Radiation hygiene assessment of working conditions at construction industry enterprises

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Abstract. The concept of safety and life support of the population in the context of urbanization is one of the most systemically important concepts of human ecology. Legislative and regulatory documents, concerning the radiation safety of the population and personnel, have been considered. Conceptual issues have been critically analyzed. The article deals with the problems of ensuring the radiation and environmental safety in the construction industry. The problem of radiation hygiene support of technological processes and construction is of particular importance. The radiation control of working conditions needs to be carried out in accordance with the legislative and regulatory acts accepted in Russia. The issues of the relevance of radiation risks have been considered in the context of working conditions in the construction industry that were specially assessed. The activities to reduce workers’ exposure from natural radionuclides should be carried out in all cases, when this dose exceeds 1 mSv/year.

1. Introduction

The modern age in the development of scientific and technological progress is characterized by an increase in the amount of ionizing radiation of anthropogenic nature, which creates an enhanced radiation background resulting from different reasons, including the implementation of building technologies.

Public interest in the problems of radiation safety of the population and personnel, dealing with sources of ionizing radiation is constantly growing. The objective of the state policy in the field of radiation safety assurance is a consistent lowering of the radiation factor on the population, personnel and environment to an acceptable level of anthropogenic impact and reducing the exposure from natural ionizing radiation sources to permissible standards. One of the negative environmental consequences of the intensification of industrial development in the latter half of the 20th century was the increase in the technogenic radiation background resulting from the redeployment of a large number of natural radionuclides (uranium, thorium and their decay products) in the process of production, which has led to a change in the radiation impact on humans. The level of the radionuclide concentration on the earth’s surface has sharply increased due to the extraction of a number of minerals from the bowels and their subsequent processing. Various construction materials, including facing materials and products account for a considerable share in the increase in the technogenic radiation background.
Considering the urgency of the problem of radiation safety assurance of the population, the International Commission on Radiation Protection has recommended to lower the radiation doses to the lowest possible level.

2. Rationale and scholarly importance of the issue
The main radioactive nuclides of natural origin in building materials are radium (226Ra), thorium (232Th) and potassium (40K). According to the World Health Organization (WHO), the annual radiation dose in buildings is consistent with the dose received during the X-ray diagnostics. Obviously, it is necessary to establish the optimization zone boundaries, ranging from an unconditionally acceptable risk to the level of interference for the construction personnel. The total impact of technogenic sources of natural origin needs to be normalized. When using the effective dose as an indicator of radiation risk, it is necessary to clarify the lower level of doses to be accounted for. Critical groups of personnel exposed to increased irradiation from natural ionizing sources are necessary to be identified.

The current strategy for radiation safety assurance of workers and the public, which has been developed in the new version of the system of normative legal acts, requires a major revision of the main practical approaches to assessing and ensuring radiation well-being [1,2].

3. Purpose
Investigation of the problem of reducing the radiation risks for workers at the construction industry from natural sources of ionizing radiation; and development of activities for radiation safety in production conditions.

4. Materials and methods of research
The probability of radionuclides to enter production is determined by the parameters of their technogenic migration, specific activity of the feedstock and, not least importantly, by the total volume of production. The conditions for radiation safety assurance at workplaces can be provided only with respect to the technology for raw materials to be used, which is specific for each enterprise. Separations of 226Ra, 232Th, 40K and their mobility in high-temperature technological processes [3] indicate the urgency of studying the ways of their migration in the sphere of production and environment with subsequent radioecological and radiation hygiene assessment of the situation observed.

The research methods are based on analytical generalizations of known scientific and practical results; qualitative and quantitative analyses of specific activities of natural radionuclides (NRN) in the samples were performed on a scintillation gamma spectrometer.

Building materials of various origins are characterized by a whole complex of physical, mechanical and technological characteristics: mechanical strength, frost resistance, water resistance and others. The problem of the radioactivity of building materials can be viewed from two interrelated points of view, i.e., radiation hygiene and technological. The former establishes permissible radiation regulations for different building materials and provides the control system; the technological approach requires constructive solutions where these regulations are considered, and the radiation doses are so low (below the normative) as far as possible in view of acceptable techno-economic indicators.

