Thermal Neutron Background Measurements in the Gran Sasso National Laboratory

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***Abstract*— In April 2008 we measured thermal neutron background flux in the underground Gran Sasso National Laboratory. The flux is equal to (5.4±1.3)×10^{-7} neutrons/(cm^2 s). We have used a set of proportional counters filled with ^{3}He. During one week exposure we registered 658 neutron signals above 155 background signals, so using this method it would be possible to measure 10 times smaller neutron flux.**

I. MOTIVATION

The Gran Sasso National Laboratory in central Italy is one of the biggest underground laboratories all over the world. Very sensitive experiments for neutrino physics, dark matter and double beta decay search have been located here in the tunnel under 1400 m of rock. This is the reason why all kinds of background radiations in the Laboratory must be exactly known. In April 2008 we have performed measurements of thermal neutron flux *"in order to demonstrate the potential sensitivity of the neutron measurement and the alpha background"* (ILIAS Panel recommendation from the letter of November 13, 2007).

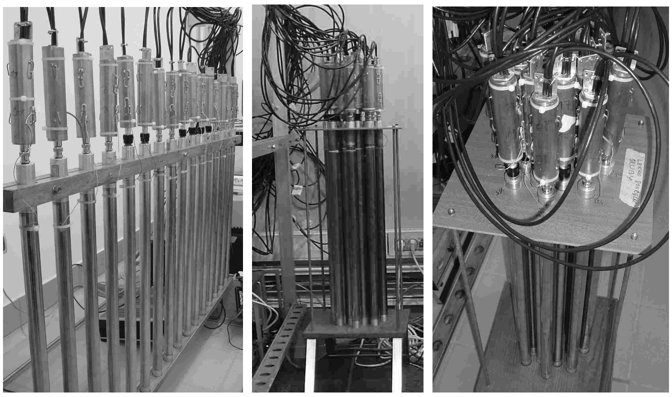

Fig. 1. Photos of detectors. Left photo shows 'line' setup. Center and right photos show the compact 'circles' layout.

II. METHOD OF MEASUREMENT

We used 16 proportional gas counters with ^{3}He with nominal pressure of 4 atm. Detectors were connected in pairs to 8 channels of 16 MHz FADC. We arranged these counters in two ways: one with large exposure and second compact with reduced exposure due to shielding of each detector by the others. We called the two detectors layouts as 'line' and 'circles' – 8 counters form 'outer circle' and 8 counters form better shielded 'inner circle' (Fig. 1). The idea of observing low level neutron flux is to see neutron peak at 764 keV above the background level due to α particles emitted inside the detector. In the helium counter thermal neutrons are registered due to the reaction

$$n +^3 He \longrightarrow p +^3 H + 764 keV.$$

Amplitudes of signals from ^{3}He counter have characteristic

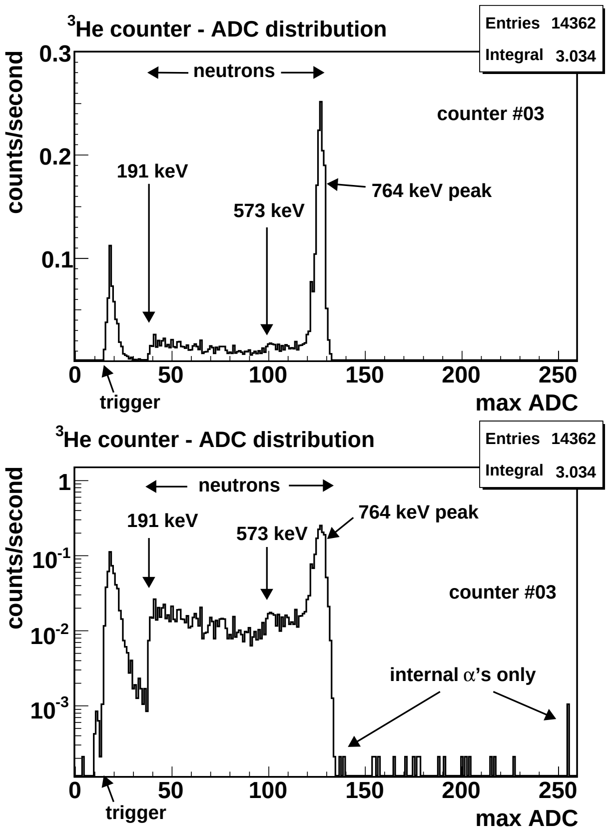

Fig. 2. Distribution of amplitudes of signals from ^{3}He counter in linear and logarithmic scale (test run with AmBe neutron source).

distribution with peak corresponding to reaction energy (764 keV), and tail of the smallest signals, corresponding to events in which one of the reaction product escapes from sensitive volume of the counter (wall effect) [1], [2].

