# On thermal neutron concentration near the ground surface

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***Abstract*. Measurements of the thermal neutron flux performed with special unshielded large area scintillator detectors reveal an existence of up-down gradient in the thermal neutron concentration in a range of several meters above the Earth's surface. Monte-Carlo simulations of the transportation of cosmic ray originated neutrons as well as radon originated neutrons agree with the measurements. The effect is caused by the difference in the neutron lifetime in two different media: air and soil.**

***Keywords*: thermal neutrons, gradient, concentration**

## I. INTRODUCTION

The first measurements of the neutron flux in the Earth's atmosphere were performed about 70 years ago (see review [1]); however, the experimental data on this problem are still scarce and unclassified, whereas the thermal neutron flux at small heights near the ground surface has not been investigated at all. Very few experimental data exist on the dependence of thermal neutron flux on the altitude. For example, in [2] one can find results of the measurements of thermal neutron concentration as a function of altitude but with a step of 200 m, where authors made a conclusion that at altitudes from 0 m to $\sim$ 2 km the neutron concentration is almost constant, thus confirming that the Earth's crust is a source of neutrons along with cosmic rays.

A specific feature of our experiment is that the measurements were performed with small steps at the same place but at different heights: from 4 m below and to 10.5 m above the ground level. First results of the measurements can be found elsewhere [3]. The experiment is conducted as a by-product of the developing of a novel type of EAS array based on the detectors capable to detect thermal neutrons [4]-[8].

## II. MEASUREMENTS

The thermal neutron detector with an inorganic scintillator in the form of a granular alloy based on ZnS(Ag)+LiF, enriched by the isotope of lithium-6 up to 90%, is used in measurements. Such counters have advantages over the generally used gas counters: fairly high efficiency and much higher operating speed. In addition, due to a low thickness of scintillator, they have very low sensitivity to a relativistic single charged particle. This is their undoubted advantage over lithium glass or plastic scintillators with boron (lithium) additives and this allows one to use them in counting regime to study variations of low intensity neutron background [9], [10]. Measurements where carried out inside the 4-storey experimental building at MEPhI site in Moscow. The detector of 0.75 sq. m area was placed at different floors of the building: from a basement to the 4th floor (from $-4$ m to 10.5 m level). Analog pulses from the PMT anode integrated with time constant $\tau \approx 5$ $\mu$s were digitized using 10 MHz flash ADC. An example of energy deposit spectrum accumulated by our neutron counter for one day using pulse shape separation technique is shown in Fig. 1. In a contrast with our previous measurements this spectrum has practically no background caused by charged particles from cosmic rays and natural radioactivity. We counted only pulses in the window between 10th and 100th channels of ADC as the "pure neutron events". It has been shown that thermal neutron flux and concentration depend on the level where the counter is located.

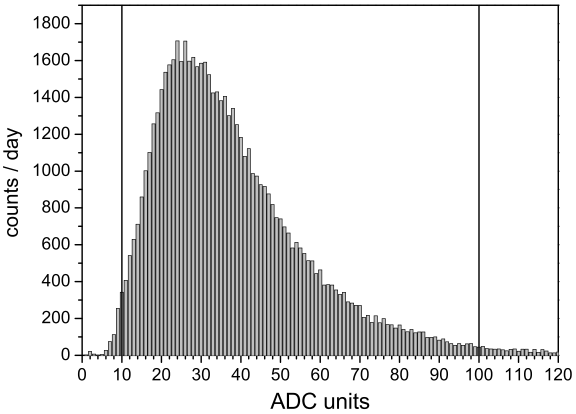

Fig. 1: One-day spectrum of the measured energy deposit in the neutron counter.

