SPATIUM
No. 36, December 2016, pp. 46-54

UDC 699.887.5:614.876(470.45)
Review paper
DOI: 10.2298/SPAT1636046S

RADIATION-RELATED HYGIENIC ASSESSMENT OF CONSTRUCTION MATERIALS IN URBANIZED COMPLEXES IN THE VOLGOGRAD REGION

Olga P. Sidelnikova, Volgograd State Technical University, Volgograd, Russia
Lidia I. Khorzova[1], Volgograd State Technical University, Volgograd, Russia
Pavel A. Sidyakin, North Caucasus Federal University, Pyatigorsk, Russia

The concept of safety and assurance of vital human activities in urbanization is one of the most significant backbone concepts of human ecology. The comfort of residential buildings is largely owed to the radiation properties of the construction materials used. Therefore, the radiation-related hygienic support of technological processes and construction procedures is an important issue for the construction industry. Solving problems associated with improving the radiation safety of urbanized complexes depends on implementing legislation in the sphere of limiting human exposure to the impact of naturally occurring radionuclides. The paper presents the results of studies carried out by the authors on the specific activities of naturally occurring radionuclides in the construction materials manufactured and used in the Volgograd region. Through these large-scale studies, it was found out that the construction materials manufactured in the Volgograd region are in compliance with the national legislative and standard requirements; they are referred to as class 1 and can be applied for the construction of residential and public buildings.

Key words: **radiation-related hygienic assessment, naturally occurring radionuclides, technogenic background radiation, effective specific activity, radiation safety of buildings.**

INTRODUCTION

Current scientific and technological development is characterized by growth in the number of technology-induced ionizing radiation sources which produce enhanced background radiation. Nowadays, the conceptual approach to the problems of radiation safety control is changing. Earlier, the radiation safety problem was reduced mainly to the assurance of radiation safety control for a limited number of potentially hazardous objects (nuclear fuel cycle enterprises, particular research and defense objects etc.), but at the present time the problem has a global character.

In order to provide human safety and to preserve health, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has developed three basic areas of activity:

- ensuring human safety;
- preservation of health;
- recommendations for improving the radiation situation (related to reducing dose rates and the specific activity of naturally occurring radionuclides (NOR), and reducing the use of industrial materials and wastes with highly active NOR etc.).

Interest in the problems of radiation safety related both to residents and the personnel working with ionizing radiation sources is permanently growing. The objectives of state policy in the sphere of ensuring radiation safety include a progressive reduction in the impact of technology-induced radiation on the population and environment in order to reach an acceptable level, and a decrease in the impact of natural sources of ionizing radiation so as to reach the allowable standards. The growth in technogenic background radiation due to the transfer of huge amounts of naturally occurring radionuclides (uranium, thorium and their progenies) in the process of industrial activity became one of the negative ecological consequences of intensified industrial development in the second half of the 20th century, and it has led to changes in human exposure to radiation. The level of concentration of these radionuclides on the Earth's surface has risen sharply as a result of mining for certain

[1] Volgograd State Technical University, 28, Lenin Avenue, Volgograd, 400066, Russia
umois@mail.ru

mineral resources from the earth's depths, and their further processing. Various construction materials and products including those used for finishing contribute significantly to the growth in technogenic background radiation. When indoors (in the absence of artificial sources), we are exposed to technologically-altered natural background radiation caused by natural sources of ionizing radiation: cosmic radiation and NOR from the soil underneath the constructed building and from the construction materials used for the building envelope, as well as radiation coming into the room with air, water and as a result of fuel combustion. High levels of human exposure to radiation have been revealed in many developed countries of the world where the doses significantly exceed permissible levels due to the use of construction materials with enhanced NOR content, and radon daughters accumulating in the indoor air. The greatest opportunities for the reduction of human exposure to radiation can be found in the justified selection of construction materials bearing in mind the amount of NOR contained in them (UNEP, 1988; NRC, 1999; Henchel, 1988).

The action of enhanced background radiation on individuals, which is determined to a great extent by the NOR in construction materials and structures, appears in the form of somatic-stochastic and genetic effects which can be observed with small doses of radiation. The risk of the manifestation of these effects increases with a growth in the amount of enhanced background radiation. Indeed, according to data from the World Health Organization, the annual indoor exposure dose is comparable to the dose received in the process of X-ray diagnostics. In addition, routine activity such as burning coal, flying by plane and staying in hermetically enclosed rooms can lead to a considerable increase in exposure level due to natural radiation.

The International Commission on Radiological Protection recommends reducing radiation exposure doses to the lowest possible level, bearing in mind the importance of ensuring radiation safety. Ensuring the radiation safety for those exposed to radiation from natural sources is based on three main principles: norm setting, justification and optimization. It should be noted that the radiation safety requirements are applied to controlled natural radiation sources in industrial, utility-service conditions and in everyday life: radon isotopes and their progenies in indoor air, gamma radiation of naturally occurring radionuclides contained in construction materials and products, naturally occurring radionuclides in water, mineral fertilizers and agricultural chemicals, as well as in manufactured products that apply mineral raw materials, and construction materials containing naturally occurring radionuclides.

