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| Document Title **LAT ACD Phototube Helium Sensitivity** | | |

# Gamma-ray Large Area Space Telescope (GLAST)

# Large Area Telescope (LAT)

# ACD Phototube Helium Sensitivity

Adapted from EGRET documents RCH 1975/07/30
and mod RCH 2001/05/01
RCH 2001/05/03
Notes on R4443 2002/05/09 DJT
More R4443 notes RCH 2003/01/27
RCH update 01/12/04 based on new information (red)

# Gas Diffusion into GLAST ACD Photomultipliers

Rogers et al. (1954, J. Applied Physics 25, #7, 868) give the partial pressure $p_i$ of component $i$ in a vessel (initially evacuated) of volume $V$, surface area $A$, and wall thickness $d$ as a function of time, for a partial pressure differential of $\Delta p_i$ :

$$p_i = \frac{AD_iS_i}{Vd}\Delta p_i\left\{t - \frac{d^2}{6D_i} - \frac{2d^2}{\pi^2 D_i}\sum_{m=1}^{\infty}(-1)^m \frac{e^{\left(-m^2\pi^2 D_i t/d^2\right)}}{m^2}\right\} .$$

In the above equation, $D_i$ and $S_i$ are the diffusion coefficient (cm$^2$/s) and solubility (pure number), respectively, for component $i$. The product $D_iS_i$ is the corresponding permeability $k_i$. The permeability $k$ has the same dimensions as does the diffusion coefficient $D$ (cm$^2$/s), but much of the literature gives k in (cm$^3$ atm mm)/(s cm$^2$ cmHg). Those numbers must be multiplied by the conversion factor (76 cmHg/atm)/(10 mm/cm) = 7.6, to convert to cm$^2$/s.

We obtain values of the permeability $k$ from Altemose (1962, Proc. 7th Symposium on the Art of Glassblowing):

| $k_i$(cm$^2$/s, 25°C) | Pyrex (Corning 7740) | Borosilicate glasses (Corning 7052 or 7056) | Soft glasses (Corning 0080 or 0120) |
|---|---|---|---|
| Helium | 7.6x10$^{-11}$ | 5.0x10$^{-12}$ | 1.7x10$^{-14}$ |
| Neon | 7.6x10$^{-15}$ | 1.2x10$^{-15}$ | 7.6x10$^{-25}$ |

(Note: Values less than about 10$^{-11}$ have been obtained by temperature extrapolation, since at room temperature they are too small to be measured. However, this seems to be a reliable extrapolation, at least for rough estimates.)

The time constants for establishing steady flow require the diffusion coefficient $D_i$, which is seldom found in the literature; $D_i$ must therefore be found from $D_i=k_i/S_i$. Solubilities $S_i$ are given by Altemose (1961, J. Applied Physics 32, #7, 1309; Table III) for helium in a variety of glasses at temperatures in the range 100°C-500°C. Altemose states that there is no evidence for variation of $S_i$ with temperature or pressure, so we use those values also at room temperature.

There is additional information on solubilities in a recent book by J.E. Shelby, *Handbook of Gas Diffusion in Solids and Melts* (ASM). However, the solubilities $S_i$ are still rather poorly determined. For helium in fused silica, the measurements range over 0.0042-0.0075; we will use 0.006. For neon in fused silica, the measurements range over 0.0008-0.0054; we will assume 0.003. Thus the neon solubility seems to be roughly half that of helium, at least in fused silica; we will use that ratio for other glasses also. For helium, Altemose gives solubilities of ~$5 \times 10^{-3}$ in Pyrex and borosilicate glasses, and $1.2 \times 10^{-3}$ in soft glasses. We will use half those values for neon. We then obtain the following diffusion coefficients:

| $D_i$(cm$^2$/s, 25°C) | Pyrex | Borosilicates | Soft Glasses |
|---|---|---|---|
| Helium | $1.5 \times 10^{-8}$ | $1.0 \times 10^{-9}$ | $1.4 \times 10^{-11}$ |
| Neon | $3.0 \times 10^{-12}$ | $4.8 \times 10^{-13}$ | $1.3 \times 10^{-21}$ |

