



Abstract

The model connecting results of measurement of Xe-131m, Xe-133m, Xe-133, and Xe-135 on noble gas system of ARIX type with a long cycle of sampling with average values of concentration activity of these radionuclides in atmospheric air is offered. The model considers: - probable changes of volumetric activity Xe radionuclides in atmospheric air during sampling; - Xe radionuclides decay in an air sample during its fixation in an adsorber; -accumulation Xe-133 at decay Xe-133m in an adsorber; -variation Xe concentration activity during sample processing. The result of these processes in the model is implemented using 5 special coefficients B and allows to improve the accuracy of the results. The numerical values of the coefficients B and the method of their calculation are presented.

1. Introduction

As a model of measurement we understand the dependence that expresses the value of the average (at time of sampling) volumetric activity of the radionuclide of xenon in atmospheric air (2) in terms of the activity of radionuclides and the amount of stable xenon in the measured preparation. In fact, the problem is reduced to obtaining the explicit form of relation (1) and transformations it into a formula connecting the average volumetric activity (2), with measured activities A_i and with other parameters of the problem.

$$\underbrace{A_i}_{\text{activity of Xe-i in the preparation}} = F(\underbrace{a_i(t)}_{\text{volumetric activity Xe-i and its isomer-time functions}}, \underbrace{G_p, \tau_s, T_i, \dots}_{\text{other parameters}}); \quad (1) \quad \underbrace{\bar{a}_i}_{\text{average volumetric activity}} = \frac{1}{\tau_s} \cdot \int_0^{\tau_s} \underbrace{a_i(t)}_{\text{function unknown}} \cdot dt; \quad (2)$$

The model should: 1) consider the decay and accumulation of radionuclides of xenon during the time of their stay the adsorber and during the time of the preparation of the measured prepare; 2) allow to estimate the additional measurement error caused by the uncertainty of the dependence $a_i(t)$ in the cycle of sampling.

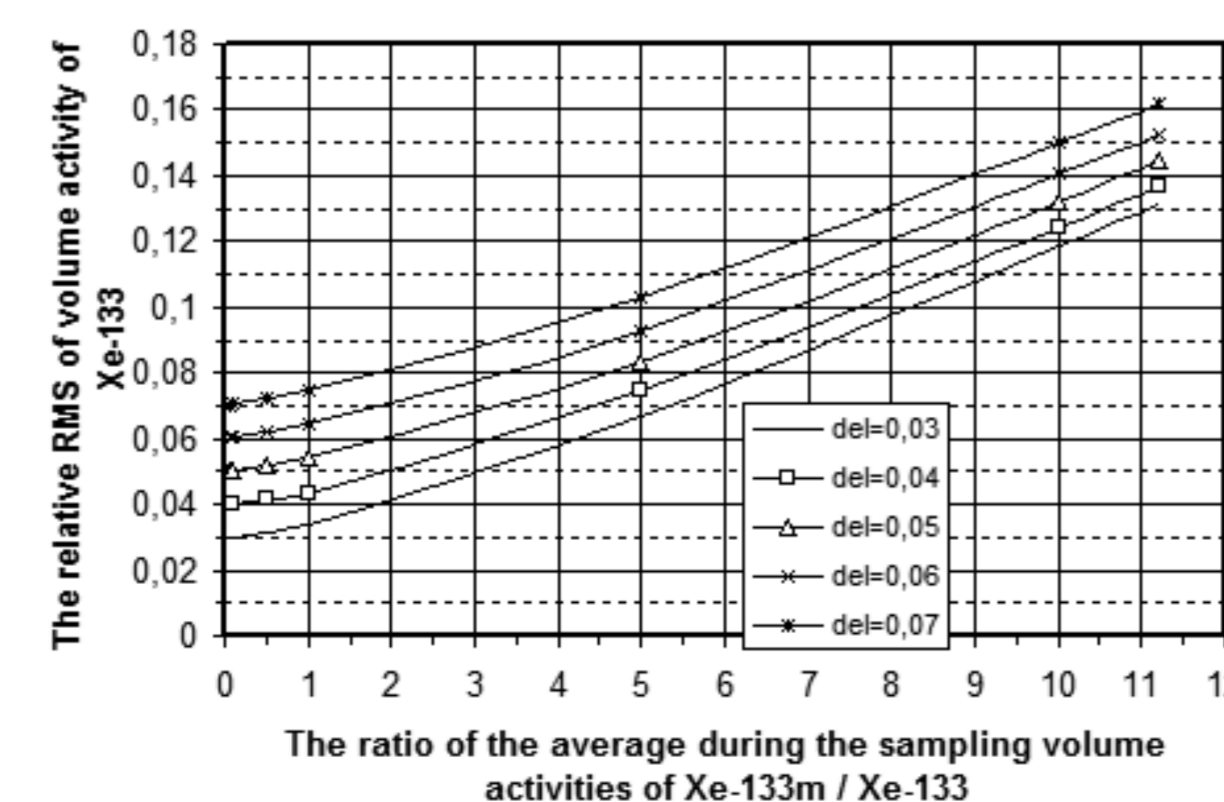
Assumptions: the absence of the precursor of radionuclides xenon, constant performance values and the extraction factor of xenon during the sampling.

