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Influence of ambient temperature on gamma scintillation detector readings

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Scintillation detectors, which are widely used in environmental field study for measurement of radiation dose, are devices that experience wide range of temperature changes when in use. One of the characteristic of scintillation detectors are that, they are very sensitive to change in temperature and hence, every scintillation detector have temperature stabilization inside them. The temperature-dependence coefficient which is part of the detector calculation is the simplest stabilization method that is used. In this work, the BDKG-03 scintillation detector which is used to measure gamma radiation was operated under a controlled condition using a climatic chamber. The BDKG-03 scintillation detector has a temperature stabilizing built-in algorithm. The dose rate and count rate of the gamma background radiation for different temperatures ranging from -40 – +40 ^{o}C in increment of 10 ^{o}C were measured and studied. The main aim of this work was to study the effect of different ranges of temperature for subsequent calculation of temperature correction coefficient. An analytical result from the experimental result shows that dose rate measurement using the built-in algorithm gives a precise reading as temperature increases. The temperature correction coefficient was found based on dependence.

Keywords: dose rate, scintillation detector, climatic chamber, temperature correction coefficient, radiation.

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Introduction

Radiation monitoring has become very essential in today's world especially after the nuclear accidents, which occurred some years back such as the Fukushima Daiichi nuclear accident that occurred at Japan in 2011 and also due to the use of radiological sources [1]. In order to monitor the amount of radiation at a particular place or in the environment, several devices have been developed. These devices include; the scintillation detectors, gas-discharge counter and so on [2]. One of the oldest used radiation monitoring detectors are the scintillation detectors which are currently been mostly used due to their sensitivity to low gamma radiation change within an environment [3]. Scintillation detectors are light emitters and they fall under a solid-state group. These detectors absorb ionizing radiation and convert them into light photons. Examples of scintillation detectors include; the plastic scintillator, NaI (TI), CsI (TI) [4]. There are several factors that affect the readings of dose when using radiation-monitoring detectors, such as environmental conditions (temperature), hence calibration factors have been concerted in them to correct these factors [5]. This work was devoted to study the influence of ambient temperature on the readings of scintillation detectors when monitoring the background gamma radiation of the atmosphere. The relevance of this work is caused by problem when using scintillation detectors such as erroneous time changes may occur that cant be traced back and hence the need for temperature correction factor for such detectors arises. Also works done in Tomsk using the gamma scintillation detector (BDKG-03) shows that the temperature correction factor in the detector are used for highly active radiation fields and not for sources of low-radiation [6]. In this work, a climatic chamber which replicates the various environmental conditions such as temperature, humidity, vibration and so on was used. Several works pertaining to other fields have been done using the climatic chamber and this shows the authenticity of its results for out task. Mensah et al. (2016) did a study on the performance of temperature and humidity of the climatic chamber. Lochlainn et al. (2015) did another work, on a comparison of climatic chamber hydrothermal characterization techniques as described in IEC6068. Due to the effect, temperature has on scintillation detectors, various studies have been made to find the dependence of temperature on these detectors and also on temperature correction. Casanovas et al. (2012) did a work, which showed that NaI detectors cause a shift in peak due to temperature change. Mitra et al. (2016) also conducted a study, which proofed that NaI detectors are affected by temperature variation in the environment.

In this work, a new temperature correction coefficient was found which would be used for calculation of dose rate for low-level radiation in the environment when using scintillation detector BDKG-03.

Materials and methods

In this study a gamma scintillation detector (BDKG-03 manufactured by ATOMTEX, Belarus) was used. The BDKG-03 is a highly sensitive scintillation counter with a sensitivity of 350 (imp/s)/ (μSv) for 137Cs which is used to measure gamma dose radiation. It measures gamma background radiation within the energy range of 50 keV – 3 MeV. It also measures the ambient equivalent dose of gamma radiation within the range of 0.03 μSv – 10 mSv and that of power ambient equivalent gamma radiation dose in a range of 0.03 – 300 μSv/h.

A climatic chamber, which is an enclosed chamber that replicates different environmental conditions such as temperature, humidity, rain, altitude, electromagnetic radiation, electrodynamic vibration, vacuum and so on, was also used. It is used to test electronic devices, specimen, industrial products, biological items and materials to know how these environmental conditions would affect them. The climatic chamber is about 1000 litres in volume, and has a temperature range of about -60 – +60 ^{o}C. It has a temperature fluctuation accuracy of $\pm$0.5% and humidity accuracy measurement of $\pm$1%RH.

