THE UKRAINIAN PILOT PROJECT "STOP RADON"

by

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In 2010 one area of Ukraine (Kirovograd area) was selected for a pilot project to reduce radon risks. The project consists of several stages: radon risk training for the public health professionals, measurements of radon concentration in schools and nurseries (more than 1000 buildings were examined), justifications of radon countermeasures and their implementation. The lognormal frequency distribution for equivalent equilibrium concentration was authentically established. The geometric mean of the indoor radon equivalent equilibrium concentration was established to 63 Bq/m^3, and standard deviation is equal to 82 Bq/m^3. The indoor radon equivalent equilibrium concentration ranged from 22 Bq/m^3 to 809 Bq/m^3. It was found that the national regulatory limit for this type of buildings was exceeded in more than 50% of the cases. The second phase of the project has a goal to remediate radon levels and reduce radon risks. Calculated exposure doses and radon risk were used to justify the remediation and assess the economic loss for the region caused by radon irradiation of the population.

Key words: Ukraine, radon, radiological risk, effective dose

INTRODUCTION

According to UNSCEAR estimation, radon is a major contributor to the doses of the population living in the moderate climate [1]. A number of epidemiological studies have been carried out during the past 10 years to establish radon's influence on the human organism and assess radon risks. As the result of this work the radon risk values were reviewed and increased. In 2011 the first radon limits were published in the IAEA International Basic Safety Standards (BSS) [2]. This fact means that radon as any other artificial radioactive source is now under the regulatory control.

According to the BSS requirements, the regulatory control consists of an established state policy and strategy for the radiation protection against particular radiation sources, analysis, and assessment of the exposure situations, as well as the existence of the countermeasures to reduce these particular exposure pathways.

The Ukrainian studies of the indoor radon levels in dwellings started in 1989. The metrological and methodological bases for the indoor radon measurements were developed during this time [3]. The special conditions for the build-up of the indoor radon levels in Ukrainian dwellings were studied and described [4]. The passive track detector method was selected to control the indoor radon levels. The quality assurance system for the indoor radon measurements has been developed and implemented at the State institution The Marzeev Institute of Hygiene and Medical Ecology (IHME).

Over 28000 dwellings have been examined in Ukraine so far. The analysis of the results revealed that in 19% of the cases the indoor radon equivalent equilibrium concentration (EEC) exceeded the regulatory established limit of 100 Bq/m^3 (corresponding to 250 Bq/m^3 of radon gas) and 5% of the dwellings exceeded 200 Bq/m^3 (corresponding to 500 Bq/m^{3}of radon gas) [5]. Several areas with high radon levels have been identified (fig. 1).

In order to prevent the unnecessary exposure of the population to radon and natural radioactivity, the national activity concentration limits were established in the Radiation Safety Requirements of Ukraine for existing buildings of EEC at 100 Bq/m^3 (corresponding to 250 Bq/m^3 of radon gas) and for newly constructed buildings of EEC at 50 Bq/m^3 (corresponding to 125 Bq/m^3 of radon gas) [6]. According to the Radi-

