

рамках данной программы дала старт национальным радоновым обследованиям и развитию региональных программ по обеспечению защиты населения от радона и других компонентов природного облучения. Однако в связи с отсутствием необходимого финансирования программа была закрыта, и в настоящее время некоторые отдельные ее положения реализуются в рамках ФЦП «Обеспечение ядерной и радиационной безопасности» на бессистемной основе. Отсутствие единого подхода к планированию и проведению мероприятий в данной области регулирования усложняет решение задач обеспечения защиты населения от компонентов природного облучения. Высокая социальная значимость радоновой проблемы обуславливает необходимость ее широкого обсуждения национальными регулирующими органами и другими заинтересованными сторонами. Итогом этой деятельности должна стать разработка единой национальной стратегии по защите населения от источников природного облучения.

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Modern approaches to public protection against indoor radon. International regulatory experience

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Intensive worldwide researches of the public exposure to radon are carried out for over 30 years. According to numerous studies being performed in many countries, radon and its progenies contribute significantly in total dose to the public. At that, dose due to inhalation of radon and its progenies is higher than that induced by other radiation sources, including sources used in medicine and those occurring in the environment due to the nuclear fuel cycle activities. Prolonged internal exposure to the human's body induced by the radon decay products is one of the key factors in the development of the lung cancer pathology. The recent results of global epidemiological studies, aimed at the risk assessment of indoor radon-induced lung cancer, have initiated the need to improve approaches to the regulation of this problem. International organizations (such as WHO, IAEA, ICRP) proposed a strategy of the public radiation protection against radon exposure and adapted this strategy to the up-to-date realities. The recent recommendations not only correct the radon activity concentration being limited in dwellings, but also change its status through converting the action level to the reference one. The strategies for limitation of the public exposure due to this component of natural radiation should be revised at the national level and an action plan for their implementation in the long term perspective should be developed. This paper deals with the key provisions of the recent international recommendations including approaches to regulate the public protection against radon exposure.

Key words: radon, epidemiological studies, lung cancer, regulation, reference level, national action plan.

Introduction

Radon is a radioactive decay product of uranium-235, -238 and thorium-232. Among the resulting radioactive isotopes (radon-219, -220, -222), radon-222, and its progeny make an a major contribution to the exposure of the population due to radon. Turning to the history of the radon problem, it should be

noted that the origin was laid in the 16th century, when was found the high mortality rate of miners in central Europe [1]. At the end of the 19th century, the disease was diagnosed as a lung cancer and suggested a direct connection of lung cancer pathology of miners with exposure to radioactive gas. Results of the first epi-

demiological studies in 60-th of the last century confirmed the connection among exposure to radon and miners to the development of lung cancer. Intensification of activities for mining and processing of uranium in the mid-20th century, sharply set up a problem of protection of personnel of uranium mines from exposure to radon and initiated the development of the first recommendations of the International Commission on Radiological Protection (ICRP), based on the establishment of restrictions of inhalation of radon in the human body [2, 3]. History of radon as a cause of lung cancer was formalized in 1986 with the recognition by the World Health Organization (WHO) of radon as a human lung carcinogen [4]. The main approaches to the regulation of this component of natural radiation, based on the possibility of monitoring of human exposure pathways from the source, were formulated in the ICRP Publication 65 (1993) [5]. In contrast to previous recommendations of the Commission in this Publication was formulated a common approach to protection of the population from radon in dwellings and workplaces. For regulatory purposes were established action levels for radon concentration in the building (600 Bq/m³ – in dwellings and 1 000 Bq/m³ in the workplaces). Transition from effective dose to volume activity determined on the basis of the concept of conditional dose transfer to epidemiological data obtained from studies of uranium miners. In fact, the action levels are a kind of border between "dangerous" and "safe" exposure to radon and progeny. The regulatory system was aimed at protection of the most exposed population group. In Europe the points of the publication was accepted widely, which, in turn, initiated a national radon surveys. Since the release of the ICRP Publication it's been over than twenty years. During this time, was significantly increased the amount of data of epidemiological studies on the direct evaluation of connection of lung cancer with radon and progeny inhalation exposure, which allowed a more detailed look at the objective of public exposure, based on research in a dwellings. ICRP publication 103 [6] changed the system of radiation protection and, in particular, approaches to the regulation of the situation of public exposure to natural sources of radiation. In this regard, there is a need revising guidelines regulating the safety of population from radon and its adaptation to modern conditions.

