RADON REMEDIATION EFFICIENCY ASSESSMENT IN THE KIROVOGRAD REGION, UKRAINE

by

***Tetiana PAVLENKO*[1], *Olga GERMAN*[2] *, *Nikolay AKSENOV*[1], *Miroslava FRYZYUK*[1], *and Anatoliy OPERCHUK*[3]**

[1]The Marzeev Institute of Public Health, National Academy of Medical Science of Ukraine, Kyiv, Ukraine
[2] Norrtälje, Sweden
[3] Ukrainian Center for Social Disease Control of the Ministry of Healthcare of Ukraine, Kyiv, Ukraine

Technical paper
http://doi.org/10.2298/NTRP1803317P

This article provides a review of radon remediation methods and an algorithm of their applications. The methods assessed are applicable for indoor radon originating from the ground beneath or around a building. It was established that radon activity concentration in underlying soil or ground ranging between 15 and 30 kBqm^{-3} would contribute to an average annual indoor radon concentration from 20 Bqm^{-3} reaching up to 1030 Bqm^{-3} in the region, *i. e.*, a 10-15 fold difference, while the average radium concentration in soil was assessed as 30 Bqkg^{-1}. The geo-morphological analysis in the investigated region classifies the top soil as very permeable, containing huge volumes of soil air which is easily transported with the temperature and pressure gradient. It was demonstrated that both soil characteristics and construction characteristics must be taken into account when designing radon remediation methods.

One hundred eighty nine buildings were investigated, remediated, and assessed as part of this research work. The average remediation efficiency was established as 50 %. The paper provides an overview of recommended remedial actions and most common mistakes made by construction experts influencing the efficiency of radon remediation.

Key words: radon, remediation, efficiency

INTRODUCTION

Protection of the population from radon in dwellings consists of several consecutive steps [1]. The first step is a long term radon measurement and analysis of the results obtained. If noncompliance to national regulations in terms of radon reference levels is established, the second step is to find out the source of radon indoors. Generally, there are three potential sources of radon indoors: the soil or ground under and around the building, construction materials, and household water, if private wells are used. The third step in the process would be to analyse the construction and engineering applications of the building in terms of their influence on radon availability to indoor air. Having assessed these abovementioned aspects a corrective action for radon reduction can be chosen.

According to data published by Pavlenko and German *et al*., radon originating from soil is the major source of indoor radon in Ukraine, namely in 95 % of cases. The article thus, deals with radon remediation solutions and assessment of their efficiency for radon entering the building from soil, as the most popular and applicable ones [2].

Available practical experiences demonstrated that radon prevention measures applied during construction or radon remediation measures, if applied correctly, could contribute to significant radon reduction indoors at a low cost compared to health deterioration that might be caused by high radon exposure. [1, 3, 4] At the same time, some radon remediation experiences from the UK achieving 5 % to 47 % of efficiency could be used as an example of varying efficiency of remediation. [5]

Many research works were published in numerous countries, confirming that radon concentration in soil air is thousands of times higher than that at the ground level. Once the soil air containing ^{222}Rn enters the building, it will result in high levels of radon activity indoors. [6, 7].

There are two principal mechanisms allowing ^{222}Rn to enter indoor air. These are the molecular diffusing and active transport with air convention caused by the pressure gradient between the soil air and the air

* Corresponding authors; e-mail: olga.german@hotmail.com

indoors [8-10]. The air pressure gradient, in its turn, is caused by the temperature difference indoors and outdoors, and due to wind direction towards the walls of a building. The higher the difference between the indoor and soil air pressure the more soil air will be sucked into a building (indoor air pressure depends on the air exchange rate and ventilation systems used, which could potentially lead to an air pressure deficit).

Apart from, or combined with soil characteristics, high radon activities indoors are caused by construction solutions and engineering applications in every separate case:
- defected ground isolation,
- low air pressure indoors,
- high permeability of soil drainage under a building or around it,
- characteristics of the building foundation, and
- other construction solutions utilized, for instance, ventilation stock or chimney, *etc*. [11]

To summarise the above, radon contaminated air from soil beneath or around a building will always move through the openings in construction and gravel filling beneath, along the pressure gradient. Radon concentration indoors depends on the uranium and radium content in soil, its permeability, moisture content and, to a lesser extent, the content of these radionuclides in building and construction materials.

