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DEVELOPMENT OF A ^{3}He/Xe GAS SCINTILLATION COUNTER TO MEASURE THE ^{3}He(n,p)T CROSS SECTION IN THE INTERMEDIATE ENERGY RANGE

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Abstract: A ^{3}He/Xe gas scintillation counter has been developed for measuring the neutron energy range from thermal to 3 MeV. Great effort was concentrated on improving the detector design to optimize light production and collection to improve the energy resolution which is primarily controlled by photon statistics. The detectors were tested using a ^{238}Pu alpha-particle source, a thermal neutron beam from the NBS reactor, and the white-neutron spectrum from the NBS linac. The detector measures an energy resolution of 17% (FWHM) for the ^{3}He(n,p)T reaction at 2.0 MeV which is sufficient for cross section measurement.

(counter; cross section; helium-3 gas; neutron; scintillation)

Introduction

For several decades it has been suggested that the ^{3}He(n,p)T reaction should be utilized for detecting neutrons over the entire neutron energy range from thermal to MeV energies. In fact, this reaction might be useful as a reference standard. The reaction has a Q value of 764 keV and is easily detected. The cross section of the ^{3}He(n,p)T reaction is large (5316 barns at thermal) and has a smooth energy dependence. This possible standard can be used in cross section measurements, for determination of neutron fluence, and for the investigation of neutron spectra emitted by nuclei. However, this cross section has not been accepted as a standard in the INDC/NEANDC standard file because of the lack of a good detector and the uncertainty of the cross section data.

Gas proportional counters (gpc)[1-5], gas scintillation counters (gsc)[6,7], and gas proportional scintillation counters (gpsc)[8-10] have been developed for cross section measurement. The gpc has rather poor timing resolution (approximately 1 μs) for time-of-flight measurements and furthermore has a low efficiency for high-energy neutrons. However, the pulse-height distributions produced can be conveniently unfolded. The gsc, on the other hand, provides both good timing resolution (< 10 ns) and high efficiency but typically suffers from poor pulse-height resolution. The gpsc tries to combine the best features of the gpc and the gsc by providing large light output, good energy resolution and good timing resolution; however, it usually is a very complex detector system having both fast- and slow-signals which must be processed separately.

The use of ^{3}He in gpc-designs is rather common today and detectors are commercially available. The gsc-design is rarely seen, in spite of its improved timing resolution. A reason for its lack of use is the difficulty with gas stability over long periods of time. The gas is highly sensitive to trace organic impurities which absorb the ultraviolet radiation.

The National Bureau of Standards (NBS) has designed, built and tested a series of ^{3}He detectors of gsc design. Great effort was concentrated on increasing the light production and collection to improve the energy resolution. This is necessary to permit adequate separation of ^{3}He(n,p)T events from ^{3}He recoil events. Detectors were tested using a ^{238}Pu alpha-particle source, a collimated thermal neutron beam from the NBS reactor, and a collimated white-source neutron beam from the neutron time-of-flight facility associated with the NBS linac.

2. Discussion

The NBS has developed[11,12] two ^{3}He/Xe gsc (figs. 1 and 2). The first detector was a stainless steel circular cylinder of length 250 mm and diameter 100 mm. Two 5-cm diameter photomultiplier tubes (RCA 8850)† were mounted onto the end windows consisting of pyrex glass, coated on their inner surface with a 30 microgram/square cm coating of the wavelength shifter diphenylstilbene (dps). The inner surface of the steel cylinder was optically polished and then coated with a 2000 Å thick aluminum layer.

