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Helium counters for low neutron flux measurements

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Abstract. We present a comparison of some characteristics of helium counters for measurements of low intensity neutron flux.

We focus on neutron flux density measurements in low background laboratories. Because of an extremely low counting rate (few events per hour or less), we have concentrated on counter parameters which are sometimes meaningless under regular conditions, i.e. background from internal alpha radioactivity, percentage of events in full energy peak, and the width of this peak. The background depends on residual radioactivity of the counter tube material and can not be eliminated. The full energy peak characteristics can be specified by counter gas composition. We will present a comparison of four types of helium gas counters.

1 Principles of helium counter

Helium counter is a gas proportional counter filled with ^{3}He. It is a perfect tool for measuring neutrons, as it is practically not at all sensitive to other types of particles. During a reaction (Crane and Baker, 1991):

$$^3\mathrm{He}(n,p)^3\mathrm{H} + Q\,(764\,\mathrm{keV}) + E_{k\ \mathrm{neutron}}$$

proton and triton are created, and registered in counter in the normal way. The cross-section for this reaction is the biggest for thermal neutrons, whose kinetic energy is negligible in comparison to the energy of the reaction:

$$E_{k\ \mathrm{proton}} + E_{k\ \mathrm{tryt}} = 573\,\mathrm{keV} + 191\,\mathrm{keV} = Q = 764\,\mathrm{keV}$$

which means that the helium counter registers neutrons as events with energy equal to Q. However, this is the case when both proton and triton stop inside the counter. If not, i.e. one of the products leaves the counter, the energy deposit will be smaller. This phenomenon, the so called “wall effect”, causes the registered energy spectrum to contain a flat tail down to 191 keV, below the full energy peak (Fig. 1).

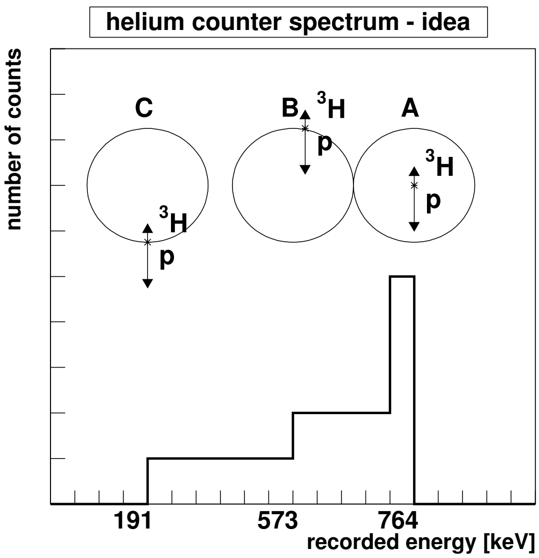

Fig. 1. Amplitude spectrum recorded by a helium counter (idea). Thermal neutrons are caught by ^{3}He nuclei during the reaction $^3\mathrm{He}(n,p)^3\mathrm{H} + Q\,(764\,\mathrm{keV})$. The reaction products, proton and triton are created with energies 191 keV and 573 keV respectively. There are three possibilities:

- A both proton and triton stop inside the counter – this situation corresponds with 764 keV peak in recorded spectrum.
- B proton stops inside and triton escapes – it corresponds with flat tail in recorded spectrum, from 191 keV to 764 keV.
- C triton stops inside and proton escapes – it corresponds with flat tail from 573 keV to 764 keV. (Tail ends referred to in points 2 and 3 overlap).

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Table 1. Counter tests summary

counter (manufacturer)		ZDAJ	General Electric	Centronics	Konsensus
length	[mm]	500	965	500	1030
diameter	[mm]	25	50	50	30
area	[cm^2]	393	1516	785	971
^{3}He pressure	[at]	4	2	2	2
amount of ^{3}He	mole	0,04	0,17	0,09	0,07
stopping gas		Kr	none	Ar	Ar
stopping gas pressure	[at]	0,5	–	0,5	2
HWHM of neutron peak	[%]	5	5	7	5
fraction of neutrons in neutron peak	[%]	57	42	67	75
efficiency of thermal neutron registration	$[\frac{\text{count}}{\text{neutron}}]$	0,69	0,68	0,69	0,53
max. α energy	MeV	6	4	4	4,5
α frequency per counter	[h^{-1}]	3,2	4,7	16,2	51,8
α frequency under 764 keV peak	[h^{-1}]	0,028	0,058	0,24	0,57
flux for which neutron peak counting rate is equal to background counting rate	$\times 10^{-7}$ [cm^{-2} s^{-1}]	1,6	1,2	5,6	12,9

Fig. 2. Tested helium counters. From top to bottom: General Electric (USA), Konsensus (Russia), ZDAJ (Poland), Centronics (UK/USA). Rulers in the photo are 20 cm in length.