The strategy for ensuring radiation safety involves the extension of radiation safety requirements to all the sources of ionizing radiation, taking into account the significance of particular types of radiation and their contribution to the total effective dose.

TOPICALITY AND SCIENTIFIC SIGNIFICANCE OF THE ISSUE

Throughout life, a person receives most radiation from natural sources. On average, they cover more than 5/6 of the annual effective dose, and the radiation from naturally occurring radionuclides contained in building construction materials amounts to more than 50% of that value.

The naturally occurring radionuclides: radium-226 (^{226}Ra), thorium-232 (^{232}Th), potassium-40 (^{40}K), and radon-222 (^{222}Rn) are most significant in terms of radiation hygiene, ecology, and controlling their presence in construction materials and products. The important consequences of the natural radioactivity of construction materials are: exposure to gamma-radiation of the whole human body and exposure of lungs tissues to radiation from the decay products of ^{222}Rn and its daughter products. Therefore, the task of building radiation safety is to develop methods for the assessment and forecasting of the radiation situation caused by naturally occurring radionuclides in order to ensure standard working and living conditions.

The radioactivity of construction materials depends on a lot of factors, among which are: the type of rock used in manufacturing; the place where it is mined; and the type of waste materials involved in the production of the construction materials in the form of the aggregate or binding matter. The radiation contamination of construction materials can be determined not only by their origin, but also by the introduction of radioactive contaminators from the environment. It is the radioactivity of construction materials that becomes the main component of the technologically-altered background due to the redistribution of NOR. Since a person stays indoors for most of the day, the leading role of the construction industry in the limitation of human exposure to radiation from ionizing natural sources is evident (Bakaeva and Kalaydo, 2015; Khorzova *et al.*, 2013; Vasilyev and Zhukovsky, 2013).

All this proves the topicality of research on ensuring radiation safety. The main results of the research demonstrate compliance with the sanitary-hygienic principles of radiation safety according to the laws and by-laws adopted in Russia, as well as particular technological methods of reducing radiation parameters in construction objects. However, the integrated analysis of possibilities aimed at reducing the indoor human exposure to radiation is not paid sufficient attention.

The growth of the requirements regarding ecologically safe construction is associated not simply with the creation of a comfortable living environment in a building, but also with ensuring the total safety of the residential space for human health.

TASK

The tasks considered here are: the study of the specific activities of ^{226}Ra, ^{232}Th, ^{40}K in construction materials, raw materials and industrial waste; the assessment of the effective specific activities of NOR in the construction sector of the Volgograd region; the reduction of the radiation load.

MATERIALS AND METHODS OF THE STUDY

The preliminary hygienic assessment of construction materials can be carried out on the basis of their effective specific activity (A_{eff}). The A_{eff} value of naturally occurring radionuclides is applied to set the standards (and control) the radioactivity of the construction materials, and it determines the rate of the indoor gamma radiation dose. The rate of the gamma radiation dose is proportional to the weighted average A_{eff} of naturally occurring radionuclides in construction materials used for buildings. The standardization and control of the A_{eff} value is a means of reducing this constituent in human exposure to radiation (Krisyuk, 2002).

The qualitative and quantitative analysis of the specific activities of NOR in samples was conducted using a scintillation gamma-ray spectrometer. The values of the specific activities of ^{40}K, ^{226}Ra, ^{232}Th were obtained through experiments, and the effective specific activities of NOR were calculated. The efficiency calibration of the gamma-ray spectrometer in Marinelly geometry was carried out by the equipment manufacturer. In order to determine the efficiency the manufacturer used the reference standards of radioactivity. For the purpose of creating the control value of efficiency, the sources contained radionuclides with energies of gamma-ray lines in the required energy range. The energy calibration of the gamma-ray spectrometer begins by placing the standard source of ^{137}Cs+^{40}K in the detection unit and the measuring process is started in the mode of energy calibration. The energy calibration of the scintillation gamma-ray spectrometry tract is conducted automatically at the tops of the total-absorption peaks in the spectrum of the built-in calibration source. In the course of the calibration process, the program automatically finds the numbers of the analyzer's channels matching the tops of the total-absorption peaks, and it assigns the corresponding values of energy and conducts the linear approximation of the energy dependence on the number of the ADC channel. After that, the newly-obtained approximation coefficients are automatically recorded in the random-access memory. The preservation of the designed-in counting characteristic of the spectrometer is checked according to the built-in spectrum of the calibration source. In addition to the calibration results, the value of the counter speed check from the calibration source in the given energy range is displayed on the monitor. The calibration is carried out prior to the background check or any measuring of the content of naturally occurring radionuclides in construction materials. The time need for the measurement of the background and the construction materials samples is 1800 s.