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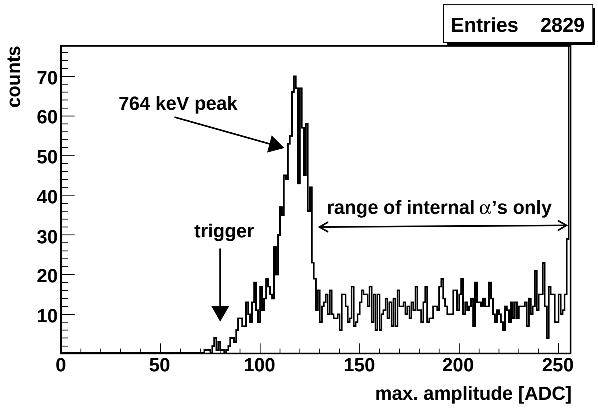

Fig. 3. Registered distribution of amplitudes of signals. Sum of 16 ^{3}He counters, 7 days of underground exposure with 'line' setup.

The distribution received during laboratory test run, with americum–berillium (AmBe) neutron source is presented in the Fig. 2 Distribution of amplitudes of signals registered during 7 days exposure in the Gran Sasso Underground Laboratory is presented in the Fig. 3. The peak at 764 keV is clearly visible, but wall effect tail is cut by the trigger. On the plot one can see flat distribution of signals bigger than 764 keV. It is probably from α radiation from counter tube walls. α particles are the main limitation of the method of very low neutron flux measurements.

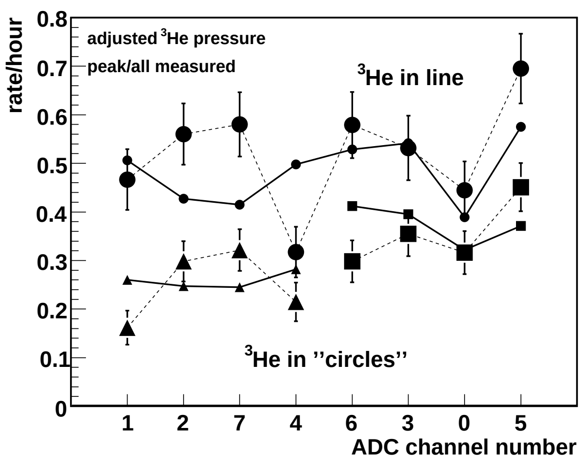

Fig. 4. Measured (dotted line) and simulated (solid line) rate of neutrons for all pairs of counters. Circles mark 'line' layout, triangles – 'inner circle', squares – 'outer circle'. Only neutrons from 764 keV peak are counted. Simulation were normalized to the thermal neutron flux equal to $5.42 \cdot 10^{-7}$ n/(cm^{2} s).

III. SIMULATIONS

In order to estimate neutron flux (in neutrons/(cm$^{2}\cdot$s)) it was necessary to compare the measured number of neutrons with the number of neutrons predicted by computer simulations for assumed neutron flux.

We used GEANT4 toolkit [3] to simulate efficiency of neutron registrations in ^{3}He counters. To find expected number of neutrons registered in LNGS measurements we simulated registration in 'line' layout and separately 'circles' for neutrons with Maxwellian energy distribution for temperature of 10°C emitted isotropically from the sphere of radius R = 3m. Comparison of measured and simulated counting rate for all pairs of counters is presented in the Fig. 4.

