FERMILAB ENGINEERING NOTE	SECTION PPD/ETT	PROJECT CDF - CLC	SERIAL - CATAGORY	PAGE 1
SUBJECT Pressure Accumulation in PMT due to Helium Permeation		NAME Mayling Wong		
		DATE 2 April 2002	REVISION DATE	

Summary:

The bulbs of the photomultiplier (PMT) tubes of the CDF-Cherenkov Luminosity Counter have a fused quartz window. The PMTs are manufactured with a 10^{-4} Pa vacuum pressure. This note shows that the pressure in the PMT will become reach 0.02-0.03 Pa due to helium permeation through the quartz window if the PMT is exposed to air for one year. The PMT pressure will reach 0.04 Pa in one year if the PMT is exposed to a pressurized environment at 8 psig (1.5 atm) that contains 5 ppm of helium.

Given:

The construction materials of the PMT are borosilicate glass for its sides and quartz for its window. The quartz window with dimensions 2.54 cm diameter and 1 mm thickness is the vacuum barrier for a PMT. The PMT is constructed so that it has a vacuum pressure of 10^{-4} Pa [1]. The permeation rate of helium through quartz is $1x10^{-10}$ cc-mm/sec/cm^2/cm-Hg at 25ºC [2]. (The definition of permeability is the mass flow of a gas in cubic centimeters per second per area in cm^2 through a thickness in mm which has a pressure difference in cm-Hg) The partial pressure of helium gas in air is 0.5 Pa, or $3.75x10^{-4}$ cm-Hg (5.2 ppm) [3]. The permeation rate for borosilicate glass is $1x10^{-12}$ cc-mm/sec/cm^2/cm-Hg [4].

Find:

The total pressure accumulation in the PMT of helium due to permeation if the PMT is exposed to:

1. Air at atmospheric pressure,
2. Isobutane at 8psig (1.5 atm) that contains 5 ppm of helium.

Solution:

The total amount of helium permeating through the quartz window is the sum of the helium permeating in short periods of time.

Assumptions:

- The permeation rate of helium through borosilicate glass is significantly smaller than the permeation rate through quartz. Thus, the accumulation of helium in the PMT through the quartz window will be considered.
- The permeation rate remains constant during a time interval.
- The pressure difference across the quartz window remains constant during a time interval.
- The PMT remains in room temperature T = 25°C = 298.15°K.

The area of the quartz window is 5.07 cm^2.

The total volume inside the PMT is calculated from its dimensions D = 25.4 mm, L = 68.0 mm. If the bulb is completely empty, the volume under vacuum is 34.4 cc.

Initial conditions:

- Partial pressure of helium in atmosphere (outside the PMT quartz window) = 0.5 Pa = $3.75x10^{-4}$ cm-Hg
- Pressure inside the PMT = $1x10^{-4}$ Pa = $7.5x10^{-8}$ cm-Hg
- The entire volume inside the bulb is empty.

First time interval:

- Time period dt_1 = 300 seconds
- Pressure difference dp_1 = $3.75x10^{-4}$ - $7.5x10^{-8}$ cm-Hg = $3.75x10^{-4}$ cm-Hg
- Amount of helium that permeated through the quartz window during this time period:

$$V_1 = \frac{10^{-10}\,\frac{cc-mm}{sec-cm^2-cm-Hg} * 300\ sec * 5.07\ cm^2 * 3.75x10^{-4}\ cm-Hg}{1\ mm}$$

$$V_1 = 5.7x10^{-11}\,cc$$

- Converting the amount of helium from volume to moles:

$$n_1 = \frac{5.7x10^{-11}\,cc}{1000\,\frac{cc}{L} * 22.4\,\frac{L}{mol}}$$

$$n_1 = 2.5x10^{-15}\,mol$$

- Assuming that helium is an ideal gas, the additional pressure in the PMT as a result of the incoming helium is calculated using the ideal gas law p=n*R*T/V:

$$p_1 = \frac{2.5x10^{-15}\,mol * 83.14\,\frac{mbar-L}{mol-K} * 298.15^{\circ}\,K}{\frac{34.4\ cc}{1000\,cc/L}}$$