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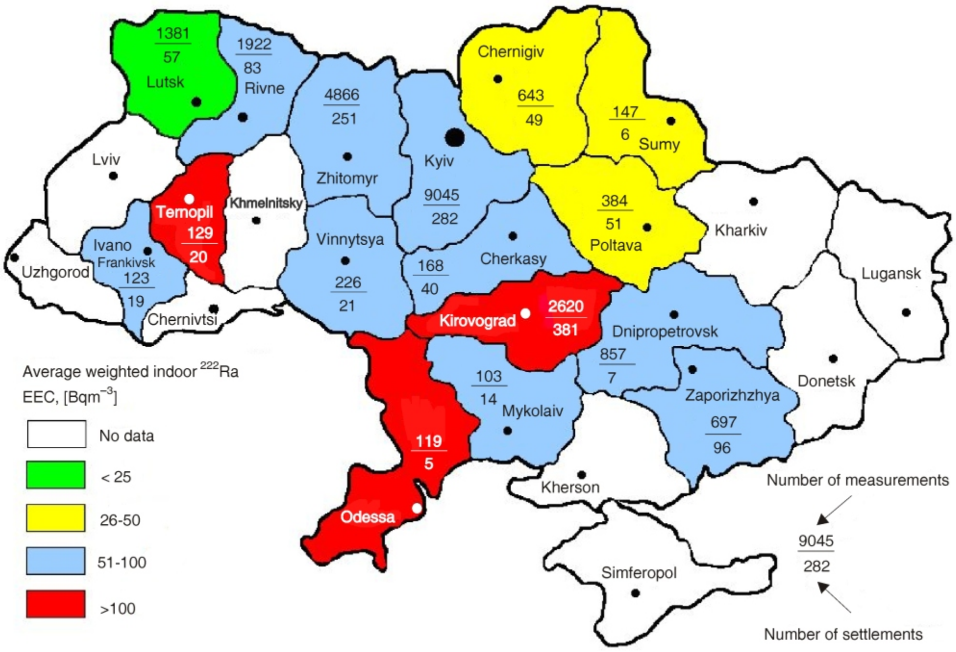

Figure 1. Average radon EEC in Ukrainian dwellings

ation Safety Requirements of Ukraine, state executive health protection authorities are responsible for the public buildings and private owners are responsible for their properties, when it comes to radon.

There are special requirements established for the nurseries and schools limiting the radon concentration to 50 Bq/m^3. In this case regional executive authorities are responsible for radon remediation.

The preliminary analysis of the data established that Kirovograd region poses the most vivid example of the territories with the radon problem. A combination of specific hydro-geological conditions in the region, allowing for the uranium mining industry development with old dwelling pool makes together with high radon levels a characteristic of the region. The analysis of the dwelling pool demonstrated that the majority of the public buildings were constructed in the 1950-1960-ies. As a rule the construction was done according to a standard model applied all over the country. Thus the pilot radon project in the region will lead to the reduction of the radon risks to the population, as well as become the basis for the recommendations on radon remediation measures in other regions of Ukraine.

The article provides the results of two activities - the international Swedish-Ukrainian project Reduction of risks caused by exposure to radon gas and natural radiation (2010-2013) and the Kirovograd regional project Stop Radon.

METHODS

Passive radon track measurement method was chosen for the needs of the project, utilizing a LR-115 film as a track detector. The detectors were exposed for two months during the heating season (November-March). After the exposure chemical etching of the film was applied and track counting was performed with the spark counter. The sensitivity of the method is estimated to 8-10 Bq/m^3.

The quality assurance procedures were applied as follows:

– to establish the registration efficiency of the track detectors (calibration) they were exposed in the radon atmosphere at the IHME laboratory of Natural Radiation Sources with known radon activity. The radon atmosphere of IHME is the secondary calibration source accredited by the National Standardization and Accreditation Authority of Ukraine. Efficiency factors were calculated based on the known activity and the number of radon tracks measured. (The first level of control).

The efficiency factor was calculated

$$E_{\text{Rn}} = \frac{\sum_{i=1}^{n}(N_i - N_0)}{tAn}, \text{track cm}^{-2}\text{Bq}^{-1}\text{m}^3\text{d}^{-1} \qquad (1)$$

where N_i is the number of tracks of detector *i*, exposed in the radon atmosphere, track cm^{-2}, N_0 – the background of LR-115 film, track·cm^{-2}, *n* – the total number of detectors calibrated, *t* – the exposure time in the radon atmosphere [d], and *A* – the radon activity in the radon atmosphere [Bqm^{-3}].

Furthermore, each film production was tested and adjusted for the optimal etching parameters. (The second level of control). This procedure was applied to each separate batch of detectors produced from the same film. 4-5 detectors of the LR-115 film were exposed to a calibration source containing Pu-239 and were called control detectors. Three detectors of the same batch were used for a background exposure. Both control and background detectors were etched together with the detectors exposed in buildings. This approach allowed for calculation of correction factors for track detection for each batch, etching optimization, and minimization of measurement uncertainty.

