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Technical Note

Inexpensive and practical sealed drift-tube neutron detector

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ABSTRACT

The design, construction, and performance of a type of sealed ^{3}He drift tubes for neutron detection are presented. Because the ^{3}He pressure is in the 25–300 mbar range, the detector costs are not dominated by the ^{3}He gas. Intrinsic neutron detection efficiencies up to 5% have been observed by using high-density polyethylene moderation. Sensitive measurements of the detector lifetime are achieved by monitoring the full-energy peak of the ^{3}He(n, p)^{3}H reaction as a function of time. The neutron peak position shows a 24-h cycle that may be explained by the physical adsorption of gases onto the wall. The estimated lifetimes of the detectors are sufficiently long and therefore, the design and the construction are robust and practical for applications such as fissile material detection.

We describe a sealed drift tube design and construction using a gas mixture at 1 bar total pressure, which includes 2.5–30% of the ^{3}He gas. The limited supply and high cost of ^{3}He motivated us to develop low-pressure ^{3}He drift tubes that take advantage of the large albedo of thermal neutrons off the polyethylene surfaces. By surrounding the tubes with approximately 1-in. thick high-density polyethylene sheets, efficiencies up to 5% have been achieved. Selection of the detector diameter (5 cm), the gas mixture, and the gas pressure ensures that the full energy of the reaction ^{3}He(n, p)^{3}H can be absorbed by gas ionization, resulting in a prominent *Q*-value peak (*Q*-peak) at 0. 764 MeV in the pulse height spectra [1–4]. Furthermore, the signals from neutron capture at the wall are also distinguishable from the γ-ray background.

The design of a cylindrical drift tube is shown in Fig. 1. The aluminum body of the tube has a 2 in. OD and 0.035 in. thick wall. The tube length is variable but usually no less than 12 in. to prevent the detection from being dominated by end-effects. Detectors of this design have been built up to 6.1 m long. Both ends are closed with a welded cap with a 1/8 in. NTP threaded hole. The anode wire, along the axis of the tube, is made of gold-plated tungsten and is 50 μm in diameter. The wire is stretched to 100 gm of tension and verified by measuring the wire vibration frequency. The wire is held in place by a construction shown in Fig. 1. The construction consists of a 1/16 in. copper tube snuggly fitted inside a polyetheretherketone (PEEK) tube, which is inserted into a 1/8 in. Swagelok feedthrough. The Swagelok seals both the Swagelok–PEEK and the PEEK–copper interfaces. The copper tube is crimped and soldered at both ends to prevent gas leakage. The detector is then helium leak checked and high-voltage tested before being filled to 1 bar of total gas pressure with 25–300 mbar of ^{3}He. The balance of the gas mixture consists of C_2H_6, ^{4}He, CF_4, and Ar. A two-person team has been able to assemble 100 detectors in one 8-h shift, indicating the robustness of the design and construction. The cost of 300 mbar ^{3}He gas is comparable to the total cost of other materials. The drift tube operates as a proportional counter at bias voltages ranging from 1400 V (300 mbar ^{3}He) to 1800 V (25 mbar ^{3}He). The relative detector efficiency as a function of the ^{3}He partial pressure is shown in Fig. 2. For thermal neutrons, the efficiencies increase linearly at

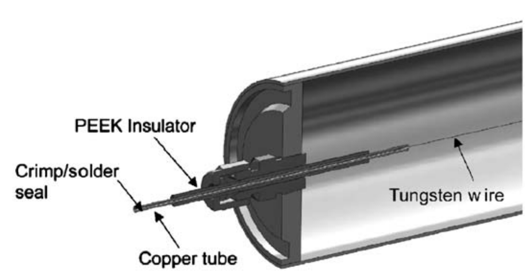

Fig. 1. Schematic view of detector construction.