A scintillation detector (BDKG-03) was placed into a climatic chamber and the dose rate and count rate of the gamma background radiation was measured by the detector for different temperatures ranging from (-40 – +40) ^{o}C. Measurement was taken in an interval of 5 minutes for every 10 ^{o}C. A dependence of dose rate and count rate against temperature was plotted and an experimental temperature correction factor was obtained from the results.

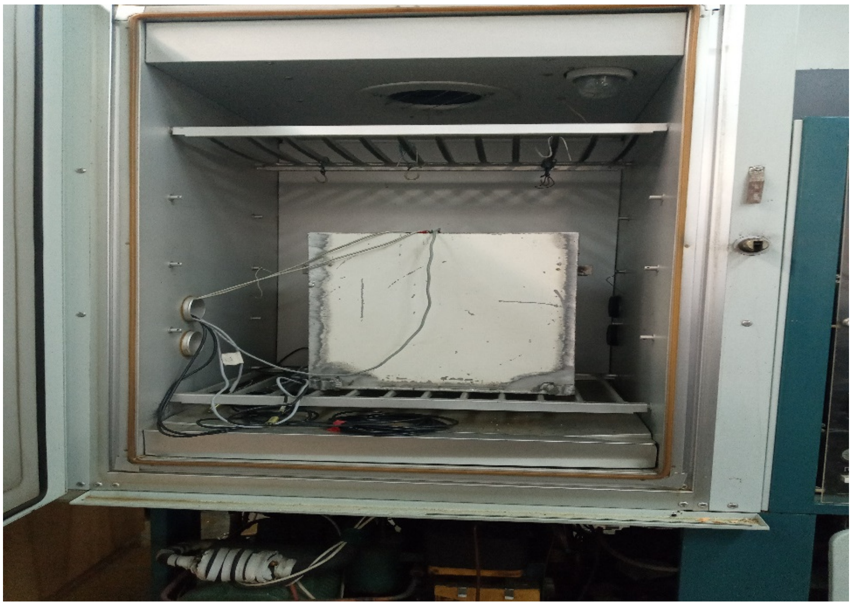

Fig. 1. Experimental setup

Built-in temperature correction factor

Correction factor refers to the mathematical adjustment of an equation or a calculation to correct the amount of deviation during measurement. It is mostly multiplied by the equation to correct the systematic error during measurement. This helps us to analyze and evaluate the results obtained during measurement, even though most results gotten during measurement maybe precise or very accurate. Every detector or instrument has a correction which helps to analyze and evaluate the result obtained during measurement. The correction factor was then multiplied by the count rate to help find the built-in algorithm of the detector. In this experiment, a correction factor k was found by dividing the average dose rate by the count rate.

