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SIMULATION OF SPECTRA OF CYLINDRICAL NEUTRON COUNTERS USING THE GEANT-4

A.V. Churakov[1,2], A.K. Kurilkin[1], J. Saiz[3]

[1] *Joint Institute for Nuclear Research, Dubna, Russia*

[2] *Dubna State University, Dubna, Russia*

[3] *University of York, York, England*

E-mail: churakov@nf.jinr.ru

It is widely known that the amplitude spectrum of the helium proportional counter produced by the irradiation of thermal and cold neutrons has a peak of full absorption with energy of 768 keV and two small "shelves", caused by boundary effects, i.e. the absorption of charged particles (proton or tritium nuclei) in the detector wall. The simulation of the amplitude spectra of cylindrical counters with different gas filling is presented in the paper. The possibility of the third peak, not coinciding with that of full absorption is shown, whilst the peak position depends on the ratio of the path length towards the counter diameter. The results obtained may be of interest for the development of low efficiency neutron detectors and neutron monitors.

Keywords: neutron, detector, proportional counter, simulation, GEANT4

1. Introduction

The ^{3}He-filled Cylindrical proportional counters are perhaps the most widely used neutron detectors. They are simple, reliable and commercially available devices with high detection efficiency of thermal neutrons and very low sensitivity to gamma rays. Proportional counters have a good enough time resolution which allows their use on diffractometers operated in time-of-flight mode.

An important characteristic of the proportional counters is the amplitude spectrum. It is known that the amplitude spectrum of the helium proportional counter irradiated by thermal or cold neutrons has a peak of full absorption with an energy of 768 KeV and two small "steps". These "wall effects" arise from the hit of primary ionizing charged particles (proton or tritium nuclei) in the detector wall. (fig. 1). When one of these particles products collides with the wall of the detector, its energy is dissipated and does not contribute to the full energy peak.

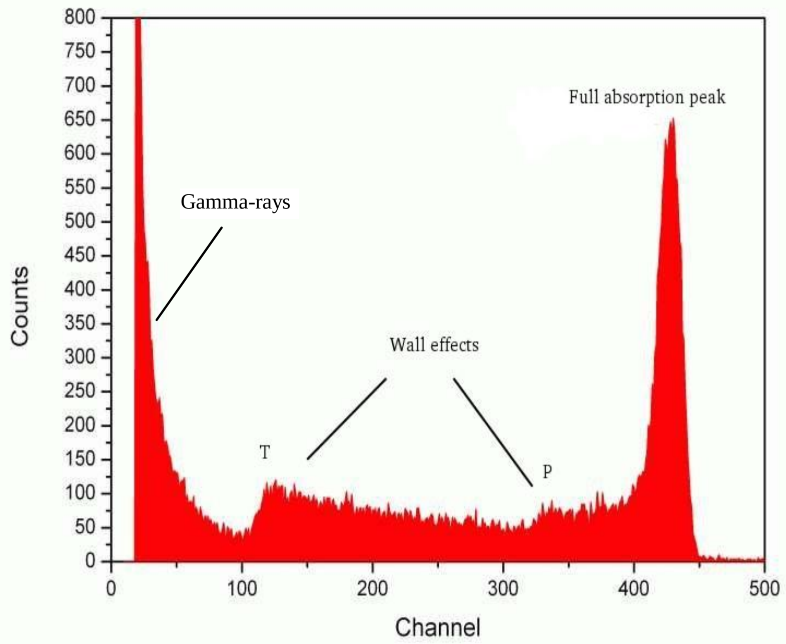

Figure 1. Typical proportional counter spectrum

2. Simulation assumption and tools

In our work, we carried out a simulation of the amplitude spectrum of the proportional counter. GEANT 4 [1] was used as a modeling tool. It was designed to simulate the tracks of elementary particles passing through matter by the Monte Carlo method. The version of GEANT4 used in our simulations is 10.03.03. In addition, the software packages ROOT [2] on its version 6.14.06, for the storage and visualization of the data, and the program SRIM 2013 [3], for calculations involving particles of primary ionization, were also used.