Examination of the amount of NOR in construction materials was carried out as follows. According to standard sampling requirements, no less than 5 samples were taken from different parts of the object. The construction materials were powdered to achieve a particle size of no more than 5 mm. These samples were kept in glass vessels of 1 liter at the required level of hermetic encapsulation for two weeks. After this, one of the samples was poured off into a Marinelly vessel, and the measurements were taken immediately to avoid the loss of the daughters ^{214}Bi and ^{214}Pb. Their half-life is about 20 minutes, which is comparable with the time needed to measure the sample, therefore additional inaccuracy caused by the given fact amounts to less than 15%. The results were based on the analysis of no less than 5 measured samples for each type of construction material in compliance with the requirements of National State Standard GOST 30108-94, 1994.

Any limit set for exposure to radiation can be extended only to those sources which allow human influence on the dose of radiation emitted (the principle of radiation controllability). Controllability is understood as more than just an in-principle possibility for influencing the created dose. The dose of indoor gamma-radiation is determined mainly by the effective specific activity of naturally occurring radionuclides in construction materials. The form and dimensions of the room, and the thickness of the walls and floors slightly influence the indoor dose rate. The value of the mean dose of exposure to radiation (or the collective dose) depends on the weighted mean A_{eff}. That is why it can be changed only through the influence on the materials used for example, by refusing to use materials with a high NOR content for residential construction. It can be achieved through the standardizing of A_{eff} in the materials mined at some deposit fields. Compliance with the standards for all the materials used in the construction of buildings guarantees the observance of standards for the gamma-radiation dose rate and the equivalent equilibrium volumetric activity of radon (EEVA).

Pre-project, project and control studies of radiation-hazardous factors (NRB-99/2010, 2010, GOST 30108-94, 1994) include:

- measuring the level of the equivalent dose rate (EDR) at the construction site (the permissible values do not exceed 0.15 mSv/h);
- measuring the content of NOR (the permissible values of A_{eff} do not exceed 370 Bq/kg);
- measuring the level of the radon flow density (RFD) at the construction site (the permissible values do not exceed 80 mBq/m²•s);
- measuring the level of the radon volumetric activity (RVA) in a residential room (the permissible values do not exceed 100 Bq/m³ for new buildings under construction and 200 Bq/m³ - for buildings already in service);
- measuring the EDR level in a residential room (the permissible values should not exceed the values of the background in open territory by more than 0.2 μSv/h).

The value of the effective specific activity $A_{eff} \leq 370$ Bq/kg has been set for the materials used for the construction of residential and public buildings. In compliance with the legislative and regulatory legal acts in force in the Russian Federation, it is necessary that the specific activity of naturally occurring radionuclides in materials used for all the new residential and public buildings under construction should not exceed 370 Bq/kg for ^{226}Ra, 259 Bq/kg for ^{232}Th, and 4810 Bq/kg for ^{40}K.

For the mixture of the stated radionuclides with their specific activity (A, Bq/kg), the condition should hold:

$$I_{ex} = A_{Ra} / 370 + A_{Th} / 259 + A_K / 4810 \leq 1 \quad (1)$$

I_{ex} – is the external hazard index with regard to the external exposure to radiation due to the γ-radiation of construction materials, which corresponds to the maximum equivalent activity value of ^{226}Ra 370 Bq/kg. For the materials permitted for all the types of construction, $I_{ex} \leq 1$ (Office European, 1999).

Construction materials in which the concentration of naturally occurring radionuclides exceeds the standard level are referred to as materials with enhanced radioactivity. Depending on the degree of radioactivity, they can be used for constructing objects where people spend significantly less time than in residential and public buildings.

The value of the effective specific activity of naturally occurring radionuclides A_{eff} is used to set the standard and control radioactivity in construction materials. According to the regulatory documents (NRB-99/2010, 2010, GOST 30108-94, 1994):

$$A_{eff} = A_{Ra} + 1.3A_{Th} + 0.09A_K, \quad (2)$$

where A_{Ra} and A_{Th} – are the specific activities of ^{226}Ra and ^{232}Th in the material, in equilibrium with the other members of the uranium and thorium series, A_K – is the specific activity of ^{40}K in the material (Bq/kg).

The effective specific activity of naturally occurring radionuclides A_{eff} in construction materials (crushed stone, gravel, sand, quarry stone and sawn stone, raw materials for cement and bricks etc.), mined at their deposit field or as an industrial by-product, as well as in industrial waste used in the manufacture of construction materials (ashes, cinders etc.) and in final products, should not exceed the following values (Radiation Safety Standards NRB-99/2010, 2010):

- for materials used for residential and public buildings under construction or reconstruction, such construction materials can be used for all types of construction without any limitations (I class) - $A_{eff} \leq$ 370 Bq/kg;
- for materials used in highway engineering within populated settlements and zones of prospective development, as well as for the construction of industrial facilities (II class) – $A_{eff} \leq$ 740 Bq/kg. When such materials are used for the construction of industrial buildings, a sufficient air exchange should be provided inside them (no less than three times an hour);
- for the materials applied in highway engineering outside populated settlements, (III class) - $A_{eff} \leq$ 1500 Bq/kg. Within populated settlements the materials belonging to class III can be used only for underground constructions where there is no human presence (sewage pipelines, sewers etc.), if they are covered with a soil layer of no less than 0.5 m or with a low-radiation material.