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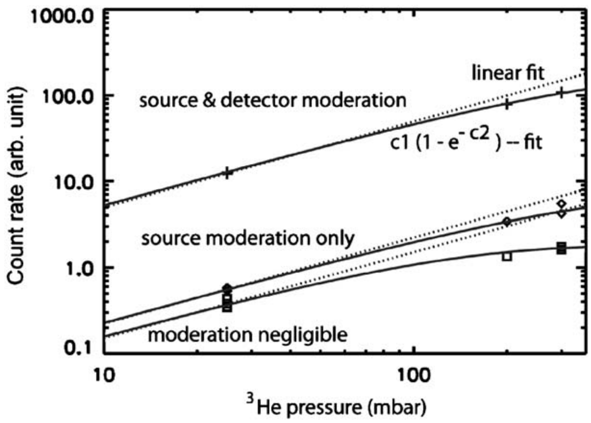

Fig. 2. Relative counter rates (a measure of intrinsic efficiency) at different ^{3}He pressures, with different degrees of moderation of a ^{252}Cf source and detectors. Linear fits (dashed lines) are expected for low ^{3}He pressures ($\leqslant$100 mbar). Deviation from linearity is observed at 200 mbar and above.

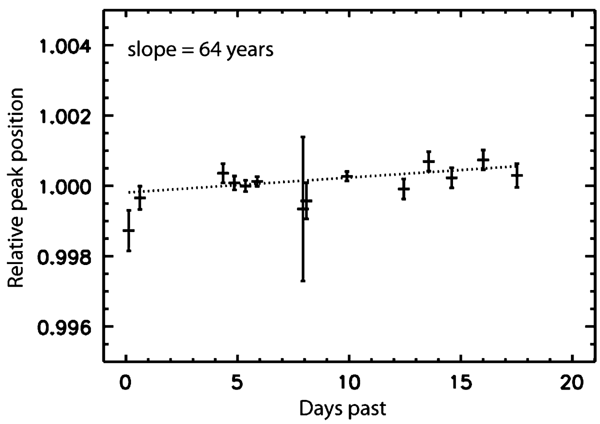

Fig. 3. Drift of the full-energy peak (Q-peak) of a 25 mbar ^{3}He tube over two weeks. Each data point is based on a neutron pulse height spectrum accumulated for $\sim$24 h. Background neutron flux ($\sim$0.16 s^{-1}) was used to produce the pulse height spectrum.

low pressures. Deviation from linearity is observed at 200 mbar and above.

The ultimate lifetime of a sealed drift tube is determined by gas leakage, outgassing of impurities from the wall into the tube, or radiolysis and polymerization of the gas species in the tube. For low neutron rates, we expect that gas leakage dominates over other factors. To test this hypothesis, we monitored the Q-peak position for a few weeks. The result for a 25 mbar ^{3}He tube is shown in Fig. 3. Each data point is based on the neutron pulse counts collected for $\sim$24 h. Only the natural background neutron flux of 0.16 s^{-1} is used in the measurement. In addition, the instrumental settings and the positions of all the parts were fixed to minimize the spurious effects caused by the anode bias drift and stray capacitances between the drift tube and the electronics. From the Diethorn formula, [2,3] gas leakage (p decreases) increases pulse heights and correspondingly, the Q-peak drifts upwards. The linear least-squares fit in Fig. 3 indicates that a 100% change in gain would take $\tau_M \sim 64 \pm 22$ years. Since the Q-peak drift due to the pressure change is not linear, that is, $M/M_0 = (p/p_0)^{-f}$, the linear extrapolation to 100% change in gain must be corrected by a factor of $f(1-e^{-\ln 2/f}) \sim 0.65$ for $f = 6$. This correction modifies τ_M to $\sim$42 years. In addition, the total leak rate (dp/dt) is given by $p_0/f\tau_M$, where p_0 is the initial fill pressure. Therefore, a very sensitive determination of the leak rate through monitoring the gain changes can be made of gas detectors, including drift tubes, by using neutrons and a small amount of ^{3}He [5].