As radon transfer from soil to indoors depends on available openings and pathways, its concentration in two neighbouring buildings could differ up to a magnitude of 2. This was demonstrated by Pavlenko in the town of Samtchintsy, Nemirov Oblast, which was built for re-settlement of Chernobyl evacuees and the standard construction model was applied throughout the whole settlement. Radon activity in these dwellings varied between 80 and 1200 Bqm^{-3} [12].

Indoor radon concentration and air exchange rate measurements performed in parallel in many countries estimated that the average ^{222}Rn inflow velocity varies between 6 and 60 Bqm^{-3} per hour. [13]. In several Swedish experiments this value was even higher [11].

It was also demonstrated, that in radon protected buildings the contribution of soil air indoors makes about 1 % of the total indoor air volume, the rest coming from the atmosphere [14]. In poorly isolated houses with several radon entry points, contribution of soil air to its total indoor volume makes up to 20 %. In such case the radon activity concentration indoors is high even if its activity in soil air is relatively low [15].

The radon remediation methods are based on knowledge of the radon sources and its transfer mechanisms, and consists of the following general approaches: maximum prevention of contacts with soil, isolation of radon entry points, radon exhaust from the ground under buildings. In engineering terms, these general radon remediation approaches are known as:
- insolation,
- pressurization, and
- ventilation.

EXPERIMENTAL

Research work phases

The experimental part of this work was performed part of the development cooperation project between the Swedish and Ukrainian authorities "Reduction of risks caused by exposure to radon gas and natural radiation" (2009-2014) and continued as the regional programme in the Kirovograd Oblast "Stop Radon" (2010-2015) [16].

In the first phase of this work, measurements of radon activity indoors were carried out applying passive radon track detectors. Radon activity in soil, Ra(U), Th, and K content in soil and the gamma dose rate were measured in the selected region (over 1200 measurements). Information on geomorphological characteristics, such as topsoil type, ground classification, moisture, landscape, *etc*.), was collected to complete the radon risk information data base. Using the database information, radon prone areas were identified.

In the second phase of the research work, active radon measurement methods were used to assess radon activity in basements and foundations of buildings with high radon activity indoors. Analysis of the construction and engineering characteristics was performed as well at this stage.

In the third phase of the work, 189 buildings with high radon activity were selected and radon remediation was justified for being implemented in those. In selecting radon remediation methods local financial possibilities were considered and methods were adjusted to some extent to the available materials. One round of consultancy was provided by the Swedish experts to the local authorities in Kirovograd.

The remediation activities were performed in 189 buildings (kindergartens and schools), by means of local radon experts and part of the "Stop Radon" project. A second round of radon activity measurements was conducted during the nearest heating period and radon remediation efficiency was assessed.

Measurements

Radon passive track detectors were utilised for indoor radon activity measurements with exposure time of at least 30 days during the heating period, and the minimum detectable activity (MDA) of 5-10 Bqm^{-3} [17].

Calibration of radon track detectors was performed as a quality assurance stage in radon activity measurements at the Marzeev Institute of Hygiene and Medical Ecology[1]. The efficiency of the radon track detectors batch was estimated in the "radon atmosphere" with known radon activity, accredited by the State Metrological Authority of Ukraine (21.01.2004). Standard etching procedures were applied for each batch of detectors.

Radon measurements in soil air were done at a depth of 80 cm and utilised the application of radon emanation measuring equipment MARKUS-10 (Sweden). Gamma spectrometric measurements for Ra(U), K, Th as well as gamma dose-rate measurements were performed in the same sample points using Exploranium GR-130 (Canada) employing a 0.7 L NaI(Tl) detector. The instrument performance checks were performed prior to every measurement using a standard procedure and radioactive source incorporated into each equipment piece. Calibration of the Exploranium detector is performed by the Geological Survey of Sweden every second year at the standard calibration platform for naturally occurring materials in Borlänge, Sweden.

