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AUTONOMOUS STATION FOR RECORDING RADIATION IN A THUNDERSTORM ATMOSPHERE AT THE TIEN SHAN HIGH MOUNTAIN COSMIC-RAY STATION

During the past decades, considerable attention has been paid to the search and registration of electromagnetic radiation accompanying lightning discharges in the atmosphere when studying processes occurring in thunderclouds. Such studies are of interest for understanding the mechanisms of lightning generation and its further development, leading to the generation of an avalanche of charged particles accelerated by an electric field, the hard bremsstrahlung of which is registered by the detectors. In this work we consider a compact measuring system, which was created at the Tien Shan High-Mountain Scientific Station for registering radiation during thunderstorm activity. A feature of the system is complete autonomy, when all its components (detectors, recording electronics, battery) are placed inside a solid metal casing, which plays the role of an electromagnetic screen and does not have any connections to external cable lines. This allows one to record radiation directly inside the thundercloud. Examples of gamma-radiation detection using a NaI crystal scintillation detector, as well as the detection of charged particles by a special detector, which is a stack of two flat scintillation detectors of a large area and a rubber filter placed between them, are considered.

Key words: thunderstorm, thundercloud, hard X-ray, high-energy cosmic rays.

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Тянь-Шань биік таулы ғарыштық сәулелер станциясындағы Жер атмосферасында найзағай сәулеленуін тіркеуге арналған автономды өлшеу жүйесі

Соңғы онжылдықтар ішінде атмосферада найзағайдың пайда болуымен бірге электромагниттік сәулеленуді іздеуге және тіркеуге, күн күркіреу кезінде пайда болатын процестерді зерттеуге көп көңіл бөлінді. Мұндай зерттеулер найзағайдың пайда болу механизмін және оның кейінгі дамуын түсінуге қызығушылық тудырады, олар электр өрісі арқылы жеделдетіліп, детекторлармен жазылады. Бұл мақалада нөсер белсенділігі кезінде сәулеленуді жазу үшін Тянь-Шань биік таулы ғылыми-зерттеу станциясында құрастырылған ықшам өлшеу жүйесі қарастырылған. Жүйенің ерекшелігі ретінде оның барлық компоненттері (детекторлар, жазба электроникасы, батарея) электромагниттік экранның рөлін ойнайтын және сыртқы кабель желілеріне қосылмай тұра қатты металл корпусына салынған кезде толық автономияға ие болуы. Бұл күн сәулесінен тікелей сәуле түсіруге мүмкіндік береді. NaI кристалды сцинтилляция детекторымен гамма-сәулеленуді анықтаудың үлгілері, сондай-ақ зарядталған бөлшектерді үлкен аймақтың екі жазық сцинтилляция детекторларының және олардың арасында орналасқан резеңке сүзгіштің жинағы болып табылатын арнайы детектор арқылы анықтау қарастырылған.

Түйін сөздер: найзағай, күн күркіреуі, жоғары энергиялы ғарыш сәулелері, қатты рентген сәулелері.

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Автономная измерительная система для регистрации грозового излучения в атмосфере Земли на Тянь-Шаньской высокогорной станции космических лучей

В течение последних десятилетий значительное внимание уделялось поиску и регистрации электромагнитного излучения, сопровождаемого разрядами молнии в атмосфере, при изучении процессов, происходящих в грозовых облаках. Такие исследования представляют интерес для понимания механизмов генерации молнии и ее последующего развития, которые ускоряются электрическим полем и регистрируются детекторами. В данной работе рассмотрена компактная измерительная система, которая создана на Тянь-Шаньской высокогорной научной станции для регистрации излучений во время грозовой активности. Особенностью системы является полная автономность, когда все ее компоненты (детекторы, регистрирующая электроника, аккумулятор) размещаются внутри сплошного металлического кожуха, играющего роль электромагнитного экрана и не имеющего каких-либо подключений к внешним кабельным линиям. Это позволяет регистрировать излучения непосредственно внутри грозового облака. Рассмотрены примеры регистрации гамма-излучения сцинтилляционным детектором на основе кристаллов NaI, а также регистрации заряженных частиц специальным детектором, который представляет собой стопку из двух плоских сцинтилляционных детекторов большой площади и размещенного между ними резинового фильтра.