The correction factor was calculated as

$$K_E \quad \frac{E_{\max k}}{E_{\max c}} \tag{2}$$

where $E_{\max k}$ is the registration efficiency for control detectors exposed in 2 geometry to a flat alpha detector containing Pu-239 and for the established etching parameters, track per particle·cm^{-2}, and $E_{\max c}$ – the registration efficiency for control detectors exposed in 2 geometry to a flat alpha source containing Pu-239 for each separate etching after exposure in dwellings, track per particle·cm^{-2}.

Radon activity in buildings was calculated as follows

$$C_{\text{Rn}}[\text{Bqm}^{\ \ 3}] \quad \frac{N_j \quad N_0}{E_{\text{Rn}}T} K_E \tag{3}$$

where N_j is the number of tracks on detector j, exposed in a dwelling, track·cm^{-2}, and T[d]– the exposure time.

To confirm the method and confidence interval several comparison measurements were performed together with the Swedish Radiation Protection Authority (SSI) and the National Institute of Radiological Science in Japan.

Models proposed in the ICRP publications 65 [7] and 115 [8] were applied for dose calculations. Reference exposure times in dwellings (T_{ref}) of 7000 hours and 2000 hours in nursery and schools were applied.

Average annual radon activity was calculated as an average for the heating season and summer time measurements.

Average annual effective dose from radon indoor exposure is calculated as

$$\begin{aligned} \overline{H}_E[\text{mSv}] \quad & 5.56 \ \ 10^{\ \ 6} \ \ 1.1 \ \ 0.4\overline{C}_{\text{Rn}}T_{\text{ref}} \\ & 2.45 \ \ 10^{\ \ 6}\overline{C}_{\text{Rn}}T_{\text{ref}} \end{aligned} \tag{4}$$

where 5.56·10^{-6} [mJm^{-3}]·[Bqm^{-3}]$^{-1}$ is the transfer coefficient, 1.1 mSv·[mJhm^{-3}]$^{-1}$ – the dose coefficient for population, 0.4 – the equilibrium coefficient for radon and radon daughters, $\overline{C}_{\text{Rn}}$ [Bqm^{-3}] – the average annual radon activity indoors, and T_{ref} – the reference exposure time indoors (the number of hours per year).

DISCUSSION

The Stop Radon project includes several phases, as mentioned before. The first two phases were conducted during 2010-2012. During the first phase of the project and in the frames of the Swedish-Ukrainian radon project five training courses similar to the ones given in Sweden by the Swedish Radiation Safety Authority, were developed and conducted by the Swedish and Ukrainian radon experts for the regional professionals: Radon Basics, Natural Radioactive Materials in Water, Radon Measurements, Radon Risk Mapping, and Radon Remediation. The trained regional experts were provided with the basic knowledge of theoretical and practical radiation protection of population, measurement units, physical and biological characteristics of radon and its daughters, methods of radon measurements in air and ground, as well as in water, radon monitoring methods in dwellings, radon activity build up, radon remediation and prevention techniques *etc*.

The goal of the training was to prepare the experts on the regional level to work with radon monitoring, remediation and prevention, as well as to communicate with the population.

The first phase of the project was completed successfully and in the following phase 1043 public buildings including 870 schools and nurseries, were investigated for the radon concentration.

At the same time public communication was performed and 140 radon guiding centers were established in the region. Also a Health Day dedicated to radon was held in all schools of the region. Pupils in the senior schools performed radon measurements and gamma radiation measurements in schools or at their homes as a part of the physics tutoring.

The analysis of the results obtained established a lognormal frequency distribution of the EEC radon activity in the air of the nurseries and schools (fig. 2). The weighted geometrical mean distribution of the EEC radon in different parts of the Kirovograd region is estimated to 91 Bq/m^3 and standard deviation to 83 Bq/m^3. This is an evidence of an uneven distribution of the results of radon activity in the region ranging from 50 Bq/m^3 to 114 Bq/m^3.