$$k = \frac{Dose\ rate}{Count\ rate} \tag{1}$$

Results and discussion

This section presents the results for dependence on temperature. Figure 2 shows

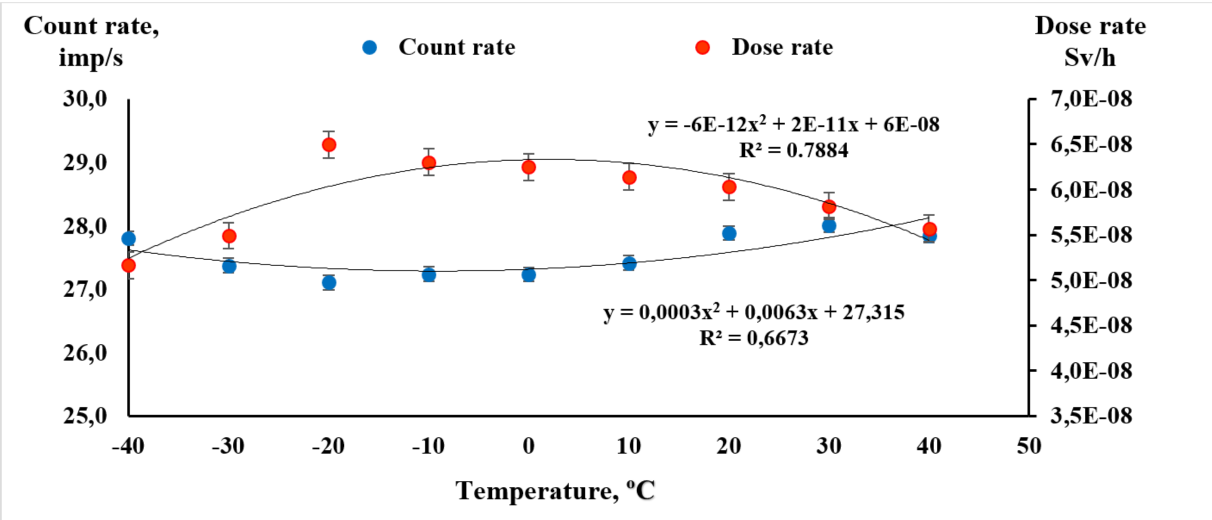

Fig. 2. Dependence of ambient dose rate and count rate against temperature

that generally the dose rate increases from -40 to -20 ^oC and it starts decreasing with increasing temperature while count rate decreases from -40 to -20 ^oC and it starts increasing with increasing temperature. The relative error for both the dose rate and the count rate were found to be between (5.0 – 5.4) % and (2.2 – 2.3) % respectively. Figure 3 shows that, the ambient temperature does not affect the count rate much since

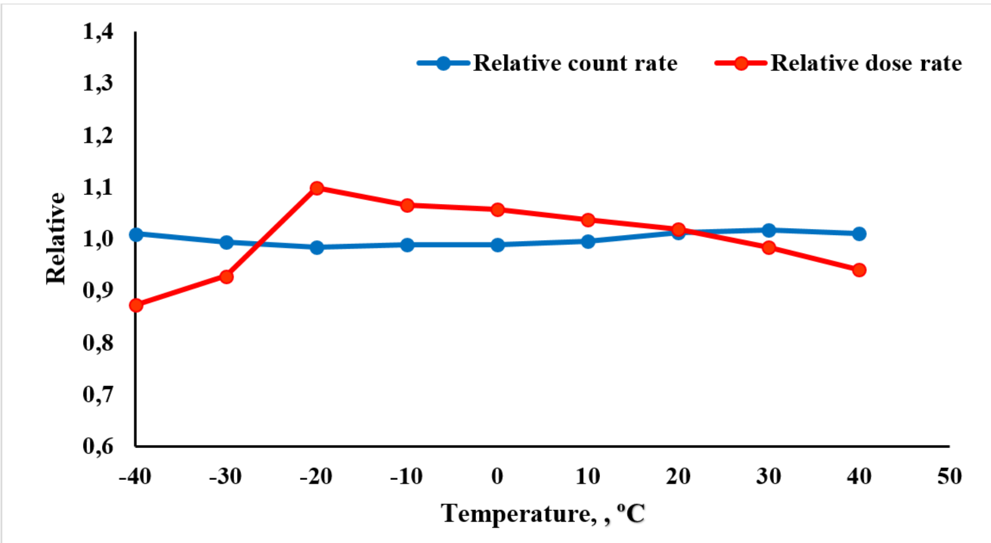

Fig. 3. Dependence of relative dose rate and count rate against temperature

the relative count rate was very close to 1, but the dose rate was very much affected especially one measured from -40 to -20^{o}C. The relative dose rate and count rate were found by dividing the individual dose rate and count rate by dose rate and count rate of the ambient temperature 20 ^{o}C.

Figure 4 shows that the temperature of the climatic chamber was almost the same as the temperature of the detector at lower temperature, but as the temperature increased (from -20^{o}C), the temperature of the detector was deviating more from the actual value. This proves the need for the temperature correction factor in the detector. The

