NEXT-100 DIMENSIONS   D. Shuman   1/9/11

Mass of Xenon in Vessel at Maximum Operating Pressure (absolute):

Assume we have either 100 or 200 kg. total Xe, and 85% of this comprises the active mass (volume of gas inside a cylinder inscribed within the QT/WLS assembly array), and 15% remains in plumbing and interstitial spaces:

$M_{Xe\_200} := 170kg$ @20bar   or $M_{Xe\_100} := 85kg$ @10bar

Maximum Operating pressures (absolute) for the 200/100 kg options:

$P_{MOPa\_200} := 20bar$ $P_{MOPa\_100} := 10bar$

Operating Temperature, physical constants:

$T_{amb} := 293K$ $R := 8.314 J \cdot mol^{-1} \cdot K^{-1}$ $M_{a\_Xe} := 136 gm \cdot mol^{-1}$

Critical Pressure, temperature of Xenon:

$P_{c\_Xe} := 58.40 bar$ $T_{c\_Xe} := 15.6K + 273K$ $T_{c\_Xe} = 288.6 K$

reduced pressure:

$P_{r\_200} := \dfrac{P_{MOPa\_200}}{P_{c\_Xe}}$ $P_{r\_200} = 0.342$ $P_{r\_100} := \dfrac{P_{MOPa\_100}}{P_{c\_Xe}}$ $P_{r\_100} = 0.171$

reduced temperature

$T_r := \dfrac{T_{amb}}{T_{c\_Xe}}$ $T_r = 1.015$

Compressibility Factors: from chart for pure gasses shown below
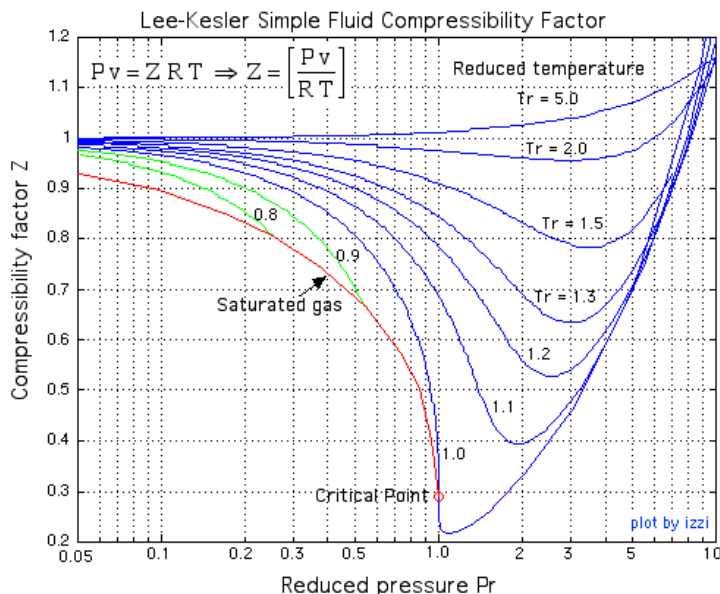$Z_{Xe\_20bar} := 0.87$ $Z_{Xe\_10bar} := .96$

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/

Fig. 6 Compressibility Factor, pure gasses

Number of moles:

$$n_{Xe\_200} := \frac{M_{Xe\_200}}{M_{a\_Xe}} \quad n_{Xe\_200} = 1.25 \times 10^3 \, mol \qquad n_{Xe\_100} := \frac{M_{Xe\_100}}{M_{a\_Xe}} \qquad n_{Xe\_100} = 625 \, mol$$

Volume required:

$$V_{Xe\_200} := \frac{n_{Xe\_200} \cdot Z_{Xe\_20bar} \cdot R \cdot T_{amb}}{P_{MOPa\_200}} \qquad V_{Xe\_200} = 1.307 \, m^3$$

$$V_{Xe\_100} := \frac{n_{Xe\_100} \cdot Z_{Xe\_10bar} \cdot R \cdot T_{amb}}{P_{MOPa\_100}} \qquad V_{Xe\_100} = 1.442 \, m^3$$

