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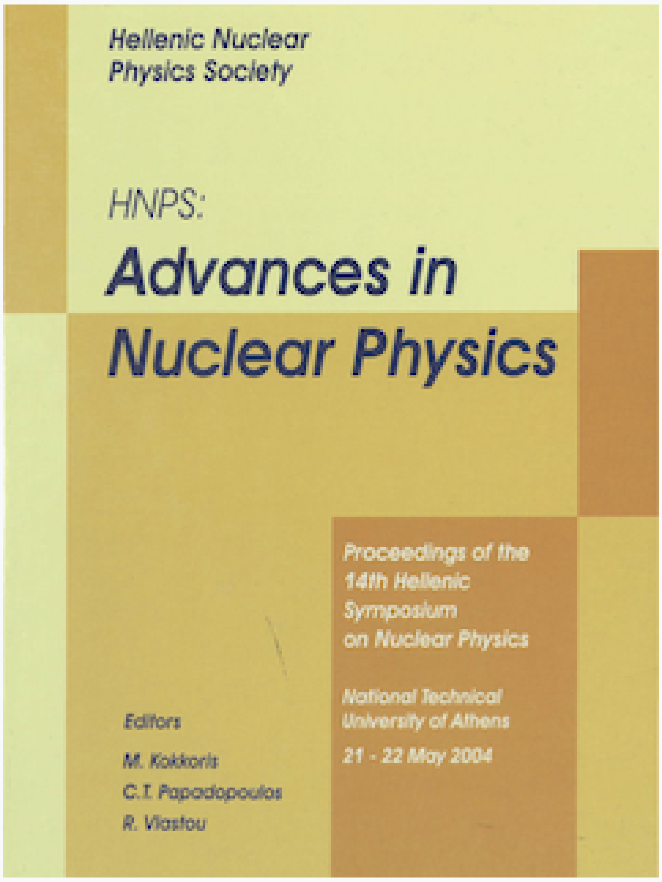


## Energy calibration of He-3, He-4 Neutron Proportional Counters

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# Energy calibration of He-3, He-4 Neutron Proportional Counters

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**Abstract**

Two helium filled proportional counters (He-3, He-4) were irradiated with neutrons in the energy range 0.025 eV – 10.7 MeV, in the Tandem accelerator, NCSR Demokritos, Athens. The full energy peak in He-3 proportional counter as well as the recoil peaks in He-3 and He-4 counters show linear dependence with neutron energy. A study of gamma ray contribution to the neutron spectra of He-4 counter was performed as a function of the pulse shaping time.

*Key words:* He-3, He-4 proportional counters, neutron detectors

## 1 Introduction

Helium filled proportional counters were widely used in the field of neutron spectrometry [1,2]. He-3 counter is a detector commonly used for neutron spectroscopy for thermal-epithermal neutrons. He-4 is suitable for fast neutrons above 1 MeV. The reason for using both detectors is due to the behavior of neutron elastic scattering cross section of $^3$He and $^4$He. $^4$He(n,n')$^4$He reaction cross section in fast neutrons is an order of magnitude higher than $^3$He(n,p)$^3$H and $^3$He(n,n')$^3$He reactions. However $^4$He(n,n')$^4$He reaction cross section is low in the thermal neutron energy (figure 1) [3].

Therefore in order to measure in a field of wide neutron energy range, as for example the spectrum produced by a spallation source, both He-3 and He-4 proportional counters have to be used. An energy and response calibration must be known in order to extract the measured spectrum. The energy calibration of the detectors, in the range of 0.5-10.7 MeV, was performed in the

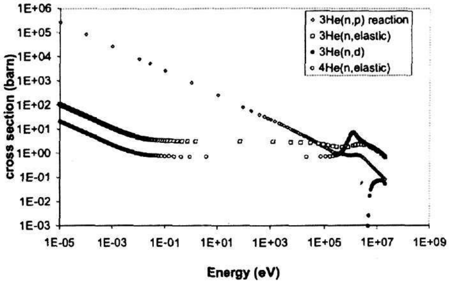


Fig. 1. Neutron cross sections of $^3$He and $^4$He reactions.

Tandem, Van de Graff accelerator facility at the Institute of Nuclear Physics, NCSR Democritos, Athens Greece. The gamma ray contribution to the spectrum of$^4$He counter was also investigated.