With 1.5 kBq/kg < $A_{eff} \leq$ 4.0 kBq/kg (IV class), the question of the material used is solved individually in every particular case on the basis of the sanitary-epidemiological conclusion of the federal executive body authorized to conduct the state sanitary and epidemiological surveillance. With A_{eff} > 4.0 kBq/kg, the materials should not be used for construction purposes.

Such classification allows a correct assessment for all types of construction materials including industrial waste with various specific activities of naturally occurring radionuclides without regard to human exposure to radiation. It should be taken into account that the standards refer not to raw materials but to final products – construction materials (cement, aggregate, crushed stone, concrete and others). This is why in cases when in the process of manufacturing raw materials undergo treatment which can change the total specific activity of radionuclides (cleaning, roasting etc.), the products of such treatment should meet the requirements of the standards.

The permissible content of naturally occurring radionuclides in mineral raw materials, and in products manufactured using such materials (articles made of ceramics and ceramic granite, natural and artificial stone etc.), as well as in the requirements for ensuring radiation safety when handling those materials and products, is set by the sanitary regulations for the limitation of exposure to radiation from natural sources (Attalla and Abdel-Moneim, 2014, Sidyakin *et al.*, 2016).

In addition to the values A_{eff} and I_{ex}, gamma-index I_{γ}, one more criterion characterizing the gamma-radiation of construction materials, and one which is currently applied in many countries is calculated according to the formula (Office European, 1999), (Righi and Bruzzi, 2006):

$$I_{\gamma} = A_{Ra} / 300 + A_{Th} / 200 + A_K / 3000. \quad (3)$$

Gamma-index is applied to determine the potential annual effective dose of public exposure to radiation which is formed due to the gamma-radiation from naturally occurring radionuclides contained in construction materials. For the construction materials which are applied in large volumes, for example concrete, the annual effective dose will be no more than 1 mSv with $I_{\gamma} \leq 1$. With $I_{\gamma} \leq 0.5$, the annual effective dose will be no more than 0.3 mSv (Righi and Bruzzi, 2006).

In the 1950s, a number of scientists began studying the concentrations of radionuclides in mountain rocks and construction materials. An analysis of studies in this sphere shows that it is necessary to use a differential approach to the selection of construction materials at the stages of designing and erecting buildings and other constructions in order to ensure the safety of human life and activities in urban areas.

RESULTS AND DISCUSSION

It is possible to carry out the comparison of construction materials according to their radiation properties by applying the A_{eff} value. The effective specific radioactivity is practically the only controlled parameter in the process of determining the ecological safety of construction materials. The value of the effective specific activity of naturally occurring radionuclides characterizes the dose rate of gamma-radiation emitted by the large amounts of material with uniformly distributed radionuclides. The coefficients in the above-mentioned expression were calculated for infinite space with uniform distribution of radionuclides and gamma-radiation spectrums (*4π*-geometry) (Goritsky *et al.*, 1990). The calculations of the gamma-radiation dose rate for a semi-finite space (2π-geometry) carried out using the Monte Carlo method gave the values of these coefficients close to those achieved in the above-mentioned relation (Saito *et al.*, 1990).

The specific activities of NOR significantly differ for various materials. The mean specific concentrations of naturally occurring radionuclides in various countries change within wide limits. Table 1 shows the distribution of NOR in the construction materials used by various countries

As seen from Table 1, the fluctuations of the specific activities of NOR in the construction materials of the Scandinavian countries are usually higher than in the analogous construction materials of other countries, and they differ

Table 1. Distribution of NOR in the construction materials used by various countries