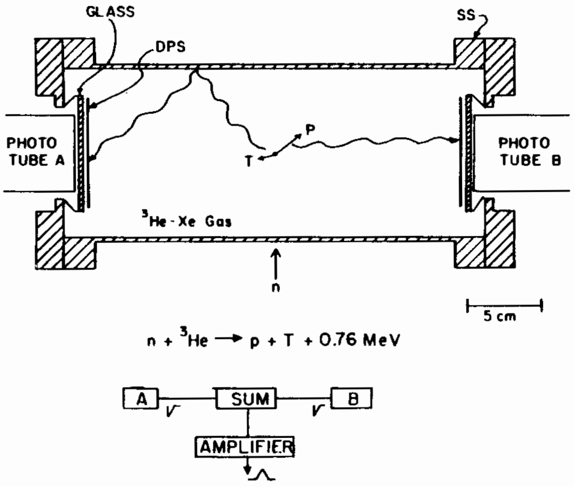

Fig. 1. The first prototype ^{3}He gas scintillation counter. Diphenylstilbene (DPS) is used as a wavelength shifter.

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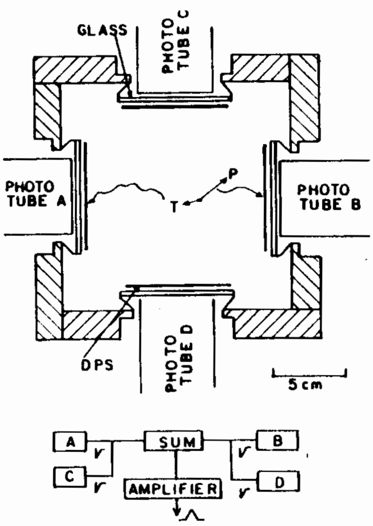

Fig. 2. The second prototype ^{3}He gas scintillation counter.

Unfortunately, the cell was exposed to air for a brief period of time. This suggests that the aluminum coating developed a 40-80 Å aluminum oxide surface layer. This type of layer has only a 10-20% reflectivity for uv radiation in the wavelength range from 1500-2000 Å, compared to a 90% reflectivity for pure aluminum[9]. The total pressure of the ^{3}He/Xe gas mixture was held constant at 30 psia. The detector was studied at the NBS 20 MW reactor and the NBS 100 MeV electron linac. The gsc-designed detector had a resolution of about 55% (FWHM) on the ^{3}He(n,p)T reaction for thermal neutrons and a resolution of about 50% for neutrons of 1 MeV (see fig. 3). The detector recovered from the linac gamma flash within 1 μs. This detector operated for over two years without significant deterioration of the light output and shows that proper use of high vacuum cleaning techniques retards gas deterioration.

A second prototype was designed and built to improve the light collection and thereby improve the detector energy resolution. The second gsc-design doubled the number of pyrex window/photomultiplier tube (pwpt) modules and also reduced the cell size by a factor of two. The new cell consisted of a stainless steel cube with 150 mm sides. The inner surfaces of this cube were thoroughly cleaned using an ultrasonic cleaner and bathed in alcohol, acetone, and freon. The inner surface of the cell was not optically polished or coated with aluminum. Four pwpt modules were mounted onto four faces looking into the cell. The remaining two faces had cylindrical inserts each capped by a 0.32 cm thick stainless steel sheet; thereby producing a uniform gas volume of 72.5 mm thickness for neutron beam entrance and exit. This second design was tested using a ^{238}Pu alpha-particle source and a collimated thermal neutron beam from the NBS reactor. The resolution from the alpha-particle source was 10% and 14% for pure xenon and a mixture of xenon/2.5% nitrogen, respectively, at a fill pressure of 27.2 psia. Small quantities of nitrogen are used to enhance light production in the 4000 Å range. The experimental setup for the experiment at the NBS reactor is shown in fig. 4. The exit diameter of the thermal column was about 1.25 cm. The neutron beam was collimated to a diameter of 1.00 cm using cadmium sheet, boral, and lead. The detector was placed approximately 23 cm from the collimator.

