Neutrons of terrestrial origin and the endogenous activity of the Earth

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As a result of ground measurements of a) thermal and fast neutrons, carried out at the Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation of the Russian Academy of Sciences (IZMIRAN), Moscow; b) thermal neutrons, carried out at the Karymshina Complex Geophysical Observatory, Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, near Petropavlovsk-Kamchatsky in 2010–2012, neutron fluxes were registered, related to earthquakes in Chile, Japan, Indonesia. The magnitude of these earthquakes was $M = 8.6 - 9$. Fluxes of neutrons were also registered during the volcanic eruption in Iceland in 2010. In 2013–2015 bursts of neutron fluxes were registered, not only by the instrumental complex with helium counters, i.e. with an energy of several MeV, but also by neutron monitors with threshold energy of 20–30 MeV. We can assume that the emergence of neutrons on the surface of the Earth is related to nuclear reactions in the Earth's interior, generating a variety of particles with high penetrating capacity.
KEYWORDS: Thermal and fast neutrons; generation of neutrons; nuclear reactions; neutron monitors; seismicity and volcanism of the Earth.

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1. Introduction

In our investigations, carried out from 1990, we studied the relationship between the endogenous activity of the Earth (earthquakes and volcanism), solar activity and neutron flows, registered on Earth [*Shestopalov and Dubovik*, 2015; *Shestopalov and Kharin*, 2006, 2014; *Shestopalov et al.*, 2013]. We analyzed data on seismic and volcanic energy released from earthquake foci and volcanic eruptions on the globe for the period from 1680 until 2014 and compared them with solar activity. As a result, centennial cycles of solar activity and endogenous activity of the Earth were revealed, approximately 100 years in length. At that a significant negative correlation between seismicity and volcanism and solar activity was found. According to our data, the third (beginning from 1680) cycle started in 1890 and ended in the late XX century. This suggests that the 1990s were the beginning of a new centennial cycle, which was to be characterized by a relatively low solar activity level and intensive seismic activity tending to preserve for approximately during the first third of the cycle.

A number of experimental observations over the past 20 years have shown that endogenous activity may be a source of neutrons [*Kuzhevskii et al.*, 1993, 1995; *Shestopalov and Dubovik*, 2015; *Shestopalov and Kharin*, 2014; *Shestopalov et al.*, 2013; *Yasunaga*, 1993]. These results have allowed one to suppose that there is a thermal neutron field near the Earth's crust, and the parameters of this field are likely to be determined by the Earth's endogenous activity. Experiments that were simultaneously carried out in 2010–2012 in Moscow and Kamchatka have verified the recording of earthquake- and volcanic eruptions-related neutrons on the Earth's surface [*Shestopalov and Dubovik*, 2015; *Shestopalov and Kharin*, 2014;; *Shestopalov et al.*, 2013]. As a result of ground measurements of a) thermal and fast neutrons, carried out at the Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation, Russian Academy of Sciences (IZMIRAN), Moscow; b) thermal neutrons, carried out at the Karymshina Complex Geophysical Observatory, Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, near Petropavlovsk-Kamchatsky in 2010–2012, neutron fluxes were registered, related to the $Mw = 8.8$ Chilean earthquake of February 27; the Eyjafjallajökull volcano's eruption in Iceland in March–April 2010; the $M = 9$ earthquake in Japan of March 11, 2011; the $M = 8.6$ earthquake in Indonesia of April 11, 2012. For recording neutron fluxes we used gas discharge counters, filled with helium-3. Both a continuous monotonic increase of particle fluxes and separate short-time increases

