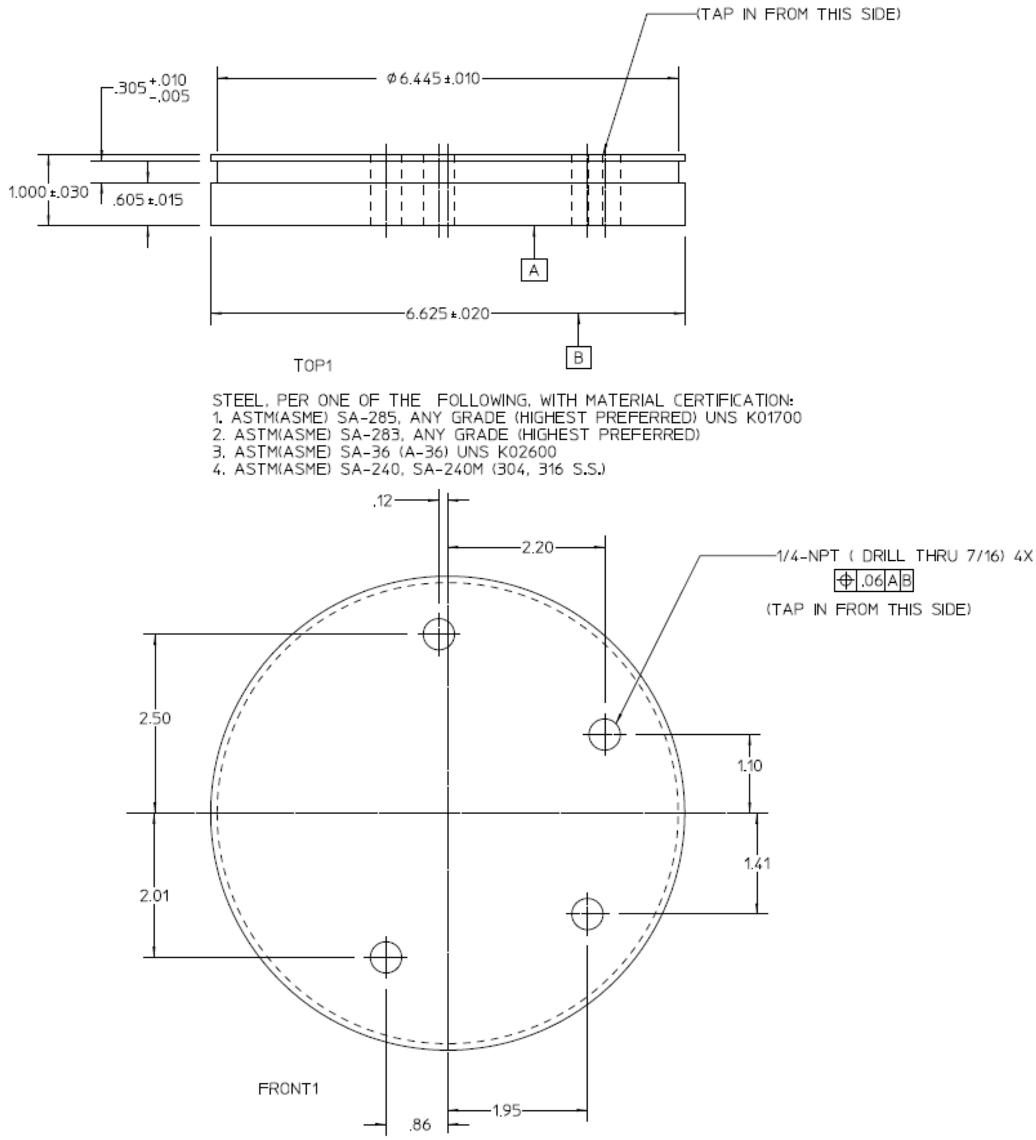
<-- check this below

$$(1 + 1.5 \cos \theta)(d_1 + d_2);$$

for doubly curved shells and formed or flat heads,

$$2.5(d_1 + d_2)$$

Lid drawing is shown below (excerpted):



