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Intrinsic background of the beta channel of the aerosol volumetric activity monitor

A. Kozyrenko, O. Letuchyi, A. Pystovyi, V. Skliarov

National Scientific Centre "Institute of Metrology", Myronosytska Str., 42, 61002, Kharkiv, Ukraine
vladimir.skliarov@gmail.com

Abstract

The work is devoted to the study of the features of generation of the intrinsic background of the measuring beta channel of the aerosol monitor in real conditions of measuring the volumetric activity of aerosols, caused by radionuclides of technogenic origin.

The influence of external factors on the generation of the level of the intrinsic background of the measuring channel of the monitor and its metrological characteristics is investigated.

The reliability of the results of measurements of the volumetric activity of air aerosols substantially depends on the correct accounting of external factors, parameters of the monitored environment and the specified operating mode of the monitor.

Aerosol volumetric activity monitors, as a rule, operate in a continuous mode, in which the aspiration method of aerosol accumulation is implemented, followed by measuring the volumetric activity of aerosols by alpha radiation and (or) beta radiation generated by technogenic radionuclides.

This article describes the results of experiments on measuring the iCAM aerosol monitor's intrinsic beta channel background under real operating conditions, and its dependence on external factors.

The studies were carried out on iCAM aerosol monitors (iCAM/D and iCAM/MF modifications) manufactured by Canberra Industries Inc. in a laboratory room in normal climatic conditions with a radon volumetric activity of 35±10 Bq·m^{-3} and an equivalent dose rate of gamma radiation of 0.13±0.02 μSv·h^{-1}.

In modern aerosol monitors, software and hardware solutions are implemented that allow to significantly reduce the background level and, as a result, to expand the measurement range of the volumetric activity of aerosols towards low values.

Keywords: aerosols; radionuclides; intrinsic background; decay products; volumetric activity.

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Introduction

The requirements for air aerosol monitors are set out in the standards for organized gas-aerosol emissions [1, 2] and for indoor air aerosols [3]. The physical unit of measurement is the volumetric radioactivity of air aerosols caused by technogenic radionuclides.

The volumetric activity of aerosols is determined by a calculation method based on measuring the activity of aerosols deposited on the filter belt over a certain period of time and measuring the volume of the sample from which aerosols were aspirated during this period of time.

The volumetric activity of aerosols with naturally occurring radionuclides, created by the decay products of ^{222}Rn and ^{220}Tn, is subject to compensation when measuring the volumetric activity of aerosols with technogenic radionuclides [4].

Compensation is carried out according to a certain algorithm that requires a large amount of calculations in on-line mode [5].

Modern aerosol monitors are software-measuring systems, in which software is an important element of the measurement procedure, affecting the reliability of the measurement results [6].

The main factors that determine the requirements for a measuring instrument, as well as significantly affecting the reliability of measurement results, are:

— very low values of the established permissible levels of intake of radionuclides through the respiratory system [7];

— measurement of low values of the volumetric activity of aerosols, requiring the use of the technology of preliminary accumulation of aerosols;

— presence of aerosols with naturally occurring radionuclides in a controlled environment;

— presence of background gamma radiation.

The intrinsic background of the measuring channel is a significant factor limiting the metrological capabilities of the monitor in the region of low values of the volumetric activity of aerosols.

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The minimum detectable activity (MDA) of the monitor in the presence of the background is determined from the following expression [8]:

$$MDA(Bq) = \frac{3}{\varepsilon \cdot \delta_{st}} \cdot \sqrt{\frac{n_f}{\Delta t}},$$

where ε is the sensitivity of the measuring channel, $s^{-1} \cdot Bq^{-1}$; δ_{st} is the user-defined relative statistical error of count rate, rel. un.; Δt is the time of measurement of activity of aerosols accumulated on the filtering element, s; n_f is the background count rate, s^{-1}.

As follows from the above expression, when measuring a useful signal in the presence of background, the measuring capabilities of the monitor will be determined by the level of the intrinsic background of the measuring channel and the given time of measuring the activity of aerosols deposited on the filtering element.

