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ESTIMATION METHOD OF PARTICLE SIZE DISTRIBUTION (PSD) OF RADIOACTIVE AEROSOLS BY USING INERTIAL SEPARATORS

Youesf Husein[1], Pripachkin Dmitry[1,2,3], Budyka Aleksandr[1,2], Karev Andrey[1,4], and Tsovyanov Aleksandr[4]

[1]Nat. Res. Nucl. University MEPhI, Moscow, Russia [2]State atomic energy Corporation "Rosatom", Moscow, Russia
[3]Nuclear Safety Institute of the Russian Academy of Sciences, Moscow, Russia
[4]State Research Center – Burnazyan Federal Medical Biophysical Center of Federal Medical Biological Agency (SRC – FMBC), Moscow, Russia

Abstract

This paper describes a new method for determining the dispersed composition of radioactive aerosols using device that containing inertial separators of aerosol particles which separating it into fractions by size.

Keywords: RADIOACTIVE AEROSOL, INERTIAL SEPARATOR, THE DEPOSITION EFFICIENCY, AERODYNAMIC DIAMETER, AMAD, VOLUMETRIC ACTIVITY

Corresponding Author:
Yousef Husein
Yousefhusein@yahoo.com

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1. Introduction

One of the most important physical and chemical characteristics of radioactive aerosols is dispersed composition - activity distribution by particle size. The method of its estimation, in general, consists of several steps: 1) The separation of the spectrum of aerosol particles into fractions; 2) Determination of activity and nuclide composition of each fraction; 3) Estimate parameters of activity distribution by size fractions for each nuclide.

The main devices for the separation of aerosols are impactors [1], filters [2], and diffusion batteries [3]. In the first two devices the separation of the aerosols take place by inertial deposition on to obstacles, and the third by diffusion deposition, based on the difference in the diffusion coefficients of aerosol particles which have different sizes.

In order to measure the activity and determine the nuclide composition of fractions, commonly used radiometers and spectrometers. According to the results of measurements ones can estimate parameters of the activity by size fractions. In the case of unimodal spectra the activity distributions made to approximate log-normal distribution (LND) with parameters μ– The activity median aerodynamic diameter (AMAD) and σ-geometric standard deviation (GSD) [4, 5].

Impactors effectively used to depose particles of size [6] larger than 1 micron. Filters are effective for particles with size from 0.1 to 1 micron. There are some devices have a design that combines inertial cascade impactor and filters [7], which have been developed for personnel use in hazardous manufactures. The range of diffusion batteries is 0.01 – 0.1 micron. Deposition of particles in all above mentioned devices defined by the relationships of deposition efficiency with the size of particles, linear velocity and structural features of the cascades. One's the more cascades, the more partition in the spectrum. On the other hand, it's more difficult to carry out the processing of the activity measurements, moreover, measurements go on (up to several days). Therefore, in terms of saving time and increasing efficiency estimation dispersed composition of radioactive aerosols, it seems necessary to reduce the number of cascades to one, and the separation into fractions would not carried out by the number of cascades, but by changing the parameters of the separation cascade, for example by changing the linear velocity. In estimation internal dose at inhalation radioactive aerosols in the human body, the operativeness is the most important factor.

This paper introduces a new method for estimating the particle size distribution of radioactive aerosols by minimizing the error function, using single-cascade inertial separator to separate the spectrum of aerosol particles into fractions, and the experiment established efficiency dependence of particle deposition with the aerodynamic diameter.

2. Construction and method of evaluation of AMAD and GSD

As a single-cascade inertial separator was used one of the cascades in impactor АИП-2 [8], developed in A.I. Burnazyan (Federal Medical and Biophysical Center-Russia) and widely used in Russia in studies of dispersed composition of radioactive aerosols. The separator is a single-cascade impactor with an adjustable effective diameter d_{50} of separation (Effective Cut-off Aerodynamic Diameter) [9], corresponding to deposition efficiency ϵ_i(x) = 0,5. At the same time when you change the value of d_{50}, linear flow rate also changes. A typical dependence of deposition efficiency with the aerodynamic particle diameter of the cascade impactor is shown in Fig. 1.