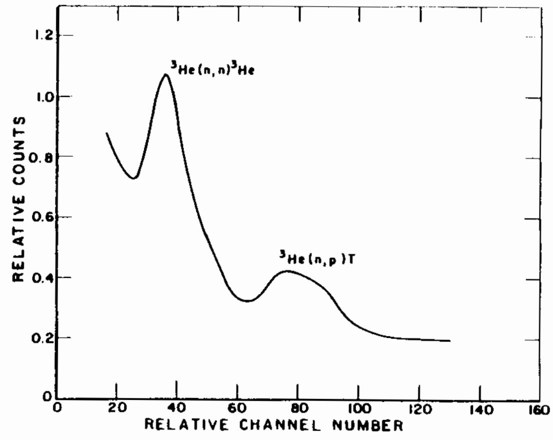

Fig. 3. Pulse-height spectrum for 1.0 MeV neutron measured by the first prototype detector.

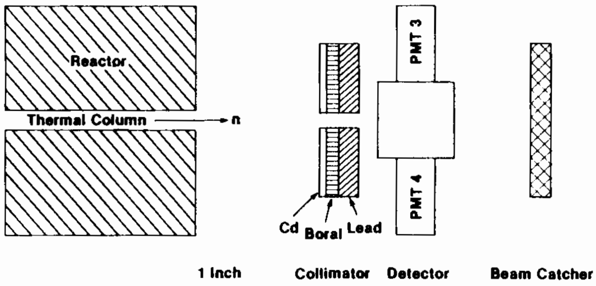

Fig. 4. Experiment arrangement at the NBS Reactor.

For personnel safety, a beam catcher was used to absorb the neutrons and gamma rays after they passed through the detector. Summing all four photomultiplier signals the energy resolution of the second detector was 32% (FWHM), making it significantly improved over the first detector whose resolution was 55%. We also measured the detector response to an incident beam at different positions across the front face of the detector. The results are shown in fig. 5. The number of

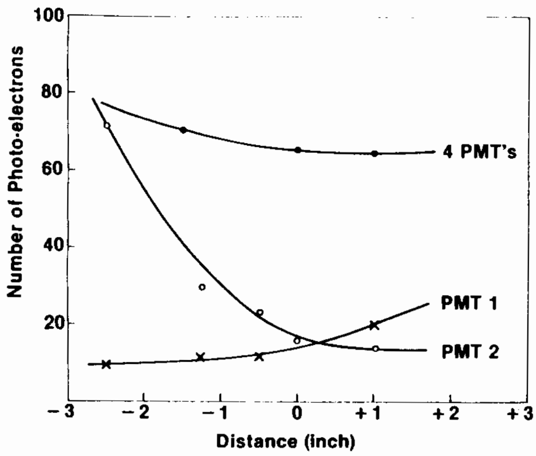

Fig. 5. Output of various photomultiplier tubes as a function of incident neutron beam position.

photoelectrons for each individual photomultiplier is sensitive to the position of the incident neutron beam. The best resolution is obtained by using a well-collimated neutron beam incident on the center of the detector. Several design changes were then added to further improve the energy resolution of the detector in order to meet the needs of cross section measurements. The most significant step was to use larger glass windows and photomultiplier tubes so that more light would be collected. This modification was made to prototype two. The original 7.5 cm diameter glass windows and 5 cm diameter photomultipliers were replaced by 10 cm glass windows and 12.5 cm diameter photomultipliers (RCA 8854),† respectively. This change improved the resolution observed with a ^{238}Pu alpha-particle source from 10% to 8%.

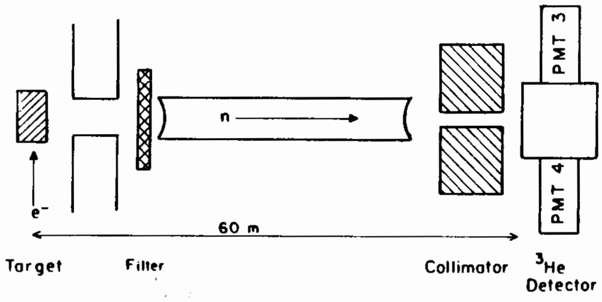

Fig. 6. Experiment arrangement at the NBS Linac.