According to the current regulations [9, 10], the determination of the intrinsic background of the measuring instrument for the volumetric activity of artificial radioactive aerosols is carried out on a clean filter element without taking an air sample.

It is obvious that the value of the intrinsic background of the measuring channel determined in this way has little relation to the background level of the measuring channel when the monitor is in the measurement mode.

As a rule, the technical documentation for aerosol monitors does not contain the values of the intrinsic background. In the documentation for monitors (radiometers, installations) of aerosols, where the values of the intrinsic background are given, they are no more than 1×10^{-3} s^{-1} for the alpha channel, and no more than 7×10^{-2} s^{-1} for beta channel.

The metrological capabilities of the measuring instrument for the volumetric activity of artificial radioactive aerosols when measuring a weak signal in the presence of a high background level are limited by the level and dispersion of the background [11].

The software of the iCAM monitor (iCAM/D and iCAM/MF modifications) allows realizing various modes of measuring the volumetric activity of aerosols. The basic mode is for measuring the volumetric activity of aerosols with averaging over a time interval of 3600 s at a constant sampling rate, with compensation in the measuring beta channel of gamma radiation and radiation from radionuclides of natural origin.

To determine the effectiveness of the background compensation of the measuring beta channel, measurements were performed in the "zero signal" mode, i.e. full-scale imitation of the operating mode of the monitor in the absence of a useful signal due to radionuclides of technogenic origin. In this case, the signal in the beta channel is only background and is formed by external factors – gamma radiation and the activity of naturally occurring radionuclides in the taken air sample.

Compensation of gamma radiation as a component of the background of the measuring beta channel is carried out in a dynamic mode. For this purpose, along with the main measuring channel of alpha and beta radiation, an additional detector is installed in the iCAM monitor, which registers only gamma radiation, the signal of which is used to compensate for this background component in the measuring beta channel.

Initially, measurements of the intrinsic background were carried out according to the measurement technique described in [9]. The measurements were performed in the beta channel of the iCAM monitor on a clean filter without pumping air.

Fig. 1 and 2 show the synchronously measured count rates in the measuring beta channel and in the compensating gamma channel when simulating the operating mode of the monitor without pumping air