Because of the wall effect, the helium counter filled with pure helium must have a large diameter, as the range of 537 keV proton, in helium, is 52 mm (in normal conditions). To make the counter smaller, a stopping gas (argon or krypton) is added to He, which increases (higher Z) the ionisation and stops the particles.

2 Characteristics of a good quality low-flux detector

– low internal α background
– narrow neutron peak (764 keV)
– big fraction of neutrons in neutron peak
– high efficiency of neutron registration

3 Background problem of low neutron flux measuring

A fundamental problem with measuring the low neutron fluxes (e.g. neutron background in an underground laboratory) is the extremely low count rate, of the order of one per hour. Therefore, the rate of non-neutron signals must also be very low.

The helium counter is practically not sensitive to other types of radiation, but it has the internal source of background - α particles emitted by the components of the counter tube. The spectrum of signals from α particles is flat and extends from 0 to several MeV, which is due to the fact that α particles are emitted at different depths of the counter material (and this is evidence that αs didn't come from the counter gas) (Amsbaugh at al., 2007).

To measure the neutron flux, the neutron peak (764 keV) is the most promising feature to exceed the particle background. Figure 3 shows, as an example, simulation for ZDAJ counter (Table 1) for two different neutron fluxes: 10^{-6} cm^{-6} and 10^{-8} cm^{-6}. As it is possible to observe, too low flux can not be measured even after a very long measuring time, as the 764 keV peak is comparable to background.

The presented effect shows the limitation of low neutron flux measurements with this method.

4 Tests of detectors.

We tested 4 He counters of different manufacturers for their suitability for measuring low neutron flux (see photo in the Fig 2). For each counter we made two measurements: one

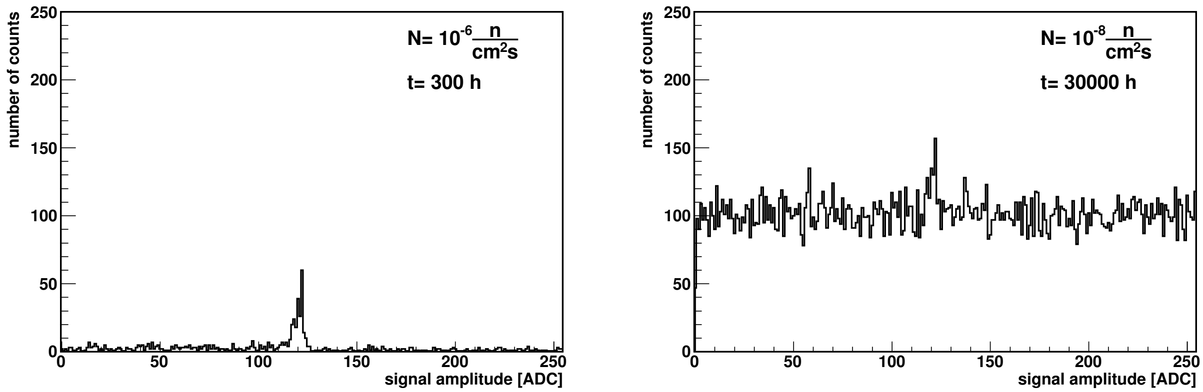

Fig. 3. Neutron peak in the α background. Simulation of amplitude spectrum recorded by a He counter. Left: simulation for neutron flux $N_1 = 10^{-6}$ neutron/cm^2 s and measuring time $t_1 = 300$ h. Right: simulation for $N_2 = N_1/100$ and $t_2 = t_1 \times 100$ (≈ 3.5 years). Too low flux can not be measured even after very long measuring time, as the neutron signal is comparable to α background.
The simulation consisted of drawing the proper amount of "neutrons", based on a true neutron spectrum measured by the counter and adding to them an appropriate amount of "αs" drawn from a rectangular spectrum. ("ADC"= channel of analog to digital converter)

with a higher amplification of analog signal, to test the parameters of neutron peak (764 keV) and then one with low amplification but the long measurement time to examine the α particle background. The results of the measurements are shown in the Fig. 4 and the Table 1. As a quantitative criterion of counter quality, we suggest the value of the neutron flux, for which spectral integral of signal around 764 keV peak is equal to the background integral in the same region. (see Table 1, last row). If this number is low, the counter is better for low flux measurements.

5 Discussion

As it is possible to observe in Table 1, the counter made by General Electric has the best quality for very low flux measurements. That is because of its very low level of α background as well as its relatively big dimensions, and big amount of helium it contains. The counter high cost is related exlusively to this amount of helium. Note that the quality of the ZDAJ counter is only a little bit worse than the quality of the General Electric counter, but the amount of helium contained in the former one is 3,5 times smaller than in the latter one. The counter price depends mainly on the amount of helium, and this is why we think the ZDAJ counter is better.