4. Determination of the coefficients of the model. The uncertainty associated with variations of volume activities of radionuclide during sampling

Parameter t -tilde in (8, 9) belongs to the interval from 0 to the duration of the sampling τ_s . The boundaries of this interval (and the border values B_i) correspond the unlikely realizations' of function $a_i(t)$. The function $a_i(t)=\text{const}$ correspond to the value of the t -tilde near the midpoint of the applicable domain. We assume that B_i is a random variable with a mathematical expectation corresponding to $a_i(t) = \text{const}$, and by a standard deviation determined from the width of the range of possible values of B_i (table). These B_i characteristics will determine the values and additional uncertainties of the measurement results.

The presence of ^{133m}Xe in the sample makes a significant contribution to the value and measurement uncertainty ^{133}Xe (7). The figure shows the standard deviation dependence of the average volume activity of ^{133}Xe on the ratio $^{133m}\text{Xe} / ^{133}\text{Xe}$ in the sampled air for accumulated statistics which is characterized by the standard deviation «del».

Coefficient	Nuclide	half-life, h	The assigned B_i for $\tau_s=12$ h	RMS B_i , %
B_{131m}	Xe-131m	287,1	0,986	$\pm 0,5$
B_{133m}	Xe-133m	52,75	0,925	$\pm 2,7$
B_{133}	Xe-133	125,94	0,968	$\pm 1,1$
B_{135}	Xe-135	9,14	0,657	± 15
B_{τ}			0,033	± 33



2. The representation of the model by a system of coefficients

The model takes into account the processes of decay and accumulation of radionuclides during their stay in the adsorber. The accumulated activity of I_i is represented in a two summands. This is the residual activity of the radionuclide of inlet air and the activity in consequence of decay of isomer (the second term is absent for ^{131m}Xe , ^{133m}Xe , ^{135}Xe).

$$I_i = v \cdot e_a \cdot \left\{ \int_0^{\tau_s} a_i(t) \cdot \exp(-\lambda_i(\tau_s - t)) \cdot dt + \lambda_i \cdot \int_0^{\tau_s} a_{im}(t) \cdot (\tau_s - t) \cdot dt \right\} \quad (3)$$

where v and e_a - performance and the extraction factor of xenon during the sampling; τ_s - is the duration of sampling; λ_i - disintegration constant of the radionuclide i . Each of the terms in curly brackets can be represented in the form of a product of average volumetric activity on the coefficients B_i (4). Coefficients, when duration of sampling is not variable, depend on only from the form $a_i(t)$ (using the t option - tilde):

$$I_i = v \cdot e_a \cdot \tau_s \cdot \left\{ \underbrace{\exp(-\lambda_i \cdot (\tau_s - \tilde{t}_i))}_{B_i} \cdot \underbrace{\frac{1}{\tau_s} \int_0^{\tau_s} a_i(t) \cdot dt}_{\bar{a}_i} + \lambda_i \cdot (\tau_s - \tilde{t}_{ir}) \cdot \underbrace{\frac{1}{\tau_s} \int_0^{\tau_s} a_{im}(t) \cdot dt}_{\bar{a}_{im}} \right\} \quad (4)$$