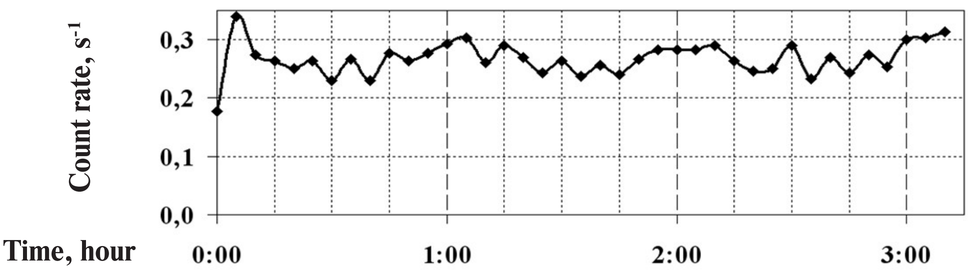

Fig. 1. The count rate of pulses in the measuring beta channel

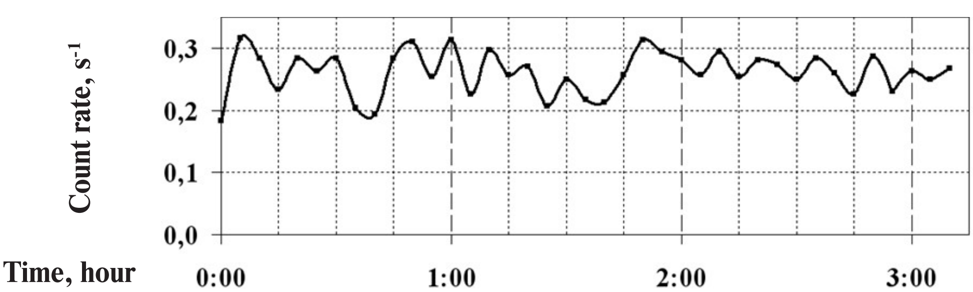

Fig. 2. The count rate of pulses in the compensating gamma channel

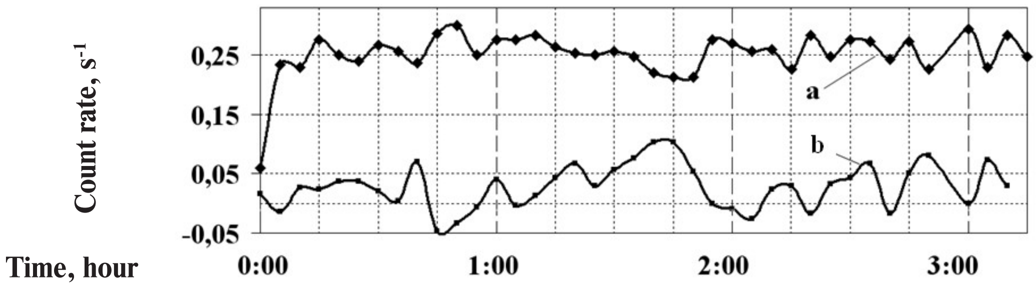

Fig. 3. The count rate of pulses in the compensating gamma channel (a) and the count rate of pulses in the measuring beta channel (b)

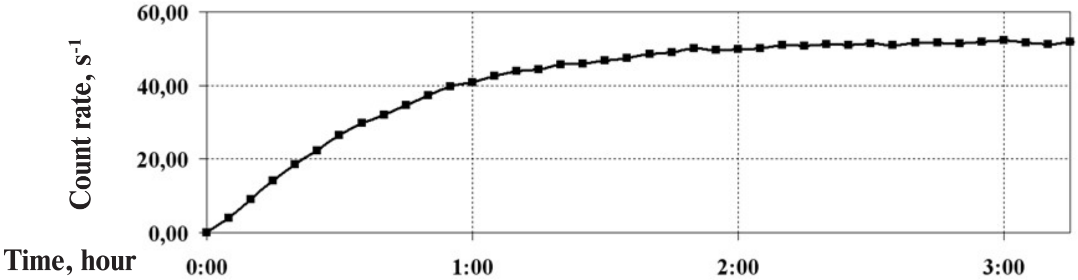

Fig. 4. Change in the pulse count rate in the beta channel due to the accumulation of beta-emitting radionuclides of natural origin on the filter element

through the filter element with the turned off gamma radiation compensation mechanism.

The average value of the pulse count rate in the measuring beta channel, due to gamma radiation, is 0.265 s^{-1} ± 0.019 s^{-1} with averaging over a time interval of 3600 s in the range from 7200 s to 10800 s.

As can be seen from the graphs shown in Fig. 1 and 2, the average count rates of the detectors are practically the same and amount to approximately 0.25 s^{-1}, with a gamma radiation level in the room of 0.13 ± 0.02 μSv·h^{-1}.

The average value of the pulse count rate in the compensating gamma channel is 0.264 s^{-1} ± 0.022 s^{-1} with averaging over a time interval of 3600 s (from 7200 s to 10800 s).

Fig. 3 shows the simultaneous measurements of the count rate in the compensating gamma channel and in the measuring beta channel with the air pumping and the activated gamma radiation compensation mechanism. This operating mode of the monitor corresponds to the operating mode when determining the level of its own background according to the verification method [9].

According to the results of statistical processing of the experimental data shown in Fig. 3, the average value of the count rate of background pulses in the measuring beta channel after compensation decreases to 2.3×10^{-2} s^{-1} ± 3.6×10^{-2} s^{-1} with averaging over a time interval of 3600 s (from 7200 s to 10800 s).

The level of the intrinsic background of the measuring channel, measured by the verification method [9], is in good agreement with the values given in technical documentation. Compensation of a part of the background, which is caused by beta radiation of naturally occurring radionuclides, is a more complex procedure, which is also carried out in real-time operation of the monitor.