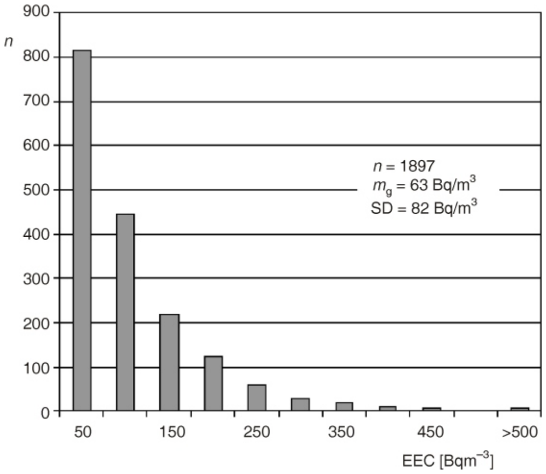

Figure 2. Frequency distribution of radon EEC indoors in the Kirovograd region;
n – number of measurements, m_g – mean geometrical radon EEC, SD – standard deviation

Figure 3. Ratio of buildings where the measured radon activity level exceeds 100 Bq/m^3

The established national radon limit for nurseries and schools of 50 Bq/m^3 was exceeded in 53% of the cases, and more than 28% of the buildings exceeded 100 Bq/m^3. Figure 3 demonstrates the average weighted radon EEC in nurseries and schools of the Kirovograd region.

The analysis of radon activity levels for different districts of Kirovograd region are presented in fig. 3 in percentage of exceeding the national limit of 100 Bq/m^3. This is to visualize the extent of the problem in this region.

When it comes to radon activities in buildings, the dwelling pool of Ukraine can be divided into three categories: detached rural buildings, apartments on the ground level of multistoried apartment buildings, and apartments above the ground level. In the Kirovograd region detached rural houses prevail. As demonstrated in other radon mapping projects in Ukraine [9, 10] the major source of radon gas in Ukrainian buildings is the ground under and around the building. Thus a number of construction characteristics will determine the amount of radon penetrating: type and quality of the isolation in the foundation and presence of a cellar, kind of building material used for floors and presence of a filling in the foundation.

It has been established that for the buildings with wooden floors mean geometric radon activity value is 1.7 times higher than for the enforced concrete floors [11, 12]. Mean geometric value of EEC in dwellings with enforced concrete floors is 57 Bq/m^3 with a standard deviation equal to 82 Bq/m^3 while for the wooden floor dwellings these values are 97 Bq/m^3, and 106 Bq/m^3 correspondently.

Filling of the ground space influences the radon activities indoors as well. In the Kirovograd region slag and crushed stone is used. The analysis of measurement results prove that radon activity is 1.2-2 times higher in the dwellings with slag filling.

The indoor radon activities obtained were used to assess doses to the population of the Kirovograd region exposed in homes and for children exposed in nurseries and schools. A season correction factor was used to obtain more precise results. For this part of Ukraine seasonal ration of winter and summer is 5, which means that radon indoor activities in winter time (heating season) are in average 5 times higher than summer activities.

Average weighted effective dose was established for children exposed in nurseries and schools to 1.7 mSv per year, ranging from 1.2 mSv to 2.43 mSv per year. Additionally, children are exposed at their homes from 1.7 mSv to 10 mSv per year. Thus, summing up the maximum calculated values, the maximum exposure doses for children in Kirovograd region can reach up to 28 mSv per year, while their exposure at home is 4 times the exposure in nursery or school (the effective dose).

Average weighted effective dose to the adult population of the region was established at 3.5 mSv per year, with standard deviation 3.5 mSv per year. Thus, knowing the structure of the dwelling pool and demographic characteristics of the region, one can assess the radiation risks and damage caused by the risk.

In the next step of the analysis the radiological risk to the population of the Kirovograd region was assessed. The risk assessment results were used to justify the intervention actions and to estimate the impact on the region.

The radiological protection system aiming at the reduction of the exposure doses and, consequently early mortality, requires justification of the intervention actions and numerical assessment of radiation risks. The radon risk factors for the region were analyzed and established as follows: total number of population (ration of rural and urban population), average age of the population as a demographic characteristic and structure of the dwelling pool. Thus the collective exposure rate for the population in the Kirovograd region is established at 2150 men Sv per year.