Since chamber will be designed for 20 bar, we can tolerate slightly higher than 10 bar pressure at 100 kg, so we design for the smaller volume:

$$n_{Xe} := n_{Xe\_200} \qquad V_{Xe} := V_{Xe\_200} \qquad P_{MOPa} := P_{MOPa\_200}$$

molar, mass, volumetric density:

$$\rho_{mol} := \frac{n_{Xe}}{V_{Xe}} \quad \rho_{mol} = 0.956 \frac{mol}{L}$$

$$\rho_{Xe} := \rho_{mol} \cdot M_{a\_Xe} \quad \rho_{Xe} = 0.13 \frac{gm}{cm^3}$$

$$v_{Xe} := \rho_{Xe}^{-1} \quad v_{Xe} = 7.688 \frac{cm^3}{gm}$$

We desire active length to be = 1.25x active diameter. then:

Active volume radius: $r_{Xe} := \sqrt[3]{\dfrac{V_{Xe}}{2.5\pi}}$ $\qquad r_{Xe} = 0.550 \, m$

and $\quad l_{Xe} := 2.5 r_{Xe}$ $\qquad l_{Xe} = 1.375 \, m$

Quartz Tube (QT) length:

items using up qt length (full length qt is needed):

shield: $l_{shld} := 20cm$

Si PMT plane: $l_{SiPMT} := 1cm$

EL grid frameset: $l_{EL} := 3cm$

cathode plane: $l_{cath} := 3cm$

QT length:

$$l_{qt} := l_{Xe} + \left(l_{shld} + l_{SiPMT} + l_{EL} + l_{cath}\right) \qquad l_{qt} = 1.645 \, m$$

Maximum available quartz tube length is over 2m so we are OK.

QT tube outer radius:

$r_{qt} := 21\text{mm}$

QT/WLS sys. nom radius (at QT axis)

$R_{wls} := r_{Xe} + r_{qt} \qquad R_{wls} = 0.571\,\text{m}$

QT dimensional tolerances

bow: OD (+/-)   ovality

$tol_{bow} := 1.5\dfrac{\text{mm}}{\text{m}}\cdot l_{qt}$ $tol_{OD} := 1\text{mm}$ $tol_{ov} := 0.5 tol_{OD}$

                    $tol_{ov} = 0.5\,\text{mm}$

$tol_{bow} = 2.468\,\text{mm}$

total tolerance:

$tol_{tot} := tol_{bow} + tol_{OD} + tol_{ov} \qquad tol_{tot} = 3.968\,\text{mm}$ OK, should be less than tube-to-tube spacing s_{qt} below

Number of QT's

$N_{qt} := 75$

Angle of QT spacing $\theta_{qt} := \dfrac{360\text{deg}}{N_{qt}} \qquad \theta_{qt} = 4.8\,\text{deg}$

Tangential QT spacing (nominal):

$s_{qt} := R_{wls}\cdot\sin(\theta_{qt}) - 2r_{qt} \qquad s_{qt} = 5.782\,\text{mm}$ check that $s_{qt} > tol_{tot}$ $tol_{tot} = 3.968\,\text{mm}$ OK

Xenon vessel inner radius, min.:

$R_{i\_Xev\_min} := r_{Xe} + 2r_{qt} + tol_{tot} + 1\text{mm} \qquad R_{i\_Xev\_min} = 0.597\,\text{m}$

Set Xenon vessel inner radius to:

$R_{i\_Xev} := 0.6\text{m}$

Note that this assumes there is no cylindrical reflector and gas distribution annulus outside the QT/WLS array and Xenon gas distribution pipes (PTFE) are located in the interstitial spaces behind the QTs.