The mechanism for compensating the background generated by beta radiation of naturally occurring radionuclides is implemented by calculating the intensity of beta radiation from the decay products of radon and thoron by alpha radiation spectra of ^{214}Po, ^{218}Po and ^{214}Bi, ^{212}Po, respectively.

Compensation of the background, which is generated by radon and thoron progeny, is carried out by the radiometer automatically in on-line mode and also makes it possible to significantly reduce the background level in the measuring beta-channel and alpha-channel.

Fig. 4 shows the time variation of the count rate in the measuring beta channel of the monitor operating with the activated air pumping and with deactivated beta radiation compensation mechanism. After turning on the monitor in the measurement mode, the pulse count rate in the beta channel slowly increases to a quasi-stationary level. This level is established when equilibrium is reached on the filtering element between the inflow of the decay products of radon and thoron and the radioactive decay of these radionuclides, which were accumulated earlier during the aspiration of aerosols.

Equilibrium is reached within approximately 2 hours from the moment the monitor is turned on. The time to reach a quasi-stationary level depends on the volumetric activity of radon in the taken air sample and on the intensity of sampling and is not a constant value. The graph shown in Fig. 4 was obtained at a sampling rate of 35 l·min^{-1} and a volumetric activity of ^{222}Rn in air of 30.0 ± 10 Bq·m^{-3}.

As can be seen from the graph in Fig. 4, the average value of the background counting rate of

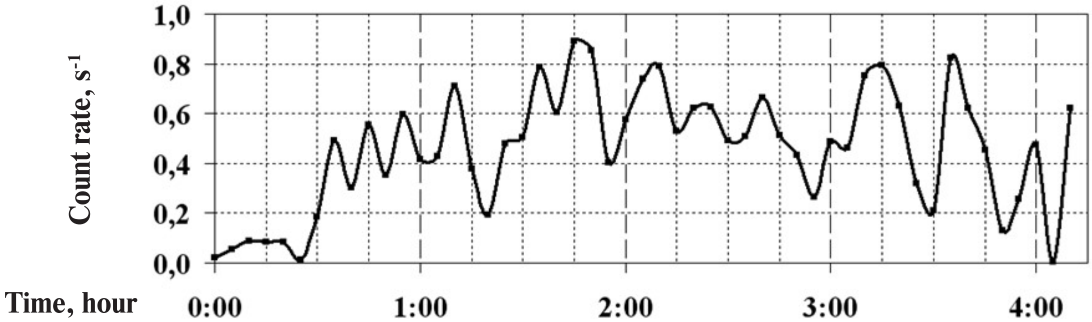

Fig. 5. Background of the measuring beta channel with the activated compensation of gamma radiation and beta radiation of natural radionuclides

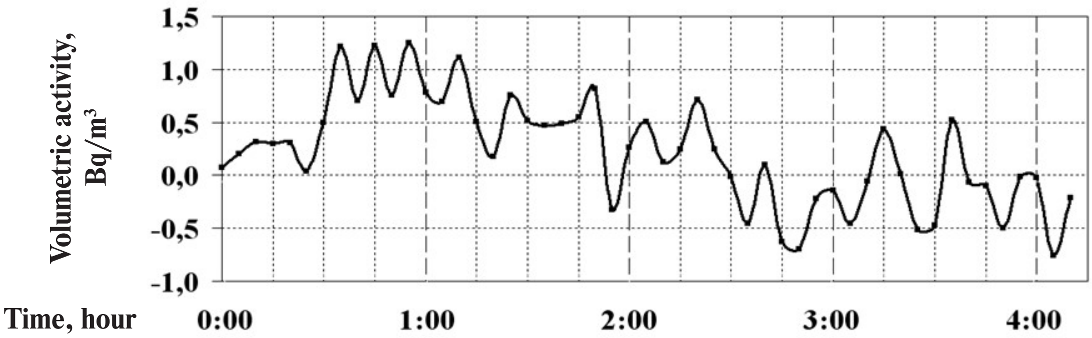

Fig. 6. Volumetric activity of aerosols measured by the iCAM monitor by beta radiation, during normal operation

the measuring beta channel of the monitor, which is caused by the decay products of radon and thoron and is reached two hours after the monitor is turned on, is 51.8 $s^{-1} \pm 0.5\ s^{-1}$.