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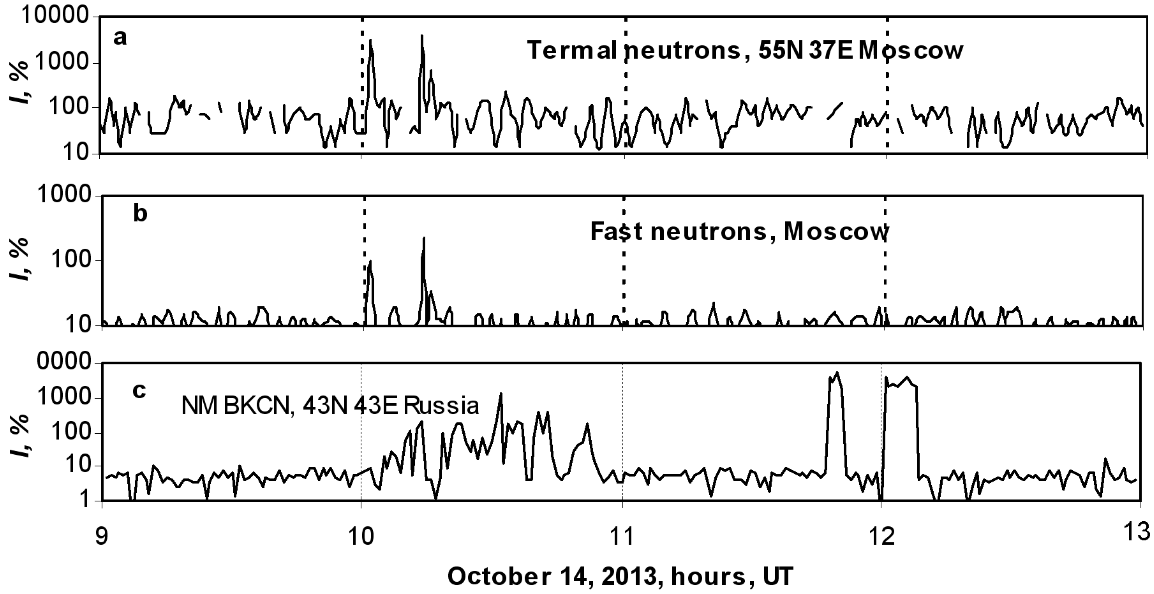

Figure 1. Temporal variations on October 14, 2013: a–b – thermal and fast neutrons flux intensity, recorded in Moscow; c – particle flux intensity, recorded by NM BKSN, Baksan, at Elbrus, Russia, uncorrected for pressure. The devices coordinates are shown at the curves. The data are in minutes.

were observed. Based on the minute data, the amplitude of this increases reached several thousands, tens and hundred thousands of percentage points. The increase in particle fluxes began to be recorded a few months prior the events. These events are analyzed in [*Shestopalov and Dubovik*, 2015; *Shestopalov and Kharin*, 2014;; *Shestopalov et al.*, 2013].

2. Neutron Fluxes Registered by Neutron Monitors

The study was continued in 2013–2015. The authors came to the following conclusion. In 2013–2015 bursts of neutron fluxes were registered, not only by the instrumental complex with helium counters, i.e. with an energy of several MeV, but also by neutron monitors with threshold energy of 20–30 MeV. The duration of these bursts was from several minutes to two days. To analyze the data from 37 neutron monitors (NMs) we used the database of the Bartol Research Institute at the University of Delaware [http://www.nmdb.eu/nest/search.php].

A network of neutron monitors recording space radiation and particle fluxes generated during major sunbursts was installed on the Earth's surface in the 50's of the XX century [*Dorman*, 1963]. Detector of a neutron monitor includes neutron counters filled with ^{10}B enriched boron trifluoride. The counters are surrounded by lead to generate neutrons and polyethylene to slow the fast neutrons to thermal. The largest increase of solar origin was registered on February 19, 1956 and January 20, 2005. The intensity of proton flux was about 5000%. In the other cases it reached hundreds and tens of percentage. The last such event was observed on December 13, 2006.

In 2013 several neutron monitors recorded proton fluxes with intensity exceeding 5000% [*Shestopalov and Dubovik*, 2015]. The duration of these bursts varied from several minutes to a day. Time profile of the increases differed from the profile caused by solar flares. According to our assumption, the particles are of a different nature, they have a terrestrial origin. These bursts occurred at a time when there weren't any flares on the Sun.

In 2013 the fluxes, not related to solar flares, were recorded by Baksan NM (BKSN), Russia, Mexico NM, Mexico, JUNG NM (IGY Jungfraujoch), Switzerland, Dourbes NM (DRBS), Belgium etc.