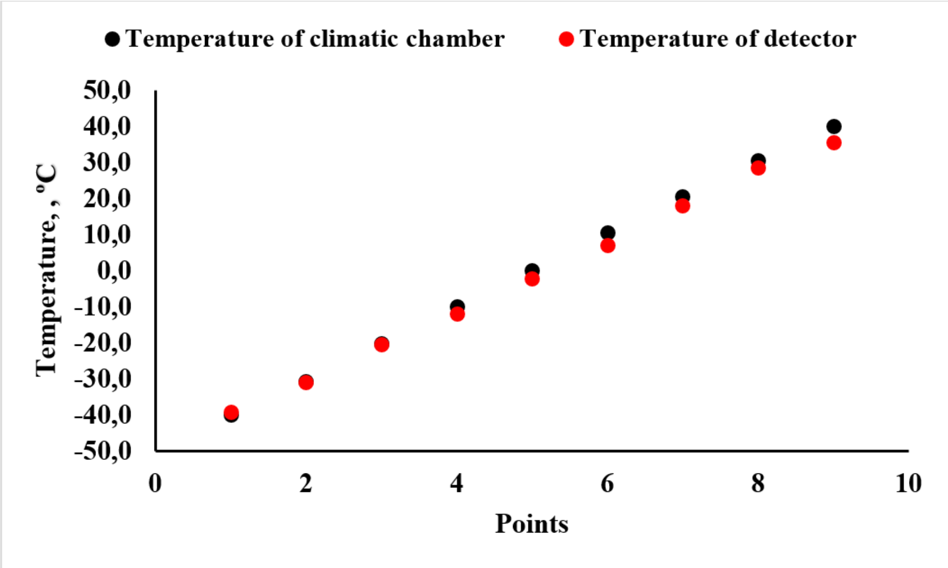

Fig. 4. Comparison of the temperatures of the detector and the climatic chamber

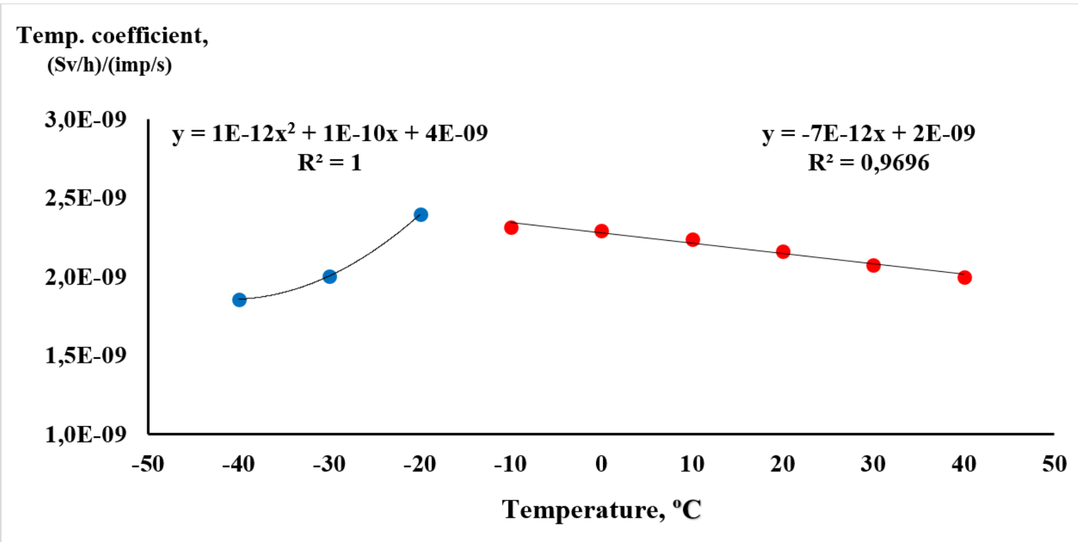

Fig. 5. Dependence of the temperature correction factor embedded in the temperature protection of the detector

dependence of temperature correction factor embedded in the temperature protection of the detector is shown in figure 5. The dependence is described with a single equation, so the graph was divided into two range from -40 to -20^{o}C and -10 to +40 ^{o}C. This proves that the temperature correction coefficient embedded into the detector is incorrect and cannot be used for low-level radiation dose. Figure 6 shows the dependence of dose rate