The scientific basis for regulation

An important stage in the formation of modern approaches to the management of the problem of population protection from radon were the results of epidemiological studies of lung cancer pathology risk made on a "case-control" for the population living in dwellings with different concentrations of radon. The necessity for such epidemiological studies was obvious, since the direct use of epidemiological data on uranium miners in the assessment of the radiation risk for the population has some significant limitations. They are primarily associated with specific working conditions, multifactor impact (dust, uranium series radionuclides, chemical carcinogens), asymmetric sampling on a number of indicators (males of middle age, a higher proportion of smokers, etc.). As part of the project initiated by WHO «The radon project» (2005-2008), we analyzed the results of the joint analysis of data from studies of the connection between the lung cancer risk and exposure to radon in dwellings [7]. Studies were conducted in Europe (13) and North America (7). The volume of the main group was 15530, the control – 22,884 people. The results of the joint analysis of studies allowed for the first time to conduct a direct assessment of risk to the public without the necessity for extrapolation of risk parameters obtained in studies of

miners. WHO noted the following key points related to the impact of radon on the health:

- Exposure to radon increases the lung cancer risk for the general population. Ratio of radon-induced lung cancer in the overall structure of this disease is in the range from 3% to 14%.
- Currently, other diseases caused by exposure to radon, have never been convincingly demonstrated.
- Most of the radon-induced lung cancers are caused likely due to prolonged exposure to low and medium concentrations of radon than high.

ICRP Publication 115 presents an analytical review of recent epidemiological studies [8]. The main conclusions are publishing a quantitative estimate of the severity of the effects of exposure to radon on human health. It is shown that the relative magnitude of the additional risk of lung cancer for the population from exposure to radon is 16% per 100 Bq/m³. The value of the additional lifetime absolute risk, as recommended by ICRP Publication 115, is $5 \cdot 10^{-4}$ on WLM (Working level month) compared with the value at $2,8 \cdot 10^{-4}$ on WLM recommended in ICRP Publication 65. In the ICRP Publication 115 was identified multiplicative nature of the interaction of inhaled exposure to radon progeny and spontaneous incidence of lung cancer. So, with minor differences in the relative values of growth of lung cancer in smokers and non-smokers, the absolute risk for them differ by more than an order of magnitude. Thus, the results of epidemiological studies suggest that the risk of lung cancer increases linearly with the long-term radon exposure, and there is no evidence of a threshold. The risk increases significantly even with volume activity (VA) of radon 100 Bq/m³ [7]. These circumstances provided the basis for the revision of acceptable levels of indoor radon. According to WHO regulation of VA indoor radon level of 100 Bq/m³ is justified from the point of view of goals of public health service to effectively reduce lung cancer mortality. In a statement on radon (November 2009, Publication 115 [8]) ICRP revised quantitative estimates of the risk of lung cancer from exposure to radon and progeny and recommended that the upper value of the acceptable level for radon in dwellings of 300 Bq/m³, compared to 600 Bq/m³ recommended in Publication 103.

Modern approaches to protection of the public against indoor exposure to radon

Currently, the basic principles of radiation safety are defined by ICRP Publication 103. Adapting to the new ICRP recommendations are based on consideration of various exposure situations where a central role to play the principle of justification and the reference level. In most cases, exposure to radon refers to the existing exposure situation as the source is usually unchanged concentration of natural radionuclides in the earth's crust. Human activities can create or change the intake path, increasing VA indoor radon compared to the background in open terrain. These paths can be controlled by preventive or corrective actions. According to the ICRP and WHO, approach in which measures to reduce radon VA is recommended only in the case of exceeding of the action level, created a misconception that exposure below this level is safe [12]. An important element of modern strategies of management of radon problem is changing of the meaning of "normative level", transition from the action level to the reference level. The reference level represents a level of dose, or risk, or concentration of the radionuclides, allowance of exceeding which is considered unacceptable when planning. If it level below should be organized optimization of protection. A consequence of using of the concept of reference level, instead

of the concept of action level, is that the optimization should be used as a justified measure above and below the reference level, and not only when it is exceeded. Thus, the basic idea of implementing modern radon policy is determined not only by reducing the individual risks from radon for the most exposed individuals, but also aimed at progressive reduction of the total collective risk for the general population.