The results of all measurements were put into field protocols and completed with information on soil, ground, moisture and landscape characteristics, weather conditions, for each measurement point. The Exploranium equipment coordinates data was used and verified by a second GPS device.

RESULTS AND DISCUSSIONS

Radon risk assessment

The results of soil measurement established that Rn-222 activity in soil air varied between 15 and 30 kBqm^{-3}, while the average Rn-222 equilibrium equivalent concentration (EEC) indoors in the same region was measured as 20-1030 Bqm^{-3} (Rn activity 50-2575 Bqm^{-3}).

The statistical distribution of EEC in the investigated region, presented in fig. 1, is characterised by log-normal distribution. The mean geometric 61 Bqm^{-3} value and the standard deviation of 102 Bqm^{-3} evidence high variability of indoor radon activity in this region.

In 5 out of 35 investigated settlements of the Kirovograd region, non-compliance to the national radon reference level (EEC 100 Bgm^{-3}) was demonstrated in all measured buildings. In 30 % of cases radon activities within the boundaries of the same settlement differed several folds. Maximum radon activities measured exceeded the national standard as much as 5-7 folds. Only 3 out of 35 settlements complied with the national reference level and buildings with elevated radon activities were not identified.

Radon activity measurements in soil air and gamma spectrometric measurements were per-

[1] New name since 2016 State Institution "O. M. Marzeev Institute for Public Health of the National Academy of Medical Science of Ukraine"

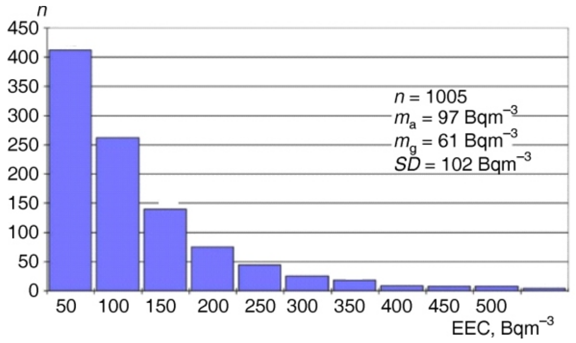

Figure 1. Statistical distribution of EEC of Rn-222 in investigated buildings of the Kirovograd region;
n – number of buildings investigated; m_a – mean arithmetic value for EEC of Rn-222; m_g – mean geometric value for EEC of Rn-222, SD – standard deviation

formed at the second stage of the research work. The most common top soil in the region chernozem (of varying quality) is built of loess, clays, loam and sandy loam ground. The ground characteristics correlate well with the radon air activity results. Actually, the ground in the region is characterised by a low concentration of radium, and radon activity consequently, but due to their structure and huge amount of available ground air, the little radon that is released into the soil air is easily transported to constructions and buildings with the soil air flow quickly along the pressure gradient.

Activity concentration of Ra-226 in soil varied between 14 and 39 Bqkg with an average of 29 Bqkg on the surface and 30 Bqkg at the depth of 80 cm. In other words, radium content did not change much with depth in the region. The average concentration of radium in the region was just few Bq higher than the country's average, but is still considered to be low compared to the world data.

This fact allows us to derive a conclusion that the high radon activities indoors are caused by specific characteristics of constructions (poor isolation from ground and lack of proper ventilation indoors), and not by high radon or radium activities in soil.

Radon remediation methods

Radon remediation in existing buildings means literally re-construction works, and requires specific considerations in regards to means and methods. There are four general radon remediation approaches (see fig. 2): isolation of ground (a), increase of indoor pressure (b), ventilation of the space under the house (c), and reduction of pressure under the house (d).