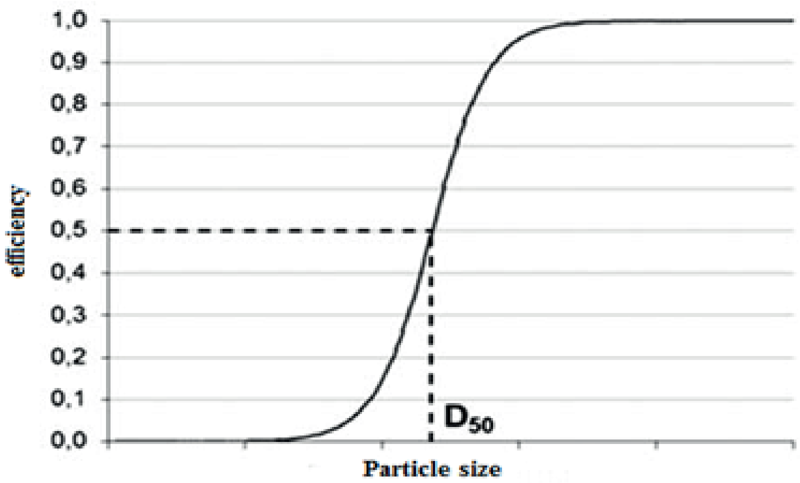

Figure 1: Dependence of deposition efficiency from the aerodynamic particular diameter of the cascade impactor.

Estimation method of dispersed composition of radioactive aerosols with AMAD & GSD – using single-cascade is the following: first step is sampling aerosols on filter and measuring the activity of the particles deposited on the filter; the second one is pumping aerosol at a fixed linear velocity through a single-cascade filter for the same period of time, and also measured the activity of the particles deposited on the filter. The last step is repeat the second one again, but with a different linear velocity. Thus, we have three values of the activity deposited on the particulate filter: $A_\Sigma$total activity, A_i activity at two values of the linear velocity on the separator. The value of A_Σ is determined by aerosol particles deposited on the filter during sampling without pumping through the separator. The filter activity A_i is determined only by the aerosol particles, which are passed through the separator at a given linear velocity. Thus, the analyzed spectrums of radioactive aerosols is divided into three parts (1):

$$\eta_1 = \frac{A_\Sigma - A_1}{A_\Sigma}; \quad \eta_2 = \frac{A_1 - A_2}{A_\Sigma} \quad \eta_3 = \frac{A_2}{A_\Sigma} \tag{1}$$

$$\sum_{i=1}^{3} \eta_i = 1$$

Where:

A_1 – activity on the filter when the linear velocity V_1, Bq; A_Σ is the total activity on the filter, Bq. In order to correctly apply suggested method, the speed V_2 must always be greater than V_1. In the review of Fuchs [10] was proposed a method of evaluating particle size distribution through partitioning the original spectrum of aerosol particles into fractions.

$$\eta_i(\mu,\ \sigma) = \int_0^{\infty} E_i(x) \cdot f\,(x,\ \mu,\ \sigma)\,dx, \quad i = 1..N \tag{2}$$

Where:

$E_i(x)$ – deposition efficiency of particles with an aerodynamic diameter x at a fixed linear speed; f(x, μ, σ) is the density distribution function of aerosol particles from original spectrum by size, μ and σ parameters of the log-normal distribution of aerosol particle by size, for radioactive aerosols AMAD and GSD, respectively.

By comparing the calculated values η_i and theoretical η_i^T, we can find the discrepancy function Q (μ, σ) (3).

$$Q\,(\mu,\sigma) = \sqrt{(\eta_1 - \eta_1^T)^2 + (\eta_2 - \eta_2^T)^2} \tag{3}$$

The values of μ and σ, for which the function (3) has a minimum value are AMAD and GSD original spectrum. This approach has been implemented in the method of multi-layer filters [11], which is widely used in Russia. In our case, the considered approach may be applied for assessing the AMAD and GSD. In order to determine $E_i(x)$ studied have been carried out on spectrums of known aerosol particles which obtained by simulator source of aerosols in working area, typical of the nuclear industry. Our study was performed on non-radioactive aerosols NaCl.

Experiment: Determination of deposition efficiency for artificial aerosol

Experimental studies of sampling in a separator were carried out in A.I. Burnazyan (Federal Medical and Biophysical Center-Russia) with participation of employees of the department №1, in national research nuclear University MEPhI. Scheme of experimental stand is shown in Figure 2. Aerosol concentration at the inlet and outlet of the separator 3 was measured with two optical counters 1 and 2 (HandHeld 3016). To prevent rebound of particles from the collector plate surface, cascade plate pre-coated with vacuum grease. Experimental stand placed in the chamber with a volume of 8 m^3.