Controllability of exposure to radon is the basis for regulation of this exposure situation. The development of strategy and tactics of regulation is the subject of recommendations and requirements of authoritative international organizations on radiation safety. Currently, the ICRP approved for publication recommendations for the protection of the population from radon in order to make modern methodology of regulation based on new scientific data and system of radiation protection postulated by ICRP publication 103. To control the exposure of the population, the Commission recommends using the universal approach, focused on management by the building or place where we have to be the situation of the individual exposure to radon, regardless of the destination of the building and the type of its inhabitants. Opinions of ICRP, IAEA and the European Commission are similar in this approach. For residential, public buildings and classical workplaces are recommended to establish a single reference level in units of radon concentration less than 300 Bq/m³. To control the exposure in the workplace ICRP suggests using graded approach. At the initial stage it is recommended to install reference level in a residential area – 300 Bq/m³, if the exposure of workers is not a consequence of their professional activities directly related to the source of radiation. If conducting of radon mitigation activities cannot reduce the content of radioactive gas in the workplace to the established standard, its value is adjusted upwards in view of the timing parameters of employee exposure compliance with the upper limit on the effective dose – 10 mSv/year (1000Bk/m³). The position of the IAEA to regulate exposure in the workplace is more conservative [9]. Jobs are divided into two categories. The first group includes public institutions in which the residence time of the population and the staff (employees) are comparable (schools, hospitals). The second group includes jobs with low residence time of the population (offices, libraries, shops, cinemas, etc.). In the first type of institutions are suggested to establish reference levels equal level in dwellings – 300 Bq/m³. In the workplace, of the second category, it is recommended to establish the reference level – 1000 Bq/m³, taking into account the timing difference of finding people at work and at home. In the event that, despite all reasonable efforts to reduce radon exposure, exposure at the workplace exceeds the reference level at the dose of 10 mSv/year (ICRP, IAEA) or 6 mSv/year (European Commission), the workers are reclassified as occupationally exposed persons. The regulation of exposure in this case is carried out by applying the principles of the protection in planned exposure situations.

One of the essential features of modern ICRP recommendations is changing of the approach to the estimation of effective dose due to the inhalation of radon progeny. The Commission has decided to use classical dosimetric models for the calculation of internal dose from inhalation pathway. Reasonability of this decision is in doubt and justifiable fears of a possible complication of control of radon in the workplace. Because of the complexity of the dosimetric models and significant variability of parameters that depend on the quality of indoor environments, we should expect a high degree of uncertainty in the estimates

of doses. Perhaps a number of issues will be removed after the publication of the ICRP to determine the numerical values of dose coefficients.

The national plan of action

The problem of ensuring of protection of the population against radon requires a complex approach to its solution. In this regard, the ICRP recommends that national regulatory authorities to develop a system of measures in the form of a national plan of action based on long-term prospects for its implementation [10]. Regulation of the situation of public exposure to radon is given special attention in the new edition of the IAEA Safety Standards. The document notes that the plan should be developed as a tool for public policy in the field of radiation safety [9]. The new EU directive accent the necessity to accept the radon programs by EU countries. Since the entry into force of the new safety standards for the EU Member States are given to 4 years for changes in national legislation. [11]

The strategic goal of the implementation of the national action plan is decrease of the radon-induced morbidity and mortality from lungs cancer. The achievement of this goal should be achieved by the in-parallel solution of two interrelated tasks.

- Reduce the proportion of persons with unacceptably high individual risk;
- Reduce the average individual risk associated with radon and progeny, for the entire population of a country.

Taking into account the specificity of the radon problem in the Plan shall be provided development and implement of special radon program, which must be defined institutional framework and mechanisms for implementation of measures to improve radiation safety in relation to this component of natural radiation.

During the preparation of the radon program is necessary to provide work on the harmonization of the existing legal and regulatory basis and development of new regulatory instruments aimed at improving of surveillance in this area. A key element is to establish the reference levels. It is an important component of radon programs and must be established by countries at the national level. The decision to establish the reference level requires the use of the optimization process, taking into account the current economic and social circumstances. The values of reference levels should be reviewed periodically during the implementation of the radon program to meet the objectives of the regulation.