Ground isolation consists either of total isolation of the floors with polyethylene or other non-permeable material or isolation of separate holes and points of entrance of communications. It is worth mentioning that the last one is very important. Based on published international experience from countries such as Sweden, Great Britain, France, and USA a rule of 98 % is

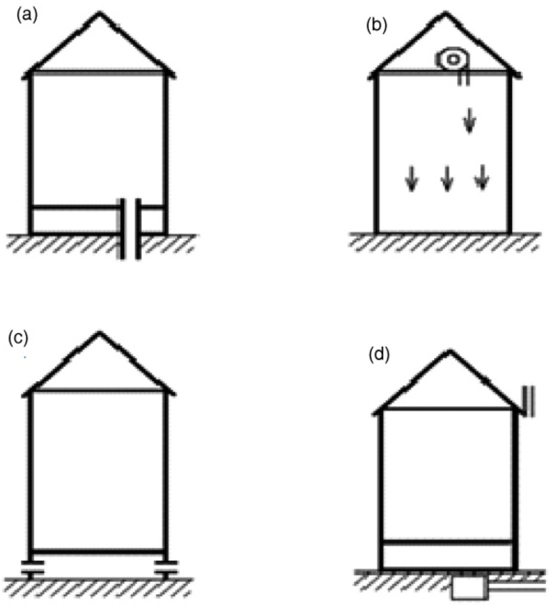

Figure 2. General radon reduction methods

derived [18-20]. "The 98 % rule" means that isolation of 98 % of holes and openings in the foundation will result in the situation when 98 % of available radon will seep into the building through the remaining 2 % of openings. This rule was also tested in a computer code, when a building was modelled with a single opening as the point of radon entrance to the indoor air. The reduction of the number or size of openings leads to an increase inflow rate of the air from under the building. The increase rate in the model was higher with every step taken to reduce the size of the opening [21]. This means that leaving 2 % of openings or holes in the floors will diminish the whole purpose of isolation. The efficiency of isolation is assessed as 2:1, *i. e.* if successful, it will allow reduction of radon activity indoors to half of its original activity.

Increase of indoor pressure (b), leads to prevention of the so-called "stuck ventilation" effect and, consequently, prevention of radon air inflow from beneath the house. To increase indoor pressure a 60 W ventilation fan is usually installed to allow the inflow of fresh outdoor air into the house. As a result, the indoor air pressure increases and the pressure gradient is from inside the building towards the ground. This method allows also the improving of the indoor air quality, it has though a problem with condensation as the air outdoors is humid. The inflow air needs to be "dried" and filtered. The method allows the reducing of indoor radon activities as much as three times its original level [5].

Forced ventilation as described above, is seldom present in private housing constructions and, particularly, in single detached houses. Another problem with the method is the need for heating the air in cold climates and it, thus, becomes costly and less attractive.

Ventilation of the space under the house (c) is applicable for foundations of all types and materials – concrete, wood *etc*. The ventilation may be natural, for example, through the permeable material in the wall, through special ventilation openings in a foundation and applying ventilation fans. This method allows the significantly reduction of indoor radon, but, if applied wrongly, leads to increased condensation under the house.

Reduction of pressure under the house (d) or the radon drainage system is an effective radon remediation method allowing reduction of radon activities by 8 to 20 times. It is achieved by installing a ventilation fan in a shallow pit under the building connected to a pipe. The air from the ground is exhausted through the pipe to the outdoors and is thus prevented from entering indoors. This radon remediation method is very popular, and in combination with isolation allows reductions of indoor radon to very low levels without risking other problems. [11, 18, 21]. A 75V ventilation fan is sufficient enough for the purpose of the method, but its efficiency may depend on the permeability of the surrounding soil.

Radon remediation in Kirovograd

The Kirovograd regional programme "Stop Radon" allowed us to scientifically justify radon remediation methods and assess their efficiency. A total of 1023 establishments for children were investigated and 189 of them were remediated in the course of this programme. It should be noted, that due to limited financial resources radon remediation actions recommended by experts were not fully implemented, which is reflected in their efficiency. Nevertheless, this was the first Ukrainian experience in radon remediation and a significant health risk reduction for children.

The results of radon indoor measurements allowed the establishing of three classes of buildings:
– EEC > 250 Bqm^{-3} (radon activity 600 Bqm^{-3}),
– EEC 100-250 Bqm^{-3}
(radon activity 250-600 Bqm^{-3}), and
– EEC < 100 Bqm^{-3} (radon activity 250 Bqm^{-3}).

Radon remediation was carried out in the buildings with radon activities 6-10 times exceeding the national reference level for schools and kindergartens, which is 50 Bqm^{-3} annual average EEC.