It is worth mentioning that the collective exposure is the major factor used for the analysis of the countermeasures' justification and the total cost estimate. It is assumed that the higher collective exposure dose, the more justified is remediation. Though justification of the remediation is based on the collective exposure dose, even other social-economic parameters are considered for decision making, as well as characteristics of "health" (a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity) [13].

The intervention can be considered justified when a positive balance of these factors is achieved. In another words, the sum of positive and negative numerical values of the consequences has to be more than 0 [14].

For the analysis of the original parameters for each exposure situation different methods of evaluation can be applied, for instance cost-efficiency analysis, cost-benefit analysis, or a monetary value is assigned. The last one is applied in situation when several criteria are assessed and ranged, for example cost-benefit analysis when all influencing factors are expressed in a monetary value. In this case the collective exposure of the population is expressed in a sum of money equal to the loss in a state budget due to the health deterioration as the result of exposure to radiation. This value is proportional to the possible lethal cases multiplied by money value not paid to the gross national product (GNP) during 15 years. Applying this approach other social factors can be assessed.

This approach is described in several international publications, for instance of the ICRP [13, 14], and national Ukrainian scientific works [15, 16].

Let us express this approach in numerical monetary values and use simple arithmetic exercise applying the following formula

$$B \quad Y \quad (X \quad R \quad W) \quad V \qquad (5)$$

where B is the benefit of planned countermeasures, Y – the monetary loss value prevented by these countermeasures, X – the countermeasures cost, R – the monetary value of physical and radiological risks caused by countermeasures, W – the possible waste handling cost, and V – the monetary value of additional benefits that can be achieved as a spin-off of countermeasures.

If $B > 0$, countermeasures (interventions) are justified.

According to expression (5) one must estimate parameter Y – monetary loss value prevented by these countermeasures. This value is calculated as

$$Y \quad \alpha S, \ \alpha \quad GPD/P \ LLE, \ \text{UAH Sv}^{\ 1} \qquad (6)$$

where α is the cost of collective exposure unit, S – the averted collective exposure, GPD – the gross domestic product, P – the total population, and LLE – the lost life time expectancy per unit collective exposure dose.

For LLE the ICRP recommends to apply a value equal to 1.01 years per 1 manSv of collective exposure [13].

Monetary value of physical and radiological risks is defined based on fact that individuals involved in works may be exposed both to radiological and physical risks in their working environment (for instance remediation of contaminated sites).

Monetary value of additional benefits that can be achieved as a spin-off of countermeasures (V) defined for specific cases only, for example, when public risk communication allows for reduction of public concern and anxiousness. In this case (Y) is defined as a monetary value equivalent to preserved health.

There is a number other issues to be considered in the decision making process for intervention: cost of measures and possible loss or damage, professional exposure of workers involved in the countermeasures, social consequences *etc*.

Thus, collective exposure dose for population is a principle criteria used for justification of intervention. When knowing the collective exposure dose other parameters can be derived. Pricing life time expectancy is an important parameter for national gross income planning and in many countries is calculated and established for defined period of time, which means this value vary from country to country and is dependent on several factors [17].

For the alpha-cost estimation, an individual contribution to the gross national income (GNI) is applied. An individual contribution is equal to the GNI divided by the number of country's population. For Ukraine it is estimated to 575.3 billion UAH (Ukraine hryvnia) of GNI divided by 46.7 million people in 2010 which makes an individual contribution to GNI equal to 12300 UAH per year (2440 USD). More information can be found in Ukrainian officially published data [16, 17].

According to the estimates the Kirovograd region with the total population of approximately 1 million people, loses approximately 1.25 million USD annually due to the radon impact on the health of the population and the justification of the remediation actions is thus obvious.

Additionally, the demographical situation analysis at several districts in combination with the dwelling pool, revealed the districts that need urgent attention.

Also in the frames of the international cooperation project with Sweden, radon remediation experts from Sweden were invited and provided expert advice on the remediation methods to be implemented. The radon remediation was implemented in Kirovograd, Znamyanka, and Mala Vyska districts.