The radiation monitoring is of special importance for this problem. One of its tasks is to select, substantiate and implement the building technologies that would ensure the radiation and hygienic standards no to be exceeded and the doses to personnel and population to be further reduced below the normative values.

All types of building monitoring are aimed at achieving its maximum quality and safety for people. The radiation monitoring of building materials can also be considered as a form of quality control of building industry products, which ensures security of a human as a user of this product.
The objects of the control can be both building materials and individual structures, as well as completed structures. However, it is quite obvious that only radiation monitoring at the level of building materials can provide the opportunity for alternative solutions (by the criterion of maximum radiation safety or minimum dose) at the design stage. Otherwise, the radiation monitoring inside finished buildings and structures will be reduced to a simple registration of the current situation, for its improvement requires huge, as a rule, economically unacceptable costs.

The task to create a radiation monitoring system within the framework of the existing structure of the building industry is most naturally solved if the radioactivity of building materials is considered as a physical property subject to control. Then another indicator will be added to the existing forms of control.

The federal law on radiation safety of the population [4] defines the concept of radiation safety of the population and personnel as a state of protection of people of present and future generations from ionizing effects harmful to their health. Normative documents (Radiation safety standards NRB-99/2009 [5], Basic sanitary rules for ensuring radiation safety OSPORB-99/2009 [6], etc.) contain requirements for protection from natural exposure in production conditions.

When natural radiation sources expose to workers under industrial conditions, the radiation safety standards are imposed on any organizations where the workers’ exposure from natural radionuclides exceeds 1 mSv/year. These include, in particular, organizations where work is performed in underground conditions (non-uranium mines, mining plants, etc.) and enterprises that mine and process mineral and organic raw materials with an increased content of natural radionuclides. The design documentation of non-uranium mines and other underground facilities should highlight the radiation safety issues.

The effective dose of irradiation from natural radiation sources of all workers, including personnel, should not exceed 5 mSv per year in production conditions (for any occupation and production).

To make a list of operating organizations, workshops or individual workplaces, where radioactivity condition resulting from natural radiation sources should be monitored, it is necessary to carry out their primary examination. If the survey in the organization does not find any cases of exceeding the exposure dose of 1 mSv/year, further radiation control is not mandatory there. However, if there is a considerable change in the production technologies that may lead to an increase in workers’ exposure, a second survey should be carried out. In organizations, where the dose exceeding of 1 mSv/year is established, but there is no excess of the dose of 2 mSv/year, selective radiation monitoring of workplaces with the highest level of workers’ irradiation should be performed. In organizations, where exposure doses of workers exceed 2 mSv/year, a close control of radiation doses and activities to reduce them should be carried out.

In case of detecting the overdosage (5 mSv/year), the administration of the organization must take all necessary measures to reduce the workers’ exposure. If this standard is impossible to be complied with, according to the working conditions, it is allowed to equate the corresponding workers to the personnel working with technogenic radiation sources. The administration of the organization informs the bodies of state sanitary and epidemiological supervision about the decision taken. Persons equated to personnel working with technogenic radiation sources in terms of working conditions are subject to all radiation safety requirements established for the A Group staff.

During the year, the average values of the radiation factors, corresponding to the effective dose of 5 mSv per year at mono-factor impact, work of 2000 h/year, an average breathing rate of 1.2 m3/h and radioactive equilibrium of radionuclides of uranium and thorium series in industrial dust, are the following:

- the rate of the effective gamma radiation dose at the workplace is 2.5 μSv/h;
- equivalent equilibrium volumetric activity of radon in the air of the breathing zone is 310 Bq/m3; and
- equivalent equilibrium volumetric activity of thoron in the air of the breathing zone is 68 Bq/m3.
The radiation monitoring and activities to reduce workers’ exposure should be carried out in all cases when the effective dose of industrial exposure from naturally occurring radionuclides exceeds 1 mSv/year [4–6]. Individual effective doses from natural sources in certain cases may exceed the permissible levels of occupational exposure to 20 mSv/year, which corresponds to the A category. Such a large contribution of natural sources to public exposure is largely determined by the fact that previously this exposure was not standardized and not controlled.