As a source of the polydisperse aerosol was applied a salt (ρ =2,16 g/cm^3), pre-sifted through a sieve with cell's size 1 mm. The NaCl particles were sprayed from a plastic dispenser 4 (with a nozzle diameter of ~ 6 mm), placed at the top of the experimental stand. To reduce the effect of sedimentation has been used a fan 5. To prevent clogging of aerosol particles inside the pump 6 (VTE 3 «THOMAS») allonge 7 was incorporated into the circuit with clean-out filter.

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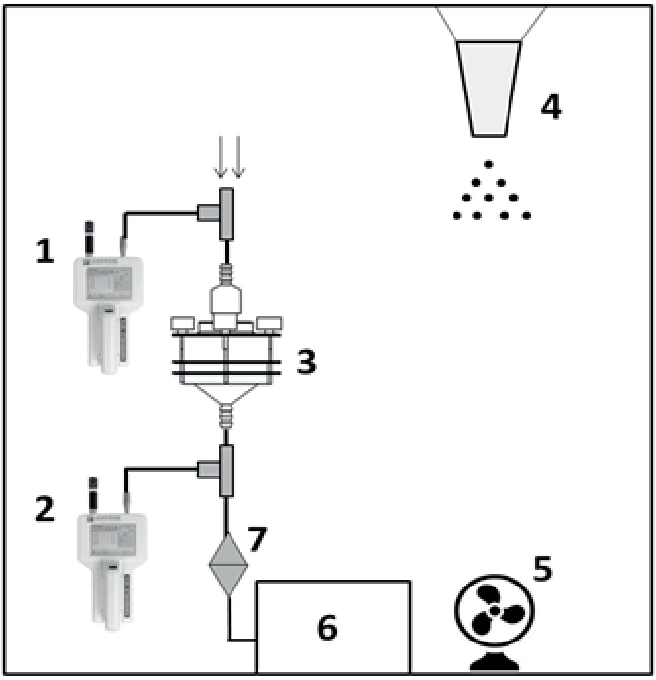

Figure 2: Scheme of experimental stand.

The density of aerosol particle NaCl closes to that of dust, which observed in the working area of the industrial enterprises. In the experiment investigated two modes of flow of air through the separator: 20 and 50 l/ min. According to calculations [9], the values of effective diameter d_{50} of separation for the considered modes is equal to 5.9 microns for flow rates of 20 l/min and 3.7 microns for flow rates of 50 l/min.

The obtained values of d_{50}, as shown in [12] that is closest to the AMAD of a radioactive aerosol in the workplace (AMAD = 5 μm). In several studies [5, 13], in the nuclear industry have been identified bimodal distribution of the aerosol particles with AMAD >1 μm. A similar pattern was observed in the assessment of disperse composition of radioactive aerosols in the premises of the Chernobyl NPP after the accident [14].

Fig. 3 shows the time variations of aerosol concentration in the various channels of counter 1 at the inlet of the separator (except for channel 0.3 μm) with the value of the volumetric flow 20 l/min. The resulting time variation is divided into minute intervals for each (the average values of concentration in channels) is calculated the median of the log-normal distribution. As can be seen in Figure 3, the dispersed composition in the chamber sufficiently unstable - after termination of spraying, the median is falling rapidly- from 4.83 microns to 2.10 microns due to the rapid deposition coarsely dispersed particles (channels 5, 10 microns). To calculate deposition efficiency, were chosen plots in the area of maximum concentration corresponding to the end of the

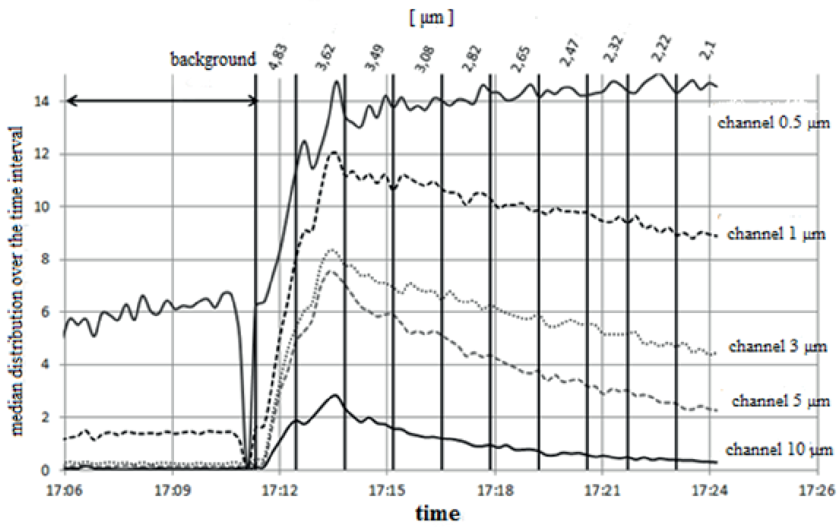

Figure 3: Concentration of aerosol at the inlet of the separator.