Type of construction material	Country, region	Specific activity, Bq/kg			A_{eff}, Bq/kg	I_{ex}	I_{γ}
		^{226}Ra	^{232}Th	^{40}K			
Earth crust (bulk earth values)		33	39	656	140	0.38	0.52
Earth soil		25	25	370	89	0.24	0.33
Brick	Denmark	42	34	-	86	0.24	0.31
	Finland	80	62	962	249	0.66	0.90
	Sweden	63	74	1136	255	0.69	0.96
	Norway	96	127	962	337	0.95	1.28
	Federal Republic of Germany	59	67	407	200	0.50	0.67
Concrete	Denmark	16	13	-	33	0.09	0.12
	Finland	61	37	370	137	0.38	0.51
	Norway	28	36	-	75	0.22	0.27
	Sweden	47	80	1295	192	0.70	0.99
	Great Britain	59	26	370	122	0.34	0.45
Lightweight aggregate	Denmark	40	45	-	99	0.28	0.36
	Norway	51	56	-	124	0.35	0.45
	Sweden	170	164	-	384	1.09	1.39
Slag aggregate	Finland	102	60	-	180	0.51	0.64
	Sweden	118	148	-	312	0.89	1.13
Granite	Federal Republic of Germany	100	81	1295	296	0.85	1.17
	Great Britain	89	81	111	200	0.58	0.74
Cement	Hungary	-	19	148	38	0.10	0.14
	Great Britain	-	19	155	39	0.11	0.15
	Algeria	41	27	422	114	0.31	0.41
	Cameroon	16-48	12-33	0-286	32-117	0.08-0.32	0.11-0.42
	Egypt	78	33	37	121	0.33	0.44
	Brazil	62	58	564	188	0.51	0.68
	Ghana	36	25	251	92	0.25	0.33
	Italy	38	22	218	86	0.24	0.31
	Nigeria	44	22	72	79	0.21	0.28
	Netherlands	27	19	230	72	0.20	0.26
Fly ash	Federal Republic of Germany	211	130	-	381	1.07	1.35
	Poland	63-610	33-320	-	106-1029	0.30-2.88	0.38-3.63
Tuff	Federal Republic of Germany	111	126	1073	363	1.01	1.36
	Italy	174	152	1813	581	1.43	1.94
Slag	Poland	19-460	22-590	-	21-1232	0.14-3.52	0.17-4.48
Gypsum	Federal Republic of Germany	14	19	259	62	0.17	0.22
	China	35	35	370	114	0.31	0.41
	Finland	37	43	1034	186	0.50	0.68
	Bangladesh	88	68	256	199	0.54	0.72
	Spain	14	17	267	60	0.16	0.22
	Turkey	45	4	11	51	0.14	0.17
	India	22	9	233	55	0.15	0.20
	Egypt	32-105	42-55	116-500	97-222	0.26-0.60	0.36-0.79
By-product Gypsum	Poland	580-740	-	-	580-740	1.57-2.00	1.93-3.70

(Source: UNSCEAR, 1982; Saito *et al.*, 1990; Ndontchueng *et al.*, 2013; Baykara *et al.*, 2011; Korna *et al.*, 2014; Turhan, 2008) approximately by an order of magnitude from the bulk earth specific activities of NOR in the corresponding mountain rocks due to the geological features of the territory. The content of NOR in the raw material of the same type depends on the deposit field. The radiation assessment of the fields of mineral resources applied to construction materials includes the determination of the gamma-radiation dose rate produced by the radioactive elements of mountain rocks in the place where they are deposited and the determination of the total specific activity of radionuclides in the rocks.

Table 2 presents the concentrations of the specific activities of NOR in construction materials in the Russian Federation (Sidelnikova, 2002).

Table 2. The specific activities of NOR in construction materials in the Russian Federation

Type of construction material	Specific activity, Bq/kg			A_{eff}, Bq/kg	I_{ex}	I_γ
	^{226}Ra	^{232}Th	^{40}K			
Soil in Russia	28	28	629	118	0.31	0.44
Clay	20.4	33.7	444	102.2	0.28	0.38
Sand	7.8	12.3	192.4	40.3	0.11	0.15
Crushed dolomites and limestone	12.6	4.8	40.7	22.4	0.06	0.08
Crushed granite	27.4	35.9	614.2	126.6	0.34	0.48
Light-weight concrete	21.8	15.2	185	55.5	0.16	0.21
Heavy-weight concrete	23.7	16.7	277	70.3	0.19	0.25

(Source: Sidelnikova, 2002)

In Russia the concentration of the average effective specific activity of NOR differs within a range of 22.4 to 126.6 Bq/kg; this does not exceed the value for class I construction materials.

The radiation control laboratory at Volgograd State University of Architecture and Civil Engineering carried out a number of studies to determine the content of naturally occurring radionuclides in construction materials and industrial waste. Table 3 gives the results of the large-scale studies concerning the specific activity of NOR for construction materials manufactured in the Volgograd region (Sidelnikova, 2002).

The effective specific activity of end construction materials and products manufactured in the Volgograd region ranges from 20.8 Bq/kg to 237.6 Bq/kg, which meets the sanitary standards for the content of radionuclides in class I construction materials according to the criterion of radiation. The value of the external hazard index I_{ex} in all the materials studied is < 1. The value I_γ is also < 1, thus if all the materials mentioned are applied for construction purposes, regardless of the volume, the annual effective dose due to gamma-radiation caused by construction materials will amount to no more than 1 mSv.

The largest values of A_{eff} refer to the interval 20-100 Bq/kg. Thus, 55.6 % of all the materials examined from the Volgograd region belong to this interval, and on average in Russia no less than 10% of the materials belong to the same interval. The smallest values for the Volgograd region can refer to the materials with A_{eff} of more than 100 Bq/kg.