## 2 Experimental

The basic characteristics of the two cylindrical proportional counters are summarized in table 1. The associated electronics consists of High Voltage, Charge sensitive pre-Amplifier, Gaussian Pulse Shaping Amplifier with pile up rejector and ADCs. Optimal settings or each detector were experimentally determined and was used for calibration of the detectors.

Table 1
He-3, He-4 proportional counter characteristics.

| **Detector** | **Pressure (atm)** | **Effective length (cm)** | **High Voltage** |
|---|---|---|---|
| $^3$He | 13 | 30 | 1630 |
| $^4$He | 18 | 50 | 2150 |

Monoenergetic neutron beams were obtained via $^7$Li(p,n)$^7$Be reaction for neutron energies up to 4 MeV. For proton energies above 2.37 MeV, neutron emission from the first exited state of $^7$Be at 429 KeV takes place producing a second group of neutrons [4]. Therefore for energies above 4 MeV the reaction $^2$H(d,n)$^3$H was applied. The monochromacity of this reaction is also limited because of the multiparticle break up reactions with low cross sections above 4 MeV.

Energy calibration measurements were performed with the anode wire of the detectors parallel to the beam direction. For $^3$He detector an energy calibration was performed for the full energy peak. For both detectors a separate energy calibration was made for recoil peaks.

The gamma ray contribution to the $^4$He spectrum was investigated by counter irradiation with $^{137}$Cs and electrons from $^{90}$Sr-$^{90}$Y source of 10 $\mu$Ci and 5 mCi intensity. The source was placed 2 cm far from the counter. The behavior of gamma rays in both counters is very similar, as it is known from previous studies in $^3$He detectors [5].

## 3 Results and discussion

Typical spectra of He-3 and He-4 counters are presented in figures 2a and 2b. In figure 2a the low energy spectrum of He-3 counter contains gamma rays and low energy neutrons produced from neutron scattering on the surrounding walls and the floor of the accelerator hall, with about equally contribution. The thermal neutron peak with energy of 765 KeV [1] dominates this part of the spectrum. At higher energies the $^3$He-recoil peak can be seen and at the high end of the spectrum the full energy peak having the energy of $E_n$+Q. The $^3$He-recoil has a maximum energy of $0.75E_n$ and is not a clear Gaussian peak due to the angular distribution of the $^3$He-recoil. The low energy part of the recoil spectrum, corresponding to large angle recoil scattering, is positioned closed to the gamma ray part of the spectrum. It is clearly seen that in the $^4$He spectrum, where the only peak appeared in the spectrum is due to the $^4$He-recoil, figure 2b. However the maximum energy of the $^4$He-recoil corresponds to $0.65E_n$.

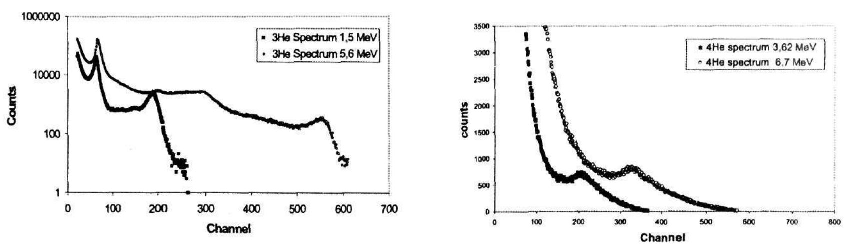


Fig. 2. Typical spectra of He-3 and He-4 proportional counters

Energy calibration of full energy peak of $^3$He detector is given in figure 3. The counter shows a perfect linearity up to 10.7 MeV examined in this experiment. However this type of counters is suitable for thermal neutron counting having high response to this energy region. But it is proved that they can also measure higher neutron energies with good energy discrimination and considerable lower response comparing to the corresponding in thermal neutrons. In

[1] The energy of 765 KeV correspond to the Q value of the $^3$He(n,p)$^3$H reaction.

those experiments it is calculated that in thermal neutrons the response of that counter is about 50% and drops to about 0.1% at about 500 KeV.