The time constants are of order $\tau_i = d^2/(\pi^2 D_i)$, from which we obtain the following values:

| $\tau_i$(s, 25°C) | Pyrex | Borosilicates | Soft Glass |
|---|---|---|---|
| Helium | $6.7 \times 10^4$ | $1.0 \times 10^6$ | $7.1 \times 10^7$ |
| Neon | $3.3 \times 10^8$ | $2.1 \times 10^9$ | $7.7 \times 10^{17}$ |

Thus for helium the diffusion approaches steady-state in a few days through Pyrex, a few weeks through borosilicate glasses, and in a few years through soft glasses. For neon, steady-state is approached in a few dozen years through Pyrex, a few hundred years through borosilicates, and through soft glass, about the time the Universe is 3 times its present age.

Ignoring the time constants, we now examine the steady-state flow, given by $p_i = (A\, k_I\, \Delta p_I\, t)/(Vd)$. The worst case (surface to volume ratio) PMT under consideration (Hamamatsu R1635), has a diameter of 1 cm, bulb length of 4.5 cm, and wall thickness (assumed) 0.1 cm. The inside volume is therefore is ~2.2 cm$^3$, and the surface area is ~14 cm$^2$. Thus in one year, we have

$p_i = 14\ k_i\ \Delta p_i\ (3.2\text{x}10^7\ \text{s}) / 0.22 = 2.0\text{x}10^9\ k_i\ \Delta p_i$.

In air, the helium and neon have concentrations of 5.2 and 18.2 ppm, or $4\text{x}10^{-3}$ and $1.4\text{x}10^{-2}$ torr, respectively. We then have, after one year, the following partial pressures in a borosilicate glass bulb (still ignoring the time constants):

| Component | $p_i$(torr, 1 yr) |
|---|---|
| Helium | $4.0\text{x}10^{-5}$ |
| Neon | $3.4\text{x}10^{-8}$ |

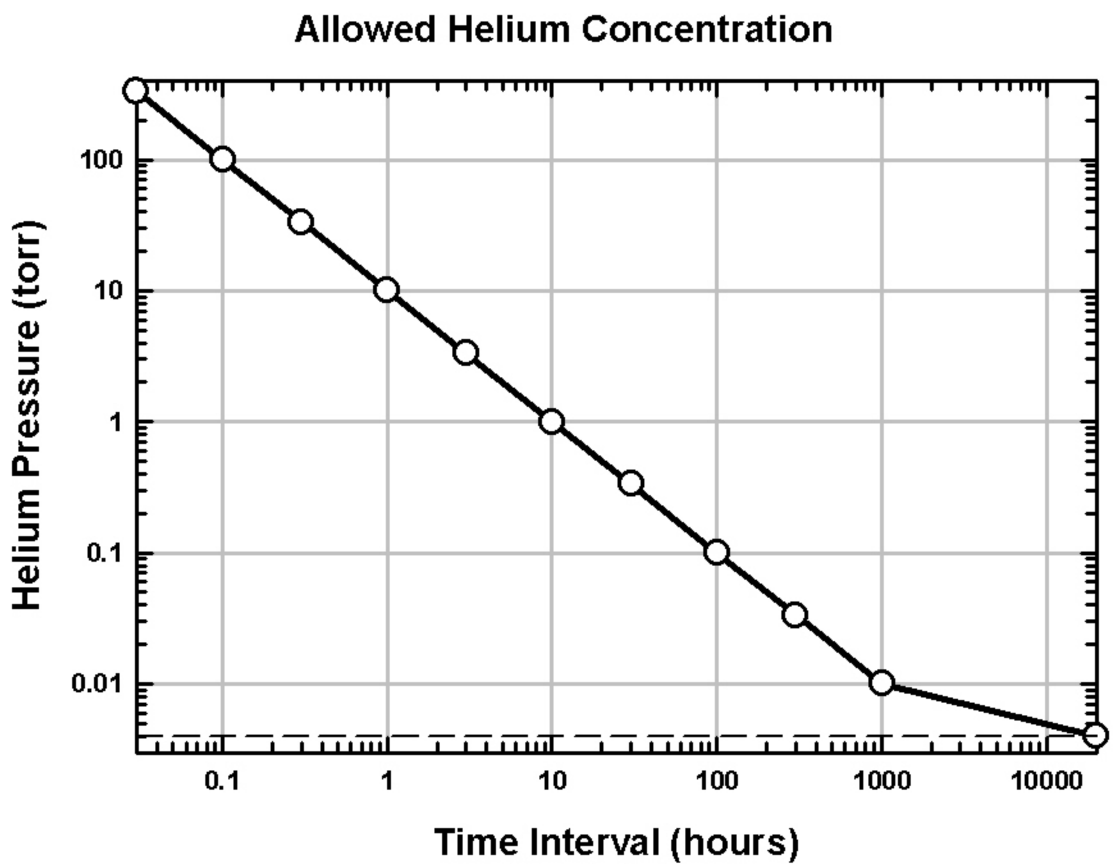
We must consider a lifetime requirement of about 2-3 years. Thus a borosilicate glass tube will reach a pressure of about $1\text{x}10^{-4}$ torr of helium; the neon is negligible. Stanford tests long ago (see J. Crawford notes) indicate substantial degradation of performance at ~$10^{-3}$ torr of helium for a much larger tube. RCA (now Burle) suggested (25 years ago, verbal communication) that $10^{-4}$ torr would be a fairly safe limit.

