Measurements of thermal neutron flux in underground laboratories, a standard proposal for the BSUIN project

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Abstract One of the goals of the BSUIN project is to propose standard methods for the characterization of underground laboratories (UL). We have proposed scheme for thermal neutron flux measurement: simple and low-cost but still very reliable. A pilot measurements were made in mines in Freiberg (Germany) and Pyhasalmi (Finland). This work is still in progress, the final stage of the BSUIN project is planned for 2020.

Keywords: Underground Laboratory, Natural Neutron Flux, Cosmic Neutrino Measurements, Dark Matter Search

1. Introduction

The Baltic Sea Underground Innovation Network (BSUIN) project [1] is aimed at making the underground laboratories in the Baltic Sea region more accessible for innovation, business development and science by improving information about the underground laboratories, the operation, user experiences and safety. Potential beneficiaries of the project are various types of underground physics, such as neutrino measurements or dark matter searching. The BSUIN consortium comprises 14 members from eight Baltic Sea countries. Six underground labs are looking for new collaboration in the project. BSUIN is EU funded as a part of INTERREG Baltic Sea program [2].

The main topic of BSUIN Work Package WP2 (Characterization of Underground Laboratories) is the development of a standard for the characterization of underground laboratories. As part of WP2, National Centre for Nuclear Research (NCBJ, Poland) is the leader of activity WP2.2 (Natural radioactive background characterization). Therefore, we proposed a scheme for measuring the neutron background, built a test setup and carried out pilot measurements.

2. Minimal setup for thermal neutron flux measurements

We decided to consider what the simplest setup for thermal flux measurements should be. It is obvious that a setup containing many counters and sophisticated measuring electronics will give more reliable results than a smaller and simpler one, but in many cases it will be overkill, unnecessarily raising the complexity and cost of the measurement. We would like to propose a setup as simple as possible, but still able to measure thermal neutron flux in underground laboratories with sufficient reliability. In our opinion, the setup should have the following features:

- to consist of at least two counters, so that the measurement uncertainty can be determined by comparing the results;
- the method of distinguishing real neutron recording from noise should exist;
- the presence of the operator during the measurements should not be necessary, which will make very long-term measurements easier.

So we built a test setup consisting of two helium counters and a simple data acquisition system.

2.1. Helium counter

In our implementation, we used two proportional helium counters of type ZDAJ NEM425A50.

The counter is made of a 50 cm long steel tube of diameter of 2.5 cm and is filled with helium-3 under pressure of 4 atm. and natural krypton under pressure of 0.5 atm.

This type of counter is a standard gas proportional counter, but filled with helium-3, which is a noble gas with high cross section for thermal neutrons capture. Charged products of the capture reaction ^{3}He(n,p)^{3}H poses 764 keV of released energy and are recorded by the proportional counter in the normal way. Therefore an amplitude spectrum recorded by the counter has a characteristic shape with a peak corresponding to 764 keV energy and a tail of smaller amplitudes for cases when one of the reaction products escaped from the active volume (it's a so-called "wall effect"). An example of amplitude spectrum, obtained with a relatively large flux of thermal neutrons is shown in Figure 1.

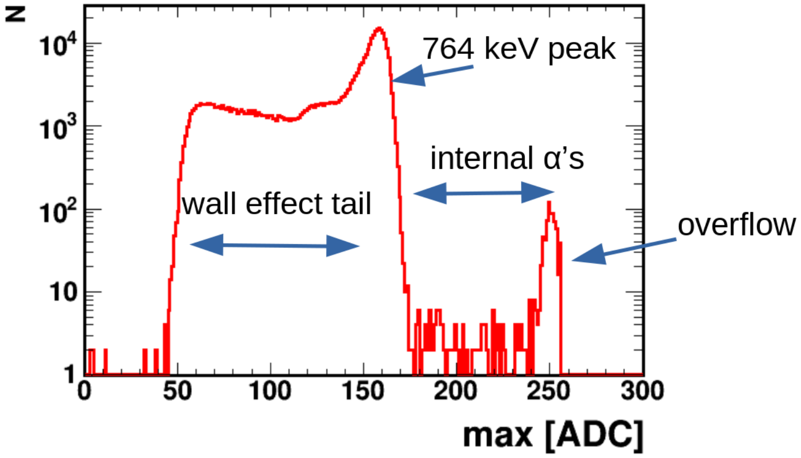

Fig1. *Amplitude spectrum measured by the helium counter with an artificial neutron source. The 764 keV peak with tail is clearly visible.*

2.2. Data acquisition system

The helium counter is a brilliant tool for neutron flux measuring because the distinction between neutrons and background signals is easy: you only need to recognize the 764 keV peak, so all you need is an amplitude spectrum. But in underground laboratories the neutrons flux from natural sources is usually very low, so noises negligible in normal conditions can distort completely the shape of the spectrum. This is the reason why the pulse-shape analysis is necessary.

