ПРИБОРЫ И МЕТОДЫ ИЗМЕРЕНИЙ

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Research Article

Dependence of cosmic ray component in background of atmosphere surface from solar magnetic activity

A. S. Zelinskiy¹, G. A. Yakovlev²

¹ Tomsk Polytechnic University, 30 Lenina ave., Tomsk, 634050, Russia

² Tomsk State University, 36 Lenina ave., Tomsk, 634050, Russia

E-mail: azelinskiys@yandex.ru

Using Geant4 toolkit the changes of the flux density and of the dose rates of the secondary cosmic radiation at the heights up to 50 m from the land surface (at a depth of atmosphere about 1030 g/cm²) and depending on solar magnetic activity were estimated. For changes of Wolf's number (sunspots) in the range of 0 - 200 the flux density of reflected from air and the soil γ - and β - particles changes from 5.7 to 7 and 0.10 – 0.13 m⁻².s⁻¹ respectively, for energy from 0 keV to several units of GeV in the ground atmosphere on one meter from the earth. These estimates are much lower than those estimates, for radiation created by the soil and atmospheric radionuclides, which had been received earlier. In comparison with a contribution of radionuclides of the soil of flux density of secondary cosmic radiation about 0.01% and 0.1%, for gamma and beta radiation respectively. The received assessment of the dose rate transferred by secondary cosmic radiation about 0.7% from rate of the formed by soil's radionuclides. In addition, an assessment of change in characteristics of secondary cosmic radiation depending on the level of solar magnetic activity presented in work. It is found that change of radiometric and dosimetric characteristics of secondary cosmic radiation depending on solar magnetic activity can be over 40%. It well repeats the changes of a dose found during a transcontinental flight. We found that the optimal average energy of spectrum of primary protons is 2.7 GeV. We can apply this feature to standards to find the most intensive periods of a secondary space gamma radiation and to use them in the experimental data, without involving the use of the Geant4. We have not found any significant contribution of secondary cosmic radiation reflected from the earth's surface. This allows us to refuse from taking into account the soil layer in the model.

Keywords: simulation, cosmic radiation, Geant4, Monte-Carlo, atmosphere, background radiation, Wolf's numbers.

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Introduction

Investigation of dynamics of a background radiation of the ground atmosphere exists practically in all countries within state programs and scientific research [1-3]. The total atmospheric background radiation consists of different components: atmospheric and soil radionuclides, cosmic radiation. Assessment of a contribution of these components to a total background radiation is a global task. Increase of solar space radiation in the form of irregular splashes as a result of flashes in the Sun is followed by formation of intensive flows of particles, generally protons (about 90%). Before reaching, the Earth's surface the charged particles of the primary cosmic rays of galactic and solar types, extending through a magnetosphere, cross a big layer of the atmosphere and are interacting with atoms of its molecules. Because of this interaction are generating the secondary cosmic rays of various types of particles. In works [4] we in details considered questions of formation of atmospheric background the radiation caused by a radioactive decay of the radionuclides, which are contained in a soil and the ground atmosphere. However, in scientific literature there are no estimates of the changes of the flux density and of the dose rates of the secondary cosmic radiation at the heights up to 50 m from the land surface (at a depth of atmosphere about 1030 g/cm^2) and depending on solar magnetic activity. This data is very important for estimates of deposits of various components in a background radiation of the ground atmosphere, and in the data of radiation monitoring devices, which on the standard norms are placed at 1 m from the land surface.

Materials and methods

Model operation of passing of the fundamental particles through a winter Earth's atmosphere was made with use of a Monte-Carlo method in the environment of Geant4 [5]. The cubic geometry was chosen with sizes of 80 km for creation of model of the atmosphere. The scheme of geometry is presented in Fig. 1.

Fig. 1. Scheme of geometry of model of the atmosphere

Thickness of a layer of soil was set in 30 cm with a density of 1.3 g/cm^3 , this corresponds to 39 g/cm^2 . Characteristic to the region [6], the structure of the soil was chosen. Thickness of a sublayer of the atmosphere was set in 200 m with a density 200 m thick with a density of 1.36 mg/cm^3 , this corresponds to 27 mg/cm^2 . In which to a height of 50 m were placed 50 detecting layers with a step of 1 m. Thickness of each of the 300 subsequent layers was 266 m and density linearly decreased from a sublayer to top. Total depth of the winter atmosphere was leveled to 1033.35 g/cm^2 . We used model [7] for obtaining parameters of the winter atmosphere with placement on 60° northern latitude. The choice of latitude is caused by placement of Tomsk Observatory of Radioactivity and Ionizing Radiation (TORIR) [8]. The results of this work will be taken into account when processing TORIR data. The standard Geant4 composition of the atmosphere was used in the work.

