A Study on performance of ^{3}He and ^{4}He proportional counter for thermal neutron detection

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1. Introduction

Gas-filled detectors are widely used for neutron detection and spectroscopy [1]. They may be used to detect either thermal neutrons via nuclear reaction or fast neutrons via recoil interaction. These gas-filled neutron detectors used mainly either BF_3 or ^{3}He, but tubes containing ^{3}He are commonly used for the thermal neutron detection because the proportional counters with ^{3}He are more sensitive to thermal neutrons than those with BF_3 [2]. They can detect fast neutrons but their efficiency is limited. ^{4}He detector can operate suitably as fast neutron detector above 1MeV [3]. These two helium gas detector's different responses are caused by the different cross sections of neutrons with ^{3}He and ^{4}He in various energy regions (Fig.1) [4].

The ^{3}He and ^{4}He proportional counter's detection mechanisms are the (n, p) reaction and the elastic scattering, respectively:

$$ {}^3_2He + {}^1_0n \rightarrow {}^3_1H + {}^1_1p + 764\ keV \quad , $$

$$ {}^4_2He + {}^1_0n \rightarrow {}^4_2He(recoil) + {}^1_0n^* \ . $$

Proportional counters containing ^{3}He have an intrinsic capability to separate gamma events from neutron events because of the high thermal neutron cross-section for ^{3}He and the large reaction energy associated with the neutron capture reaction. The reaction energy is shared with triton (191keV) and proton (573keV), and two particles are attributed to the detection signal. While a recoiled ^{4}He particle contribute to the pulse height distribution in ^{4}He counter [5]. To improve an accuracy of neutron measurement, it is necessary to test the detector response experimentally.

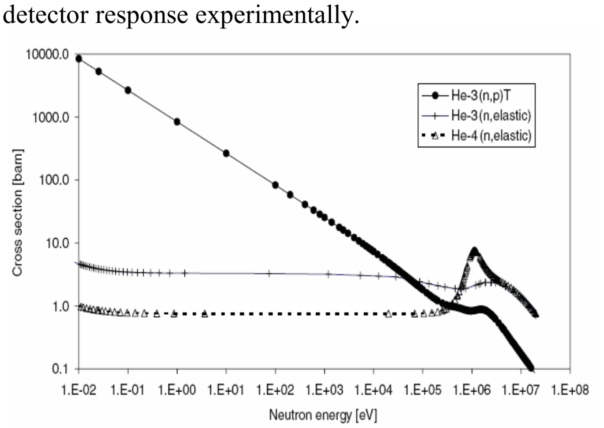

Fig. 1. Cross section of ^{3}He and ^{4}He reaction with neutrons [2].

In this paper, we studied characteristics of two helium filled counters which have same structure and gas pressure of ^{3}He or ^{4}He in order to get response functions when they are used for thermal neutron detection. The pulse height distribution according to shaping time and applied high voltage bias and the influence of the shaping time on gamma ray sensitivity was measured. Also we studied the resolution as a function of bias voltage and shaping time.

2. Methods and Results

2.1. Experimental setup and method

The detection systems consist of a high voltage supply (Ortec 556), a preamplifier (Canberra 2006), amplifier (Canberra 2025), and a multichannel analyzer. The experimental setup is shown in Fig. 2. The ^{3}He and ^{4}He proportional chambers used in this study have same structure and same gas pressure. These detectors were manufactured by LND Inc. and those diameters are 5cm and effective lengths are 30cm. The gas pressure is 5atm and gas compositions consist of mostly helium gas and a little CO_2 as quenching gas.

All measurements are done using thermal neutron from 5Ci ^{241}Am-Be which were moderated by thick paraffin, because this source emits fast neutrons with 5MeV as an average energy. The detectors are aligned to the vertical direction with anode wire in order to extend active region.

We also measured the spectrum by gamma ray in order to determine the appropriate shaping time and evaluate gamma ray sensitivity. Gamma ray source used for this study is ^{60}Co(10μ Ci) and the spectrums were measured at various shaping time from 0.5 to 12μ sec and all detection time durations were 10minutes.

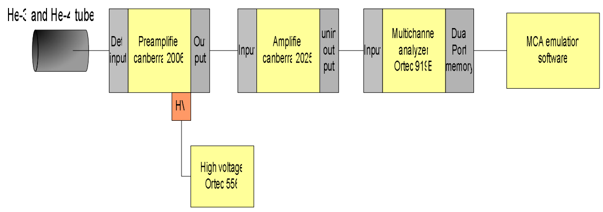

Fig. 2 Experimental detection and pulse processing system for helium gas detector

2.2. Discussion and Result

The gamma-ray sensitivity of the ^{3}He and ^{4}He filled detectors were measured according to shaping time in the range from 0.5 to 12μsec and they are shown in Fig. 3. Applied high voltages of ^{3}He and ^{4}He tube are 1200V and 1000V, respectively. The detectors were irradiated with two incidence directions; vertical and parallel direction against anode wire by gamma ray from ^{60}Co.