Our data acquisition system has been designed to save oscilloscope-like waveforms for all received signals. For each counter we use a simple device with a single channel ADC controlled by a microcontroller. The ADC samples the signal every 700ns, and after the trigger keeps 50 samples of the waveform. Every device is independent and self-triggered, powered and control by a PC computer via the USB port. Example waveform recorded for neutron is shown in Figure 2.

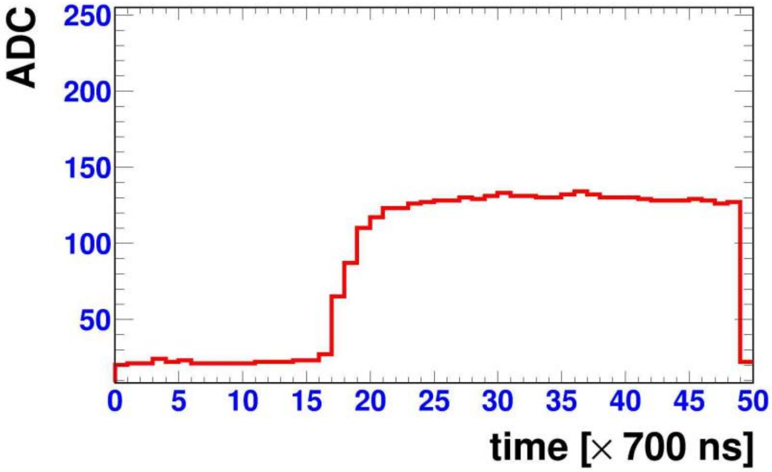

Fig2. *An example of waveform registered for neutron*

2.3. Remote control

Because the setup consists of only two helium counters, data acquisition time must be relatively long (several weeks). Such long presence of an operator would be very expensive so this forces the construction of the setup as remotely controlled. The setup of the main PC computer can be fully controlled via Internet using the ssh client or open source remote desktop program “Remmina”[4]. PC can be turned on and off by the standard Linux program “rtcwake”, additionally, thanks to special PC power supply configuration, reset of all devices powered by USB is possible.

3. Data analysis

In our case data analysis was aimed at distinguishing neutrons from other signals recorded by helium counters. These “other signals:” can be divided into three groups:

- normal electronics noise – this type dominates at low amplitudes, but its intensity decreases exponentially with the increase in amplitude, so it rarely appears in the area of 764 keV peak. The electronics noise intensity depends on the quality of the used electronics.
- alpha particles from counter’s internal parts – helium counter parts contain natural radioactive isotopes that emit alpha particles. These particles travel random lengths

before they reach the active volume of the counter, which is why the recorded amplitude spectrum has a flat shape (shown in Figure 1). The shape of alpha signal is exactly the same as neutron signal, but alpha spectrum can be easily studied for amplitudes greater than the 764 keV peak and subtracted from the neutron spectrum.

- high voltage “sparks” – this type comes from the current flow on the surface of insulators in the high voltage connectors. Recorded pulses can have any kind of amplitude, so they mimic neutrons. Fortunately, the rise time for "sparks" is much shorter than for neutrons, so these two cases can be distinguished by pulse shape analysis.

A useful tool for pulse shape analyzing is the two-dimension histogram “rise time” versus “maximum pulse amplitude” shown in Figure 3 (in fact, in this figure “pulse maximum time” is shown instead of “rise time”, but these times differ by a fixed value).

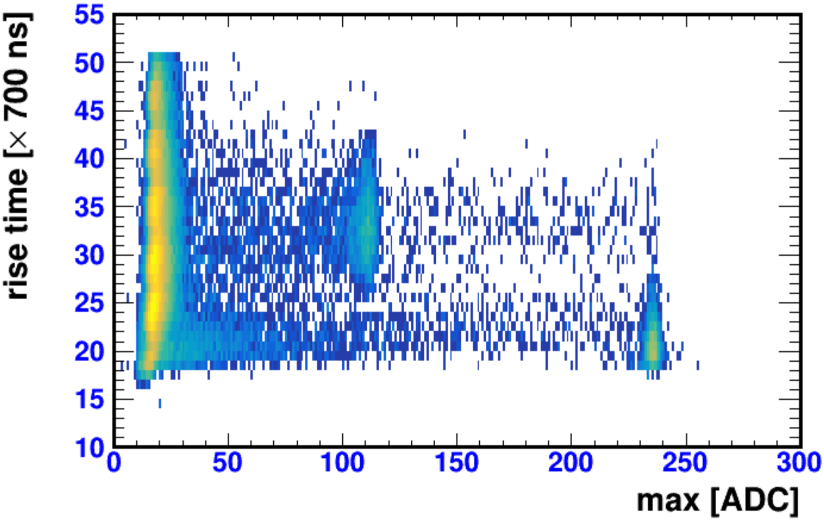

Fig3. *Two dimension histogram “rise time” versus “maximum pulse amplitude”*

The points in the histogram are arranged in a few distinct groups.