The compensation mechanism for the beta radiation of natural radionuclides can significantly reduce the level of intrinsic background in the measuring beta channel of the monitor.

Fig. 5 shows the measured count rate in the beta channel with the activated background compensation mechanism, under conditions similar to the measurements shown in Fig. 4.

The average background count rate in the beta channel, when the iCAM monitor is operating in normal mode, is 0.495 $s^{-1} \pm 0.234\ s^{-1}$ with averaging over the 3600 s interval from 10800 s to 14400 s. This value of the intrinsic background of the beta channel is an order of magnitude higher than that measured by the verification method [9] and is shown in Fig. 3.

The pulse count rate in the measuring beta channel of the monitor recorded after compensations is automatically converted into a measurable physical quantity – the volumetric activity of aerosols with technogenic radionuclides (Fig. 6).

The average value of the volumetric activity of aerosols when simulating the operating mode of the monitor with a zero useful signal is 0.014 $Bq{\cdot}m^{-3} \pm$ $\pm 0.438\ Bq{\cdot}m^{-3}$ with averaging in the interval 3600 s from 7200 s to 10800 s.

Conclusions

Measurements of the intrinsic background of the measurement beta channel of the aerosol monitor by the method of simulation of the operating mode with a zero useful signal were carried out.

It was shown that the main source of the generation of the intrinsic background of the beta channel, when the monitor was operating under normal conditions, was the beta radiation of the decay products of natural radionuclides.

The use of the compensation mechanism simultaneously with a significant decrease in the average value of the background count rate in the measuring channel leads to an increase in the signal dispersion with respect to the initial value.

The intrinsic background values of the monitor beta channel, measured in the operating mode of the device, are significantly higher than the intrinsic background level measured according to the verification procedure [9]. Due to this circumstance, the metrological characteristics of aerosol monitors indicated in the operational documentation turn out to be overestimated.

Власний фон бета-каналу монітора об’ємної активності аерозолів

А.М. Козиренко, О.М. Летучий, А.С. Пустовий, В.В. Скляров

Національний науковий центр "Інститут метрології", вул. Мироносицька, 42, 61002, Харків, Україна
vladimir.skliarov@gmail.com

Анотація

Роботу присвячено вивченню особливостей формування власного фону вимірювального бета-каналу монітора аерозолів у реальних умовах вимірювання об’ємної активності аерозолів, обумовленої радіонуклідами техногенного походження.

Досліджено вплив зовнішніх факторів на формування рівня власного фону вимірювального каналу монітора та його метрологічні характеристики.

Дослідження проводилися на моніторах аерозолів iCAM виробництва фірми Canberra Industries Inc. у лабораторному приміщенні в нормальних кліматичних умовах з об’ємною активністю радону 35±10 Бк·м$^{-3}$ і потужністю еквівалентної дози гамма-випромінювання 0,13±0,02 мк^{3} в·год$^{-1}$.

У сучасних моніторах аерозолів реалізовані програмно-технічні рішення, які дозволяють значно знизити рівень фону, і як наслідок – розширити діапазон вимірювання об’ємної активності аерозолів у бік низьких значень.

Проведено вимірювання власного фону вимірювального бета-каналу монітора аерозолів методом імітації робочого режиму з нульовим корисним сигналом.

Показано, що основним джерелом формування власного фону бета-каналу, при роботі монітора в нормальних умовах, є бета-випромінювання продуктів розпаду природних радіонуклідів.

Використання механізму компенсації одночасно зі значним зниженням середнього значення швидкості рахунку фону у вимірювальному каналі призводить до збільшення дисперсії сигналу по відношенню до початкового значення.

Значення власного фону бета-каналу монітора, виміряні в робочому режимі приладу, істотно вище рівня власного фону, виміряного відповідно до методики повірки. Таким чином, метрологічні характеристики моніторів аерозолів, зазначені в експлуатаційній документації, виявляються завищеними.