Figure 1 shows intensity bursts of neutron fluxes, registered in Moscow, and by Baksan NM in October 2013. The figure shows that the time of particle fluxes recorded in Moscow and Elbrus was different. It can also be noted that the intensity of particle fluxes recorded by NM BKSN exceeds the intensity of the ones recorded in Moscow.

Figure 2 shows an event, recorded in March 2015. It is also seen that the time and amplitude of fluxes was different. It is seen in the figure that the characters of variations in the intensity of thermal and fast neutrons are different for those registered in Moscow and by NM. It can be also noted that the intensity of the particle fluxes registered in Belgium exceeds the intensity of neutrons registered in Moscow.

Let us investigate an event in August 2015. Figure 3 shows some of the minute data of neutron monitors at an increase time.

Figure 3a shows that the increase in particle fluxes recorded by Tixie NM, Russia, took place on August 7–9.

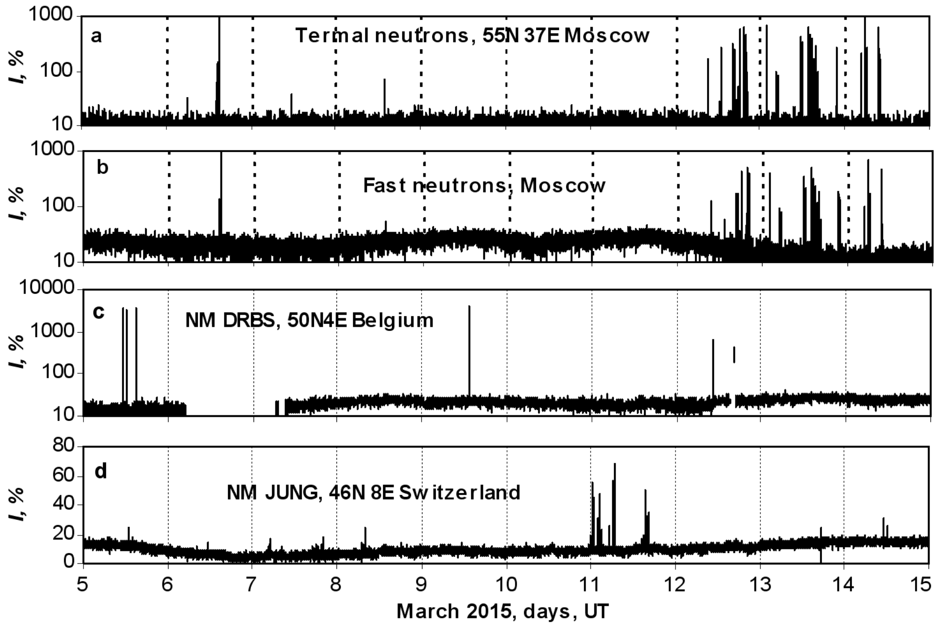

Figure 2. Temporal variations on March 5–14, 2015: a–b – thermal and fast neutrons flux intensity, recorded in Moscow; c–d – particle flux intensity, recorded by DRBS, Belgium, JUNG, Switzerland, uncorrected for pressure. The devices coordinates are shown at the curves. The data are in minutes.

Both a continuous monotonic increase of particle fluxes and separate short-time increases were observed. The duration of these increases reached several hours, the maximum amplitude – about 1500%. In general, this increase was observed during approximately two days. Figure 3b shows the NM Mexico data. It is seen in the figure that at the forefront of increasing the intensity of particle fluxes reached about 1100%. Then the data were not available for the total period of increase. At the trailing edge before neutron fluxes regression the intensity was about 1500%.