The description of physical processes of QGSP_BERT was chosen for modeling on the basis of comparison of results of work of processes recommended by the developer [9]. We didn't use QGSP_BERT_HP as on TORIR are not present measurements of neutron beams. It should be noted that the calculation errors are determined exclusively by internal methods of calculating Geant4, as well as by the accuracy of the evaluation of the interactions [10] accuracy of the models used [7, 11] and can not be directly evaluated.

Within the framework of one school [12, 13] semi-empirical model [11] is a continuation of the model laid down in GOST 25645.150-90. The main difference between these models is the description of low-energy component of cosmic rays. For protons, this energy is less than 0.04 GeV. Given geomagnetic cutoff is the minimum energy of protons used in our models was not less than 1.5 GeV. As the primary source of radiation, we used the proton spectrum obtained from the GOST 25645.150-90 model and took into account geomagnetic cutoff. In models according to GOST 25645.150-90 and [11] to calculate the spectrum of protons is used the number of sunspots (monthly mean Wolf's numbers) as well as annual cycles. Therefore, to assess the dependence of the contribution of the secondary cosmic rays on the Wolf number in the characteristics of ionizing fields created by soil radionuclides, calculations were carried out for December 2017. To estimate the change of secondary cosmic rays with height growth the Wolf number equal to 100 was used. Thus, in our model, when the Wolf numbers varied from 0 to 200, the calculated average energy of the proton spectrum varied in the range of 2.5-4.8 GeV, and the proton flux density was $3615\text{-}1164 \text{ particle} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, is presented in Table. 1.

Table 1

Correspondence of some Wolf's numbers to the characteristics of the primary proton spectrum as of December 2017

Wolf's sunspot numbers	0	25	50	75	100	125	150	175	200
The average energy spectrum of protons, GeV	2.5	2.7	2.9	3.1	3.4	3.7	4.0	4.4	4.8
Flux density, protons $\cdot \text{m}^{-2} \cdot \text{s}^{-1}$ (all energy spectrum)	3615	3343	2945	2542	2176	1856	1584	1355	1164

Table 2

Correspondence of some Wolf's numbers to the characteristics of the primary proton spectrum as of December 2017

Components of secondary cosmic rays	Flux density direct radiation	Flux density radiation reflected from the soil and air	Dose rates in air
Photons	20	20	23
Beta –	16	25	20
Beta +	16	36	18
Muons –	20	-	20
Muons +	25	-	22
Protons	45	-	40

Results and discussion

Results are given in Tab.2 and Fig. 2-4 with designations: g – gamma radiation; e–(+) – beta(+) - radiation; p – protons; m–, m+ - muons. We are seeing that flux density and dose rates of secondary cosmic rays reach the peak at Wolf's 0–25 numbers this is consistent with the data [14] obtained during a transcontinental flight.

Table 2 shows that the flux density decreases on 16 – 45%, and dose rates on 18 to 40% when the number of Wolf increases from 0-25 to 200%.

Fig. 2. Dependences of the dose rates of components the secondary cosmic rays from Wolf's number

Fig. 3. Dependences of flux density of components the secondary cosmic rays from Wolf's number

Fig. 4. Dependences of flux density of gamma the components of secondary cosmic rays from Wolf's number

In absolute values the total dose rate transferred to air by all components of secondary cosmic rays is from $4.8 \cdot 10^{-4}$ to $3.9 \cdot 10^{-4} \mu\text{Gy/h}$, for the interval Wolf's numbers 25-200. Moreover, as a percentage that gives a contribution 0.7% from value of dose rate $0.07 \mu\text{Gy/h}$, which is calculated in work [6] for soil radionuclides.

Flux density the secondary cosmic rays component of gamma and beta, are reflected from air, the soil, makes 5.7 - 7, and $0.10 - 0.13 \text{ m}^{-2} \cdot \text{s}^{-1}$, respectively, that is significantly lower than flux density, formed by soil and atmospheric radionuclides. Moreover, as a percentage give a contribution 0.01% and 0.1%, respectively, in comparison with a contribution of radionuclides of the soil to the background radiation [6].

From the figure 4 and table 1 we find the optimal characteristics of the primary cosmic rays optimal average energy spectrum of primary protons is 2.7 GeV. In the future, we can apply this characteristic to the standards GOST 25645.150-90 and [11] to find the most intense periods of secondary cosmic gamma radiation moving on the scale of sunspots and eleven summer solar cycles without using the Geant4 toolkit.