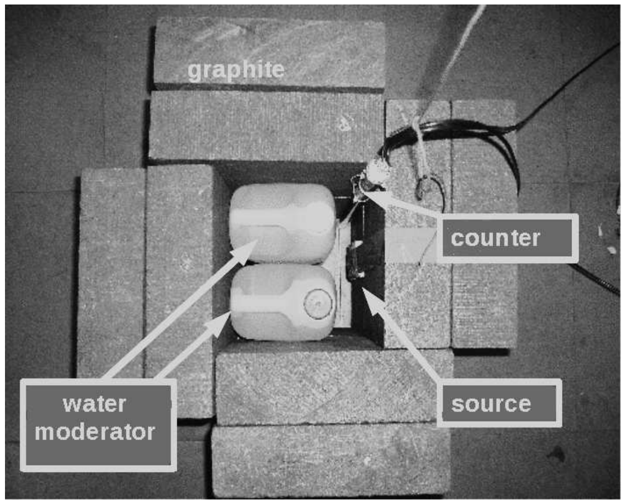

Fig. 5. Experimental setup for verifying the accuracy of simulations. Tested counter was placed inside a graphite chamber (20 cm thick wall) together with the AmBe neutron source and water moderator (20 l). Measurement was reconstructed by Monte Carlo simulation with 98% agreement.

In order to verify accuracy of our simulations we calculated efficiency of a single ^{3}He neutron counter. We received 98% agreement between results of simulations and measurements in a specially built experimental setup in our Łódź Laboratory (Fig. 5). It was a graphite chamber with 20 cm thick walls. Inside we placed the tested counter, AmBe neutron source and 20 l of water moderator (in plastic containers). The chamber walls reflect neutrons, so setup inside was isolated and easy to simulate, because influence of environment was negligible.

IV. RESULTS

We exposed our detectors to thermal neutron flux in two layouts: for a week with high neutron registration efficiency ('line' setup – 16 counters) and for 10 days in 'circles' setup in order to check our method.

Overall result of the neutron flux was obtained as the mean value of results for each counter pair in both runs in the Gran Sasso tunnel: 8 points from 'line' measurements and 8 points from 'circles' measurements. Results are presented in the Fig. 6.

We obtained the thermal neutron flux equal to

$$(5.4 \pm 1.3) \times 10^{-7}\ \text{neutrons/(cm}^2\ \text{s).}$$

Fig. 7 shows neutron flux density measurements in many energy ranges made in the Gran Sasso Laboratory.

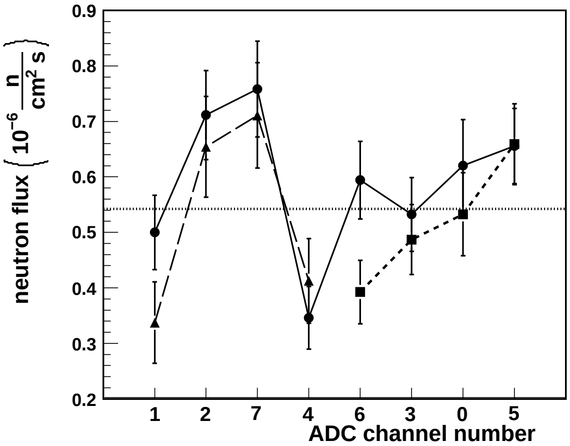

Fig. 6. Average neutron flux (horizontal dotted line) and flux values obtained from simulations and measurements for separate counter pairs for layout 'line' (dots), inner circle (triangles), and for outer circle (squares) in 'circles' layout. Indicated errors are statistical, only.

V. FUTURE PLANS

We plan further measurements at higher neutron energies at Gran Sasso and Boulby. We are going to determine neutron energies by using multi-thickness moderator.

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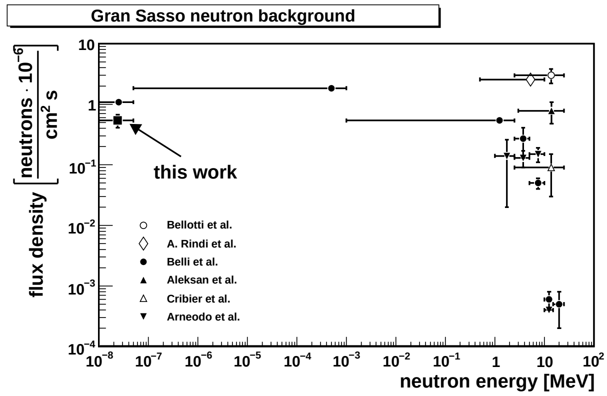

Fig. 7. Compilation of neutron flux density measurements in the underground Gran Sasso Laboratory [10]. The data used is derived from [4], [5], [6], [7], [8], [9]. Horizontal bars mark energy ranges. The MeV energy range measurements were made using different scintillation technics.

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