The modified prototype two detector was tested at the NBS linac (see fig. 6). The detector was located at the 60 meter time-of-flight station. The linac was operated at 720 Hz with an electron pulse width of 50 ns to produce neutrons by the (γ,n) reaction in a thick water-cooled tungsten target. The neutron beam was collimated to 2.5 cm diameter in order to reduce the wall effects. The ^{3}He detector gas filling consisted of a mixture of 25% ^{3}He and 75% xenon at a pressure of 28 psia. Two parameter data, i.e., pulse-height and time-of-flight, were simultaneously accumulated from the detector. The data were stored into arrays of 512 pulse-height channels by 1024 time-of-flight channels. Each time channel was 16 ns wide. The gamma flash from the tungsten target was the timing reference used for definition of the neutron energy scale. The typical pulse-height distributions for neutron energies of 1 and 2 MeV are shown in figs. 7 and 8. The peak due to the ^{3}He(n,p)T reaction is well separated from the distribution of ^{3}He recoils. The measured resolution was approximately 17% (FWHM) at 2 MeV neutron energy.

In summary the resolution measured by thermal neutrons went from 55% (FWHM) for the first prototype detector to 32% for the second detector under similar conditions. After modification, the second prototype was further improved. The resolution for neutrons in the 1-10 keV region was 24%. Also, this improvement was seen for the alpha-particle peak which went from 10% to 8% (FWHM). Such improvement to the energy resolution is a key step toward a successful measurement of the ^{3}He(n,p)T cross section.

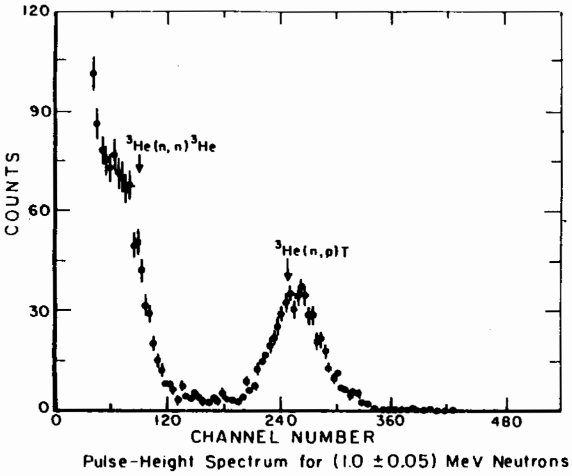

Fig. 7. Measured pulse-height spectrum for 1.0 MeV neutrons.

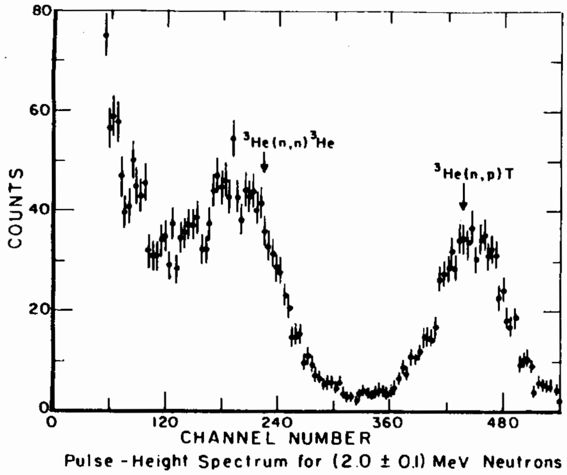

Fig. 8. Measured pulse-height spectrum for 2.0 MeV neutrons.

Conclusion

The measurements at the NBS linac show that the detector works well. The ^{3}He(n,p)T peak is well separated from the ^{3}He recoil distribution. The energy resolution is about 20% in the MeV energy region. Such resolution is suitable for measurement of the ^{3}He(n,p)T cross section. Our detector is presently being used to measure the ^{3}He(n,p)T cross section relative to the ^{10}B(n,α)^{7}Li cross section from 1 eV to 750 keV. These data will be published separately.

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[†] Mention of commercial products does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products identified are necessarily the best available for the purpose.

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