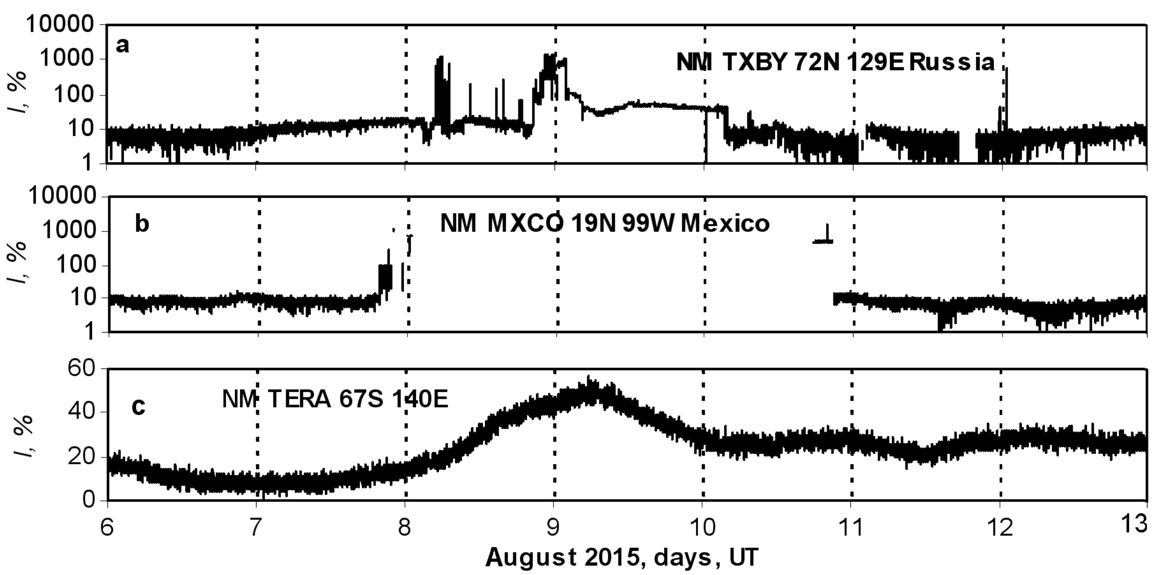

Figure 3. Temporal variations in August 2015: a–c – particle flux intensity, recorded by NM Tixie, NM Mexico, NM Tera, minute data, uncorrected for pressure. NM coordinates are shown at the curves. However, the lack of NM data can't always be explained by the failure of equipment. Perhaps not all NM are able to record large particle fluxes. Their registration systems, at Mexico NM in particular, are not designed for large increases.

A slight increase, the maximum of which correlated with the maximum increase in particle fluxes at Tixie NM, was recorded by Terre Adelie NM (see Figure 3c).

How can we explain the lack of data from the neutron monitors in this case? Most often it can be related to instrumental failures.

Thus in 2013–2015 not only bursts of thermal and fast neutron fluxes were observed, but also bursts of particle fluxes, recorded by neutron monitors. At that the amplitude in some cases exceeded 5000%. The duration of these bursts was from several minutes to two days.

3. Discussion

The reported facts allow us to suppose that the Earth's seismic and volcanic activity and the generation of particle fluxes can be interrelated. An increase in these fluxes prior to an earthquake is observed even at great distances from the disaster area. To explain the probable mechanisms of neutron generation, the following facts should be taken into consideration [*Shestopalov and Kharin*, 2014; *Shestopalov et al.*, 2013].

3.1. Source of the Internal Energy of the Earth

Over the several past decades, spacecraft missions "Pioneer 10", "Pioneer 11", "Voyager 1" and "Voyager 2" carried out infrared radiation measurements of heat flows on the planets. It was found that large planets – Jupiter, Saturn, Neptune, Uranus and Earth not only get their energy from the Sun, but also have their own internal energy sources [*Hanel et al.*, 1981, 1983; *Pollac et al.*, 1986, 1993].

The problem of the source of internal heat of the Earth remains controversial. There are several hypotheses that describe the absorption and dissipation of heat by our planet. The approximate level of the Earth's heat is known, but the nature of heat remains a matter of debate. According to the majority of hypotheses, the radioactive decay of long-lived isotopes of uranium and thorium plays a significant role in heat flows of Earth's interior [*Avsjuk*, 1996]. According to another point of view, the planet contains heat remaining from the time of its formation [*Pollac et al.*, 1993].

The KamLAND Collaboration [2011] evaluated, what is the contribution of each of these two sources by studying antineutrinos produced by the decay of radioactive elements. The researchers analyzed the data collected by KamLAND neutrino detector on the island of Honshu in Japan and calculated the amount of heat from Earth's interior produced by the decay of radioactive elements. It was found that this process yields about 50% of the total amount of heat released by our planet.