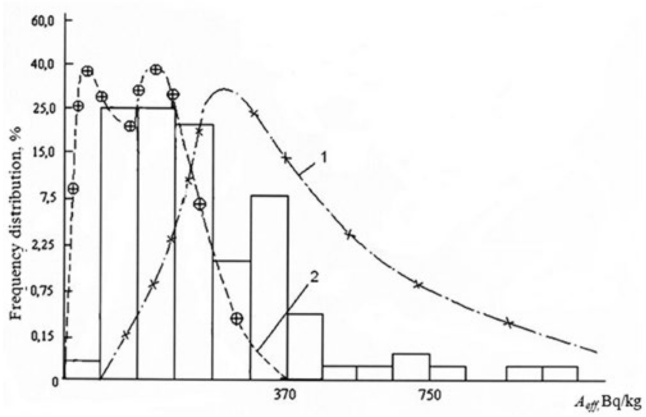

Figure 1. Frequency distribution of A_{eff} in mineral raw materials and construction raw materials in the Volgograd region (2) and in CIS countries (1) (Source: Sidelnikova, 2002; Sidelnikova and Kozlov; 2013)

The data obtained through these measurements were applied for the assessment of the construction materials' contribution to the background radiation of indoor spaces. It can be concluded from the above that the population of the Volgograd region is exposed to radiation from materials with A_{eff} less than 100 Bq/kg to a greater degree than from those with A_{eff} larger than 100 Bq/kg.

Table 3 and Figure 1 show that the effective specific activities of both end construction products and raw materials being used in the Volgograd region meet the sanitary standards for the content of radionuclides in construction materials. Due to the considerable variability of natural radioactivity, the range of the individual doses of the public exposure to radiation reaches one order of magnitude or more even within one and the same territory. Therefore, the necessity arises to determine the level of radiation exposure caused by natural sources for the whole population.

According to the results of the investigation, local construction materials can be applied for all types of construction including for residential use.

The data presented here make up only part of the study. For the Volgograd region, the distribution of construction materials according to the effective specific activity appears to be asymmetrical, both with the linear scale and the logarithmic scale along the specific activity axis. The asymmetry is smaller with the logarithmic scale, i.e. the distribution is closer to the logarithmic scale than to the normal one. The possibility of the distribution to be polymodal increases with a larger standard deviation. In such cases the reliability of the assessment of the limits for the total activities intervals decreases. Therefore, the data obtained by the authors should not be considered as evidence of the impossibility to reveal a high total activity of NOR.

Raw construction materials are characterized by a large range of variability in the naturally occurring radionuclide activity. This is an important fact testifying to the possibility of radiation quality management for construction materials and products which excludes or reduces a proportion of the raw materials with high radioactivity. The positive experience convincingly denies the assertion that it is

Table 3. The scope and results of studies of the specific activities of naturally occurring radionuclides in construction materials manufactured in the Volgograd region