- The vertical band for amplitudes smaller than ~45 ADC corresponds to the normal electronics noise.
- The horizontal band for rise time smaller than ~29 ticks of time corresponds to high voltage “sparks”.
- The remained vertical band with a clear stain at ~120 ADC and ~35 ticks of time corresponds to neutrons and alphas. The stain corresponds to peak 764 keV.

The impact of rejection of ‘sparks’ on the spectrum of amplitudes is shown in Figure 4.

Analysis like this allows us to determine the true frequency of neutron counts in the counters and after comparing with the MC simulation, determine the neutron flux.

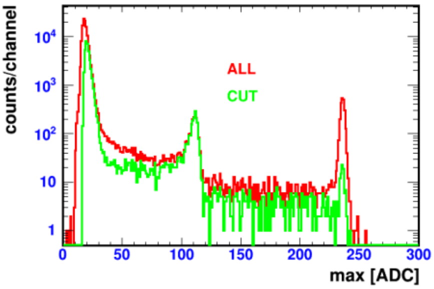

Fig4. *Amplitude spectrum registered in Freiberg mine in Saxony (Germany) after 45.5 days of data acquisition . The red line marks the raw spectrum, the green line – spectrum after subtraction of "sparks".*

4. Pilot measurements

To test the setup we have carried out measurements of the neutron flux in two mines: in Freiberg, Saxony (Germany) and in Pyhasalmi (Finland). These preliminary tests have shown that the setup is a useful tool for measuring neutron flux in the underground, but requires improvements and further tests.

4.1. Freiberg

Measurements were carried out at -250 m, in the network server room, near the "Reiche Zeche" shaft. The room was about 3x3x3 m, brick walls and a concrete ceiling.

The measurements were divided into two phases. In the first phase the setup consisted of two bare helium counters (as described above), and the measured results were used to determine the neutron flux. The registered amplitude spectrum for one of the counters is shown in Fig4, the thermal neutron flux calculated from the measurement results is equal to $(3.1\pm 0.3)\cdot 10^{-6}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

It is a rather high flux, but Reiche Zeche is an old silver mine, so a high level of natural radioactivity is expected. The first phase setup is shown in the Figure 5 on left panel.

Fig5. *Setup used in Freiberg (Germany) in Reiche Zeche shaft Left: Bare counters for the first phase measurements. Right: Counters in borax shield for the second phase measurements.*

In the second phase of measurements the setup from the first phase was surrounded by a cover made of polyethylene bottles filled with technical borax. The shield decreased the neutron flux reaching the setup due to neutron capture by boron-10 contained in borax. The second phase setup is shown in the left panel of Figure 5.

The second phase was a test of the setup and the analysis method: the rate of neutron counts should decrease, but the rate of internal alpha particle rate should not. The measurement lasted 30 days and confirmed that the apparatus is working properly. The comparison of the first and second phase results is shown in Figure 6.

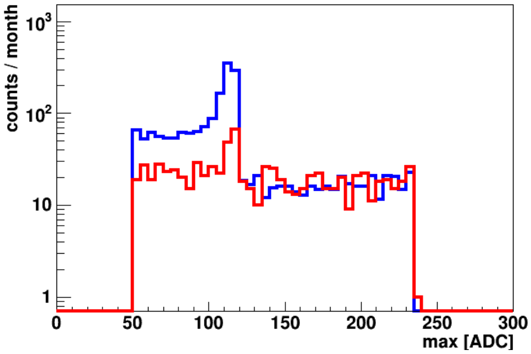

Fig6. *Results obtained in Freiberg (Germany) in Reiche Zeche shaft. Comparison of the first (the blue line) and second (the red line) phase amplitude spectrum*

4.2. Pyhasalmi

Measurements were carried out at -1444 m, in a special laboratory hall. The data acquisition system was similar to that used in Freiberg (with several improvements), but in this case the setup consisted of 10 bare helium counters. The data collection time was only about a week, which was enough due to the relatively high counting rate. Thermal neutron flux is probably 10 times greater than flux in Freiberg, but the data analysis is still in progress. The setup used in Pyhasalmi is shown in Figure 7.

Fig7. *The setup used in Pyhasalmi (Finland)*

5. Conclusion

As a part of the BSUIN project we have proposed a simple and low-cost but still very reliable scheme for thermal neutron flux measurement. Pilot measurements were made in mines in Freiberg (Germany) and Pyhasalmi (Finland). This work is still in progress, the final stage of the BSUIN project is planned for the year 2020.

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Baltic Sea Region
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