Thus for the Hamamatsu R1635, helium leakage might become significant if there were a launch delay of several years. For the R4868, the situation is only slightly better, because the ratio of volume to surface area is only slightly larger. For the R5611, the ratio of volume to surface area is better than for the R1635 by a factor of almost 2. For the R4443 that we are using (13.5 mm diameter, 71 mm length, wall thickness 1.2 mm), the volume to surface area is about 25% better than that of the R1635, and the thicker wall (1.2mm v 1.0) adds additional margin. Thus excess helium concentrations should be avoided, but special efforts to reduce helium levels below the normal atmospheric concentration are not needed.

**Additional Notes on ACD PMT Hamamatsu R4443**

Hamamatsu has told us that, for our purposes (uncorrelated pulse counting), our PMTs will work fine with internal helium pressure at least as high as the normal atmospheric partial pressure of helium, 5.2 ppm x 760 torr = 0.004 torr. (This is a little higher than the value presented in G. Lichti's calculation for GBM). If we ask for a margin of a factor of 100 (because there is a lot of uncertainty in the calculation; however, not nearly as conservative as the factor of 3400 used in Lichti's calculation), this gives us a limit of $4x10^{-5}$ torr. The figure below has been changed to reflect this.

The GLAST GBM detector also uses PMTs, so GBM has issued a document, GBM-MPE-TN-1-1, which shows a figure giving acceptable external helium partial pressures as a function of duration. The GBM document does not extend to time intervals more than a few months. Furthermore, it does not cover short time periods with high helium concentrations. Therefore a different figure is shown below, for use with the ACD.




With the relaxed assumption mentioned above, the figure above is obsolete. See revised calculations and figure below.