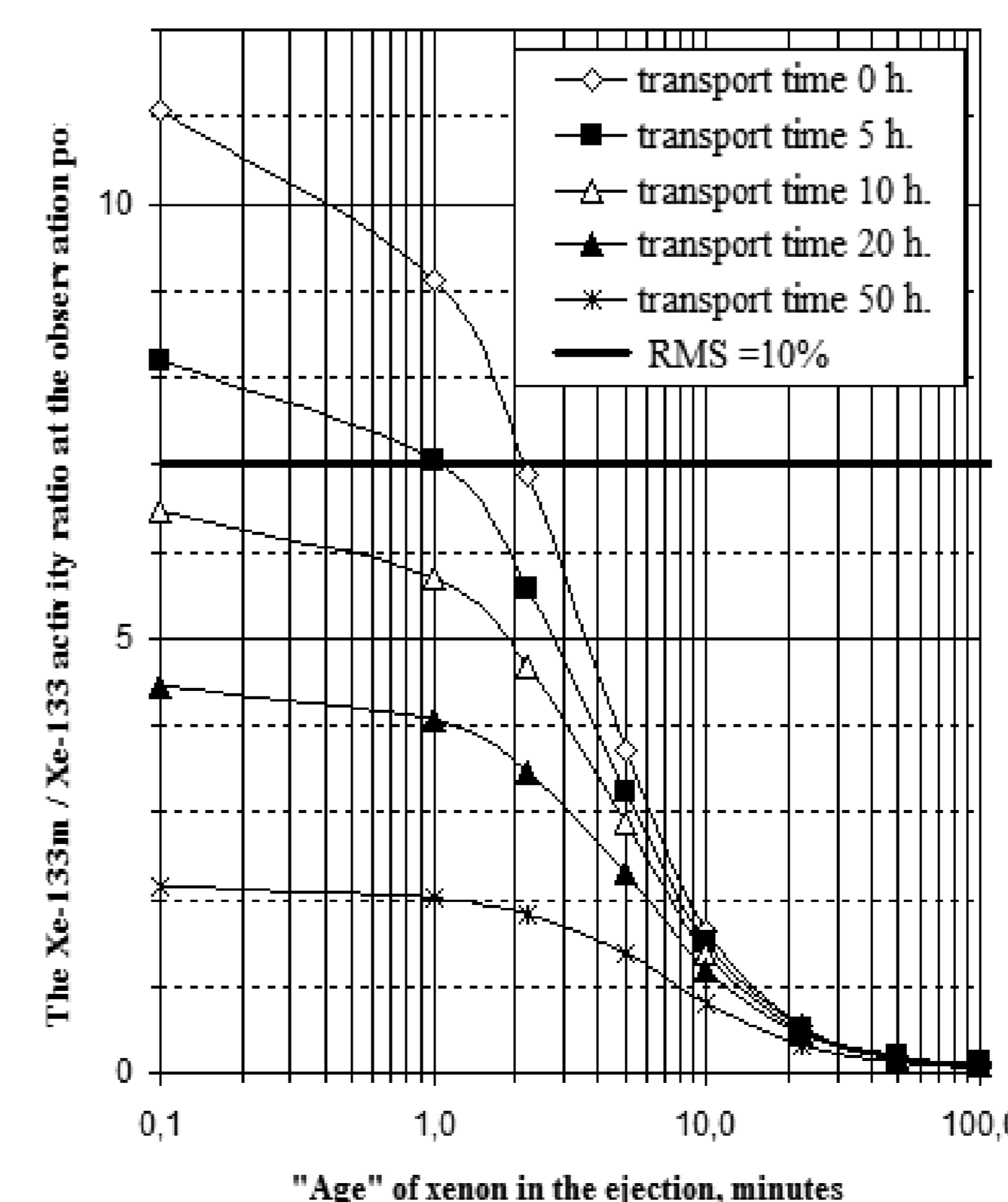
$$\text{Thus,} \quad I_i = v \cdot e_a \cdot \tau_s \cdot (B_i \cdot \bar{a}_i + B_{ir} \cdot \bar{a}_{im}) \quad (5)$$

Activity of a radionuclide A_i of the measured preparation we were obtaining by substitution (5) in the well-known relation describing the change in activity of the two genetically connected radionuclides.