5. Results and discussion

In the process of radiation monitoring of building materials, one of the important issues is the determination of the content of natural radionuclides in finished products with the NRN values of raw materials to be known. Forecasting the content of natural radionuclides in building materials makes it possible to obtain materials that meet the requirements of radiation safety at the design stage.

Most building materials are composite and consist of two or more components. Therefore, the effective specific activity of natural radionuclides depends not only on the \( A_{\text{eff}} \) values of individual components, but also on their content and ratio [7].

The effective specific activity of the composite materials obeys the additivity rule; according to it, a property is a linear function between the content of individual components (in % by mass or in per-unit notation) and the value of a property for this component. Consequently, the \( A_{\text{eff}} \) of a composite material with the \( A_{\text{eff}} \) values to be known for individual components, and their contents can be calculated by the formula:

\[
A_{\text{eff}} = A_{\text{eff}1}V_1 + A_{\text{eff}2}V_2 + \ldots + A_{\text{eff}n}V_n / (V_1 + V_2 + \ldots + V_n),
\]

where \( A_{\text{eff}1}, A_{\text{eff}2}, \ldots, A_{\text{eff}n} \) are the effective specific activities of components of the composite materials; and \( V_1, V_2, V_n \) are the fractions of the components in the material.

For concrete, the formula takes the form:

\[
A_{\text{eff}}^{\text{con}} = A_{\text{eff}c}V_c + A_{\text{eff}s}V_s + A_{\text{eff}g}V_g / (V_c + V_s + V_g),
\]

where \( A_{\text{eff}c}, A_{\text{eff}s}, \) and \( A_{\text{eff}g} \) are the effective specific activities of cement, sand and gravel; and \( V_c, V_s \) and \( V_g \) are the contents of cement, sand and gravel in per-unit notation.

In the production of building materials and structures, some types of minerals and materials, products of their industrial processing, as well as production wastes whose values of the effective specific activity of natural radionuclides (\( A_{\text{eff}} \)) may exceed the permissible values for building materials of I, II, III and even IV class according to the NRB-99/2009. These include, in particular, bauxites that are used in the manufacturing of refractory products, grinding powders for optical production, alloying additives with rare-earth components (scandium yttrium, lanthanum and others) for coating molds, etc. Their main difference from conventional building materials is a primarily limited use. A number of industries are impossible without their application (for example, metallurgy without refractories) to work. Therefore, due to the technological value, specificity and limited application, these types of raw materials and supplies are expedient to be separated into a specific group.

Despite the increased natural radioactivity of these materials, their annual use in the economy of the country is small and specific in comparison with the materials applied in construction of residential houses, public and industrial buildings, and by adhering to certain requirements, the exposure limits of the population and production personnel regulated by the NRB-99/2009 are fully observed.

The total dose of industrial exposure to workers when handling these materials depends on the \( A_{\text{eff}} \) value, amount of materials in the workplace, duration of work with them, dust content of the air in the breathing zone, room ventilation and a number of other parameters. However, the main factor that all other things being equal determines all the components of the radiation doses (external gamma irradiation, internal irradiation due to inhalation of radon isotopes and their daughter products and aerosols of long-lived radionuclides) for materials is the \( A_{\text{eff}} \). It should be taken into account that the classification of materials by the \( A_{\text{eff}} \) value has been introduced to ensure the radiation safety of the
enterprise workers and plan the types and volume of radiation monitoring. Depending on the Aeff value, all materials were divided into 4 classes (Aeff is less than 0.74 kBq/kg; 0.74-1.5 kBq/kg; 1.5-4.0 kBq/kg and more than 4.0 kBq/kg); a system of corresponding restrictions was formulated for each of them. Criteria for the radiation safety are based on permissible levels of exposure to workers in manufacturing enterprises from the natural sources of ionizing radiation with the following required conditions to be met to ensure the radiation safety when handling materials:

- ensuring the radiation safety of employees engaged in handling the materials at enterprises;
- ensuring the radiation safety of the population living in the exposure zone of enterprises using the materials and population that uses the home products made by these enterprises; and
- ensuring radiation-safe conditions for the collection, storage and disposal of wastes produced by enterprises using the materials.