Ключевые слова: гроза, грозовое облако, жесткий рентген, высокоэнергетические космические лучи.

Introduction

During the past decades, considerable attention has been paid to the search and registration of electromagnetic radiation accompanying lightning discharges in the atmosphere when studying processes occurring in thunderclouds. Such studies are of interest for understanding the mechanisms of lightning generation and its further development, leading to the generation of an avalanche of charged particles accelerated by an electric field, the hard bremsstrahlung of which is registered by the detectors. Examples of such works are experiments conducted at the height of mountains in Armenia [1, 2] and Japan [3]. At the complex installation of the Tien-Shan high-mountain station [4, 5], similar experiments on the detection of hard X-ray and gamma radiation from thunderclouds were launched in the mid-2000s (the Thunderstorm experiment). In the course of these works, the fine time structure of short-duration gamma-ray flashes that accompany lightning discharges on a time scale of the order of hundreds and thousands of microseconds [6, 7, 8, 9, 10, 11] was discovered, and the first estimates of its energy spectrum were obtained in energies from tens of keV to several of MeV [12]. The correlation of processes in a thunderstorm atmosphere with high-energy cosmic rays was also studied [13, 14]. In addition, thermal neutron flashes were observed at the facility at moments of lightning discharges [15, 16, 17]. Recent studies have carried out measurements of all types of high-energy radiation that accompany lightning discharges [18, 19, 20].

According to theoretical predictions, as well as the results of the simulation of the development of electron avalanches in the electric field of a thundercloud, the distribution function of electrons in the corners is strongly elongated in the direction of their acceleration (along the field). Since the direction of the electric field in a thunderstorm field is usually vertical, the generated electron avalanches, as well as gamma-rays of bremsstrahlung propagate mainly in the vertical direction. In addition, gamma rays have relatively small range in the atmosphere (hundreds of meters). Considering all this, detectors designed for their registration should be located close to the area of generation of radiation; preferably directly inside the thundercloud. At the same time, special attention should be paid to protecting recording systems from accompanying close lightning discharges of powerful electromagnetic interference, which, with insufficient attention to this issue, can lead to a strong distortion of measurement results, as well as to a rapid and complete lay-up of the installation resulting in disruption of work. The most suitable for such conditions is the experiment scheme using portable gamma-radiation detectors based on modern microprocessor technology of a compact data collection system and a battery-powered power supply system independent of external sources, which should ensure autonomous operation of the tracking station throughout the entire period of thunderstorm (1-2 hours). In this case, the entire measuring system as a whole (detector, recording electronics, battery) must be placed inside a solid metal casing, which plays the role of an electromagnetic screen and does not have any connections to external cable lines.

The relief of the surrounding mountain slopes of the Tien-Shan High-Mountain Station provides a convenient opportunity to conduct experiments of this kind, allowing one to place the tracking stations at altitudes of 300-500 m above the Station's average level (3340 m above sea level), moreover in such case the detectors are immersed directly inside the thunderclouds that are passing over the mountain pass of the Station. At the same time, relatively convenient access to the tracking stations and their continuous connection with the information network of the Tien-Shan Station is maintained, which allows organizing round-the-clock staff duty at these stations to maintain their continous operation, as well as processing and analyzing the incoming data using the computer systems of the station in real time mode. During 2015-2017, such an autonomous tracking station (Fig. 1) was gradually created at a point located on the mountain ridge surrounding the Tien-Shan station, at an altitude of ~ 3800 m above sea level (~ 400 m above the average level of the Station).

