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Earthy source of natural neutrons

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Abstract *- a process of neutron production s decay of the soil radon was simulated with Geant4 Monte Carlo toolkit. It is shown that such a source significantly weaker being compared with that of the cosmic ray albedo origin.*

Keywords – *radon, soil, nuclear reaction, alpha-particle, neutron, Monte Carlo simulation*

I. INTRODUCTION

The main part of the atmospheric neutrons of the natural origin is produced by showers initiated by cosmic rays. At smaller than 1 *km* distances from the ground, the neutron flux is added with one more component namely albedo neutrons. These are neutrons of the same atmospheric origin but scattered and moderated in the soil or produced by cascade energetic particles in nuclear reaction with the soil substance. The albedo flux constitutes a distinct peak of thermal ($\approx 2.5\cdot10^{-8}$ *MeV*) and epithermal energies ($\approx 2.5\cdot10^{-8}$–$4\cdot10^{-7}$*MeV*) in the lethargy (i.e., neutron flux×energy vs. energy) spectrum [1] increasing as the distance from the ground decreases.

Several papers were published in the last years assuming natural underground radon as one more source of detectable fluxes of atmospheric neutrons. Such neutrons are born in (α,n) reactions of α-particles produced in the decay chain of radon isotopes with soil components. This hypothesis was used to relate observed variations of atmospheric neutron flux with various geophysics phenomena [e.g. 2-14]. However, no quantitative estimation of the hypothesis has been performed yet. This paper presents results of simulation of the process of neutron production started with a decay of radon isotopes and subsequent propagation of the neutrons to the ground surface. The simulation was performed on the base of Geant4, a widely used Monte Carlo toolkit for the simulation of the passage of particles through matter [15].

II. SIMULATION MODEL

The decay chains of the natural ^{220}Rn and ^{222}Rn isotopes resulting in the emission of monoenergetic α-particles are shown in Table 1. Decay rates of radon progenies are controlled by the radon isotope concentration is the same within each chain due to secular equilibrium. In this simulation velocity directions of the decay, α-particle were distributed isotopically.

The number of produced neutrons in (α,n) reaction depends on chemical soil composition (see. Table 2). One can see that only three elements (Al, Ca, and Na) own a noticeable cross-section. The soil density was assumed to be 1 g/cm^3.

Table 1. Decay chains of the natural radon isotopes

Isotope	**^{220}Rn** →	^{216}Po →	^{212}Bi →	^{212}Po →	^{208}Pb
α-particle energy, *MeV*	6.3	6.8	6.1	4.7	Stable
Isotope	**^{222}Rn** →	^{218}Po →	^{214}Po →	^{210}Po →	^{206}Pb
α-particle energy, *MeV*	5.5	6.0	7.69	5.3	Stable

Table 2. Soil composition used in the simulation

Element	O	Si	Al	Fe	Ca	Na	K	Mg	Others
Abundance, %	46.6	27.7	8.1	5.0	3.6	2.8	2.6	2.1	1.5
Cross-section at 6.8MeV, mb	0	0	100	0	50	180	0	0	

III. RESULT AND DISCUSSION

Because of very short ranges of the α-particles born, they produce neutrons or/and stop practically in a point of decay. The total spectra of the neutrons produced by α-particles specified in Table 1 are shown in Fig.1.

During successive scattering in the soil, some a part of the neutrons reaches the ground surface and egress to the atmosphere. A probability of that depends on a depth where (α, n) reaction occurred (see Fig. 2).

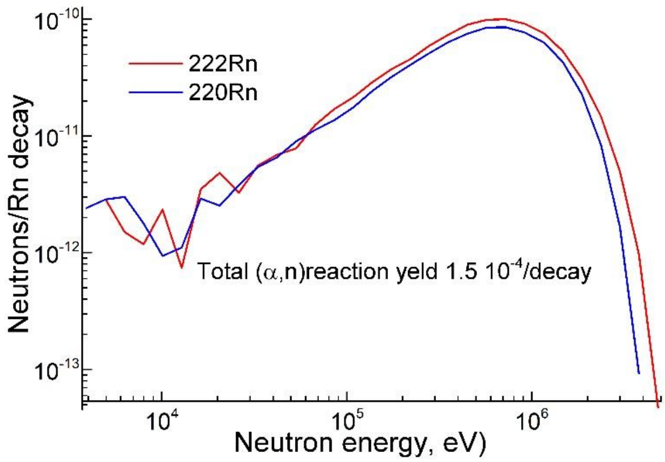

Fig.1 Total neutron spectra produced in reactions of α-particles from radon isotopes decay with soil.

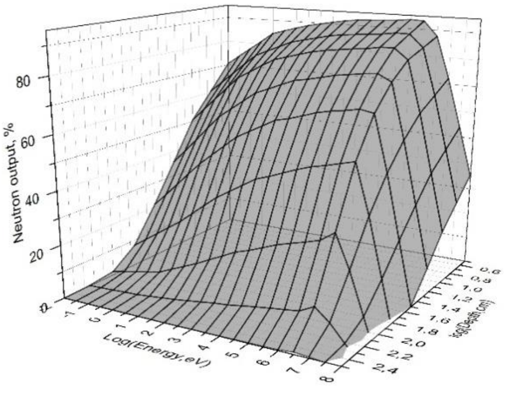

Fig. 2 A probability of a neutron escape from the ground from different ground depths. The numbers next to the curves mark neutron production depths in *cm*.