In this paper we analyzed the data shown in [*Hanel et al.*, 1981, 1983; *Pollac et al.*, 1986, 1993]. Figure 4a and Figure 4b shows the mass-luminosity relationship for: a) the following planets: Earth, Uranus, Neptune, Saturn, Jupiter; b) the same planets and the Sun. The luminosities and masses, expressed in Earth-based units, lie along the coordinate axes, i.e. m_e and L_e are the mass and luminosity of the Earth.

The functional dependency of the luminosity of the planets on their mass is as follows: $L = 0.79\, m^{1.6}$, and for the same planets and the Sun – $L = 0.08\, m^{2.4}$. Thus, the luminosity of the Sun and planets is proportional to their mass to an extent greater than one, i.e. has the power series form.

The average relative error of the theoretical level deviation from the actual level was calculated: for planets it equals $\approx 30\%$, for planets and the Sun – $\approx 250\%$. Given the general property of stationary stars of the functional dependence of luminosity on the mass (luminosity of stars is proportional to mass raised to a power greater than one), it can be assumed that the source of the internal energy of the planets is the same as that of the Sun, i.e. thermonuclear reactions.

3.2. The Reason of Appearance of Neutrons on the Earth's Surface

It is known that strong earthquakes, such as the earthquakes in Sumatra (December 28, 2004), Chile (February 27, 2010) and Japan (March 11, 2011) caused a change in the duration of the day and the orientation of the Earth's revolution axis [http://www.jpl.nasa.gov/news/], i.e., it is obvious that strong earthquakes cause disturbances covering all geospheres of the planet [*Shestopalov and Kharin*, 2014;; *Shestopalov et al.*, 2013]. These disturbances may reflect the drift of the core and its induced vibrations with a broad spectrum of frequencies relative to the viscoelastic mantle [*Barkin*, 2008].

At present, many scientists believe that fluctuations in the Earth's revolution should be searched for in interactions between the mantle and the core. The drift of the core and the intensification of its cyclic displacements are accompanied by elastic deformations of the mantle and respective abrupt changes of the stress and thermodynamical state of all its layers. It has been found that the internal energy of a body increases during deformation and matter transforms into a qualitatively new activated state, at which reactions and processes impossible under normal conditions can run [*Enikolopov et al.*, 1986]. Thus, under a mechanical effect implemented in a plastic domain, the transition of rock material into an activated-ionized state can be achieved. The observed bursts of several minutes in length in fluxes of neutrons and other particles allow us to conclude that processes in the Earth's interior, leading to the generation of particles, run very fast. This means that short-term increases in pressure and temperature, caused by nuclear reactions in the Earth's interiors, can occur in an earthquake hypocenter. This conclusion is indirectly confirmed by investigations of the isotopic composition of helium from diamond deposits of metamorphic complexes in Central Kazakhstan which were formed due to paleoearthquakes [*Blyuman*, 2003; *Shukolyukov et al.*, 1996]. Investigations show the anomalously high ^{3}He/^{4}He ratio values, unusual for diamonds. Thus, earthquakes may create favorable conditions for nuclear reactions, including the presence of deuterium and ^{3}He