As mentioned earlier, the analysis of radon and radium content in soil, and construction characteristics of the typical rural building of the Kirovograd region demonstrated that radon activities indoors depend primarily on the latter. All the investigated buildings with elevated radon activities indoors had several common characteristics, namely:
– poor isolation of ground with a huge number of openings towards the ground, open holes around the entrance points of communications,

– space under the floors was not ventilated, and
– lacking or wrong ventilation system indoors.

Based on the construction characteristics two major groups of buildings can be distinguished:

– one storey building of bricks, without a cellar,
– two-three storeyed building with some cellar or crawl space for communications.

The Ukrainian radiation hygiene regulations and their enforcement make it possible to exclude building materials as a source of radon. This was also proven by gamma dose-rate measurements , which ranged between 0.23 and 0.28 μSvh^{-1}. Water supply for the investigated buildings is certified and contains neither radon no other NORM. Thus, the only possible indoor radon source in all cases was soil/ground under the buildings.

Based on all available characteristics of the buildings in question, radon remediation methods were recommended for each individual case.

The best remedial efficiency is expected to be achieved by application of the radon slab suction system in combination with isolation of the ground. There could be several points for installation of suction points, depending on the total area of the building and number of bearing walls.

Two concrete examples of recommended radon remediation installations are presented below.

Case 1. Kalinovka kindergarten is a one storeyed of red bricks building, 50 cm underground space and wooden floors with broad gaps between planks. The floor is covered with plastic or fabric carpet in some rooms, while other rooms have no cover at all. Windows in the building are very old and there is no installed ventilation system, but periodic opening of windows is done for letting some fresh air in during the summer time. The windows are sealed and not opened during the whole heating period.

A set of investigation measurements was carried out in and around the building with the following results:

– indoor dose rate 0.07-0.09 μSvh^{-1},
– annual average radon EEC 191 Bqm^{-3}, and
– short-term measurement of radon in the space under the floor varied between 400 Bqm^{-3} in the kitchen and hallway and 1040 Bqm^{-3} in the playroom.

The following radon remediation measures were recommended for the Kalinovka kindergarten:

– install a forced ventilation system to achieve an normal air exchange rate,
– isolate floors and entering points of all communications and pipes, and
– install a radon slab suction system with several action points.

Case 2. Municipal secondary school in Znamenka is a red bricks building, with wooden floors covered with parquets. The underground constructions accommodate communications (mainly pipes). Windows in the building are new with a high level of insulation. A natural draught ventilation system is achieved by outflow channels. No inflow channels for ventilation have been installed.

A set of investigation measurements was carried out in and around the building with the following results:

– indoor dose rate 0.07-0.09 μSvh^{-1},
– annual average radon EEC 191 Bqm^{-3}, and
– short-term measurement of radon in the space under the floor varied between 400 Bqm^{-3} and 1910 Bqm^{-3}.

The following radon remediation measures were recommended for the Znamenka kindergarten:

– install outflow ventilation channels and achieve a normal air exchange rate,
– isolate floors and entery points of all communications and pipes, and
– install a radon slab suction system.

As noted earlier, radon remediation recommendations were planned and engineered individually for each case. Unfortunately, they were not fully or correctly implemented by the contractors, which led to somewhat varying efficiency: in some cases radon activity increased after competition of works.

EFFICIENCY ASSESMENT

To assess the efficiency of radon remediation measures long term radon measurements were performed in 189 schools out of 200 chosen for remediation in the region.

It was established that when radon remediation works were fully completed in the Novoarkhangelsk district, radon activity decreased 5 folds, in the Kropivnitsky town (former Kirovograd) radon activities decreased 3.2 folds and in the Ulyanovskiy and Alexandrovskiy district radon activities decreased 2.8 folds. In all other cases the efficiency of remediation was significantly lower. In two cases radon activity increased twice after remediation. A 48% decrease of radon activity was achieved on average for the pilot region.