Figure 1 – Left: remote tracking station near the top (400 m above the Tien Shan station, 3750 m above sea level). In the center: shielded scintillation gamma detector with an autonomous power supply system. Right: compact microprocessor data acquisition system

Instrumentation

The tracking station is intended for registration of hard electromagnetic radiation generated at the time of lightning discharges. For this purpose, a scintillation gamma detector based on an inorganic NaI(Tl) crystal with a diameter of 110 mm and a height of 110 mm, with an efficiency of 20-80% with respect to the detection of gamma radiation in various energy ranges is used. A block diagram of the registration of gamma radiation is presented in Fig.2. The scintillation crystal is coupled to a photomultiplier tube FEU-110; electrical signals from the anode of the PMT are fed to a 12-channel pulse discriminator, which allows measuring the amplitude spectrum of the input signals in a 30-fold amplitude range. Absolute energy calibration of the detector was performed using a set of radioactive gamma sources; The discriminator thresholds were tuned to 12 different energy values in the range of 30 keV – 1 MeV. The intensities of the pulses generated by the discriminator are continuously recorded using a measuring system built on the basis of the microprocessor set STM32F407/STM32F-4DISCOVERY [21]. Measurement of the intensity of scintillation signals is performed simultaneously in two time ranges: continuous monitoring of the current intensity with a time resolution of 1 s and measurement of time intensity scans with a resolution of 30-100 μs over a time interval of -1 – +1 s relative to the moment of lightning discharge. The measuring system is equipped with an autonomous power supply based on a car battery and a voltage converter, ensuring the possibility of its independent operation for at least 2-3 hours during the passage of thunderstorm clouds. The scintillation detector, the recording electronics and the autonomous power supply system are inside a solid metal box made by welding from sheet metal with a thickness of 2 mm.

The time course of development of a lightning discharge, which serves as a source of gamma radiation, is recorded using a special radio antenna system that operates at the Tian-Shan station in synchronization with the detectors located on the mountain ridge of the upper autonomous station. Mutual time synchronization of the data acquisition system in a stand-alone unit with a system of radio detectors (as well as with detectors located on the station's territory, intended to record a possible signal from the neutron component generated during the lightning discharge radiation process, which serves to locate the lightning position by a system of acoustic sensors, etc.) is produced in the period of clear weather between thunderstorms with an accuracy of no less than 1 millisecond via a computer network (using the ntp protocol), or by means of GPS-receivers.

During the summer seasons of 2016 and 2017, the autonomous gamma-radiation detection system at the upper detector station operated continuously for four months, starting in mid-May until mid-September. During this time, continuous monitoring records of the intensity of atmospheric gamma radiation were obtained for 12 energy ranges with a resolution of 1 s, which are supposed to be used for further studies related to the behavior of gamma radiation background in the atmospheric surface layer during clear weather and during precipitation.

