Project: PS-TGT-12-001 Hall A Tritium Target

Tittle: Estimated pressure in tritium cell and permeation rate

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Author: Dave Meekins

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Code(s) of Record:

Reference Codes and Sources:

- Losowski et. al. Leak testing of Conflat-type flanges under internal pressure (2004)
- Holt et. al. Tritium permeability of the Al target cell (2012)
- DOE Handbook of Tritium Handling and Safe Storage
- Swagelok MS-01-22 Bellows Sealed Valves

Description:

General target cell calculations for tritium quantity, pressure in cell, permeation, and fugacity from beam disassociation.

Reference Drawing(s):

TGT-103-1000-0013	Cell assembly with shipping covers

Units and definitions:

$Ci := 3.7 \cdot 10^{10} \cdot Bq$ one Curie

$M_{He} := 4 \cdot \frac{gm}{mol}$ molar mass of He

$M_{H2} := 2 \cdot \frac{gm}{mol}$ molar mass of protium H2

General properties of tritium:

$t_{0.5} := 12.32 \cdot yr = \left(3.888 \cdot 10^{8}\right)\ s$ Half life of T2

$\tau := \frac{t_{0.5}}{\ln(2)} = \left(5.609 \cdot 10^{8}\right)\ s$ mean lifetime

$\lambda := \frac{1}{\tau} = \left(1.783 \cdot 10^{-9}\right)\ \frac{1}{s}$ decay const

$M_{T2} := 6\ \frac{gm}{mol}$ Molar mass of T2

$t_{day} := 1 \cdot day$ time = 1 day

$R_{day} := 1 - e^{-\lambda \cdot t_{day}} = 0.015\%$ Decay rate per day

General properties of aluminum 7075

$M_{AL} := 26.98 \cdot \frac{gm}{mol}$ molar mass of Aluminum

$\rho_{AL} := 2.7 \cdot \frac{gm}{cm^{3}}$ Density of Al

Dimensions of the cell

Volume estimate for the cell including fill valve:

$D_1 := 0.5 \cdot in$	bore of main body
$L_1 := 9.52 \cdot in$	length of main body
$V_1 := \pi \cdot \frac{D_1^{\ 2}}{4} \cdot L_1 + \frac{4}{3}\ \pi \cdot \left(\frac{D_1}{2}\right)^3$	volume in main body
$D_{et} := 0.775 \cdot in$	entrance window bore in main body
$D_{fill} := 0.125 \cdot in$	ID of fill tube section in main body
$L_{fill} := 1.063 \cdot in$	length of fill tube on main body
$L_{et} := 2.83 \cdot in$	entrance window bore in main body
$D_{win} := 0.75 \cdot in$	OD of entrance window
$V_2 := \pi \cdot \frac{D_{fill}^{\ 2}}{4} \cdot L_{fill} = \left(2.138 \cdot 10^{-4}\right)\ L$	vol of active length of main body
$V_3 := \frac{\pi}{4} \cdot \left(D_{et}^{\ 2} - D_{win}^{\ 2}\right) \cdot L_{et} = 0.001\ L$	volume in re-entrant window bore
$V_{in} := V_1 + V_2 + V_3 = 0.033\ L$	total volume in main body
$L_{stem} := \left(\frac{1.06}{2} + 1.595\right) \cdot in$	eff length of valve stem
$D_{stem} := 0.125 \cdot in$	ID of stem
$V_{stem} := \frac{\pi}{4} \cdot L_{stem} \cdot D_{stem}^{\ 2}$	Volume of stem

total volume in cell:

$$V_{cell} := V_{in} + V_{stem} = 0.034\ L$$

This will have to be measure for a more accurate result

Area:

The surface areas of the thin sections of the cell will be required to determine the permeation through the cell. These are determined via the CAD model.

$$A_{main} := 2 \cdot 3.331 \cdot in^2 + 0.438 \cdot in^2 = 0.005\ m^2$$ Main body

$$A_{ent} := 0.196 \cdot in^2 = \left(1.265 \cdot 10^{-4}\right)\ m^2$$ Entrance window

$$A_{tube} := L_{et} \cdot \pi \cdot D_{win} = 0.004\ m^2$$ area of ent window tube

Cell Pressure:

To estimate the cell pressure at room temp, we assume a fill of 1090 Ci of T2 at 100% purity.

$N_{act} := 1090 \cdot Ci = \left(4.033 \cdot 10^{13}\right)\ Bq$ total target activity

$N_T := \dfrac{N_{act}}{\lambda} = 2.262 \cdot 10^{22}$ total number of T atoms

$n_{T2} := \dfrac{N_T}{2 \cdot N_A} = 0.019\ mol$ mols of T2

$m_{T2} := n_{T2} \cdot M_{T2} = 0.113\ gm$ total mass of T2

$\rho_{T2} := \dfrac{m_{T2}}{V_{in}} = 0.003\ \dfrac{gm}{cm^3}$ target density

$L_{T2} := \rho_{T2} \cdot 25 \cdot cm = 0.085\ \dfrac{gm}{cm^2}$ nuclear target length

$n_{act} := \dfrac{N_{act}}{n_{T2}} = \left(2.147 \cdot 10^{15}\right)\ \dfrac{Bq}{mol}$ activity of T2 per mol