5. The applicability of the model for radionuclide IMS stations

^{133m}Xe makes a noticeable contribution to the measurement uncertainty of the average volumetric activity of ^{133}Xe , which depends on the ratio of $^{133m}\text{Xe} / ^{133}\text{Xe}$. The value of this ratio depends on the fissile material and the type of reaction, the features of the ejection and the time of its transfer to the point of observation. The figure shows the ratio $^{133m}\text{Xe} / ^{133}\text{Xe}$ at the observation point, depending on the "age" of the ejection and the time of its transfer in the atmosphere. The calculation is performed for instantaneous fission of ^{235}U neutron fission spectrum. Relationship below the horizontal bold line correspond to the measurement uncertainty ^{133}Xe of less than 10% (del=0,05 in the previous slide). This is achieved with a transport time of more than 7.5 hours for any value of the "age" of xenon in the ejection.

Thus, the model provides an acceptable accuracy of determining the average volumetric activity for tasks solved by radionuclide stations of IMS.



3. Basic relations of the model

The measured amount of stable xenon G_p (cm^3) is determined from the characteristics of the measuring complex by the instrumentality of the relationship:

$$G_p = v \cdot \tau_s \cdot e_a \cdot e_p \cdot g$$

where g is the volume concentration of stable xenon in the atmosphere and e_p - coefficient of extraction of xenon in the preparation device of the measuring volume. Taking this into account, we obtain basic relations of the model. They express the average volumetric activity of radionuclides of xenon in the air in terms of the activity of radionuclides and the amount of stable xenon in the measured preparations,

$$\bar{a}_i = \frac{g}{B_i \cdot \exp(-\lambda_i \cdot \tau_p)} \cdot \frac{A_i}{G_p} \quad i=131m, 133m, 135 \quad (6)$$

$$\bar{a}_{133} = \frac{1}{B_{133} \cdot \exp(-\lambda_{133} \cdot \tau_p)} \cdot \left\{ \frac{g \cdot A_{133}}{G_p} - \{B_{ir} \cdot \exp(-\lambda_{133} \cdot \tau_p) + B_{133m} \cdot (-\lambda_{133} \cdot \tau_p)\} \cdot \bar{a}_{133m} \right\} \quad (7)$$

$$\text{where} \quad B_i = \exp(-\lambda_i \cdot (\tau_s - \tilde{t}_i)); \quad (8)$$

$$B_{ir} = \lambda_{133} \cdot (\tau_s - \tilde{t}_{ir}) \quad (9)$$

Specific values of the coefficients depend on the nature of function $a_i(t)$ in the cycle of sampling. This function determines the value of the t -tilde parameter in (8, 9) and she is usually unknown.

6. Conclusion

1. The dependence of the volume activity of ^{131m}Xe , ^{133m}Xe , ^{133}Xe , ^{135}Xe on time in the air is usually unknown. This uncertainty causes an uncontrolled displacement of the obtained values of the average (for time sampling) volumetric activity's of radionuclides. Offsets are determined by the processes of decay-the accumulation of radionuclides during sampling. They grow with increasing its duration and become significant when the duration of sampling more than 4-6 hours.
2. The proposed measurement model takes into account the decay and accumulation of xenon radionuclides, depending on the time of their receipt in the adsorber of the sampling device, and also during the preparation time of the measured preparation.
3. The model does not impose restrictions on the character of the time dependence of the volume activity of xenon radionuclides in the ambient air. The uncertainty of this dependence is taken into account by identify the coefficients of the model with random variables. Their numerical characteristics determine the displacement and additional uncertainty of the measurement result. A method is proposed for calculating the numerical characteristics of the coefficients, depending on the parameters of the measuring cycle.
4. The model provides an acceptable for IMS task the accuracy of determining the average volumetric activity even at high value of the ratio of $^{133m}\text{Xe} / ^{133}\text{Xe}$ (independent outputs at an instantaneous fission of ^{235}U by neutrons of the fission spectrum or neutrons, 14 MeV).
5. We hope that our proposals and evaluations will find their application in data processing programs used in IMS.