In figure 3 the calibration of He-3 detector of full energy peak is presented. Figure 4 shows of He-3 and He-4 calibration corresponding to $^{3}$He and $^{4}$He recoils. Excellent energy linearity can be resulted for both cases of full energy peak and recoils proving that they can be used for any energy estimation in a neutron spectrum. In this case we have to take care with the response because for the response estimation one has to integrate the whole recoil spectrum corresponding to the angular distribution. Also the FWHM of recoil peaks is larger than that of a full energy peak which typically is of the order of 7% for thermal neutrons.

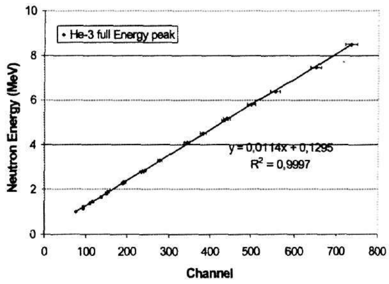


Fig. 3. Energy Calibration of He-3 proportional counter.

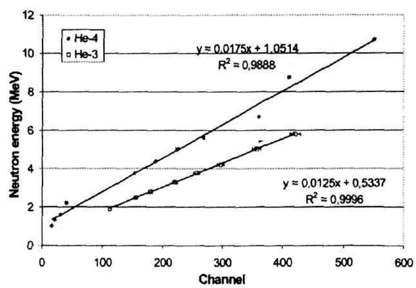


Fig. 4. Energy Calibration of He-3 and He-4 (recoil peak) proportional counter

Gamma ray pulses can easily be distinguished from neutron induced pulses in a proportional counter from the pulse rise time and pulse height [6]. Gamma ray pulses have typically larger rise time comparing to those of neutrons, which typically have $2\mu$sec. Gamma rays give smaller pulse heights although some low energy neutrons may give also small pulse heights. If a spectrum is taken by a small shaping time however gamma rays can be excluded, having larger rise times. But when the neutron energy increases small shaping times are not sufficient for neutron pulse integration, so the acquisition of false events in lower energy parts of the spectrum is inevitable. It is interesting so, to know all parameters involved in spectrum acquisition in order to fix optimal conditions for working in a wide neutron energy range. From the other hand the knowledge of gamma ray behavior can also be used for the deconvolution of a spectrum taken by a proportional neutron counter. However high voltage can play also an important role on the spectrum quality but for this energy calibration experiments high voltage was setting as suggested by the provider and it is shown in table 1. Spectra taken from gamma rays of $^{137}$Cs and electrons of $^{90}$Sr-$^{90}$Y sources are identical and cover the same part of low energy channels. This test was made with $^4$He counter because the region of the low energy spectrum is clearer in this detector while in $^3$He low energy neutrons coexist with gammas in the same low part of the spectrum. The acquisition was made for various shaping times from 2-12 $\mu$sec. The data have fitted perfectly by an exponential function $y=Ae^{-bx}$

In figure 5 the exponent of the fitted data as a function of the shaping time is given. It is resulted that higher shaping times introduce more gamma pulses to the spectrum as it was expected from the theory. In higher shaping times a tendency to saturation is appeared, which means that further increase has no significant influence on the spectrum. For that reason a shaping time of 6 $\mu$sec can be a compromise to work with neutrons in the presence of gamma rays. This value of shaping time is used for energy calibration experiments of this work for both counters.

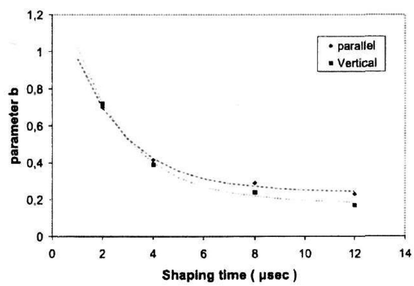


Fig. 5. Variation of the exponential parameter as a function of the shaping time

## 4 Conclusion

Energy calibration of He-3 and He-4 proportional counters was performed in the neutron energy range 0.025 eV to 10.7 MeV. Full energy peak of $^3$He follow a perfect linear behavior and can be used for neutron measurements up to some MeVs. Recoil peaks for both detectors show also a very good linearity up to high energies. He-4 counter can also be used for energies below 1 MeV.

A shaping time of 6 $\mu$secis a compromise between small shaping times needed for neutrons and larger shaping times for gammas as it is concluded from the experiment. The knowledge of the region where gammas are measured in the spectrum as well as the shape of their contribution can be used for the analysis of the neutron spectrum in mixed fields of neutrons and gammas.


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