Ключові слова: аерозолі; радіонукліди; власний фон; продукти розпаду; об’ємна активність.

Собственный фон бета-канала монитора объемной активности аэрозолей

А.М. Козыренко, А.Н. Летучий, А.С. Пустовой, В.В. Скляров

Национальный научный центр "Институт метрологии", ул. Мироносицкая, 42, 61002, Харьков, Украина
vladimir.skliarov@gmail.com

Аннотация

Работа посвящена изучению особенностей формирования собственного фона измерительного бета-канала монитора аэрозолей в реальных условиях измерения объемной активности аэрозолей, обусловленной радионуклидами техногенного происхождения.

Исследовано влияние внешних факторов на формирование уровня собственного фона измерительного канала монитора и его метрологические характеристики.

Достоверность результатов измерений объемной активности аэрозолей воздуха существенно зависит от корректного учета внешних факторов, параметров контролируемой среды и заданного режима работы монитора.

Мониторы объемной активности аэрозолей, как правило, работают в непрерывном режиме, при котором реализуется аспирационный метод накопления аэрозолей, с последующим измерением объемной активности аэрозолей по альфа-излучению и (или) бета-излучению, создаваемой техногенными радионуклидами.

В статье изложены результаты экспериментов по измерению собственного фона бета-канала монитора аэрозолей iCAM в реальных условиях работы и его зависимости от внешних факторов.

Ключевые слова: аэрозоли; радионуклиды; собственный фон; продукты распада; объемная активность.

References

1. IEC 60761-1:2002. Equipment for continuous monitoring of radioactivity in gaseous effluents – Part 1: General requirements. Second edition. 63 p.
2. IEC 60761-2:2002. Equipment for continuous monitoring of radioactivity in gaseous effluents – Part 2: Specific requirements for radioactive aerosols monitors including transuranic aerosols. Second edition. 50 p.
3. IEC 61172:1992. Radiation protection instrumentation – Monitoring equipment – Radioactive aerosols in the environment. 83 p.
4. DSTU IEC 61578:2008 (IEC 61578:1997, IDT). Radiation protection instrumentation. Calibration and verification of the effectiveness of radon compensation for alpha and/or beta aerosol measuring instruments. Test methods (in Ukrainian).
5. Sean D., Sonoya T., John M., Luis D., Rose T. The iSERIES™ Radon Progeny Compensation Algorithm and its Application to Air Filters. Sandia Report, SAND2012-9173. 19 p. Available at: https://digital.library.unt.edu/ark:/67531/metadc842786/m2/1/high_res_d/1055933.pdf
6. Pyrkov I., Ivanov E., Poliantcev S., Yarina V. Programmnoye sredstvo, kak element metodiki izmereniy (rascheta) [Software as an element of the methodology of measurement (calculation)]. *ANRI*, 2018, no. 3(94), pp. 2–7 (in Russian).
7. DGN 6.6.1-6.5.001-98. State health and safety regulations. Radiation safety standards of Ukraine (NRBU-97) (in Ukrainian).
8. Isayev A.G., Babenko V.V., Kazimirov O.S., Grishin S.N., Ievlev S.M. Minimalnaya detektiruyemaya aktivnost. Osnovnyye ponyatiya i opredeleniya [The minimum detectable activity. Main concepts and determinations]. *Problems of Nuclear Power Plants Safety and of Chornobyl*, 2010, issue 13, pp. 103–110 (in Russian).
9. GOST 8.527-85. State system for ensuring the uniformity of measurements. Measuring instruments of artificial radioactive aerosols volumetric activity. Verification procedure. 12 p. (in Russian).
10. GOST 8.527-2013. State system for ensuring the uniformity of measurements. Measuring instruments of artificial radioactive aerosols volumetric activity. Verification procedure. 9 p. (in Russian).
11. Bregadze Yu.I., Stepanov E.K., Yaryna V.P. (Eds.). Prikladnaya metrologiya ioniziruyushchikh izlucheniy [Applied Metrology of Ionizing Radiation]. Moscow, Energoatomizdat Publ., 1990. 264 p. (in Russian).