With an increase in the height of observation to fifty meters, there is an increase in the flux density of the gamma component of the secondary cosmic rays for the direct radiation by 4.5% and 35% for the reflected, Fig. 5.

Fig. 5. Dependence of flux density of the direct and reflected photon radiation of secondary cosmic rays from height and relation reflected to direct of flux density

From the figure 5 we find the optimal characteristics of the primary cosmic rays optimal average energy spectrum of primary protons is 2.7 GeV. In the future, we can apply this characteristic to the standards GOST 25645.150-90 and [11] to find the most intense periods of secondary cosmic gamma radiation moving on the scale of sunspots and eleven summer solar cycles without using the Geant4. Analyzing the ratio of the reflected and direct radiation fluxes, we see that there is an increase with the height of observation. Although the thickness of the soil in the model was 29 g/cm^2 and exceeded the thickness of the lower atmosphere, 1000 times the growth of reflected radiation is not affected.

Conclusions

The analysis of the results this modelings has allowed revealing some dependencies of changes of the flux density and of the dose rates of the secondary cosmic radiation at the heights up to 50 m from the land surface (at a depth of atmosphere about 1030 g/cm^2) and in depending on solar magnetic activity. Calculation of results of changes in characteristics of secondary cosmic rays depending on Wolf's numbers well matched with experimental data. In relative terms, such changes can reach 40%. With increasing height above soil level, we also see the increase in the flux density of direct and reflected gamma of component of secondary cosmic rays. Such an increase can reach 35% for 50 m. For change of Wolf's number (sunspots) in the range of 0 - 200 the flux density of reflected from air and the soil γ - and β - particles changes from 5.7 to 7 and $0.10 - 0.13 \text{ m}^{-2}\cdot\text{s}^{-1}$ respectively, for energy from 0 keV to several units of GeV in the ground atmosphere on one meter from the earth. These estimates are much lower than those estimates, for radiation created by the soil and atmospheric radionuclides, which had been received earlier. In comparison with a contribution of radionuclides from the soil, contribution of the flux density of secondary cosmic radiation is about 0.01% and 0.1%, for gamma and beta radiation respectively. The received assessment of the dose rate transferred by secondary cosmic radiation is about 0.7% from rate of the formed by soil's radionuclides. We have not found any significant contribution of secondary cosmic radiation reflected from the earth's surface. This allows in the future to refuse from taking into account the soil layer. We found that the optimal average energy of spectrum of primary protons is 2.7 GeV. We can apply this characteristic to the standards GOST 25645.150-90 and [11] to find the most intense periods of secondary cosmic gamma radiation without using the tool Geant4. On the basis of data on the number of sunspots [15], the results of this work can predict the behavior of secondary cosmic radiation in the readings of devices for continuous monitoring of radioactivity in real time.

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**Зависимость компоненты космического луча на фоне
поверхности атмосферы от солнечной магнитной активности**

А. С. Зелинский¹, Г. А. Яковлев²

¹ Томский политехнический университет, 634050, Россия, г. Томск, пр. Ленина, 30

² Томский государственный университет, 634050, Россия, г. Томск, пр. Ленина, 36

E-mail: azelinskiys@yandex.ru

С помощью инструментария Geant4 было произведено моделирование плотности потока и мощности дозы вторичного космического излучения на высотах до 50 м от поверхности земли (на глубине атмосферы около 1030 г/см²) и оценена их зависимость от солнечной магнитной активности. Для чисел Вольфа (количества пятен) в диапазоне от 0 до 200, плотность потока отраженных от воздуха и почвы γ - и β -частиц изменялась от 5.7 до 7 и 0.10 - 0.13 м⁻²·с⁻¹ соответственно для энергии от 0 кэВ до нескольких единиц ГэВ в приземной атмосфере на расстоянии одного метра от земли. Эти оценки намного ниже полученных ранее оценок для излучения, создаваемого почвенными и атмосферными радионуклидами. В сравнении с вкладом радионуклидов почвы в плотность потока, вклад вторичного космического излучения составляет около 0.01% и 0.1% для гамма- и бета-излучения соответственно. Полученная оценка мощности дозы, передаваемой вторичным космическим излучением, составляет около 0.7% от мощности дозы от радионуклидов из почвы. Кроме того, в работе представлена оценка изменения характеристик вторичного космического излучения в зависимости от уровня солнечной магнитной активности. Установлено, что изменение радиометрических и дозиметрических характеристик вторичного космического излучения в зависимости от солнечной магнитной активности может превышать 40%. Полученные результаты позволяют отказаться от учета слоя почвы в представленной модели.

Ключевые слова: моделирование, космическое излучение, Geant4, Монте-Карло.

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