## New Calculation

$$p = (A\,k\,\Delta p\,t)/(Vd)$$

where $A = 2\pi rl + 2\pi r^2 = 2\pi \times 0.67\ cm \times 5.8\ cm + 2\pi \times 0.67^2\ cm^2 = 27\ cm^2$

$V = \pi r^2 l = \pi \times 0.60^2\ cm^2 \times 5.7\ cm = 6.4\ cm^3$

$d = 0.12\ cm$

$k = 5.0\times10^{-12}\ cm^2/s$

$p = 4\times10^{-5}\ torr$ (the allowable pressure)

We actually want $t$, the time it takes to get to the allowable pressure for a given $\Delta p$ :

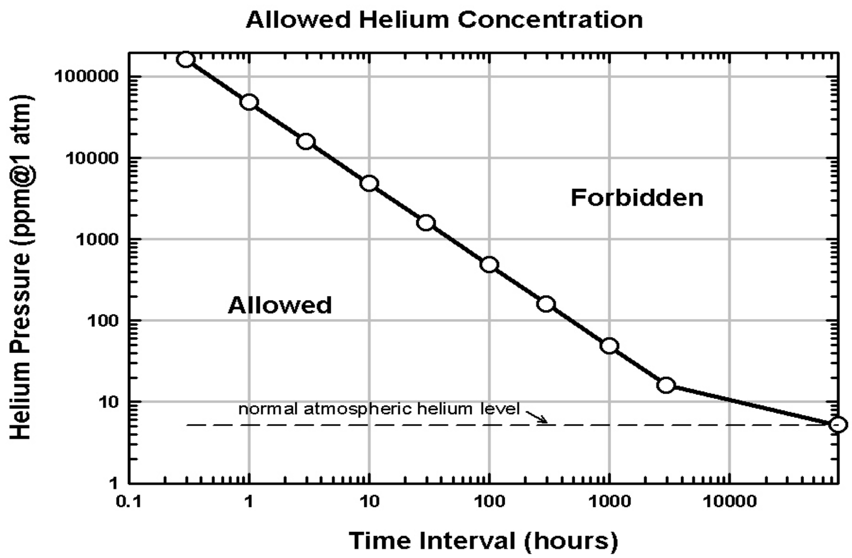
$$t \times \Delta p = (pVd)/(Ak) = (4\times10^{-5}\ torr \times 6.4\ cm^3 \times 0.12\ cm)/(27\ cm^2 \times 5.0\times10^{-12}\ cm^2/s)$$

$$= 2.3\times10^5\ torr\ s = 63\ torr\ hours = 2.6\ torr\ days$$

If $\Delta p$ is in ppm (at one atmosphere),

$$t \times \Delta p = 1.7\times10^8\ ppm\ seconds \approx 48{,}000\ ppm\ hours \approx 2000\ ppm\ days$$

New Figure:




The limits shown should provide a safety margin of a factor of ~100 for ACD. Even with the known uncertainties in the measurement of the diffusion constant, that safety margin is acceptable.

A comparison of the GBM and ACD PMTs is given in the table below:

| | Part No. | Volume V ($cm^3$) | Area A ($cm^2$) | Bulb Thickness t (cm) | Bulb Material | Diffusion Constant k ($cm^2\ s^{-1}$) | Rate Ak/(Vt) ($s^{-1}$) |
|---|---|---|---|---|---|---|---|
| GBM | R877 | 521 | 434 | 0.2 | Borosilicate glass | $5\times10^{-12}$ | $3\times10^{-11}$ |
| ACD | R4443 | 6.6 | 26.6 | 0.12 | Borosilicate glass | $5\times10^{-12}$ | $17\times10^{-11}$ |

Thus the ACD PMTs are about a factor of 6 more sensitive to external helium than are the GBM PMTs.

**Conclusions:**

1. **The PMT's must not experience extended time intervals with helium levels much greater than that in air (5 ppm, 0.004 torr). If there is any risk of such elevated helium levels, monitoring is essential.**
2. **If there is any risk of elevated helium levels for extended time periods, some provision for reducing the helium level around the PMT's is required. Bagging and purging with standard dry nitrogen planned for the LAT ( < 1 ppm helium) is acceptable.**
3. **The figure above shows the allowable helium concentration in the ACD environment for a wide range of time intervals.**
4. **Any possibility for exposures in excess of that shown in the figure must be cleared with ACD.**
5. **Note that the allowable helium exposure must be allotted between GSFC, Spectrum-Astro, and the launch site.**