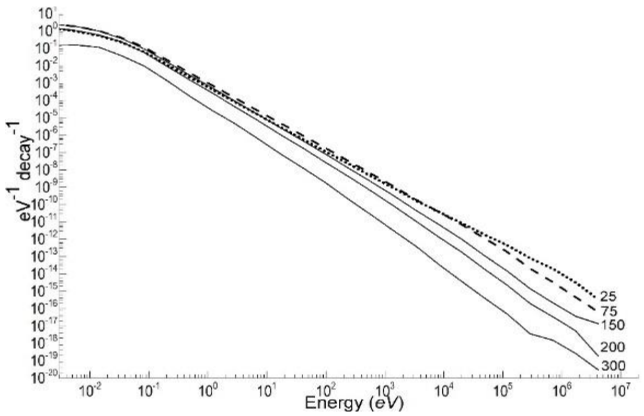

Fig. 3 The spectra of the radon decay origin neutrons egressed from different deptαhs. The numbers next to the curves mark the depths of the neutron production in *cm*.

One can see that the 3-meter depth is maximal from which the neutrons have a chance to reach the ground surface.

Fig.3 shows how the neutron spectra produced in radon decay chains (see Fig. 1) at various depth transform by the time they reach the ground surface

The resulting spectrum at the surface is obtained integrating over the depth a product of neutron production rate by spectra at the surface shown above. The maximal soil radioactivity is supposed to be about a rate of 10^6 Bq/m^3. Fig.4 presents the corresponding result is in a standard form of a lethargy spectrum compared with experimental data [1].

It is seen that both spectra have maxima at the thermal energy range where a difference between them is minimal and reaching more than three orders of magnitude.

It is interesting to compare the result obtained in Fig.1 with analytical estimation using explicit experimental data on (α,n) reaction in aluminum. One need for than to integrate several neutrons produced by a particle along with its range. Eq.1 describes a process of decrease of a particle energy E and

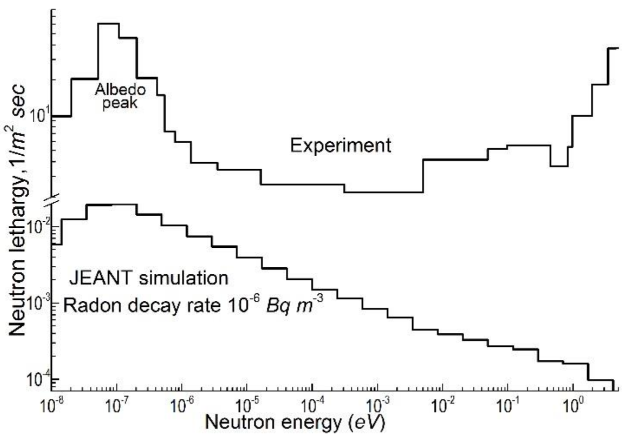

Fig. 4 The simulated lethargy spectrum of the neutrons of the ground radon origin

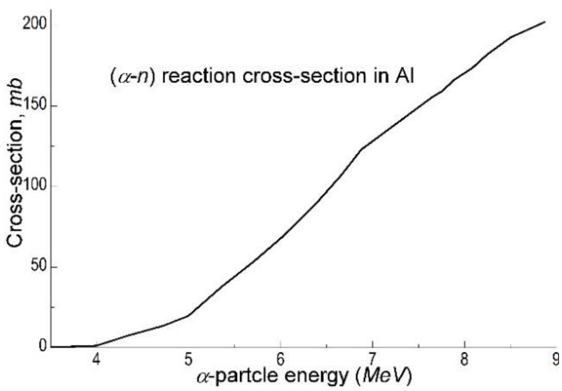

Fig. 5 Energy dependence of (α,n) reaction cross-section in Al

corresponding cross-section σ(E) [15] (Fig.5) during its passage through a matter of density ρ_S, (here $P(E)$ and $V(E)$ are stopping power and velocity energy dependencies respectively).

$$E'_\alpha(t) = P\big(E_\alpha(t)\big)\cdot V_\alpha\big(E_\alpha(t)\big)\cdot \rho_s \qquad \text{(Eq.1)}$$

Then a resulting number of the neutrons produced by one particle is an integral of a product $\sigma(E(t))\cdot V(E(t))$ over the particle range time multiplied by several atoms per 1 cm^3. For an α-particle of 6.8 MeV energy, it is 2 *ps*. Assuming ρ_S = 1 g/cm^3 and the maximal known radon concentration in soil of 10^6 $1/cm^3$ we obtained a production rate of $1.5\cdot 10^{-4}$ per an α-particle. Despite such an exact match with the simulated value (Fig.1), this only a reasonable agreement, because the estimate was made for pure aluminum without consideration of real soil composition.

IV. CONCLUSIONS

A simulation of production and propagation of the neutrons produced in the ground as a result of the decay of natural radon shows that such a source cannot provide a noticeable flux being compared with those of the albedo neutron. Analytical estimation based on experimental (α,n) cross-section is in reasonable agreement with the result of the Geant simulation.

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