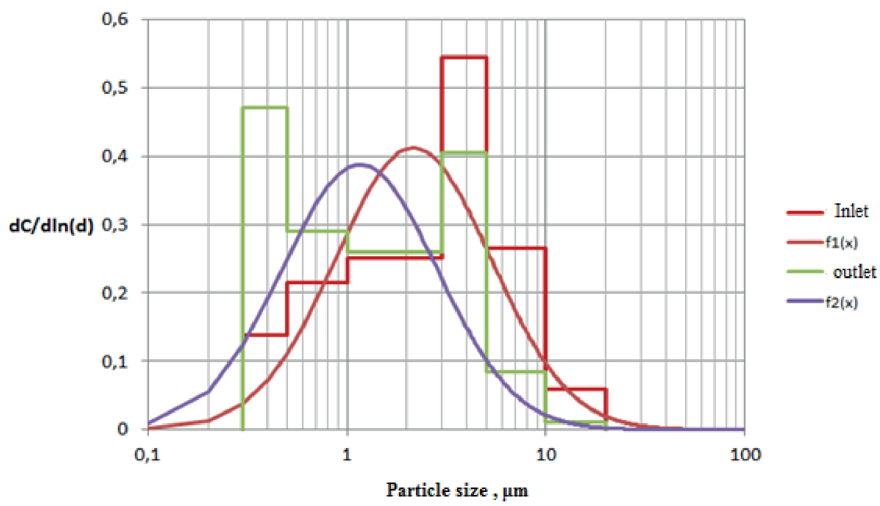

Figure 4: Spectra of NaCl aerosol at the inlet and the outlet of the separator, flow rate 20 l/min.

period of spraying substance, where the median of the distribution, as a rule, is maximum.

Experimental histogram at the inlet and outlet of the separator, and built for them the probability density function of LND [4] for flow rate 20 l/min is shown in Fig.4, for a flow of 50 l / min - Fig. 5. The histograms were averaged by 10 measurements. Parameters LND for flow rate 20 l/min (input: μ = 4,8 ± 0,3 μm, σ = 2,5; output: μ = of 2.6 ± 0.2 μm, σ = 2,5), and for flow rates of 50 l/min (input: μ = 5,3± 0,3 μm, σ = 2,1; output: μ = of 2.6± 0.2 μm, σ = 2,2).

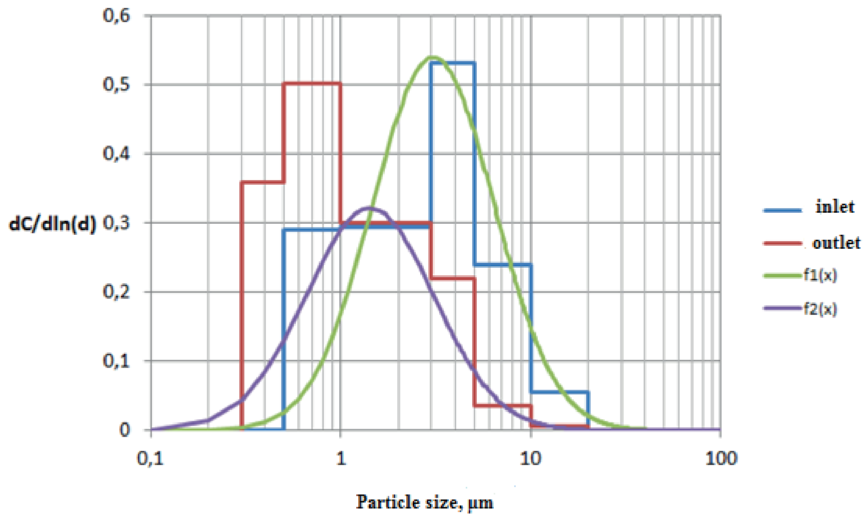

Figure 5: Spectra NaCl aerosol at the inlet and outlet of the separator, flow rate of 50 l / min.