## III. CALCULATIONS

We performed calculations of thermal neutron transportation using the Monte-Carlo method in two modifications: with and without a building where the measurements were carried out. In both cases partial thermalization process was simulated starting from a velocity

$v = 10\ v_0$, where $v_0 \approx 2200$ m/s is thermal neutron velocity. Starting points of these epithermal neutrons were distributed uniformly inside a wide volume of air (300 m height and 200 m diameter) around the detector site and in a 15 m – layer of soil under this volume. If neutron escaped this volume during the scattering it was returned back. We thus supposed an existence of dynamic equilibrium in neutron concentration between different volumes. For simplification we also supposed that soil as well as concrete are dry and consist of $SiO_2$ only. This simplification could not change significantly obtained results: in any case, lifetime of thermal neutrons in solid media is short ($\sim$ 1 ms), while that in air is long ($\sim$ 50 ms). This difference is the origin of the effect we present here: the longer the lifetime, the higher is the neutron concentration in the corresponding medium. Therefore, thermal neutron concentration in air must be much higher than in soil. A border between two media is transparent for neutrons and one could not see a break in the concentration. Instead one should see a gradient in the concentration, just what we record. Another parameter affecting the result is a ratio of the amount of neutrons produced by cosmic rays in air and in upper layer of soil and that produced by natural radioactivity (mostly by radon gas and mostly in soil [9]). The neutrons are produced permanently in the Earth's crust due to $(\alpha, n)-$ reactions on the light nuclei such as Al, Na, Mg, Si etc. Note that spontaneous decays of heavy nuclei (U or Th) can also produce neutrons but our estimation has shown that this branch is rather weak. The ratio between neutrons generated by natural radioactivity and by cosmic rays was introduced in our simulation "by hand" (from $\delta$ = 0.17 to 0.81).

## IV. Results

The results of the measurements as well as results of the corresponding Monte-Carlo simulations of the height dependence of the thermal neutron concentration are shown in Fig. 2. It can be seen that we obtained a reasonable agreement with expectations taking into account the details of the experiment. Such a strange behavior of the points at heights from 0 to 10 m is caused by the building screening effect. For comparison, we show in Fig. 3 the results of the calculations made for open air (without building). It is seen that in this case the neutron concentration gradient looks more clear and smooth. The value of the measured [3] gradient of thermal neutron concentration above the ground level (the air - soil border ) is $dC/dh \approx 1.27{\times}10^{-4}$ m$^{-4}$. From this and measured [3] diffusion flux $J$ = 2.5 m$^{-2}$s$^{-1}$ one can estimate the neutron diffusion coefficient as $D = J(dC/dh)/v \approx 9.1$ m. Using known ratio $D = \lambda/3$ one could estimate the length of the mean free path of neutrons in air as $\lambda \approx 27$ m. This value is close to the tabulated mean free path of thermal neutrons in air. The existence of the gradient in neutron concentration results in the anisotropy of thermal neutron flux in this region. Fig. 4 presents the results of our Monte-Carlo simulations showing the existence of the neutron anisotropy above and below the ground surface. We show again the results with different values of the parameter $\delta$. One can see here that in accordance with the value of the neutron diffusion coefficient $D$ in air obtained above, the anisotropy as well as the neutron gradient disappears at height $h \gg D$ or $h \approx 50$ - 100 m. The value of $D$ in soil is much less and that is why the isotropy below the surface is achieved at a depth of several meters. It is seen also that the anisotropy above and below the surface has different sign as could be expected.

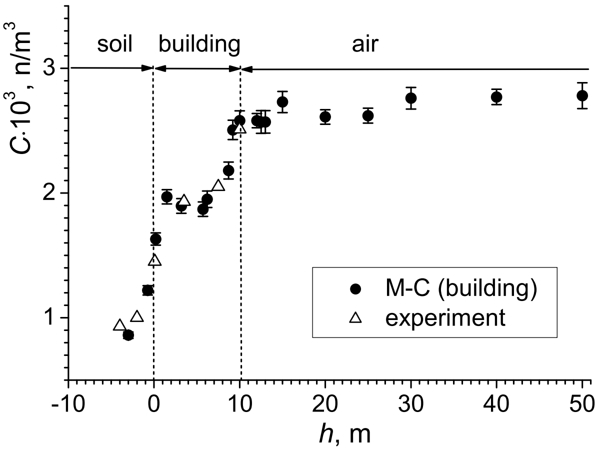

Fig. 2: Measured and calculated thermal neutron concentration inside the building as a function of height $h$.