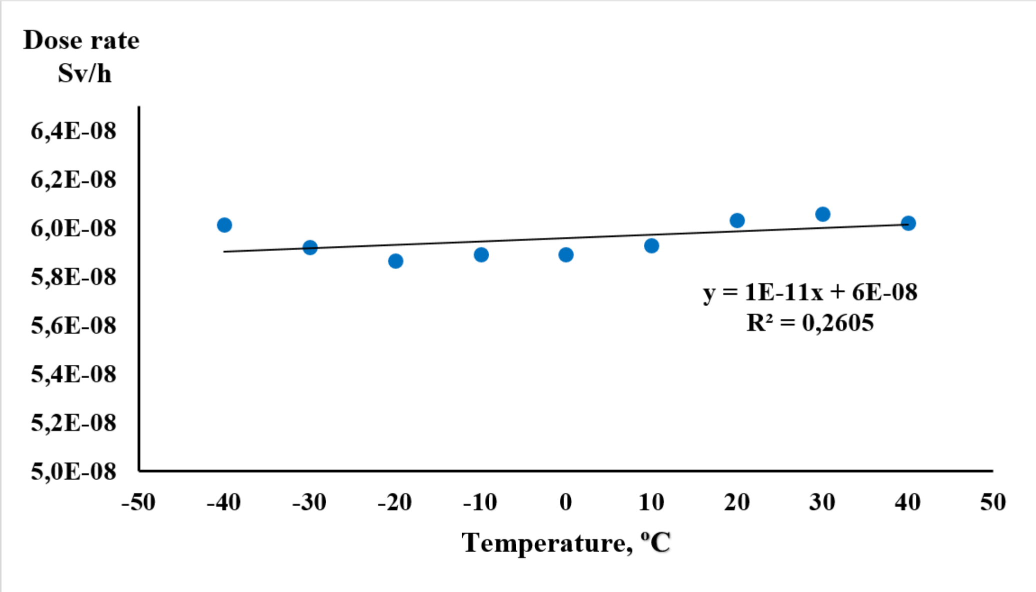

Fig. 6. Dependence of dose rate on temperature without using the built-in detector algorithm

on temperature without using the detector built in algorithm. This was calculated using the count rate and the temperature coefficient at ambient temperature. The temperature coefficient, k at ambient temperature of the detector was found as $k = 2.163 \cdot 10^{-9}[\frac{Sv/h}{imp/s}]$ using equation (1), with a standard deviation of $\pm 7.317 \cdot 10^{-10}[\frac{Sv/h}{imp/s}]$. A linear equation $y = 10^{-11} \cdot x + 6 \cdot 10^{-8}$ was generated from the graph.

The comparison of algorithms is shown in figure 7. The experimental algorithm was found from the equation of the line of the graph for dependence of dose rate on temperature without using the built-in algorithm, which was found as:

$$\begin{gathered} y = 10^{-11} \cdot x + 6 \cdot 10^{-8} \ \approx \ H,\ but,\ H = N \cdot k(T),\ k(T) = x_1 \cdot T + x_2 \\ \Longrightarrow k(T) = \tfrac{H}{N},\ \ and\ using\ value\ of\ \ N[k(T=20)] = 27.88\ imp/s \\ \Longrightarrow x_{1,2} = 3.58 \cdot 10^{-13}\ \ and\ \ 2.158 \cdot 10^{-9},\ respectively \\ \Longrightarrow H = N \cdot (3.58 \cdot 10^{-13} \cdot T + 2.152 \cdot 10^{-9}) \end{gathered} \tag{2}$$

Where H – dose rate, N – count rate k – temperature coefficient and T – temperature.

Figure 8 shows the comparison of the factory and the experimental correction coefficient on temperature. Form the equation of experimental algorithm for dose rate, $H = N \cdot (3.58 \cdot 10^{-13} \cdot T + 2.152 \cdot 10^{-9})$, it can be concluded that the factories algorithm for temperature coefficient k cannot be used for calculation of dose rate for low level radiation. Therefore, the correct temperature coefficient is $k(T) = 3.58 \cdot 10^{-13} \cdot T + 2.152 \cdot 10^{-9}$

Conclusions

The results for the dependence of dose rate measurement on temperature using the built-in algorithm gives unreliable results for low-level radiation since the dose