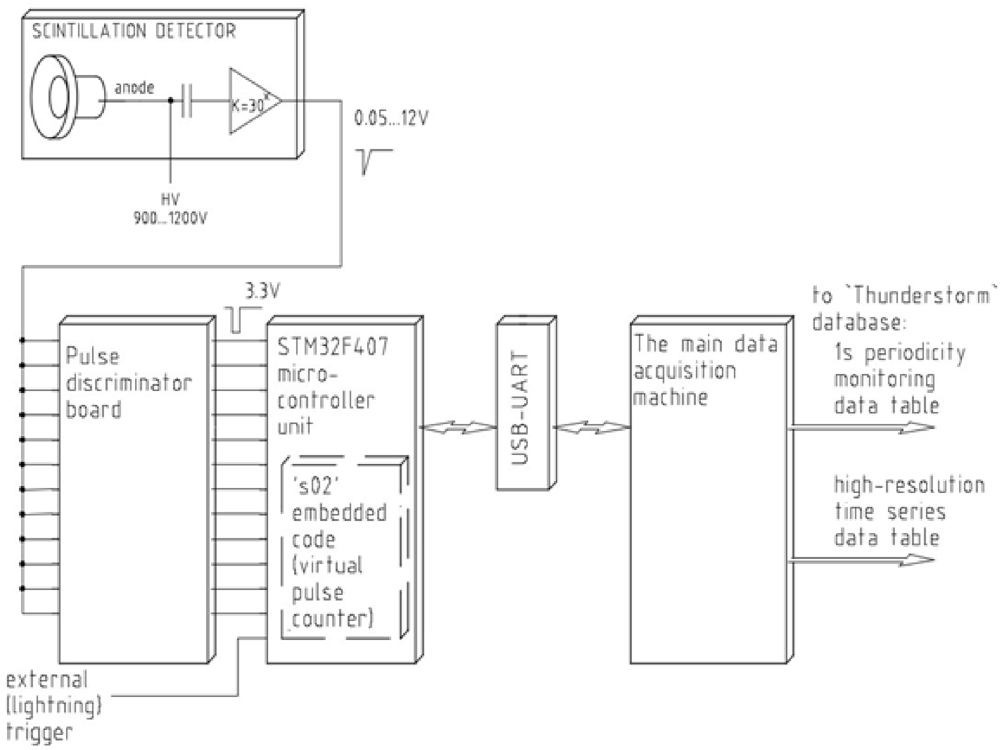

Figure 2 – Block diagram of the gamma radiation detection system

The peculiarity of the autonomous radiation registration station is in the principle of selection of events associated with close atmospheric discharges. Indeed, the selection based on triggers from lightning, which are effectively produced by the radio system of the Tien-Shan station and broadcast via cable lines to all installations located in its territory, is inapplicable in the conditions of a remote location due to the impossibility of direct cable communication with its common trigger station system, and at the same time, the use of any modern means of communication via a radio channel (such as wi-fi, etc.) is not possible because of the need to work directly during thunderstorms. Therefore, the set of programs that provide control of the data collection system of an autonomous point was supplemented with an algorithm for generating its own, purely logical trigger that triggers the recording of temporal intensity distributions of signals from particle detectors with high temporal resolution. The essence of this algorithm is that the software system continuously monitors the intensity of the current stream of input pulses and itself, in a purely software way, generates the trigger signal necessary for its synchronization at the moment when this stream satisfies certain conditions established at the time of launching the program. In particular, when registering the temporal distributions of the intensity of gamma radiation during the summer season of 2017, the condition "a total number of at least 12 pulses over three consecutive time distribution intervals (ie 480 μs)» was applied. In addition, the program complex provides for the possibility of mutual binding of all programs that otherwise independently control the various systems of detectors located at an autonomous point, but can synchronize their work with a trigger signal generated by one (any) of them.

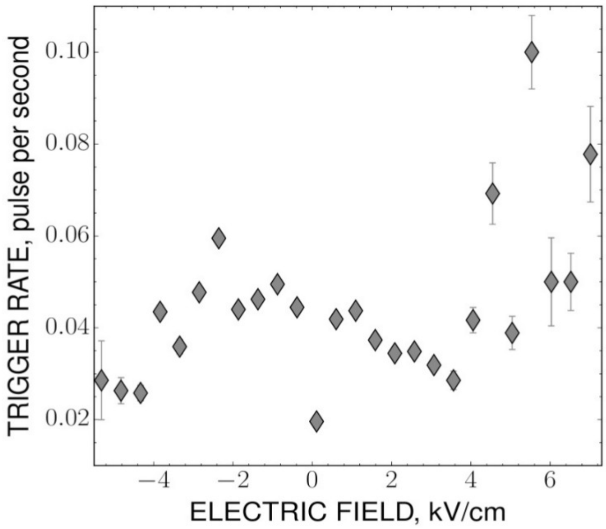

Figure 3 – The frequency of operation of the software trigger, depending on the electric field

Figure 4 – Detector of charged particles

The graph presented in Fig. 3 illustrates the generation frequency of the software trigger (according to the above algorithm) for different periods of time, depending on the strength of the atmospheric electric field, which was measured by a special detector located at the Tien Shan Station. It can be seen that the number of trigger signals per second is minimal in the period of time when the field is close to zero, has a moderate value as the thunderstorm clouds passing a station carrying a negative (relative to the "ground") charge, and increases dramatically as the positively charged of clouds. Thus, this graph shows a reasonably reasonable dependence of the intensity of triggering of the software trigger algorithm on the field strength: it turns out to be maximum with a positive field, which really should accelerate negatively charged particles (cosmic ray electrons) from the thundercloud in the direction of the measurement setup.