Investigation of the achieved results revealed the following:

– radon activity was reduced only slightly when mistakes were made in air exchange rates,
– floor and communication systems were poorly isolated or isolation was not implemented at all, which reduced the efficiency of the radon suction system (without approval), and
– radon activity increased in several cases when contracting companies replaced the recommended ventilation system with a different type (without approval).

Practical experience of insufficient or incomplete remedial actions, replacement of the recommended technical solutions by people with no knowledge or lack of understanding of radon remediation and ventilation systems demonstrated poor efficiency of the work or, in some cases had the opposite effect.

For example, in a few schools radon activity indoors increased compared to the original ones. In these cases a contractor made a decision to replace ventilation systems without any underlying calculations or engineering. Outflow ventilation channels equipped with a fan at a two meter height from the floors without performing any isolation of the floor and communications was installed. As a result, the inflow of soil air indoors increased and radon activity doubled.

The best remedial effect was achieved for those cases where radon ventilation was combined with correctly and fully done isolation.

CONCLUSIONS

It was demonstrated that soil permeability and construction characteristics of buildings should be considered when choosing the radon remediation method, to account for radon availability and mobility. As shown in the Kirovograd region, though radon activity in soil air was low, ranging from 15 $kBqm^{-3}$ to 30 $kBqm^{-3}$, indoor radon activities reached up to 1030 Bqm^{-3} (EEC). This is due to the typical soil of the region, which is characterised by high permeability and contains a huge amount of free soil air, which moves easily, together with radon, along the temperature and pressure gradient. Careful calculation of air exchange rates, understanding and knowledge of its influence on radon activity indoors and hygiene parameters of the indoor air are necessary prerequisites for carrying out any replacement or changes in ventilation systems. This pilot programme of radon remediation confirms the need to inform the population of the risk of radon in general as well as the need for education and training of radon remediation experts and contractors, in particular to promote understanding and correct implementation of radon remediation measures.

AUTHORS' CONTRIBUTIONS

Authors of the article participated in its creation in the following way:

T. Pavlenko – general management and work planning, general analysis, article conclusions, and article writing. O. German – radon remediation planning, radon and gamma spectrometric measurements in soil, remediation efficiency analysis, and article writing. N. Aksenov – quality assurance of measurements, indoor radon measurements, and support in radon remediation planning. M. Fryzyuk – indoor radon measurement and analysis of measurement results. A. Operchuk – support in soil measurements, in building construction diagnostic, and support in remediation efficiency assessment.

REFERENCES

[1] Janssens, A., *et al*., Protecting Against Indoor Exposure to Radon/29th Hanford Symposium on Health and the environment, October 15-19, 1990, Columbus, Battelle press 1991, pp. 1065-1084

[2] German, O., Radon Risk Mapping is an Important Tool for Radiation Protection of Population, Ukraine, *Hygiene of the Settlements, 51* (2008), 1, pp. 302-306

[3] ***, ICRP Publication 115, Lung Cancer Risk from Radon and Progeny and Statement on Radon, (ed. C. H. Clement), *Annals of the ICRP, 40* (2010), 1

[4] ***, ICRP Publication 126, Radiological Protection against Radon exposure, (ed. C. H. Clement), *Annals of the ICRP, 43* (2014)

[5] Dole, J., *et al*., Protective Responses to Household Risk: a case Study of Radon Mitigation, *Risk Analysis, 1* (2010), 1, p. 134

[6] Jensen, C. L., *et al*., The Norwegian Radon Mapping and Remediation Program, *Proceedings*, Third European IRPA Congress Helsinki, Finland, June 14-18, 2010). – Helsinki, (2010), pp. 488-677

[7] Ielsch, G., *et al*., Mapping of the Geogenic Radon Potential in France to Improve Radon Risk Management: Methodology and First Application to Region Bourgogne, *Journal of Environmental Radioactivity, 101* (2010), 9, pp. 813-820

[8] Evdokimov, V., Ozonof, D., Compliance with EPA Guidelines for Follow-Up Testing and Mitigation After Radon Screening Measurements, *Health Phys., 63* (1991), 2, pp. 215-217

[9] Nero, A. V., *et al*., Characterising the Sources, Range and Environmental Influences of Radon-222 and Its Decay Products, *Science of the Total Environment, 45* (1985), 1, pp. 233-244