$$p_1 = 1.8x10^{-9}\,mbar$$

$$p_1 = 1.8x10^{-7}\,Pa$$

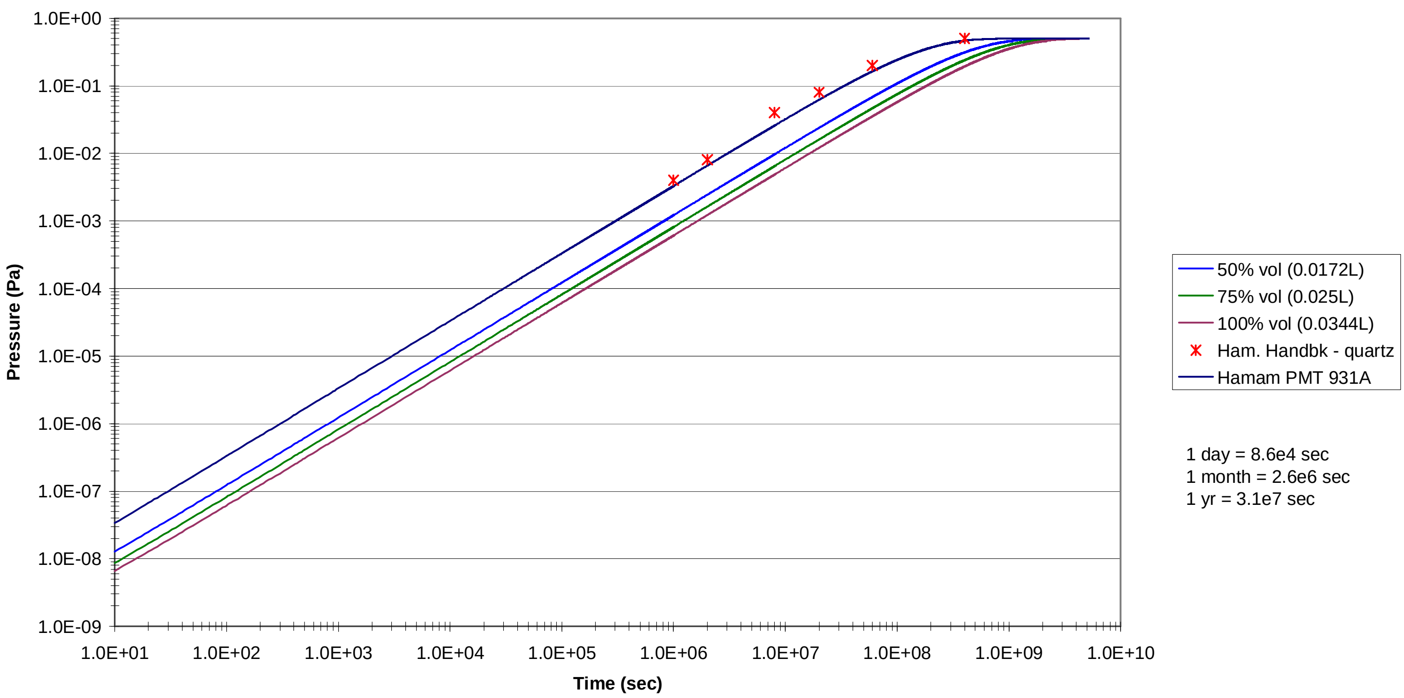
The calculations are repeated for additional time intervals. This method of modeling is used to determine pressure accumulation for the PMT volume that is 100% empty space, 75% empty space, and 50% empty space. The model is also compared to the pressure data listed in the manufacturer's handbook [1]. The following assumptions were made about the handbook's data:

- The Hamamatsu PMT that was modeled was 931A.

- The entire bulb of the PMT is made of quartz.
- The bulb thickness is 2 mm.
- The empty bulb volume is 32 cc.
- The bulb surface area through which the helium permeates is 51.1 cm^2.