Material	Where sample was collected	Number of samples	A_m, Bq/kg				I_{ex}	I_γ
			^{40}K	^{226}Ra	^{232}Th	A_{eff}		
Binding materials								
Cement M500-D20	AO "Sebryakovcement"	5	100.1	35.3	22.5	73.3	0.20	0.26
Cement M500-D0	AO "Sebryakovcement"	5	60.7	20.5	12.3	41.8	0.12	0.15
Gypsum G - 4	AO "Sebryakovcement"	3	26.3	12.6	10.9	29.1	0.08	0.11
Lime	KSSM (Integrated plant for silicate construction materials)	3	72.2	71.3	8.4	91.5	0.24	0.30
Gypsum G - 6	Plant for gypsum articles	5	45.0	9.25	6.5	21.6	0.06	0.08
Gypsum G - 8	Plant for gypsum articles	3	137.7	11.6	9.4	35.6	0.10	0.13
Lime	AOZT SIM (Silicate and insulation materials Plant)	5	40.4	76.2	12.5	96.0	0.26	0.33
Wall materials and articles								
Ceramic brick	Elshansky Ceramic Plant	3	118.2	28.3	30.1	77.8	0.21	0.28
Silicate brick M50	AOZT SIM	4	59.8	14.9	8.9	31.6	0.09	0.11
Silicate brick	AOZT SIM	3	71.5	16.8	7.2	32.3	0.09	0.12
Ceramic brick	AOZT VKZ (Volgograd Ceramic plant)	3	531.2	56.6	49.4	166.5	0.45	0.61
Silicate brick M75	AO VKSSM	5	47.5	28.7	9.7	45.4	0.12	0.16
Ceramic brick	AOZT Keramik-3	5	926.1	41.3	45.4	159.8	0.43	0.67
Ceramic brick	AOZT Keramik-3	4	689.3	32.7	36.9	139.6	0.38	0.52
Ceramic brick	AOZT Plus	3	516.7	53.5	52.9	166.7	0.45	0.62
Silicate brick M50	AO VKSSM	4	20.7	15.0	3.1	20.8	0.06	0.07
Asbestos Cement Products								
Asbestos-cement board	Sebryakovsky plant for asbestos cement products	3	118.6	28.3	30.2	77.9	0.21	0.28
Asbestos-cement tubes	Sebryakovsky plant for asbestos cement products	3	116.3	30.7	19.6	66.3	0.18	0.24
Concrete and Reinforced Concrete								
Concrete B-15	ZhBI-1, Volgograd (Reinforced concrete products plant)	3	321.7	19.8	13.3	64.6	0.17	0.24
Concrete B-20	ZhBI-1, Volgograd	3	57.6	29.3	4.6	40.2	0.11	0.14
Concrete B-30	ZhBI-2, Volgograd	3	56.1	27.1	5.85	39.5	0.11	0.14
Concrete B-30	ZhBI-4, Volgograd	4	411.0	21.9	23.5	87.6	0.24	0.33
Concrete B-40	ZhBI-2, Volgograd	5	838.8	21.9	31.9	134.9	0.36	0.51
Concrete B-20	ZhBI-2, Volgograd	3	234.6	15.7	17.7	58.8	0.16	0.22
Concrete B-15	ZhBI-1, Mikhaylovka	5	62.5	15.9	7.8	31.4	0.08	0.12
Concrete B-20	PSP "Vektor", Mikhaylovka	5	59.6	17.5	20.7	49.7	0.13	0.18
Porous Aggregates for Concrete								
Expanded clay	ZhBI-1, Volgograd	3	849.5	50.9	59.3	200.8	0.54	0.75
Expanded clay	ZhBI-1, Volgograd	3	698.5	28.4	43.2	144.4	0.39	0.54
Expanded clay	ZhBI-1, Volgograd	5	823.4	37.2	56.3	180.9	0.49	0.68
Expanded clay	Saratov plant of lightweight aggregates	5	386.5	35.4	15.7	88.8	0.24	0.33
Expanded clay	ZhBI-1, Volgograd	3	720.6	27.8	35.1	135.1	0.37	0.51
Expanded clay	KBI, Srednyaya Akhtuba (Integrated plant of concrete products)	4	938.2	52.4	42.1	187.3	0.51	0.70
Expanded clay	PO "Stroyindustriya", Volzhsky	5	854.1	25.1	53.4	167.7	0.45	0.64
Expanded clay	PO "Stroyindustriya", Frolovo	5	798.7	33.6	48.7	165.3	0.45	0.62
Ceramic Materials and Products								
Ceramic finishing tile	AOZT VKZ (Volgograd Ceramic plant)	4	289.5	149.1	38.6	224.3	0.61	0.79
Glazed finishing tile	AOZT VKZ	3	302.6	144.3	51.6	237.6	0.64	0.84
Belt roofing tile	AOZT VKZ	3	578.5	83.9	48.7	196.9	0.53	0.72
Arris hip tile	AOZT VKZ	3	543.6	54.2	41.2	154.4	0.42	0.57
Sanitary ceramic products	AOZT VKZ	5	373.8	84.4	53.7	186.5	0.50	0.68
Ceramic tubes	AOZT VKZ	3	652.3	74.6	62.1	211.4	0.57	0.78
Floor tile	AOZT VKZ	3	531.5	56.4	49.2	166.1	0.45	0.61
Glazed floor tiles	AOZT VKZ	3	501.6	132.7	51.8	243.2	0.66	0.87
Subway tile	AOZT VKZ	5	143.7	144.4	29.9	195.8	0.53	0.68

(Source: Sidelnikova, 2002)

impossible to influence the level of public exposure to radiation caused by natural sources.

The problem of getting ecologically safe construction materials using natural and man-made raw materials can be solved through a systematic approach which involves implementing a package of measures including the chemical binding of natural and man-induced radionuclides to form stable slightly-soluble compounds and their removal from the raw material content, or blocking them in the material structure.

With knowledge of the distribution of natural and man-made radionuclides in the structure of the initial raw components and of the behavior in the process of technological processing while producing construction materials, it is possible to assess their content in the end products at the design stage and to be in time to introduce the corresponding corrections.

At the present time, the determination of the class of a material according to the radiation safety criterion involves only the determination of the A_{eff} of NOR. However, this parameter does not characterize, for example, the hazard of radon emission to the full extent. The materials referred to as safe according to their NOR content may turn out to be very dangerous according to their radon content due to its high emitting ability. Revealing the special role of radon in human exposure to radiation in the living environment and in industry that is far away from radiation-hazardous technologies is one of the reasons for the increased attention to the problem of radon, to its origin and accumulation in indoor spaces (Lukuttsova, 2001; Khorzova *et al.*, 2016).

CONCLUSIONS

Safe residential space is the most important component of a healthy lifestyle. The problems of radiation safety in buildings can be efficiently solved if the issue is under control at all the stages of the construction procedure. Obviously, a compulsory radiation-related hygienic assessment of raw materials is necessary for the management of their quality during construction works. Therefore, it is necessary to control both the construction materials and construction sites together and not rely on the assessment of only one parameter. All the types of construction control should be focused on reaching the maximum quality, and on ensuring the non-exceedance of radiation-related hygienic standards, as well as on human safety.