[10] Eaton, R. C., Scott, A., Understanding Radon Transport Into Housing, *Radon. Prot. Dosimetry, 7* (1984), 1-4, pp. 251-254

[11] Clavensjo, B., Akerblom, G., Radon Book, Measures Against Radon in New Buildings, Formas, Stockholm, 2004

[12] Pavlenko, T.,A., *et al*., Exposure Doses Due to Indoor Rn-222 in Ukraine and Basic Directions for Their Decrease, *Radiation Measurements, 28* (1997), 1-6, pp. 733-738

[13] Nero, A. V., Lowder, W. M., Indoor Radon, *Health Phys., 45* (1986), 2, pp. 273-574

[14] Arvela, H., *et al*., Radon Prevention in New Construction in Finland: A Nationwide Sample Survey in 2009, *Radiation Protection Dosimetry, 148* (2012), 4, pp. 465-474

[15] Otton, J. K., *et al*., The Geology of Radon (Electronic resource) U. S. Government Printing Office, Available at: http://energy.cr.usgs.gov/radon/georadon

[16] Pavlenko, T., *et al*., The Ukrainian Pilot Project "Stop Radon" *142 Nucl Technol Radiat, 29* (2014), 2, pp. 142-148

[17] ***, Method of Radon-222 Activity Measurement Indoors with Passive Track Detectors "Track 2010Z", Methodology MBK 6.6.2.-063-2000, Kiev, 2000

[18] Clavensjo, B., Akerblom, G., Radon Book: Radon Measures in Existing Buildings, Stockholm, 2007

[19] Woolliscroft, M., The Principles of Radon Remediation and Protection in UK Dwellings, Conf. "Radon 2000 – Achievements and Aims" (London, March 26-27, 1992), *Radiat. Prot. Dosim, 42* (1992), 3, pp. 211-216

[20] Birovljev, A., *et al*., Effects of Ventilation on Radon Concentrations on Norwegian Kindergartens (Electronic Resource) Radon in the Living Environment: Proceed. Intern. Workshop (Athens, Greece, 19-23 April 1999). – Available at: http://www.aivc.org/resource/effects-ventilation-radon-concentrations-norwegian-kindergartens

[21] Uglow, C. E., Background Ventilation of Dwellings, Building Research Establishment Report BR162, Garston: BRE, (1989), pp. 87-92

Received on November 23, 2017
Accepted on July 4, 2018

Татјана ПАВЛЕНКО, Олга ГЕРМАН, Николај АКСЕНОВ, Мирослава ФРИЗЈУК, Анатолиј ОПЕРЧУК

ПРОЦЕНА ЕФИКАСНОСТИ РЕМЕДИЈАЦИЈЕ РАДОНА У ОБЛАСТИ КИРОВОГРАДА У УКРАЈИНИ

У овом раду дат је преглед метода ремедијације радона као и алгоритам њихових примена. Процењене методе примењиве су при ремедијацији радона који потиче из земљишта испод или из околине зграде. Установљено је да концентрација активности радона у земљишту испод зграде у опсегу од 15 до 30 kBqm^{-3} може допринети просечној годишњој концентрацији радона у затвореном простору од 20 Bqm^{-3} све до 1030 Bqm^{-3} у овом региону, што је повећање од 10 до 15 пута, док је просечна концентрација радијума у земљишту процењена на 30 Bqkg^{-1}. Геоморфолошка анализа у испитиваном подручју класификује горњи слој земљишта као веома пропустљив, са великим запреминама ваздуха у земљишту који се лако може кретати услед градијента температуре и притиска. Показано је да при пројектовању метода ремедијације радона карактеристике земљишта и грађевинске карактеристике морају бити узете у обзир.

У току овог истраживања, испитано је 189 зграда за које је ремедијација пројектована и потом оцењена. Просечна ефикасност ремедијације износила је 50 %. Овај рад даје преглед препоручених акција ремедијације и најчешће грешке које се јављају при изградњи објеката које утичу на ефикасност ремедијације радона.

Кључне речи: радон, ремедијација, ефикасност