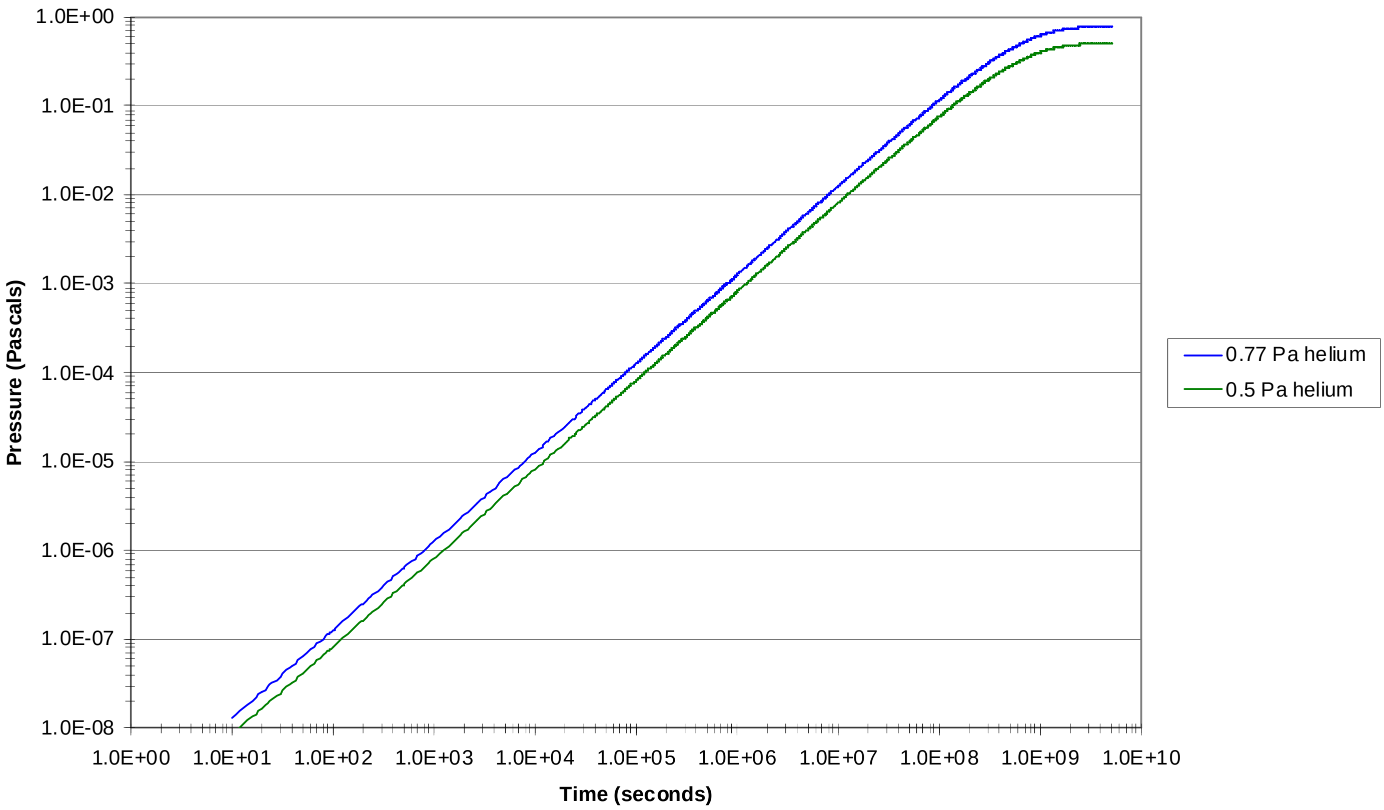
Figure 1 shows the helium accumulation inside the PMT over time.

Figure 1 - Pressure Accumulation in PMT due to Helium Permeation
CLC PMT - Hamamatsu R5800Q; Function of Volume of Empty Space inside PMT



As seen in Figure 1, if the CLC's PMT is left exposed to air at atmospheric pressure for one year, the pressure inside the PMT becomes 0.02-0.03 Pa, depending on the amount of empty space there is inside the bulb. It would take about 31 years for the pressure inside of the PMT to equal the partial pressure of helium in atmosphere. Figure 2 shows the pressure accumulation inside the PMT if it is exposed to pressurized isobutene at 8 psig (1.5 atm) that contains 5 ppm of helium.

Figure 2 - Pressure Accumulation in PMT due to Helium Permeation
CLC PMT - Hamamatsu R5800Q; Comparing the Effects of Outside Helium Partial Pressure



After one year of exposure to the higher partial pressure of helium, the pressure inside the PMT would be 0.04 Pa, assuming the bulb of the PMT R5800Q had 75% of empty space.

References:

1. Hamamatsu Photomultiplier Tubes catalog, April, 2000.
2. Dr. Larry Zeng, GE Quartz Worldwide, private conversation.
3. O'Hanlon, J.F., A User's Guide to Vacuum Technology, 2nd edition, John Wiley & Sons, 1989.
4. Roth, Vacuum Sealing Techniques, Pergamon Press, 1966.