The simulated cylindrical counter was irradiated with a uniform flow of thermal neutrons. The particle generator emulates the thermal neutron beam of energy (0.0253 eV). Neutrons pass through the geometric model of the detector, taking into account their interaction with the walls of the detector. The wall thickness was considered to be 0.2 mm, which corresponds to typical counter wall thicknesses. The rate of neutrons was considered low enough to neglect double and triple events. In the simulation, it was assumed that each interaction between a neutron and a ^{3}He nucleus happening in the sensitive volume of the detector, will be registered, and the induced charge proportional to the energy losses of particles in the volume of the counter will be collected at the anode. When the primary particles are completely absorbed in the volume of the counter, the fluctuation of the charge induced on the anode has a normal distribution. The same assumption was believed to be true for all other energy values of primary ionizing particles. The value of the energy resolution of the detector determines the dispersion of the induced charge distribution. On the other hand, the modeling did not take into account the part of the spectrum caused by gamma radiation, since the level of the gamma background is determined mainly by the neutron source [4] and the proportional counters themselves have a sufficiently low sensitivity to gamma radiation.

3. Results and discussion

We started by modelling the spectrum of a standard proportional counter. In many scientific facilities, counters of the SNM-18 type and their numerous analogues have been used. For comparison we chose the "Helium-18-200" counter, produced by JSC "Consensus" [5], which is similar to the SNM-18. On the left side of figure 2 the measured spectrum for these counters is presented. On the right hand side, the simulation of the neutron component of the spectrum is shown. The simulation results are in excellent agreement with the measured spectrum (fig. 2).

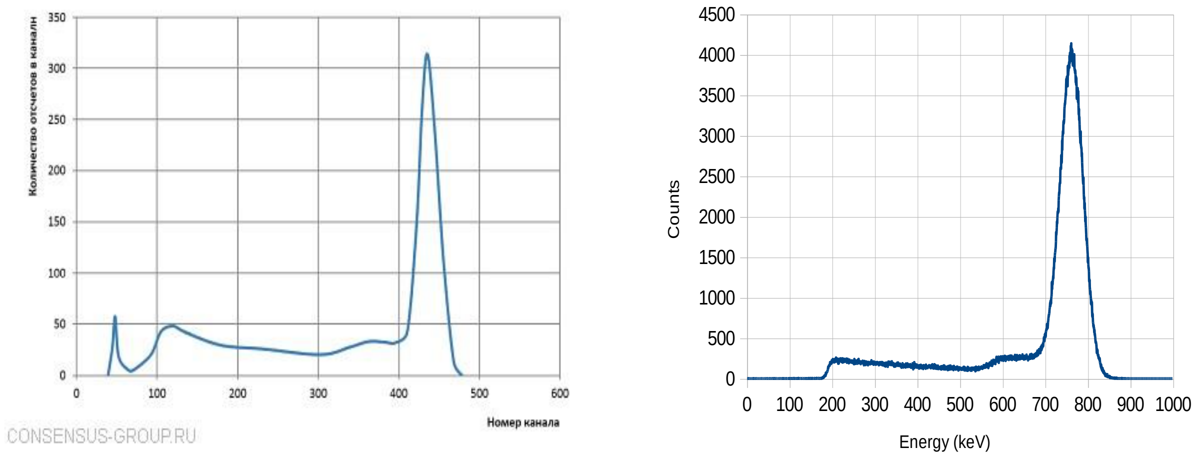

Figure 2. Measured (left) and simulated (right) proportional counter spectra

It is necessary to say a few words about the efficiency of cylindrical detectors. Counters of SNM-18 type are believed to absorb almost all thermal neutrons. However, this is not quite true. The maximum efficiency of such counters is 86% in a narrow area strictly in the middle of the detector, and the average efficiency of the detector, because of the cylindrical shape, will be 74 %. In large-diameter detectors, the bulk of neutrons are counted near the input window, so the effect of the detector's cylindricity is smaller. However, the amount of gas required to fill the detector increases in proportion to the square of the diameter, which causes a significant increase in the cost of the experimental installation. It would be more rational to cover the area of interest with a double layer of neutron counters, saving on the quite expensive gas.