Xenon Vessel wall thickness

$t_{Xev} := 1\text{cm}$ Note, this is likely a practical minimum which allows sealing and fastener attachment at flange; wall thickness can be thinner elsewhere (see below), and some outward extension past this at the cathode may be permissible.

Buffer gas annulus thickness, at main service flange

$t_{bg} := 2\text{cm}$ Though this annulus is tapered, the EL "cathode" grid HV will be near the flange and will have a substantial voltage (?30 kV). Also, the HV cable feeding the EL cathode grid will enter in through this annulus and has a finite width, of perhaps 7mm

Pressure Vessel inner radius:

$R_{i\_pv} := R_{i\_Xev} + t_{Xev} + t_{bg} \qquad R_{i\_pv} = 0.63\,\text{m}$

Vessel wall thicknesses

Pressure vessel

maximum allowable material stresses, from ASME 2009 Pressure Vessel code, sec. II part D, table 1B:

Grade 1 Titanium $S_{max\_Ti\_g1} := 10000\,psi$

Grade 2 Titanium $S_{max\_Ti\_g2} := 14300\,psi$

Grade 9 Titanium (3Al-2.5V) $S_{max\_Ti\_g9} := 25700\,psi$ (all annealed)

Grade 10200-O25 Copper (OF) $S_{max\_C10200} := 6700\,psi$

Maximum Operating Pressure (MOP), gauge:

$$MOP_{pv} := \left(P_{MOPa} - 1\,bar\right) \qquad MOP_{pv} = 19\,bar$$

Maximum allowable pressure, gauge (from LBNL Pressure Safety Manual, PUB3000)
at a minimum, 10% over max operating pressure:

$$MAWP_{pv} := 1.1 MOP_{pv} \qquad MAWP_{pv} = 20.9\,bar$$

then, for inner radius: $R_{i\_pv} = 0.63\,m$

for both xenon and pressure vessels, use ASME code formula (sec VIII, UG-27, eq(1) for min vessel wall thickness:

minimum wall thickness, grade 2 Titanium: $E_w := 1$ maximum weld efficiency: use fusion (E-beam or diffusion) welding and radiograph welds

$$t_{pv\_min\_g2} := \frac{MAWP_{pv} \cdot R_{i\_pv}}{S_{max\_Ti\_g2} \cdot E_w - 0.6 \cdot MAWP_{pv}} \qquad t_{pv\_min\_g2} = 1.371\,cm$$

minimum wall thickness, grade 9 Ti (3Al-2.5V)

$$t_{pv\_min\_g9} := \frac{MAWP_{pv} \cdot R_{i\_pv}}{S_{max\_Ti\_g9} \cdot E_w - 0.6 \cdot MAWP_{pv}} \qquad t_{pv\_min\_g9} = 0.759\,cm$$

minimum wall thickness, Copper, OF grade, annealed

$$t_{pv\_min\_Cu} := \frac{MAWP_{pv} \cdot R_{i\_pv}}{S_{max\_C10200} \cdot E_w - 0.6 \cdot MAWP_{pv}} \qquad t_{pv\_min\_Cu} = 2.971\,cm$$

Note that this is nominal wall thickness, not near flanges; main service flange thickness will be determined by bending moments from fastener loads. Also at cathode end , radius is larger and will require a proportional thickness increase.

Xenon inner vessel minimum wall thickness:

use max. stress in PMMA = 0.1Sy

$$S_{y\_PMMA} := 78\,MPa \qquad S_{y\_PMMA} = 1.131 \times 10^4\,psi$$

$$S_{max\_PMMA} := 0.1 S_{y\_PMMA} \qquad S_{max\_PMMA} = 7.8 \times 10^6\,Pa$$

Assume maximum differential pressure: $dP_{Xe} := 0.1\,bar$

then, minimum thickness: $t_{Xe\_min} := \dfrac{dP_{Xe} \cdot R_{i\_Xev}}{0.1 S_{y\_PMMA} - 0.6 dP_{Xe}}$ $t_{Xe\_min} = 0.078\,cm$