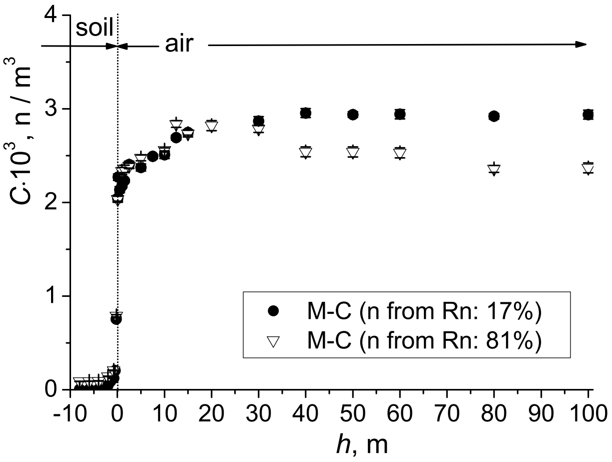

Fig. 3: Calculated thermal neutron concentration as a function of height $h$ without building.

We have also estimated the ratio between neutrons produced by cosmic rays and that originated from natural radioactivity at our site at different levels (above and below ground level) using barometric coefficient measurements. The ratio depends on the measurements location: an addition of Rn originated neutrons was

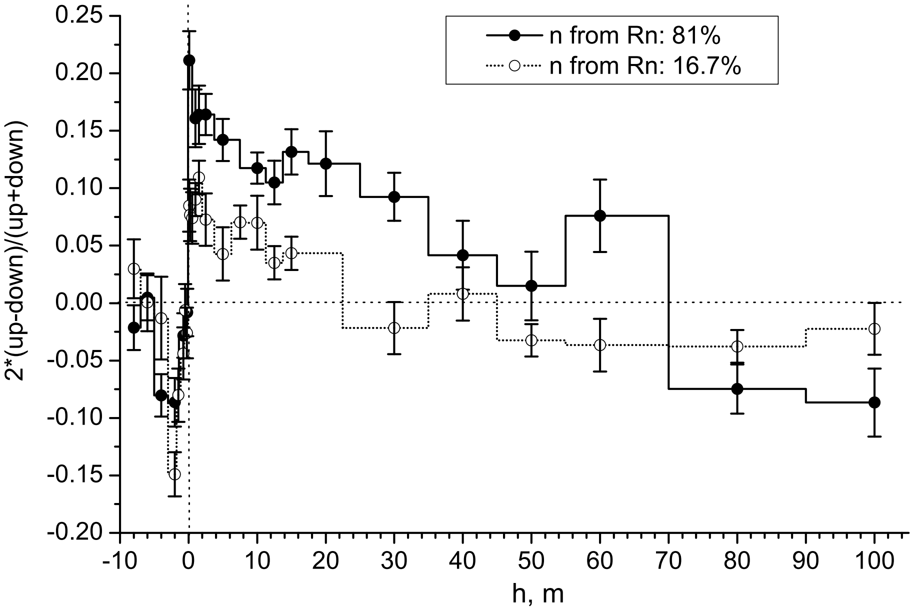

Fig. 4: Calculated thermal neutron anisotropy near the ground surface.

found to be equal to 17% at height $h$ = 10.5 m and equal to 39% in the basement where $h$ = -2.5 m [3].

## V. CONCLUSION

We have measured the thermal neutron concentration below and above the ground surface using large scintillator detectors for thermal neutron detection. It has been shown that there exists a gradient in the neutron concentration directed downward in air above the ground level and directed upward in soil below the border "soil-air". The absolute value of the gradient in air just above the ground surface was found to be $dC/dh \approx 1.27\times10^{-4}$ m$^{-4}$. There also exists thermal neutron anisotropy caused by this phenomenon. The origin of the phenomenon can be understood if one takes into account different lifetimes of thermal neutrons in two different media: air and soil or rock (or any other solid or liquid medium). Thermal neutrons are accumulated in a medium where they live longer before the capture.

We have estimated the ratio between neutrons produced by cosmic rays and that originated from natural radioactivity in our cite. As it was found the measured ratio depends on the height where the measurements are carried out. In further analysis we hope to obtain the neutron production rate originated from cosmic rays and from radioactivity by comparing our results with the Monte-Carlo simulations.

## VI. ACKNOWLEDGMENTS

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