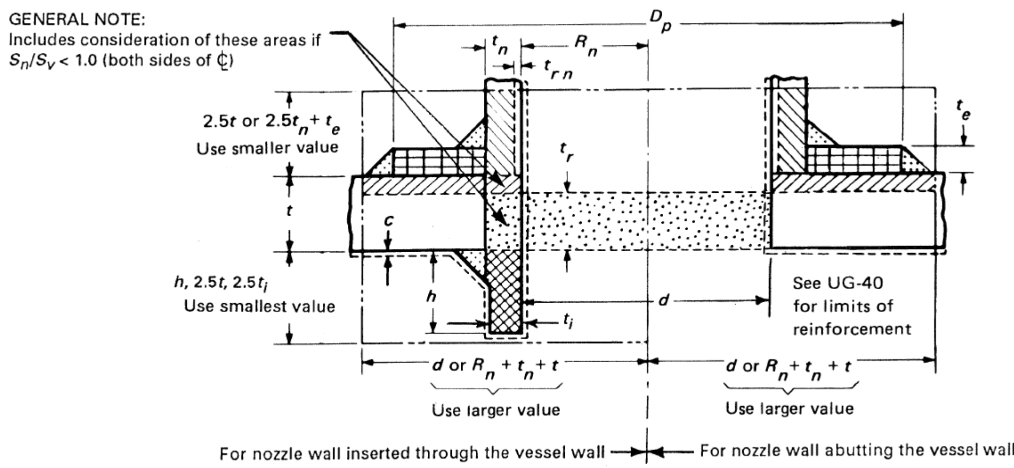
holes do not form clusters so (d) is not applicable; closest hole spacing is

$d_s := 2.5\text{in}$ These are 1/4NPT holes $d_o := .44\text{in}$

Reinforcement is not needed, and in fact, 1/2-NPT holes could be used, where d=.73in

Nevertheless we calculate here:

FIG. UG-37.1 NOMENCLATURE AND FORMULAS FOR REINFORCED OPENINGS



We have no nozzle, weld or reinforcement, reinforcement area is only available as extra shell thickness

$d := d_o$ $\quad d = 0.44\,in$ $\quad F := 1.0$ $\quad f_r := 1.0$ $\quad f_{r1} := 1.0$ $\quad E_1 := 1$ $\quad f_{r2} := 1$

$t_r := t_{min}$ $\quad t_r = 0.579\,in$ $\quad t = 1\,in$ $\quad t_n := 0in$

Area or reinforcement required:

$$A_{req} := d \cdot t_r \cdot F + 2t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) \qquad A_{req} = 0.255\,in^2$$

Area available in shell:

$$A_{1a} := d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$
$$A_{1b} := 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$A_1 := \max(A_{1a}, A_{1b}) \qquad A_1 = 0.842\,in^2$$

$$A_1 > A_{req} = 1$$

Cap and Lid material certs:

Outokumpu Stainless Plate, Inc.

OUTO KUMPU

Certificate of Analysis and Tests

OUR ORDER 0276973 - 01 HEAT & PIECE 852271-2A 08/23/11

SOLD TO: SHIP TO: UC ~~11202~~ 11193 Derek Shuman

--- YOUR ORDER & DATE ---

796 7/22/11

--- ITEM DESCRIPTION ---

HEAT & PIECE 852271 - 2A
WEIGHT 7272
FINISH 1
GRADE 304LP / 304P UNS-S30403 / UNS-S30400
DIMENSIONS 1.000 X 101.000 X 243.000 EXACT

--- SPECIFICATIONS ---

*** MFG IN NEW CASTLE, IN, USA
AMS 5511H WITH EXCEPTIONS
PLUS [illegible] PRODEC
ASTM A240-11A ASME SA240-10E
ASTM A167-[illegible]
MIL-S-5059D WITH EXCEPTIONS
ASTM E112-96E2
ASTM A312-11 CHEM&MECH ONLY
NO SPECS REQUIRED ON INVOICE
QQ-S-763F COND A CHEM ONLY
NACE MR0175-2003/ISO 15156
NO WEEE RELEVANT SUBSTANCES
ASTM A262-02A PRACTICE A
PRODEC QUALITY