The deposition efficiency $E\,(\overline{x})$ was calculated by the formula:

$$E(\overline{x}) = \frac{C_{\text{BX}}(\overline{x}) - C_{\text{BbIX}}(\overline{x})}{C_{\text{BX}}(\overline{x})} \quad (4)$$

Where: C_{BX}- average concentration accounts at the inlet of separator, cm^{-3}; C_{BbIX}- average concentration accounts at the outlet of separator, cm^{-3}: $\overline{x}$ - the average of aerodynamic diameter over the measuring channel in microns.

Fig.6 presents the experimental values of deposition efficiency of aerosol particles over the aerodynamic diameter. The effective diameter of the separation d_{50}, determined on the basis of experimental data are: ~ 6,0 μm to 20 l/min and ~ 3,9 μm to 50 l/min. Values of d_{50}that are calculated by the formulas in [9] and are obtained by experimental data, agrees within the error limits. Based on experimental data by least squares method [15] we can obtain the functional dependence of deposition efficiency E(x) and the aerodynamic diameter of x. It is assumed that the efficiency curve has the form (5):

$$E\,(x) = \frac{1}{1 + e^{-(kx+b)}} \quad (5)$$

Where: k and b – parameters, depends on the design of the separator and linear velocity. After calculating the parameters k and b we obtained dependence *E(x)*, also shown in Fig.6

By knowing the dependence of E(x) with aerodynamic particle diameter (5), we can substitute it into the expression (2) and find $\eta_i\,(\mu,\sigma)$. Then, the obtained expression $\eta_i\,(\mu,\sigma)$ put in (3) and define both of μ and σ corresponding to the minimum of the

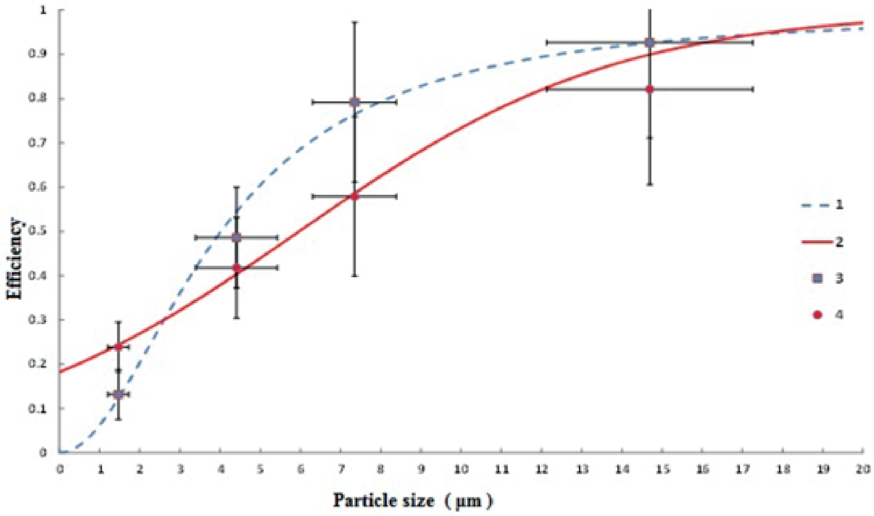

Figure 6: Dependence of deposition efficiency E(x) from the particle size (aerodynamic diameter). 1, 2 - approximation 3.4 experimental data at a flow rate 50 and 20 l / min, respectively.

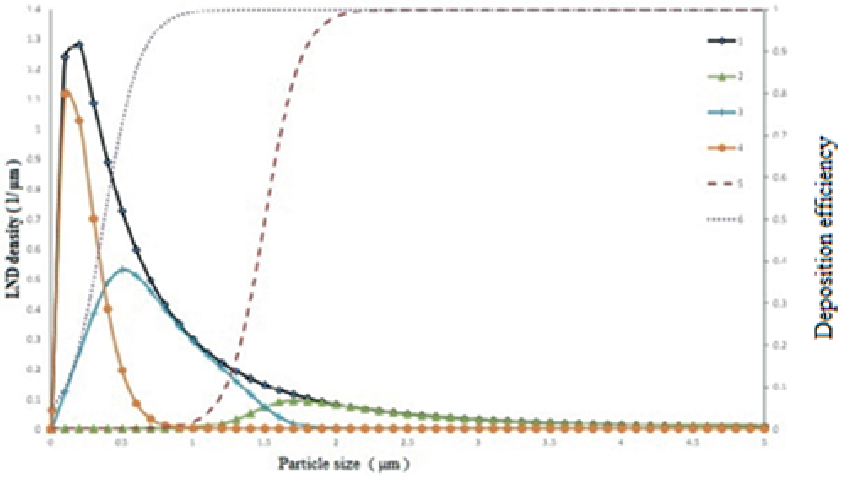

Figure 7: Splitting the original spectrum LND in parts through efficiency curves. 1 - Original spectrum; 2, 3, 4 – spectra of the particles after application of the separator; 5, 6 - deposition efficiency.