The ^{3}He tube has the largest sensitivity at 4μsec shaping time and the ^{4}He tube has best sensitivity at 6μsec. Because of the long range of the electron produced by gamma ray interaction, more time will be required to collect them completely [5].

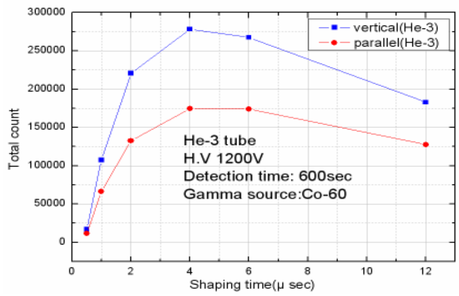

Fig. 3. Gamma ray sensitivity of ^{3}He proportional counter according to the shaping time.

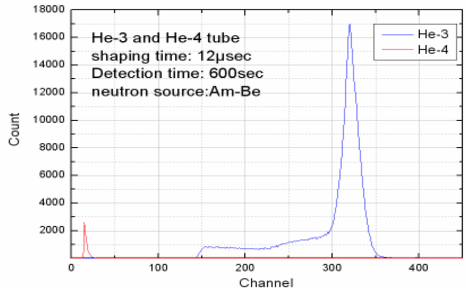

Fig. 4. Pulse height distributions of ^{3}He and ^{4}He counters when the detectors were irradiated with thermal neutron.

We also obtained gamma ray sensitivity when the detectors were irradiated in the directions perpendicular and parallel to the anode wire. This experiment showed that gamma ray sensitivity for the perpendicular irradiation is larger than for the parallel irradiation.

We measured thermal neutron spectrum by using a moderated Am-Be neutron source. Typical pulse height distributions detected with ^{3}He and ^{4}He counters are shown in Fig. 4. Because ^{4}He's scattering cross section at thermal neutron region is much smaller than ^{3}He's capture cross section, pulse height of ^{4}He is much lower than ^{3}He. The pulse height distributions and energy resolutions according to applied high voltages and shaping times were obtained. ^{3}He and ^{4}He counter with a very low voltage applied, the multiplication is not present and recombination can be observed. Counters containing ^{3}He and ^{4}He need a higher voltage above 1000V in order to obtain enough gas gain.

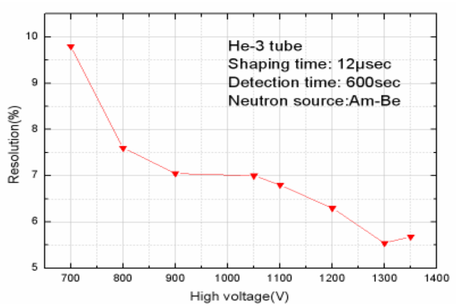

Fig. 5. Energy resolution of ^{3}He tube according to bias voltage.

The overall energy resolution of ^{3}He tube as a function of the applied high voltage is measured by the MCA with 12μsec shaping time. Fig. 5 shows the energy resolution according to the applied high voltage for the ^{3}He tube. The resolution goes better with the voltage increase because the statistical fluctuation was improved. But the resolution degrades after a certain voltage because the space charge effects become predominant [6]. And the resolution as a function of the shaping time for ^{3}He tube is evaluated in order to use at the best operation condition. The result showed that the resolution is best at 12μsec shaping time constant.

3. Conclusion

We studied the response of two commercially available cylindrical proportional chamber containing ^{3}He and ^{4}He by thermal neutrons from a moderated Am-Be neutron source. Gamma ray sensitivity of these detectors was examined by using ^{60}Co gamma ray irradiations with perpendicular and parallel directions to anode wire and for various shaping times of amplifier. The gamma ray contribution can be minimized with smaller shaping time but large shaping times are needed to improve the resolution. We obtained pulse height distribution and energy resolution data according to applied high voltage and shaping time for thermal neutron. This experiment showed that the counters containing ^{3}He and ^{4}He need a higher voltage than 1000V in order to obtain enough gas gain. And the tube resolution is improved with the voltage increase but the resolution degrades after a certain voltage because the space charge effects become predominant.

Acknowledgements

This work has been carried out under the Nuclear R&D program of the Ministry of Science and Technology (MOST) and supported by the iTRS Science Research Center/Engineering Research Center program of MOST/Korea Science and Engineering Foundation.

Reference

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