At higher neutron-counting rates of 1.0–30.0 s^{-1} by using a ^{252}Cf source, we have also observed diurnal oscillations in the Q-peak position (Fig. 4). The 24-h cycle of the Q-peak tracks the ambient temperature oscillations over the same period. In addition, by raising the tube temperature temporarily with a heat gun, the Q-peak position is found to drift downward, corresponding to the decrease in the pulse height, on the same time scale. The Q-peak then relaxes back to the pre-heating values once the heat gun is turned off. Temperature effects on drift tubes were reported before but are different from our observations [6,7]. We can rule out thermal expansion of the tube volume as a possible cause. The observed gain decrease due to heating contradicts the expectation of the gain increase due to the

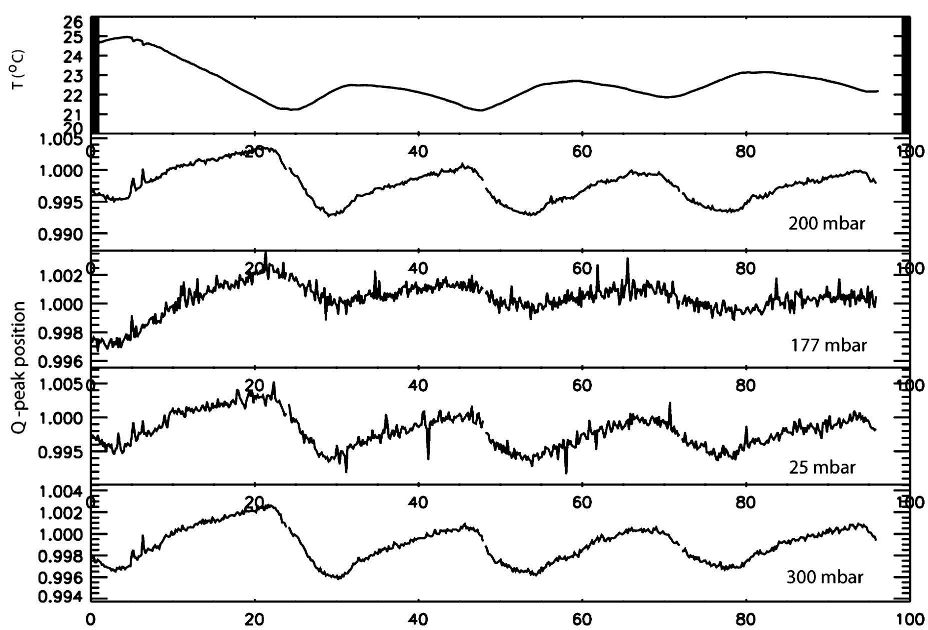

Fig. 4. The Q-peak positions of four sealed drift tubes at different ^{3}He pressures (as indicated) as a function of time for 96 h (10 min per time bin). Short-term fluctuations (for 177and 25 mbar, in particular) are due to combined effects of Poisson statistics and electronic noise. All tubes show diurnal oscillations that track the ambient room-temperature oscillations. Higher temperatures correspond to lower gains.

volume expansion. In addition, the thermal expansion coefficient of aluminum is $2.1–2.5 \times 10^{-5}$ in./in. °C, which can only account for ~1% of the observed gain change. A plausible cause of the diurnal oscillations is the alternating *net* adsorption/desorption processes[1] between the gas and the wall, resulting in the gas density and the gain oscillations [8,9]. Physical adsorption and desorption are reversible processes that should not change the lifetime of a drift tube. Therefore, monitoring the diurnal oscillation provides a quantitative way to monitor the wall conditions.

In summary, a practical low-cost sealed drift tube design using low-pressure ^{3}He gas has been presented. By using 25–300 mbar of ^{3}He gas, the cost of the ^{3}He is not the dominant factor in the total material cost of the detector. High-density polyethylene moderators increase the intrinsic neutron detection efficiency up to 5%. Sensitive measurements of the detector lifetime have been achieved by monitoring the position of the full-energy peak of the ^{3}He(n, p)^{3}H reaction as a function of time. The peak position has a 24-h cycle that is anti-correlated with the ambient room-temperature fluctuations. The design and the construction are robust since the measured gas leakage is sufficiently small.

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[1] Apparently, both adsorption and desorption happen all the time. The *net adsorption* refers to the situation when there is more adsorption than desorption, and vice versa for the net desorption.