Tidal effect in the radon-due neutron flux from the Earth's crust

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Abstract. Baksan Neutrino Observatory's results on variations of thermal neutron flux below and above the ground surface measured with an unshielded scintillator detector are presented. Experimental evidences were obtained of the existence of seasonal wave in the long-term thermal neutron flux variations as well as correlation between this variations and lunar periods.

Introduction.

Well-known radioactive noble gas radon arises from decay chains of uranium and thorium (contained in terrestrial crust) and then diffuses into atmosphere. Simple but fruitful idea - to record a variation of radon concentration in strained terrestrial crust as an indicator of local seismic activity - is used during long time by geophysical community amongst a lot of other factors preceding or accompanying earthquakes. Information about concentration of radon in atmosphere is also a matter of interest in some applied scientific programs. Commonly used devices for measurement of radon concentration are based on recording of α,β-particles resulting from decay processes of radon nuclei in air. There are well known discomforts in using this method, for example humidity, atmospheric wind or ventilation of volume under control. But there is another possibility to monitor radon concentration, and directly in the crust. First it was assumed in ref. [1] that the terrestrial crust could be a possible source of neutrons, arising from (α, n)-reactions on the light nuclei of crust elements after α-decays of radon (^{222}Rn) and thoron (^{220}Rn), then thermalizing inside and diffusing out of crust to the atmosphere: radon-due neutron production mechanism. Hence, any variation of concentration of radon and thoron inside the crust will induce variation of neutron production, and that can be used for radon concentration monitoring with some specific neutron detector [2-5].

1. Detectors.

Instead of standard gas counters, we used solid state detecting compound ^{6}LiF+ZnS(Ag) to record thermal neutrons through the reaction ^{6}Li (n, α) ^{3}H + 4.78 MeV. Resulting α-particle and triton activate scintillator ZnS(Ag) viewed by a photomultiplier. Output signals from PMT are put to a digital oscilloscope. Such recording methods guarantees more reliable set of data in comparison with a traditional gas counter and integral discriminator counting rate. The method is free of above-mentioned demerits of the standard method and also has an advantage in comparison with neutron monitors that are insensitive to outer thermal neutron flux due to polyethylene moderator shield. Scintillator area was equal to 0.7 m^2. Detection efficiency is equal to ~20%. The experiment is carried out at Baksan Neutrino Observatory, North Caucasus, 1700 meters a. s. l., 43^o N, 43^o E both above ground level and underground at the depth of ~1000 m w. e. In the same room (without ventilation) a NaI detector of 8 cm x 8 cm was also installed to monitor gamma ray background above E_γ=0.6 MeV.

2. Experimental Results. Surface detector.

It is naturally to expect following the radon-due neutron production mechanism – the existence of variations of thermal neutron flux from terrestrial crust, similar to generally known periodical tidal wave in ocean, which occur twice during a Moon-day period. Hence, it was also naturally to apply a frequency analysis (FFT: Fast Fourier Transformation) to accumulated data to search for some well-known periodicities arising from well developed theory of Moon-Earth-Sun dynamics. Detailed results of this analysis can be found elsewhere [6].

As one can see from fig.1, with significance > 3 σ we can recognise semidiurnal periodicities: K2=11.95±0.01 h, P2=12.03±0.01 h, M2= 12.40±0.01 h, S2=12.00±0.01 h; where S2 is exactly a half of a solar day, while M2, P2, K2 are different modes of second harmonics of Moon day. All prominent peaks are in good agreement with theoretically predicted periodicities. On the other hand, more elaborate amplitude-phase analysis (out of the frame of this article) one must to do for, one must to subtract the trivial solar-time meteo-due waves from the observed S1 and S2 waves having in the mind to extract possible genuine tidal neutron S1 and S2 modes. And finally we would like to note that the absence of meteo partners for K2, P2, and M2 peaks gives a good chance to exclude a hypothesis in favour of meteo origin of these peaks.

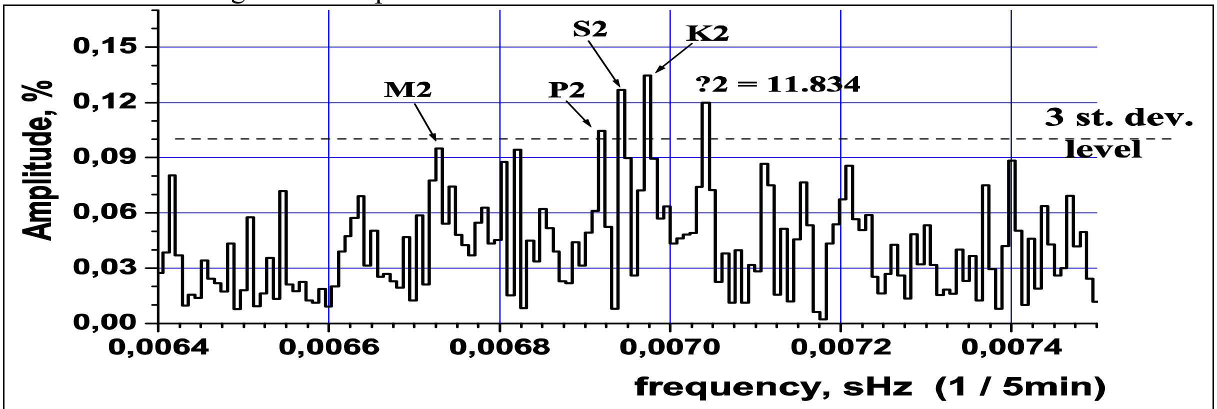

Fig.1. Moon's semidiurnal periodicities in thermal neutron flux.