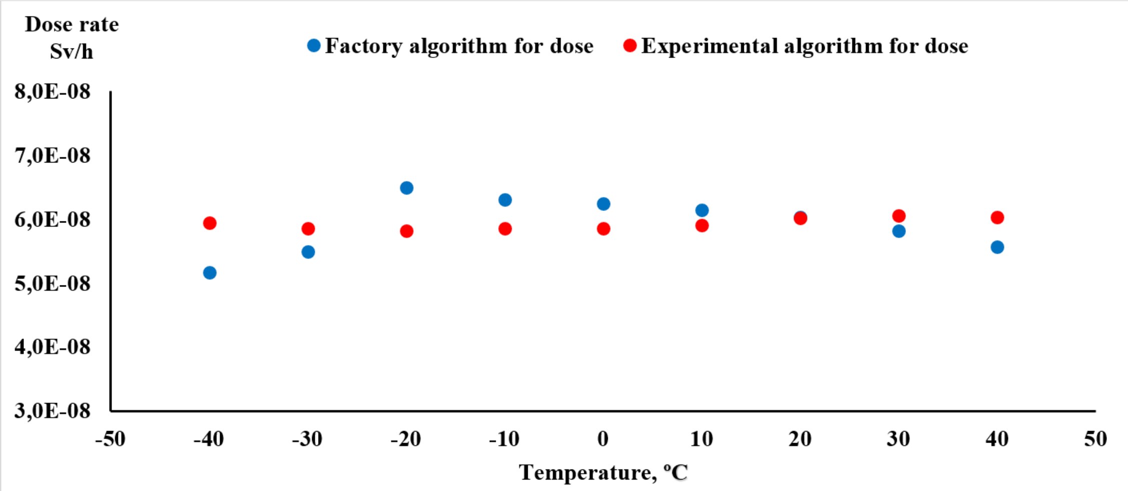

Fig. 7. Comparison of factory algorithm and experimental algorithm

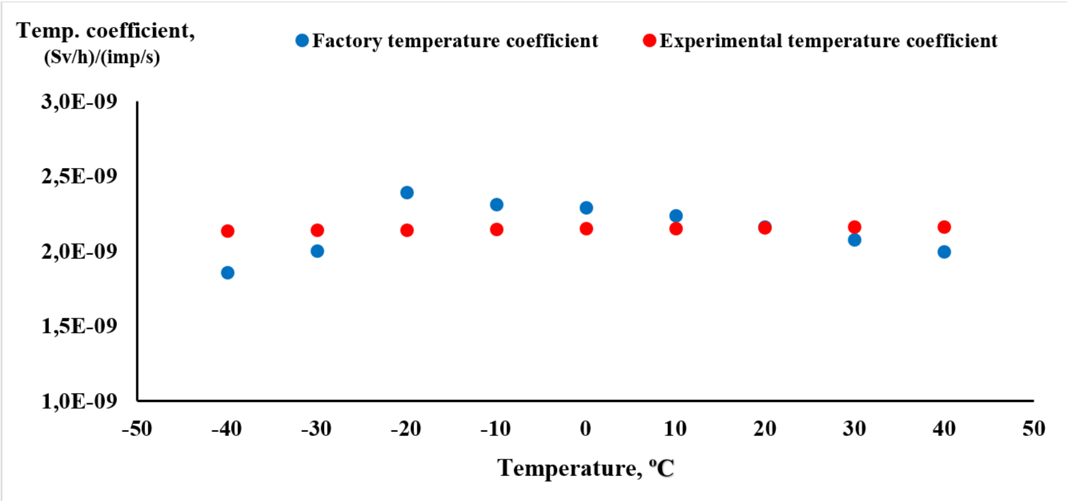

Fig. 8. Comparison of factory and experimental temperature correction coefficient

rate detector measurements were unstable. The results also revealed that the detector readings for dose rate depends on environmental factor (temperature), hence the need for temperature correction coefficient arises. The built-in algorithm for temperature correction give two equations instead of one for low dose hence making the embedded temperature correction coefficient incorrect. An expression was found for calculating the correction factor based on the detected dependence of the detector reading for temperature. The new correction factor obtained for calculating the dose rate in the detector was found to be $k(T) = 3.58 \cdot 10^{-13} \cdot T + 2.152 \cdot 10^{-9}$.

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MSC 550.35 Научная статья

Влияние температуры окружающей среды на показания гамма-сцинтилляционного детектора

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Сцинтилляционные детекторы широко используются в исследованиях окружающей среды для измерения дозы облучения и представляют собой устройства, которые используются в широком диапазоне температур. Одной из характеристик сцинтилляционных детекторов является чувствительность к изменениям температуры, и, следовательно, каждый сцинтилляционный детектор имеет встроенный алгоритм температурной стабилизации. Коэффициент температурной зависимости, который является частью автоматических расчетов детектора, представляет собой простейший метод стабилизации. В данной работе сцинтилляционный детектор БДКГ-03, используемый для измерения гамма-излучения, работал в контролируемых условиях с использованием климатической камеры. Сцинтилляционный детектор БДКГ-03 имеет встроенный заводской алгоритм стабилизации температуры. Были измерены и исследованы мощность дозы и скорость счета фонового гамма-излучения для различных температур от -40 до +40 ^{o}C с шагом в 10 ^{o}C. Основной целью данной работы было изучение влияния различных диапазонов температур для последующего расчета температурного поправочного коэффициента. Результат эксперимента показывает, что измерение мощности дозы с использованием встроенного алгоритма дает более точные показания в верхнем диапазоне рабочих температур.

Ключевые слова: мощность дозы, сцинтилляционный детектор, климатическая камера, температурный поправочный коэффициент, ионизирующее излучение.

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Авторский вклад и ответственность. Все авторы участвовали в написании статьи и полностью несут ответственность за предоставление окончательной версии статьи в печать. Окончательная версия рукописи была одобрена всеми авторами.

Финансирование. Исследование выполнялось без финансовой поддержки фондов.