FROM SLABS IMPORTED FROM BRITAIN
AMS 5513J WITH EXCEPTIONS
ASTM A276-10 CHM&MECH CON-A
ASTM A480-11A ASMESA480 10ED
ASTM A479-10A CHEM&MECH ONLY
OUTOKUMPU MACH TEST LP020
MEETS RQMTS UNS S30302 T302
QQ-S-766D AMENDIII EX.P4.5.2
LIST HEAT/PIECES ON INVOICE
ASTM A666-03 ANN COND ONLY
MEETS EU ELECTRICAL ROHS
DFAR 252.225-7014 & ALT 1
ASTM A262-02A PRACTICE E

PLATES & TEST PCS SOLUTION ANNEALED @ 1900 DEGREES FAHRENHEIT MINIMUM.
THEN WATER COOLED OR RAPIDLY COOLED BY AIR
FREE FROM MERCURY CONTAMINATION AT CURRENT DETECTION LIMITS
HOT ROLLED, ANNEALED & PICKLED (HRAP)

--- MECHANICAL & OTHER TESTS ---

HARDNESS HRBW	79
GRAIN SIZE	6
YIELD STRENGTH (PSI)	43013
TENSILE STRENGTH (PSI)	91950
BEND	OK
INTERGRANULAR CORROSION	OK
ELONGATION % IN 2"	54.7
REDUCTION OF AREA %	53.5

CMTR'S FURNISHED BY
CUSTOMER TCI ALUMINUM/NORTH
P.O.# 32991 S.O.# 6777
DESC. 24 x 24
QTY. 1PC

--- CHEMICAL COMPOSITION ---

CARBON	(C)	.016
MANGANESE	(MN)	1.38
PHOSPHORUS	(P)	.030
SULFUR	(S)	.021
SILICON	(SI)	.41
CHROMIUM	(CR)	18.36
NICKEL	(NI)	8.12
COBALT	(CO)	.15
COPPER	(CU)	.46
MOLY	(MO)	.38
NITROGEN	(N)	.07
COLUMBIUM	(CB)	.010
TITANIUM	(TI)	.009
ALUMINUM	(AL)	.005
TIN	(SN)	.016
TANTALUM	(TA)	.001

ISO 9001-2008
SAI Cert#CERT-0033834

WE HEREBY CERTIFY THAT THE MATERIAL HEREIN HAS BEEN MADE AND TESTED IN ACCORDANCE WITH THE LISTED SPECIFICATION(S) AND THAT THE RESULTS OF ALL TESTS ARE ACCEPTABLE.

JAMES DOUBMAN,QUALITY ASSURANCE MANAGER

Outokumpu Stainless Plate, Inc.
P.O. Box 370
New Castle, Indiana 47362

The remainder of the vessel will consist of Swagelok tube fittings, stainless steel, in tube sizes from 1/4 to 7/16. Swagelok pressure ratings are based on the size of the lowest rated end connection, which is 1/4-NPT. From Swagelok publication MS-01-140.pdf :

Pressure Ratings

Ratings are based on ASME Code for Pressure Piping B31.3, Process Piping, at ambient temperature.

NPT/ ISO Pipe Size	316 SS and Carbon Steel				Brass			
	Male		Female		Male		Female	
in.	psig	bar	psig	bar	psig	bar	psig	bar
1/16	11 000	760	6700	460	5500	380	3300	230
1/8	10 000	690	6500	440	5000	340	3200	220
1/4	8 000	550	6600	450	4000	270	3300	220
3/8	7 800	540	5300	360	3900	270	2600	180
1/2	7 700	530	4900	330	3800	260	2400	160
3/4	7 300	500	4600	320	3600	250	2300	160
1	5 300	370	4400	300	2600	180	2200	150
1 1/4	6 000	410	5000	350	3000	200	2500	170
1 1/2	5 000	340	4600	310	2500	170	2300	150
2	3 900	270	3900	270	1900	130	1900	130