The third phase of the pilot project consists of planning and implementation of radon remediation actions and their efficiency evaluation.

Over 300 nurseries and schools are in need of radon remediation actions. At the beginning of the remediation planning experts from Sweden were invited who provided recommendation for the typical buildings and described possible construction solutions. Moreover, in the frames of the trainings conducted together with the experts of SSM (Sweden) the participants received the Radon Book [17]. The Radon Book contains information on all possible radon countermeasures and it was translated into Russian language as a part of the Swedish-Ukrainian radon project. Further on, planning and implementation of radon remediation was performed by the Kirovograd region experts.

In spring 2013 radon measurements were performed again to assess the remediation efficiency. An average reduction of radon activity by 1.5-2 times was demonstrated. The indoor radon activities were not reduced below the established limit everywhere, thus the investigations are continued and more root-cause analysis will be performed.

CONCLUSIONS

The analysis of radon EEC in dwellings and public buildings established a significant variance of radon activities in different settlements. The difference in radon activities between two neighbouring houses can be as much as double. The established national radon limit for nurseries and schools of 50 Bq/m^3 was exceeded in 53% of the cases, and more than 28% of the buildings exceeded 100 Bq/m^3. Average weighted effective dose for children (totally at home and in nurseries/schools) is established at 3.4 mSv per year, reaching maximum of 28 mSv per year, while exposure at home is 4 times the exposure in a nursery or school (the effective dose). Average weighted effective dose to the adult population of the region was established at 3.5 mSv per year.

The Kirovograd region is assessed to lose approximately 1.25 million USD annually due to the radon impact on the health of the population. The justification of the remediation actions is obvious. It was established that the constructional characteristics of a building is the major influencing factor when it comes to radon activities. It is proved in the course of the analysis that a few aspects are particularly important: (a) presence or absence of a cellar and types of insulation between the floor and the ground, (b) types of floors, which enhances the insulation towards the cellar/ground, and (c) types and presence of filling in the foundation.

The Radon monitoring programs should be accompanied by extensive public communication. Programs for children, like dedicated lectures in schools, are particularly efficient. This approach provides children with a basic necessary knowledge about radon and will also reach the parents, as the majority of those are interested in what their children learn at school.

The implementation of the third phase of the radon pilot project proved that radon remediation should be chosen and adjusted for each building separately. This work must be done by professionals having expertise and experience in planning and performing this kind of works.

AUTHOR CONTRIBUTIONS

The research work was done under the leadership of T. Pavlenko. The dose calculations and assessment as well as measurement methods and quality assurance were done by all authors. Article writing and editing was done by O. German.

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УКРАЈИНСКИ ПИЛОТ ПРОЈЕКАТ „СТОП РАДОНУ"

Украјинска Кировградска област изабрана је 2010. године за спровођење пилот пројекта у циљу смањења ризика од излагања радону. Пројекат се остварује у више етапа: кроз обуку о ризицима од радона професионалаца за јавно здравље, мерење концентрације радона у школама и породилиштима (више од 1000 објеката), и утврђивање оправданости мера за смањење концентрације радона и примену тих мера. Утврђена је веродостојна лог-нормална расподела за еквивалентну равнотежну концентрацију. Установљена је геометријска средња вредност еквивалентне равнотежне концентрације радона у унутрашњости објеката од 63 Bq/m^3, са стандардном девијацијом од 82 Bq/m^3. Вредности еквивалентне равнотежне концентрације радона у унутрашњости објеката налазе се у опсегу од 22 Bq/m^3 до 809 Bq/m^3. Утврђено је да је вредност концентрације радона већа од националне граничне вредности за овакав тип зграда у више од 50% испитаних објеката. Друга етапа пројекта има за циљ смањења нивоа радона и ризика од радона. Прорачунате дозе излагања и ризик од радона искоришћени су да потврде оправданост ремедијације и за процену економског губитка области услед излагања популације радону.

Кључне речи: Украјина, радон, радиолошки ризик, ефективна доза