To bury industrial wastes with Aeff of more than 1.5 kBq/kg, it is necessary to ensure their reliable isolation, when the effective dose of radiation for the critical population group does not exceed 10 μSv/year [8].

The annual effective dose of γ-radiation can be determined in accordance with [9]:

\[ E = 4.74 \times A_{eff}, \mu V. \]

Taking into account the radiation classification of building materials, the annual effective dose of gamma irradiation for the personal of I, II, III and IV class is 1754, 3508, 7110 and 18960 μSv.

The establishment of a radiation safety class of material now is only reduced to the definition of the NRN Aeff. However, this indicator does not fully characterize, for example, the danger of radon emission. The NRN safe materials can be extremely dangerous with respect to radon due to its high emanating ability. Revealing the special role of radon in irradiating people in domestic conditions and in industries far from radiation-hazardous technologies is one of the reasons for increased attention to the radon problem, the conditions of its formation and indoor accumulation [10-12].

Currently, in compliance with the Procedure for certification of work places according to working conditions [13] and the Guide on hygienic assessment of factors of working environment and work load R 2.2.2006-05 [14], the parameters of the radiation background of industrial buildings and structures are not considered as factors to be assessed when conducting a special assessment of working conditions.

6. Conclusions

Hygienic aspects of the radiation safety of personnel in the construction industry, that is, the impact of the working process factors and radiation factors of the production environment on the person, on the one hand, and protection of the person from the damaging ionizing effect, on the other one, must be ensured by

- conducting a package of measures of legal, engineering, technical, sanitary-hygienic and educational character; and
- implementation of regulations, norms and standards in the field of radiation safety by government bodies of the Russian Federation, state authorities of the subjects of the Russian Federation and local government bodies.

Thus, scientific ideas and regulatory requirements in the field of radiation safety need to be implemented to solve the problem of workers and population to be limited from natural radiation sources, which enables optimizing the protection system and reducing the radiation risks.

References:

[1] Sidelnikova O P 2011 Limitation of workers’ exposure in enterprises by natural sources of ionizing radiation Vestnik VolgGASU. Series: Construction and architecture 25 (44) pp 159–163

[2] Goritsky A B, Popov I P and Sidelnikova O P 1993 Natural Radioactivity: Irradiation doses for Ukrainian Population and basic directions of their decrease International Congress "Radiation and Humanity" (Tokyo: Congress Publishing House) 127 pp 877–891
[3] Sidelnikova O P 1998 Reducing the influence of the activity of natural radionuclides of building materials on the radiation safety of residence. D. S. thesis. (Volgograd) p 375
[4] Federal Law No.3-FZ of 1996 on radiation safety of the population.
[5] Radiation safety standards (NRB-99/2009) (Moscow)
[6] Basic sanitary rules for ensuring radiation safety (OSPORB-99/2009). SR 2.6.1.799-99 (Moscow)
[7] Lukutcova N P 2010 Decreasing radioactivity of raw and building materials: monograph p 218
[8] Stamat I P, Krisyuk E M et al 2000 Handling of mineral raw materials and materials with an increased content of natural radionuclides Materials of the scientific-practical conference "Actual problems of limiting the population’s irradiation from natural sources of ionizing radiation" (Moscow) pp 147–149
[9] Sidelnikova O P 2002 Radiation control in the construction industry: textbook (Moscow: ASV)
[10] Health Effect of Exposure to Radon. Committee on Health Risks of Exposure to Radon (BEIR IV) 1999 (Washington: National Academy Press)
[11] Moravska L 1983 Influence of Sealats on radon-222 Emanation Rate from Building Materials Health Phys. 44 pp 416–418
[12] Sidelnikova O P 2013 Necessity of certification and control of construction industry objects on grounds of radiation Alternative energy and ecology 12 pp 51–54
[13] The procedure for certification of work places according to working conditions 2007 The Order of the Ministry of Health and Social Development of the Russian Federation 569
[14] R 2.2.2006-05 2005 Guide on Hygienic Assessment of Factors of Working Environment and Work Load Criteria and Classification of Working Conditions (Moscow)