The main elements of the radon programs.

Radon survey

At the beginning of implementation of the radon program and periodically is necessary to assess the risk to the population associated with exposure to radon in homes. For this the program must be planned estimated average exposure of the population to radon and distribution parameters of this magnitude. The results of the national radon survey constitute the information base for decision making on expediency of establishing or changing reference levels, taking into account the principle of optimization of protection. The main result of radon surveys should be developing of radon maps of the country with circumstantiation of potential radon hazardous territories.

Radon mitigation actions

In radon program should be developed measures to reduce public exposure to radon. Their implementation is based on two approaches: preventive and corrective. The strategy of preventive protection measures aimed at holding of public exposure

to the minimum reasonably achievable level in the current condition. Whatever of the location of the houses, the category of persons in these houses and the type of exposure situation, exposure to radon can be optimized by taking it into account during the planning, developing and construction of a building or selection of its location. Experience in implementing of European programs shows that the correct application of preventive measures in new houses is the most cost-effective and efficient.

The strategy of corrective measures is aimed at reducing of exposure to the lowest reasonably achievable level. This part of the strategy concerns mainly existing buildings or premises. In this case, the exposure control must be provided as far as possible, through control of the building (or premise) and the conditions of its using, regardless of the category of persons inside the building.

Stakeholders informing

The success of the government strategy for radon depends on the decisions made by individuals to reduce the risk in their home. Solution of radon problem requires the involvement of a large number of citizens, so informing is an important part of the radon program. In addition, the experience shows that the important role played introduction of local authorities and implementation of mechanisms for their interest in this matter. Information distribution of radon problem should contribute to maximize the involvement of experts in the field of building and other fields. In this regard, within the framework of the radon program should include training of professionals, such as architects, civil engineers, doctors, specialists in radiation protection, employers, trade union representatives and other experts. In the country it is advisable to establish a national database for storing measurements of radon and other information related to radon program. Collected in the database information should include parameters such as radon levels before and after the radon mitigation actions, building characteristics, the type of protective measures, installation costs, the annual cost of operation and maintenance, etc.

Division of responsibility

The extent of implementation of reasonable action to ensure to radon safety is largely determined by the extent of responsibility for the situation of exposure. National policy for radon should be aimed at solving problems in the field of legal responsibility, in particular liability of the seller of house or building to the customer, the owner to the lessee, and the employer to the employee. Therefore the national action plan should consider the mechanisms of division of responsibility and control over their observance. Requirements should be proportionate to the degree and type of responsibility and should be applied after the evaluation show that in this situation the strong requirements are more effective than stimulating.

Coordination with other national programs

The National Strategy for protection against radon should be coordinated with other government programs and priorities in the field of health protection. The problem of reducing of cancer risk incidence associated with exposure to radon cannot be viewed in isolation from the dominant risk factor in the development of this disease – smoking. Synergistic effect of smoking and radon, an important element of a strategy aimed at reducing the risk of common lung cancer incidence is the coordina-

tion of national programs to reduce public exposure to radon in dwellings and restriction of smoking. Special importance this approach has in reducing of the cancer risk of people living in homes with low levels of radon, where the costs of implementing the radon mitigation activities increase significantly. Strategy to protect the population against radon should also be coordinated with the national program of energy conservation. Improving the energy-saving technologies and their application in the construction of new buildings often leads to a decrease of air renewal and, consequently, increased levels of indoor radon.

Adapting of modern recommendations of international organizations to the practice of domestic regulation

In regulation of public exposure from natural sources the Russian Federation follows to the recommendations of international organizations. The country has a multi-stage control system, based on the control of the main ways of public exposure. After the release of ICRP Publication 65 in Russia was formed the federal targeted program "Radon". The implementation of activities under this program was the start of a national radon surveys and the development of regional programs to protect the population from radon and other components of natural radiation. However, due to lack of funding the program was closed, and now some of its individual provisions is realized in the framework of the Federal Target Program "Nuclear and Radiation Safety" on an unsystematic basis. The lack of a unified approach to the planning and execution of activities in the field of regulation complicates the tasks to protect the population from natural radiation components. High social importance of radon problem determine necessity of its maximum discussion by national regulatory authorities and other stakeholders. The result of this work must be development of unified national strategy for protection of the population from natural sources of radiation.

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