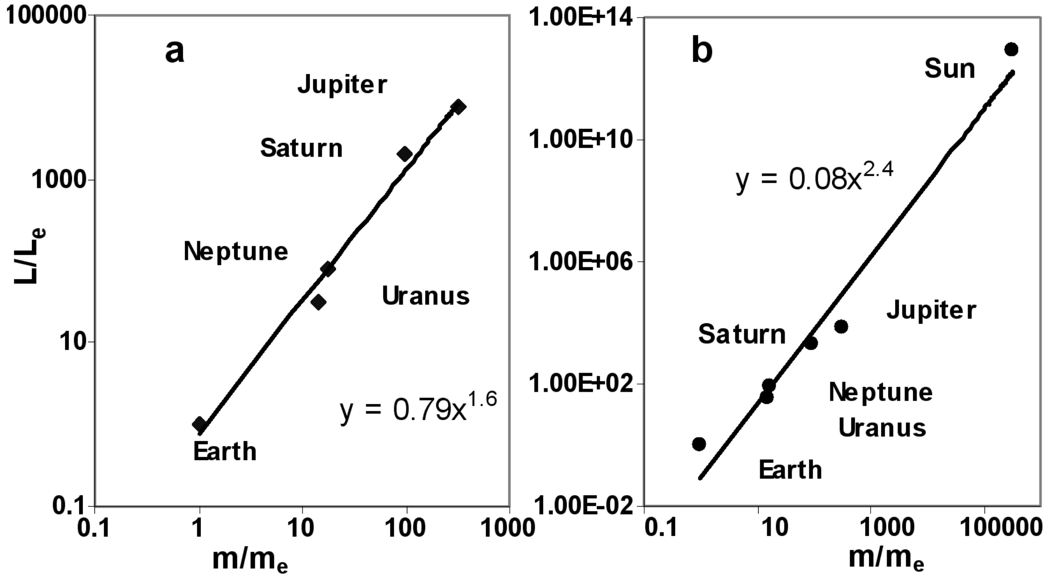

Figure 4. Mass-luminosity relationship for: a) the planets: Earth, Uranus, Neptune, Saturn, Jupiter, b) planets and the Sun. The luminosities and masses, expressed in Earth-based units, lie along the coordinate axes, i.e. m_e and L_e are the mass and luminosity of the Earth.

[*Perez et al.*, 1996]. Hydrogen fluxes from the Earth's core were reported in [*Larin*, 1980].

However, the question arises as to how such neutrons reach the Earth's surface without attenuation? In terms of modern concepts, the geophysical medium consists of blocks of different sizes (from very large to very small) [*Sadovskii et al.*, 1987], i.e., the medium is not continuous but hierarchically discrete. This system is open for energy exchange with the environment and can bound elastic energy, and these properties allow one to consider it as a dynamical energy-containing medium. Activity is the property of such a medium. Temporal changes in rock properties are not related to matter motion, but mostly to changes in the stress-strain state of the geomedium [*Shestopalov and Kharin*, 2014;; *Shestopalov et al.*, 2013].

As a result, energy transfers from one structural element to another in different directions and a deformation front appears that propagates in different directions within the Earth's crust. This propagation of the deformation front can be interpreted as a process of gradual transmission of tectonic load from one structural element in the geomedium to another at a finite rate. In this case different particles and fields with high penetrating capacity can be generated. Interacting with the geomedium the fields can consistently generate neutrons and other particles, providing their transmission and appearance at the Earth's surface [*Shestopalov and Kharin*, 2014;; *Shestopalov et al.*, 2013].

The study of these processes will lead to new discoveries in particle physics. To study these processes we need to carry out additional experiments. The first step is to produce multiple thermal and fast neutrons detectors, and to install them in different active zones and at some depth below the Earth's surface.

4. Conclusions

1. A number of experimental observations over the past 20 years have shown that endogenous activity may be a source of neutrons. Ground measurements were carried out at the Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation, Russian Academy of Sciences (IZMIRAN), Moscow and at the Karymshina Complex Geophysical Observatory, Kamchatka Branch, Geophysical Survey, Russian Academy of Sciences, near Petropavlovsk-Kamchatsky. For recording neutron fluxes we used gas discharge counters, filled with helium-3.
2. In 2013–2015 bursts of neutron fluxes were registered, not only by the instrumental complex with helium counters, i.e. with an energy of several MeV, but also by neutron monitors with threshold energy of 20–30 MeV. The duration of these bursts was from several minutes to two days. The amplitude in some cases exceeded 5000%.
3. We can assume that the emergence of neutrons on the surface of the Earth is related to nuclear reactions in the Earth's interior, generating a variety of particles with high penetrating capacity. Interacting with the geomedium the fields can consistently generate neutrons and other particles, providing their transmission and appearance at the Earth's surface.
4. The study of these processes will lead to new discoveries in particle physics.
5. Our study is both of academic and practical interest. The fact that the Earth's seismic and volcanic activity

is a source of neutrons and other particles, and that an increase in these fluxes can be seen at a considerable distance from the events can be used as a possible precursor to predict the time of these events.

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