Next step was a frequency analysis of day-to-day variations of counting rate. Now we have to remind here three most important basic Lunar month periods: *Anomalistic*, T_a = 27.554 day, $\omega_a=2\pi/ T_a$, *Draconic*, T_d = 27.212 day, $\omega_d = 2\cdot\pi /T_d$ and *Synodic*, T_s = 29.531 day, $\omega_s = 2\cdot\pi /T_s$. Taking it into account we developed a simple model (ADS-model [3]) describing the experimental data. An essence of the model is an attempt of description of changing in time gravitational force in terms of amplitudes and phases of fixed basic periods of Moon rotation around Earth: Anomalistic, Draconic and Synodic. Hence we have tried to fit the observed day-after-day variations of counting rate (CR) by superposition of sinusoidal functional corresponding to basic periods taking into account also second harmonics: $CR(t) \sim (1+A(t,\omega_a)) \cdot (1+D(t,\omega_d)) \cdot (1+S(t,\omega_s)) - 1$. Amplitudes and phases in the model are free parameters leading to max ratio R / χ^2 , where R is a coefficient of correlation between experimental curve and the model fit. R≈0.8 has been obtained.

3. Results of underground measurements.

Underground measurements with neutron detector also shown various periodicities: seasonal, monthly, diurnal and semidiurnal. To show this we used superimposed epoch analysis. Fig.2 shows the seasonal variation of neutron flux underground along with variations of underground temperature and humidity. The amplitude of the neutron counting rate variation is close to 2% (in fact this is only a lower limit because the detector own background did not subtracted). Semidiurnal waves both in solar and in lunar time are shown in fig. 3. It is interesting that different delay exists between the solar or lunar culmination and the maximal counting rate.

The NaI detector data shown absolutely another behavior: it has clear diurnal solar wave with maximum at 6 h and counts around Th peak (2.6 MeV) has semidiurnal lunar wave similar to that in neutron detector, but with a different delay (phase) after the moon culmination.

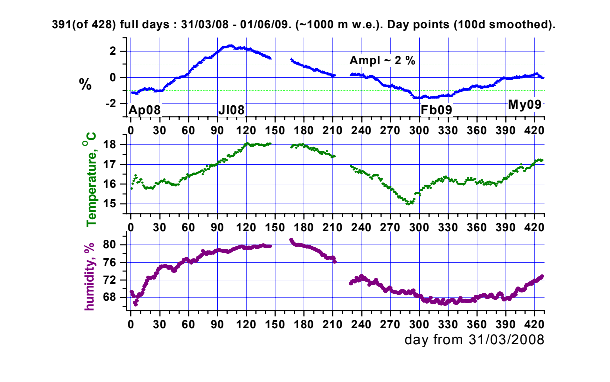

Fig.2. Seasonal variation of thermal neutron flux, temperature and relative humidity underground.

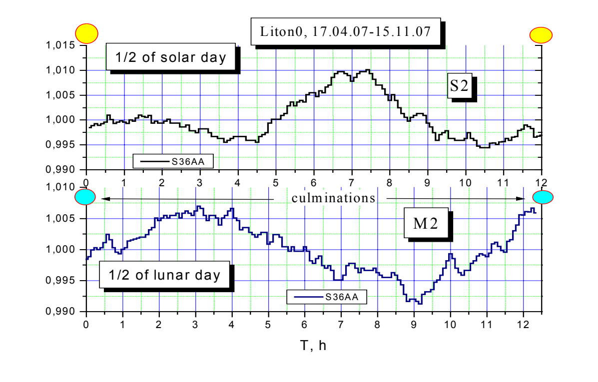

Fig.3. Semi-diurnal variations of thermal neutron flux deep underground.

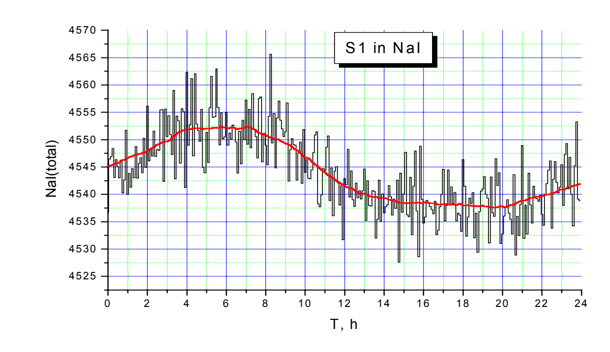

Fig.4. Solar diurnal wave in NaI detector.

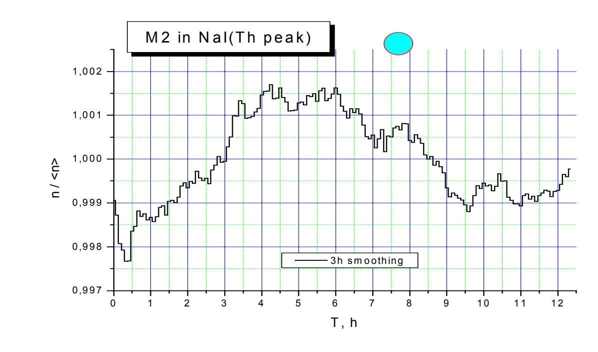

Fig.5. Moon's semidiurnal wave in gamma-rays.

5. Conclusion.

1. A novel experimental approach to record variations of radon concentration is presented. The method is based on the recording of thermal neutron flux from the Earth's crust.
2. The existence of seasonal, monthly and diurnal variations of neutron flux above and below the ground level has been established.
3. The method is based on nuclear physics and could be used in:

applied geophysical researches as a part component of the seismic station net;
radon-neutron monitoring of the environment and of global radon-neutron Earth's field;
low background experiments;
any applications where a control and monitoring of low intensity fluxes of neutrons is needed.

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