In the summer season of 2017, the autonomous detector system at the remote tracking station was supplemented by a charged particle detector (Fig. 4), which is a stack of two flat scintillation detectors of a large area and a rubber filter placed between them. Unlike the crystal scintillator, which is used in the gamma-ray detector, the sensitive elements of the newly installed detector are formed by a large area scintillation plastic (1x1 sq. M), which, due to its small atomic weight and small thickness (1 cm), has a high efficiency with respect to the detection of charged particles, and low with respect to gamma radiation [22]. Charged particles – electrons are supposed to be generated during atmospheric electrical discharges, and the new detector is designed to directly register them.

The rubber absorber filter between the scintillator planes with a total thickness of ~ 60 g/cm^2 serves to isolate the contribution from charged particles of different energy to the total signal and allows a rough estimate of the energy spectrum of the detected radiation by the presence or absence of coincidence signals between the scintillator planes. In the future, this type of detector is supposed to be supplemented with another 2-3 sensitive rows of scintillators.

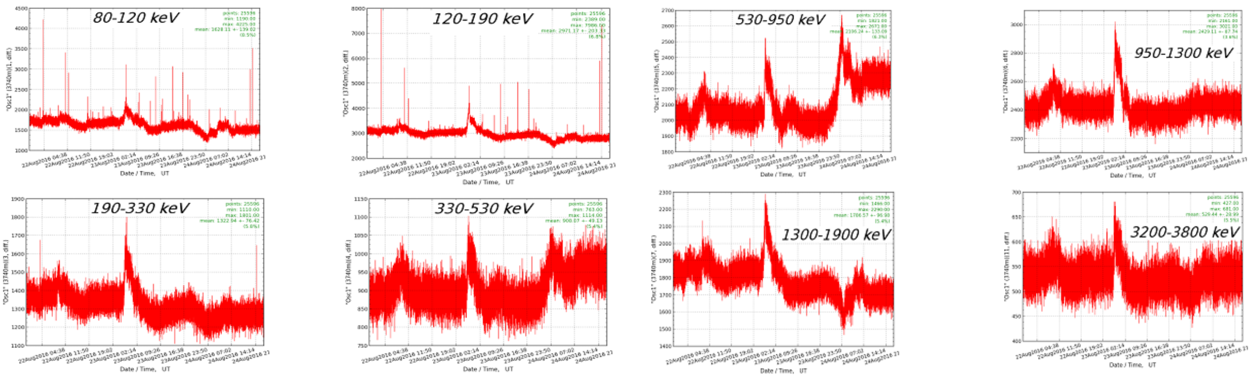

Figure 5 – Signal intensities in different energy ranges of gamma radiation at the level of an autonomous detector point for three days in August 2016