REFERENCES

Attalla, M.F., Abdel-Moneim, A.M. (2014) Evaluation of ecological impact of naturally occurring radionuclides contained in raw materials for ceramic industry. *Radiochemistry, No. 3*, pp. 282-287.

Bakaeva, N.V., Kalaydo, A.V. (2015) Experimental study of the background radiation factors in buildings. *Biosphere Compatibility: human being, region, technologies, No. 4* (12), pp. 20-27. (in Russian)

Baykara, O., Karatepe, S., Doğru, M. (2011) Assessments of natural radioactivity and radiological hazards in construction materials used in Elazig, Turkey. *Radiation Measurements, No. 46*, pp.153-158.

EC Directorate-General Environment, Nuclear Safety and Civil Protection (1999) Radiological Protection Principles concerning the Natural Radioactivity of Building Materials 112. Office for Official Publications of the European Communities, Luxembourg.

Goritsky, A.V., Likhtareva, T.M., I.P. Los, Sabaltyr, V.P. (1990) *The radioactivity of construction materials*. Kyiv: Budivelnik. (in Russian)

National Research Council, Committee on Health Risks of Exposure to Radon (1999) *Health Effect of Exposure to Radon – BEIR IV*. Washington: National Academy Press.

Henchel, D.B. (1988) *Radon Reduction Techniques for Detached Houses. Technical Guidance* (Second Edition). US Environmental Protection Agency. EPA/625/5/-87/019.

UNSCEAR (1982) Ionizing radiation: Sources and biological effects // Report of 1982. New York. Vol. 1 .

Krisyuk, E.M. (2002) Levels and consequences of human exposure to radiation. *ANRI Journal*, No. 1, pp. 4-12. (in Russian)

Khorzova, L.I., Sidyakin, P.A., Abarinov, A.N. (2013) Organization of radiation-related ecological studies in resort cities of the Caucasus Mineral Waters region. In collected works: Indoor air and environmental quality. *Proceedings of XI International Scientific Conference*, pp. 49-55. (in Russian)

Khorzova, L.I., Sidyakin, P.A., Yanukyan, E.G. (2016) Radiation Situation at Construction Sector Objects in Caucasus Mineral Waters Region and Prospects of its Decrease. *Procedia Engineering*, ICIE 2016, No 150, pp. 2031-2035.

Korna, A.H., Fares, S.S., El-Rahman, M.A. (2014) Natural radioactivity levels and radiation hazards for gypsum materials used in Egypt. *Natural Science*. Vol.6, No.1, pp. 5-13.

Lukuttsova, N.P. (2001) Construction materials from an ecological aspect. Bryansk: Publ. house BGITA. (in Russian)

National State Standard GOST 30108-94. (1994) *Building materials and elements. Determination of specific activity of natural radioactive nuclei.* Moscow: Gosstroy Rossii. (in Russian)

Ndontchueng, M.M., Simo A., Nguelem, E.J.M., Njinga, R.L., Beyala, J.F., Kryeziu, D. (2013) Preliminary Investigation of Naturally Occurring Radionuclide in Some Six Representative Cement Types Commonly used in Cameroon as Building Material. *International Journal of Science and Technology*, Vol. 3 No. 10, pp. 365-371.

United Nations Environment Programme (1988) *Radiation. Doses, effects, risks*. Transl. from Engl. Moscow: Mir. (in Russian)

Radiation Safety Standards NRB-99/2010. (2010) Moscow. (in Russian)

Saito, K., Petoussi, N., Zankletall, M. (1990) Calculation of organ doses from environmental gamma rays using human phantoms and Monte Carlo methods. Part 1. Monoenergetic sources of natural radionuclides in the ground. GSF-B2/90.

Righi, S., Bruzzi L. (2006) Natural radioactivity and radon exhalation in building materials used in Italian dwellings. *Journal Environmental Radioactivity*, No. 88, pp. 158-170.

Sidelnikova, O.P. (2002) Radiation surveillance in construction industry / Teaching aid. Moscow: ASV. (in Russian)

Sidelnikova, O.P., Kozlov, Yu.D. (2013) Effective specific activity of naturally occurring radionuclides in construction materials of the Volgograd region, *Internet-Vestnik VolgGASU*, Issue 2 (27). (in Russian)

Sidyakin, P.A., Shchitov, D.V., Fomenko, N.A., Aleokhina, I.S., Murzabekov, M.A. (2016) The issue of hygiene of Stavropol region construction materials on radiation grounds. *Modern High Technologies*, No. 3-2, pp. 280-283. (in Russian)

Turhan, S. (2008) Assessment of the natural radioactivity and radiological hazards in Turkish cement and its raw materials. *Journal of Environmental Radioactivity,* No. 99, pp. 404-414.

Vasilyev, A.V., Zhukovsky, M.V. (2013) Determination of mechanisms and parameters which affect radon entry into a room. *Journal Environmental Radioactivity*, No. 124, pp. 185-190.

Received September 2016; accepted in revised form December 2016.