All examined detectors could be used for neutron measurements. However, one of them (Konsensus) is rather unsuitable for very low neutron flux measurements, because of its relatively high level of α background.

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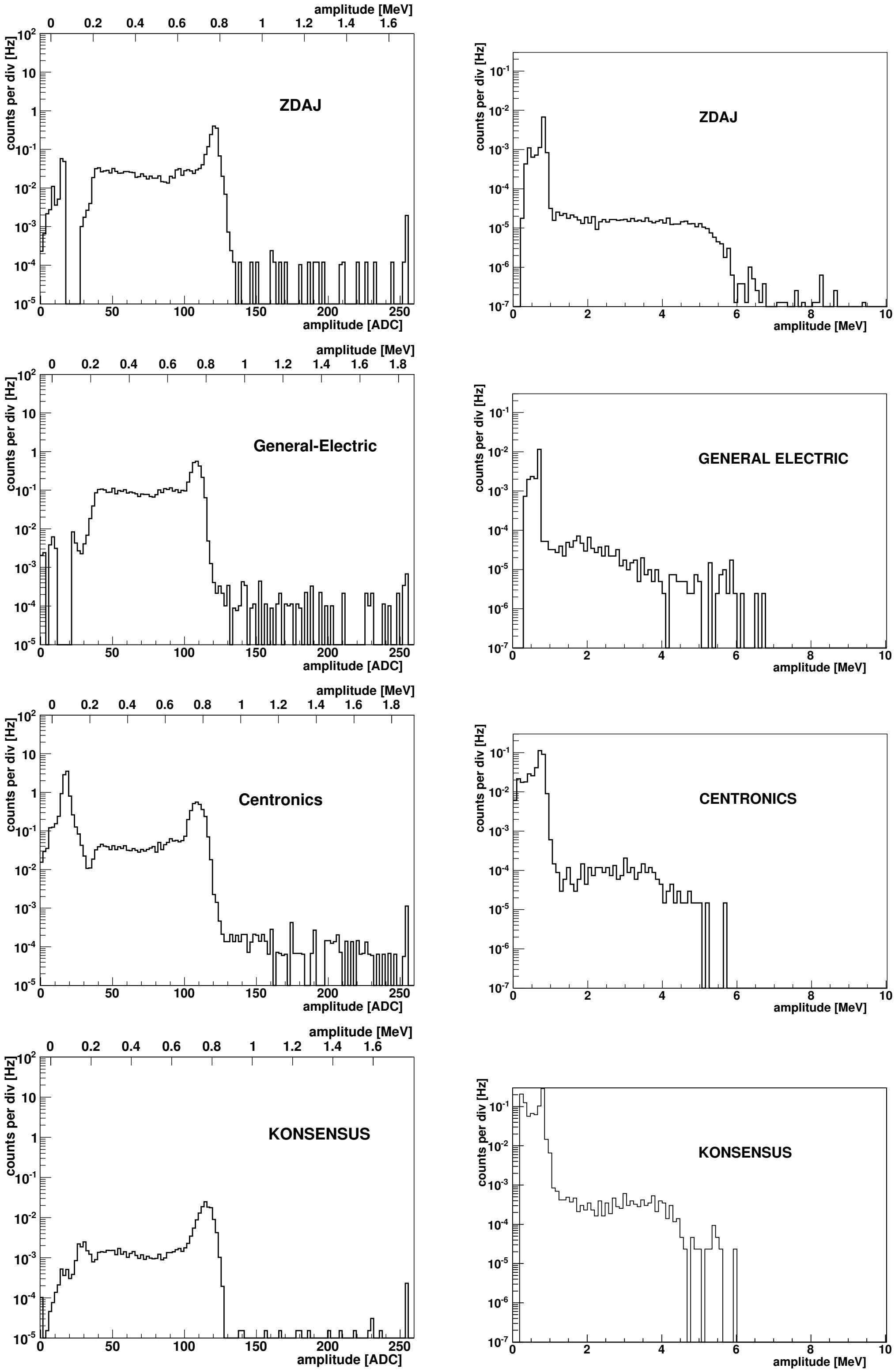

Fig. 4. Spectra of amplitudes recorded by the tested helium counters. Left: measurement with a higher amplification, neutron peak is visible at 764 keV. Right: measurement with low amplification and the long measurement time, see neutron peak (764 keV) and flat-spectrum from α background. Flat spectrum reaches a few MeV energy, this energy is typical for α particles from radioactive dacays.