$T_{room} := 295 \cdot K$ assumed room temp

$z_{T2}(P) := 1 + P \cdot 8.32 \cdot \dfrac{10^{-7}}{torr}$ compressibility

$Z := z_{T2}(200 \cdot psi) = 1.009$ assumed compressibility of T2

Total absolute pressure in cell

$$P_{cell} := \frac{n_{T2} \cdot Z \cdot T_{room} \cdot R}{V_{cell}} = 199.766\ psi$$

At STP we have

$$T_{stp} := 273.15 \cdot K$$

$$P_{stp} := 760 \cdot torr$$

$$V_{stp} := \frac{n_{T2} \cdot R \cdot T_{stp}}{P_{stp}} = 0.421\ L$$

Stored energy in the cell: pressure and chemical

$$E_{pres} := P_{cell} \cdot V_{cell} = 46.463\ J$$ pressure energy

$$H_{H2O} := 242000 \cdot \frac{J}{mol}$$ heat of formation H2O

$$E_{HTO} := H_{H2O} \cdot n_{T2} = \left(4.545 \cdot 10^{3}\right)\ J$$ stored chem energy in cell

$$E_{tot} := E_{HTO} + E_{pres} = \left(4.592 \cdot 10^{3}\right)\ J$$ total energy

$$TNT := \frac{E_{tot} \cdot lbm}{1488617 \cdot ft \cdot lbf} = 0.001\ kg$$ equiv energy in lb of TNT

$$R_s := 50 \cdot \frac{ft}{lb^{\frac{1}{3}}}$$ consequence factor

$$R := R_s \cdot TNT^{\frac{1}{3}} = 2.004\ m$$ Safe keep out zone for no bio effet at all

Permeation:

Diffusion rate from the cell at room temp shall be determined from the estimated hydrogen permeation rate and scaled by the square root of the mass ratio.

$t_{main} := 0.018 \cdot in$ cell wall thickness

$t_{ent} := 0.01 \cdot in$ ent window thick

$t_{tube} := 0.125 \cdot in$ wall thick ent window tube

$P_{atm} := 14.7 \cdot psi$ atm pressure

$D_{7075} := 6 \cdot 10^{-11} \cdot \frac{m^2}{s}$ Diff coef conservative

$C_H := 1 \cdot 10^{-9}$ conservative estimated solubility of H in Al alloy

$\chi_{AL} := \frac{\rho_{AL}}{M_{AL}} = \left(1.001 \cdot 10^{5}\right) \frac{mol}{m^3}$ molar density of Al

Hydrogen permeation rates through various parts of cell

$$Q_1 := \chi_{AL} \cdot C_H \cdot \frac{D_{7075}}{t_{main}} \cdot A_{main} \cdot \sqrt{\frac{P_{cell}}{P_{atm}}} = \left(2.218 \cdot 10^{-13}\right) \frac{mol}{s}$$

$$Q_2 := \chi_{AL} \cdot C_H \cdot \frac{D_{7075}}{t_{ent}} \cdot A_{ent} \cdot \sqrt{\frac{P_{cell}}{P_{atm}}} = \left(1.102 \cdot 10^{-14}\right) \frac{mol}{s}$$

$$Q_3 := \chi_{AL} \cdot C_H \cdot \frac{D_{7075}}{t_{tube}} \cdot A_{tube} \cdot \sqrt{\frac{P_{cell}}{P_{atm}}} = \left(2.999 \cdot 10^{-14}\right) \frac{mol}{s}$$

The leak rate through the two CF flanges is estimated from the leak rate for He which is scaled for H2. Note that these are conservatively very high.

$$L_{He} := 2 \cdot 10^{-10} \cdot atm \cdot \frac{cm^3}{s}$$

$$L_{T2} := L_{He} \cdot \sqrt{\frac{M_{He}}{M_{H2}}} = \left(2.828 \cdot 10^{-10}\right) atm \cdot \frac{cm^3}{s}$$

$$Q_4 := L_{T2} \cdot \frac{1}{T_{room} \cdot R} = \left(1.168 \cdot 10^{-14}\right) \frac{mol}{s}$$

The leak rate through the valve stem and seal is listed by Swagelok

$$L_{He} := 4 \cdot 10^{-9} \cdot atm \cdot \frac{cm^3}{s}$$

$$L_{T2} := L_{He} \cdot \sqrt{\frac{M_{He}}{M_{H2}}} = \left(5.657 \cdot 10^{-9}\right) atm \cdot \frac{cm^3}{s}$$

$$Q_5 := L_{T2} \cdot \frac{1}{T_{room} \cdot R} = \left(2.337 \cdot 10^{-13}\right) \frac{mol}{s}$$

The total leak rate is scaled from the estimated leak rate for H2 for T2

$$R_{T2} := \sqrt{\frac{M_{H2}}{M_{T2}}} = 0.577$$ scale factor

$$Q_T := \frac{\left(Q_1 + Q_2 + Q_3 + 2 \cdot Q_4 + Q_5\right)}{\sqrt{3}} = \left(3.001 \cdot 10^{-13}\right) \frac{mol}{s}$$

$$TT := Q_T \cdot 1 \cdot yr = \left(9.471 \cdot 10^{-6}\right) mol$$

The total activity released in one year is then conservatively estimated at:

$$N_{act} := TT \cdot n_{act} = 0.55\ Ci$$

Note that many of the above assumptions are very conservative and the true leakage is expected to be much less. None the less the valve represents the dominant leak and the possibility of pinch welding should be considered.