We simulated changes in amplitude spectra of SNM18 - type counters caused by the gas mixtures. Helium is a fluid gas, so in some years, depending on the quality of the detectors, the gas mixture may leak out of the sealed housing, and the efficiency and amplitude spectrum of the counter will change. The results are shown at (fig. 3), where the pressure is expressed as a percentage of the initial pressure value, 9 bar. The initial composition of the gas mixture is 8 bar ^{3}He+ 0,95 bar Ar +0,05 bar CO_2

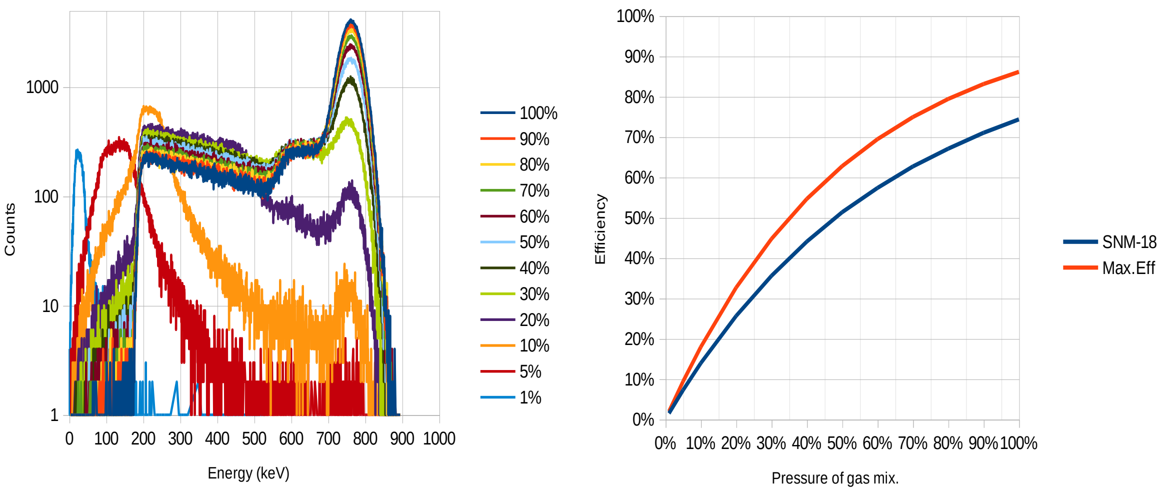

Figure 3. Amplitude spectra (left, logarithmic scale) and counter efficiency (right) as a function of the gas mix pressure. The gas mix pressure is represented as a percentage of the initial pressure. Blue line – average counter efficiency, red line – maximum counter efficiency (in the middle of the counter).

At 100% to 30% of the initial pressure, the spectra look like the typical counter spectrum (fig.1), and the decrease in pressure by half does not lead to any noticeable changes in the amplitude spectrum. At 20% of the original pressure and below, the spectra are not similar to the classic, familiar spectrum of the cylindrical counter. On the 20% spectrum we see the peak of full gathering, a strong peak from the triton and a new peak arises, superimposed to it. On subsequent spectra, this new peak almost completely suppresses the peak of full absorption.

The explanation for this new peak is the following one; primary ionization energy is spent mainly in the ionization of the gas mix and losses in the counter walls. The amount of primary ionization charge collected at the detector anode depends on the number of electron-ion pairs remaining in the detector volume. When the pressure decreases, the mileage of charged particles increases. Calculations were carried out using the program SRIM 2013. At a pressure value of about 30% of the initial total, the particle range is of 16.97 mm, which is comparable to the diameter of the detector. Further pressure reduction leads to an increase in the length of the track, and it no longer fits completely into the volume of the detector. It follows from the simulations that this is the most likely value of the track, that depends mainly on the ratio between the diameter of the detector and the maximum length of the track.

