Permeation of He Through Silica Seals

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1 Permeation Rate

Helium permeates through glassy materials such as the fused silica used in feedthrough insulators in the endcaps of the SNO Neutral-Current Detectors. Dushman and Lafferty [1] provide a graph of the permeation rate through various glasses (their Fig. 9.20). The rate for a given material follows a relationship of the form,

$$\log_{10}(K) = \frac{\alpha}{T} + \beta,$$

where α and β are constants, and T is the absolute temperature. The permeation rate K is in units of STP cm^3 per second and scales as follows,

$$K \times \left[\frac{\text{Area}}{\text{1sq.cm}}\right]\left[\frac{\text{1mm}}{\text{Thickness}}\right]\left[\frac{\text{Pressure}}{\text{1cmHg}}\right].$$

Fitting the data shown in [1] for fused silica gives $\alpha = -1062$ and $\beta = -6.45$, so that

$$K = 3.54 \times 10^{-7} 10^{-1062/T}.$$

The silica tubing (Heraeus-Amersil Suprasil T21) used in the detectors is 5 mm OD and has a 0.8-mm wall. The length of the cylindrical section through which He can escape to the outside is 7.5 mm. The fill pressure is 2.5 atmospheres of 85:15 ^{3}He:CF$_4$. With these parameters, and at 293 K, if the gas were ^{4}He, the permeation rate would be

$$1.3 \times 10^{-8} \text{ STP cc/s}$$

per endcap.

2 Mass Dependence

There seems to be no information on the dependence of permeation on isotopic mass M. One expects that processes that depend on temperature will contain factors of $\sqrt{M}$. If the only dependence is in β, the effect on K is 13% between ^{3}He and ^{4}He. If the only dependence is in α, the effect on K is a factor of 3.

3 Data

An endcap was pressurized with ^{4}He at 20 psig (34 psia), and the leak rate monitored over time with an Alcatel 110 leak detector. The initial leak rate was $< 3.5 \times 10^{-10}$ cc/s, but after 20 hours had risen to 7.5×10^{-9}, to be compared with the expected value of 15×10^{-9}.

Permeation rates for ^{4}He through fused silica disks were measured by Stephenson [2], who found general agreement with the data in [1]. The data of Stephenson shows an unexplained discontinuity (about 30%) in the value of β above 52 C, most likely an experimental problem. Stephenson showed that the time constant to reach an equilibrium permeation velocity is of order 10 hours at 83 C for 1.5-mm thick silica disks.

Four short prototype detectors for SNO containing the standard gas mix and standard (pyrolytic graphite coated) feedthroughs were placed in a whole-body leak test chamber at room temperature ($\sim$ 25 C). The detectors had been filled five weeks previously. They showed ^{3}He leak rates of 1.2, 1.0, 1.3 and 0.9 x 10^{-7} STP cc/s. These values are higher than would be expected if the isotopic mass dependence were only in β, but in reasonable agreement with it being in α. The endcaps were subsequently tested individually to confirm that each gave half the rate of the whole detector, and that the pinchoff seals were leaktight.

4 Conclusions

As expected, the silica feedthroughs are permeable to He. The dependence on isotopic mass was not known beforehand, and appears to be substantial (a factor of about 3-4 between ^{3}He and ^{4}He). Nevertheless, the permeation rate is within our initial specification that the gas loss should be less than 0.1% per year. At a rate of 0.6 x 10^{-7} cc/s per endcap, the loss rate is 1.2 l/yr, which is 0.04% of the total inventory of 3230 STP l in 750 m of detector.

The counters are welded together at the time of deployment, which means from that point on the escaping ^{3}He is trapped in the interspace between counters. At infinite time, the He pressure equalizes, and (since the counters contain more than enough gas to be "black" to neutrons) the effective length of He absorber in SNO increases by 3.8%. Since there is absorption but no detection of captures in the endcap region, and since the total capture efficiency depends almost linearly on the length of ^{3}He-filled tube deployed, to first order, there is no change in the detection efficiency. At worst, if the total capture efficiency of the array stayed unchanged, the detection efficiency would drop by 3.8% of its initial value. The thermal neutron capture cross section for ^{3}He is $\sigma = 5330$ b, and one can estimate the time dependence of the efficiency loss in a model in which a cylinder (the endcap volume) is placed in a uniform flux. The increasing density of ^{3}He causes the efficiency of the array to approach equilibrium as

$$\eta(t) = \eta(0)[1 - 0.038\left(1 - e^{-n(t)\sigma}\right)],$$

where $n(t)$ is the number of ^{3}He atoms cm^{-2}. The permeation rate of 1.0×10^{-7} STP cc/s gives $n(t)\sigma = 0.02t$, where t is in years. Thus the loss in efficiency in 10 years is nearly 0 and certainly less than 0.7%.

We conclude there are no major concerns with gas permeation through the feedthroughs at the measured levels.

References

[1] S. Dushman and J.M. Lafferty, *Scientific Foundations of Vacuum Technique* (Wiley, New York, 1962).

[2] T. J. Stephenson, "Measurements of Helium Permeation Through Glasses and Plastics" SNO-STR-90-091; Los Alamos National Laboratory Preprint LA-UR-90-3076, 1990.