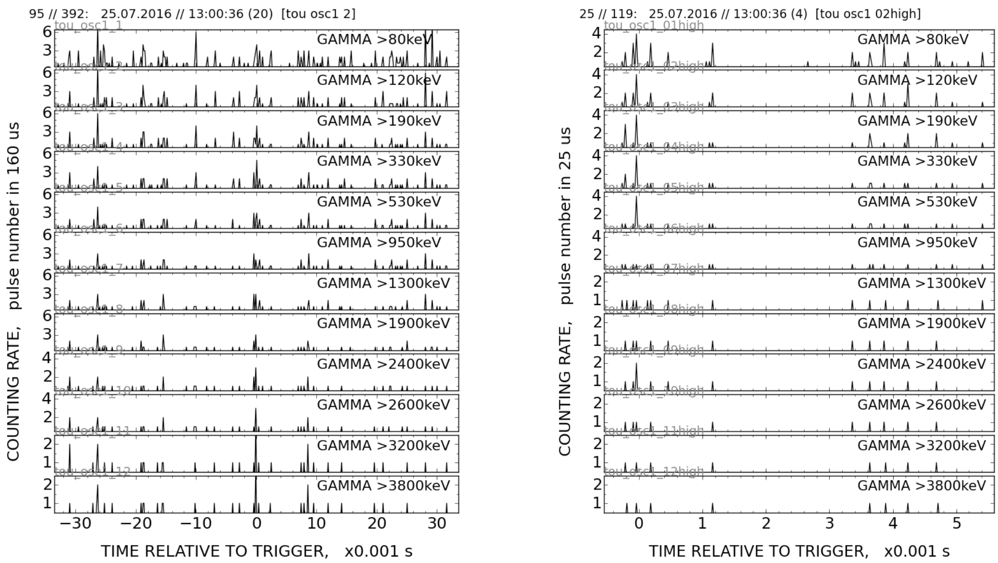

Figure 6 – The intensity distribution of gamma radiation in the time vicinity of the electric discharge, resolution – 160 µs (left) and 25 µs (right)

The output signals of a large area scintillation detectors and the coincidence signals between them are recorded by a common data acquisition system of an autonomous detector point, similar to the signals of a gamma-ray detector. A special condition was added to the software algorithm for generating an autonomous trigger that ensures the selection of events in which signals from a charged particle detector are observed: recording time intensity distributions with high temporal resolution was initiated when recording at least 5 pulses from any of the planar scintillators during one interval time scan (160 µs).

First results

Fig. 5 presents examples of the results of measurements of the intensity of signals in different energy ranges of gamma radiation at the level of an autonomous detector point for three days in August 2016. Measurements of the intensity of scintillation pulses from a gamma detector were carried out continuously with a period of 1 s. The sharp increase in the intensity of gamma radiation on the afternoon of August 23 is associated with the passage of a thunderstorm cloud near the Tien Shan Station and precipitation.

Fig. 6 shows the distribution of the intensity of gamma radiation in the time vicinity of electrical discharges, measured in the same events with a resolution of 160 µs and 25 µs.

Fig. 7 shows the results of recording the intensity of signals from scintillation detectors of charged particles. The intensities of scintillation signals from the upper (plastic-up) and lower (plastic-low) detectors, as well as signals of coincidence between them (plastic-coin.), measured with a 1-second period during the passage of a thunderstorm during the afternoon of August 23 are presented.

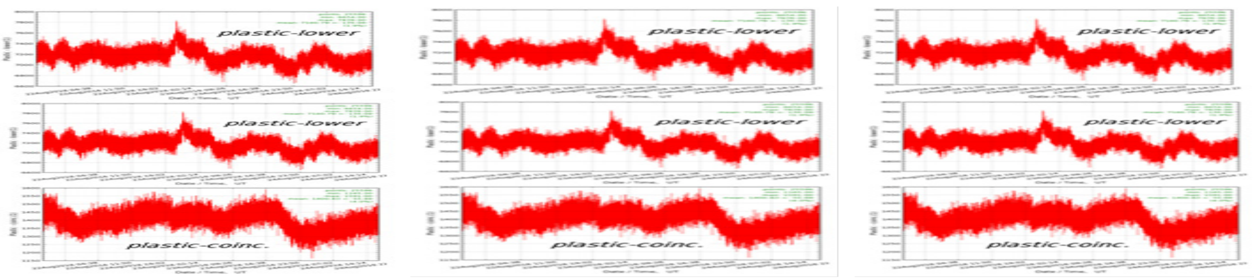

Figure 7 – The time course of the intensity of the signal of the plastic detector; below – a coincidence signal between the lower and upper detectors