function Q (μ,σ). Determining the minimum of the function Q (μ, σ) analytically is impossible, therefore, to find it necessary to use numerical methods.

We show in the conventional example of how to use the proposed method to estimate μ and σ. Figure 7 shows: density function of LND with parameters μ and σ (1); curves of deposition efficiency E_1 *(x)* and E_2 *(x)* (5), (6); and parts of the original spectrum (2), (3), (4) in which is separated after applying a "filter". In Fig.7 on the left original spectrum and its parts, and on the right-deposition efficiency.

Let's assume that all the particles of the original aerosol spectrum have a spherical shape, and for simplicity also let's assume that the activity of the particle is proportional

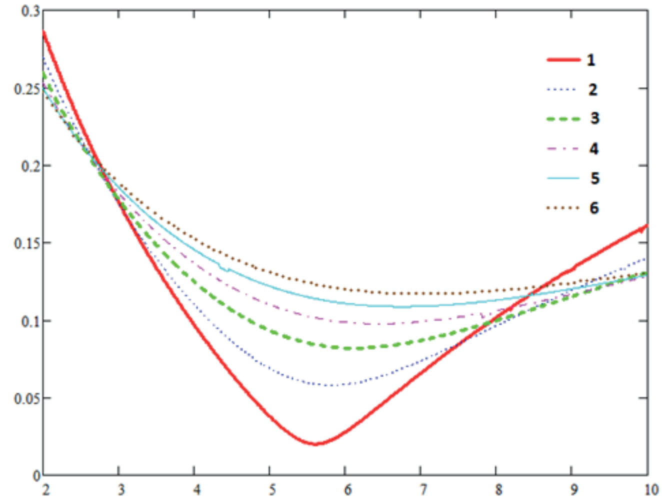

Figure 8: The function Q (μ,σ) depending on σ with μ fixed. σ = 2 (1), σ = 3 (2), σ = 4 (3), σ = 5 (4), σ = 6 (5) and σ = 7 (6).

to its mass. By using a random number generator we get a set of N aerosol particles, obeying the LND with the given parameters μ and σ. We calculate the activity of each particle from the resulting set, and summing up the activity of the particles deposited on the filter that pumped with different modes to define values of A_Σ and A_i. Using formulas (1) we can calculate η_i. On the other hand, according to the formula (2), we can obtain the expression$\eta_i(\mu, \sigma)$. As noted above, the search for the minimum function Q (μ, σ) in a general way only possible with the help of numerical methods. The graphic shows, how to implement a minimum function Q (μ, σ) for the required pair μ and σ (Fig. 8). From Fig. 8 it follows the function Q (μ,σ) which is close to its minimum at μ = 5,5 μm and σ = 2.

Thus, the method indeed allows finding the parameters of the distribution radioactive aerosols by size and μ, σ for which the function Q (μ, σ) is minimal. Using single-cascade inertial separator, operating in two modes at a flow rate of 20 and 50 l / min, allows us to split into fractions (parts) spectra of radioactive aerosols. However, it should be noted that error in estimating μ and σ may depend on many factors: the spectrum of the original aerosol, deposition efficiency and the type of error the function Q (μ, σ). Therefore, to reveal regularities of influence for these factors on the evaluation of μ and σ is necessary to carry out additional studies of the spectra of radioactive aerosols.

3. Conclusions

This paper present a new method of evaluating characteristics disperse composition of radioactive aerosols by AMAD and GSD. The obtained experimental dependence of the deposition efficiency for aerosol particles in single-cascade inertial separator used for the implementation of the proposed method. Dependence of the deposition efficiency with the aerodynamic diameter of aerosols is obtained by using simulator industrial aerosols. The method can be applied for unimodal spectra radioactive aerosols, which approximated by the log-normal law. In the future, we are planning to evaluate AMAD and GSD of radioactive aerosols in industrial environments.

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