Amplitude spectra for different detector diameters are presented. The gas filling used was the standard one. Up to about 5 mm, we did not observe the distortion of the spectrum and the appearance of the third peak, since the mean free path of particles in the gas mixture 8 bar ^3He + 0.95 bar Ar +0.05 bar CO_2 is about 5.1 mm, but at smaller diameters, the changes in the spectrum and the third peak are clearly visible.

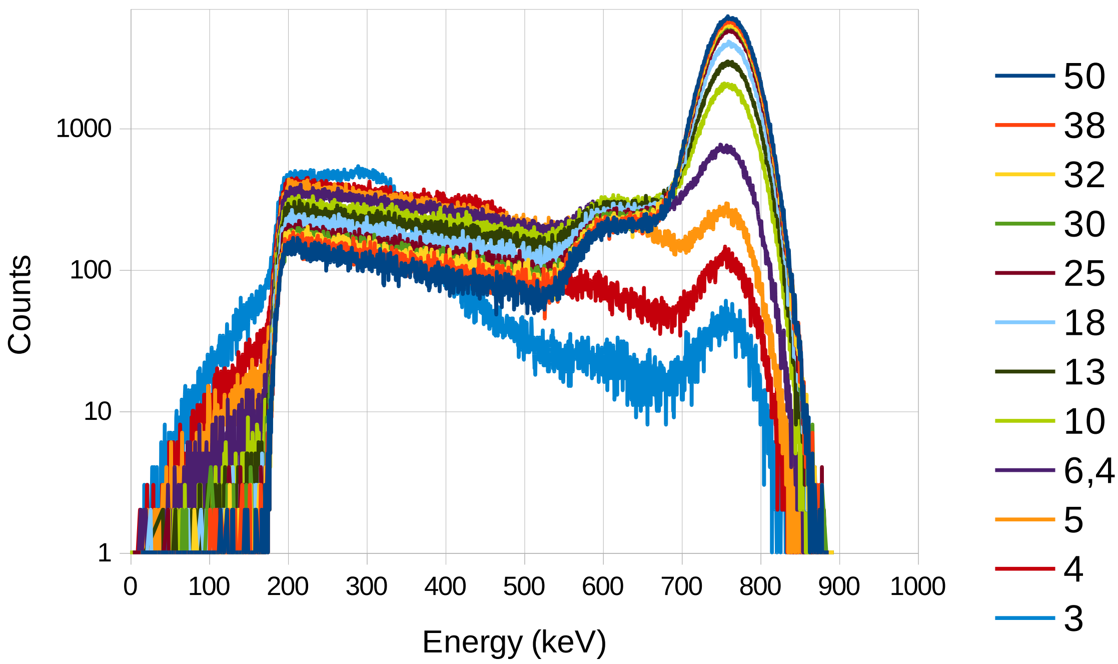

Figure 4. Measured (left) and simulated (right) proportional counter spectra

4. Conclusion

Amplitude spectra of ^{3}He-filled proportional counters were simulated (Fig. 4). The appearance of an additional peak (Landau peak) is shown. This peak is caused by the incomplete stacking of the tracks of primary ionization particles in the counter volume. The position of the peak depends on the ratio between the diameter of the counter and the range of the primary ionization particles. The results of this work can be used in the development of some types of new neutron detectors, such as neutron detectors with small gas pressure: monitors, low-background cold neutron detectors, neutron calorimeters («neutron telescopes»). The appearance of the new peak under the low gas pressure must be considered in the developments of thin position-sensitive proportional counter tubes with resistive readout and during calibration of slow neutron counters.

References

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