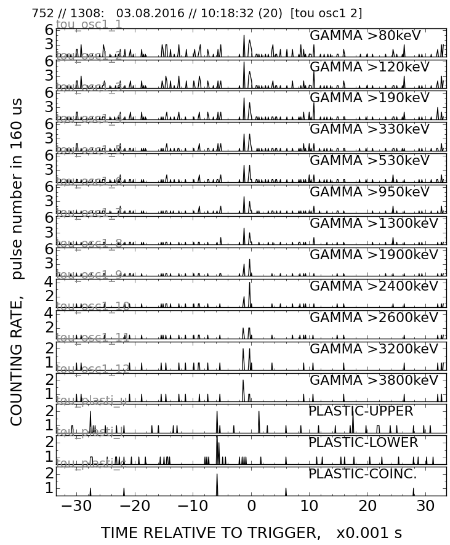

Figure 8 – An example of the registration of a temporary change in the intensity of signals from a gamma detector and detectors of charged particles in the time around triggering

The temporal distributions in Fig. 8, represent the intensity course of signals from a gamma detector and charged particle detectors (the three lower distributions on each panel are labeled as PLASTIC-UPPER, PLASTIC-LOWER and PLASTIC-COINC) recorded with a resolution of 160 µs with an internal trigger from the channels of the charged particle detector.

Conclusion

An autonomous tracking station for detecting radiation directly inside the thundercloud was created at the Tien-Shan High-Mountain Scientific Station. Its main elements are gamma-radiation and charged particle detectors, a compact data acquisition system and a battery-powered power supply system independent of external sources, which ensures the autonomous operation of the measuring point throughout the entire period of thunderstorm (up to two hours). The first data on the measurements of the intensities of gamma radiation and the charged component demonstrated the efficiency and high reliability of all the systems of the autonomous registration point. The developed new approach to conducting an experiment under conditions of thunderstorm activity makes it possible to expand the field of observation of radiation almost unlimitedly by increasing the number of observation points and placing them at different heights of the mountain massif.

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ИЗМЕРЕНИЯ ЭМАНАЦИИ ИЗОТОПОВ РАДОНА В ЖИЛЫХ И АДМИНИСТРАТИВНЫХ ПОМЕЩЕНИЯХ

Данная работа посвящена изучению распределения альфа-активности природных радионуклидов в школах-интернатах, находящихся вблизи зон тектонических разломов г.Алматы. Измерения были произведены в школах-интернатах, которые одновременно являются и жилыми, и административными помещениями. В результате измерений была построена 2D-топология распределения плотности потока альфа-излучения изотопов радона и их ДПР от высоты измерения (этажности) для каждой школы-интерната и 2D-топология распределения плотности потока альфа-излучения от расстояния до тектонического разлома. По результатам измерений был найден коэффициент концентрации радона от расстояния от тектонического разлома. Используя полученную закономерность можно построить график зависимости объемной альфа-активности для других школ, если известно их расстояния от тектонического разлома.

Ключевые слова: радон, дочерние продукты распада радона, альфа-активность, тектонические разломы, природный радиационный фон.

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Measurements of emanation of radon isotopes in residential and administrative buildings

The distribution of alpha activity of natural radionuclides in boarding schools located near the tectonic fault zones of Almaty was studied. Measurements were made in boarding schools, which are both residential and administrative buildings. As a result of the measurements, a 2D topology of the distribution of the alpha-radiation flux density of radon isotopes and their daughter decay products from the measurement height (number of storeys) for each boarding school was made. In addition, a 2D topology of the distribution of alpha-radiation flux density from the distance to the tectonic fault was compiled. According to the measurement results, the concentration coefficient of radon was found depending on the distance from the tectonic fault. Using the obtained regularity, it is possible to construct a graph of the dependence of volume alpha activity for other schools, if their distance from the tectonic fault is known.

Key words: radon, radon decay daughter products, alpha activity, tectonic faults, natural radiation background.

