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Problems in radon measurements in context of epidemiological studies

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Epidemiological case control study is considered to be primary instrument to investigate the relationship between population indoor radon exposure and risk of lung cancer. A number of such studies had been completed in last 15 years and others are running now. Considering indoor radon and progeny some specific efforts should be undertaken to assess the exposure. While the lungs exposure after inhalation arises mainly due to radon progeny, in the case of the radon gas measurements application the researchers have to address the disequilibrium between radon and radon progeny. It is widely accepted by researchers and approved by ICRP that worldwide average value of equilibrium factor is 0.4 though real equilibrium factor value can deviate significantly from average. Temporal variation of indoor radon concentration complicates the evaluation of exposure as well. Three types of variation can be emphasized: diurnal, seasonal and long time. Experimental and modeling investigation of radon entry shown that pattern of indoor radon temporal variation firmly depends on relationship between entry rates of primary radon sources (diffusive and advective) and influencing factors are construction characteristics, climatic condition and life style. To find appropriate parameters describing radon disequilibrium and temporal variation it is necessary to perform special investigation in the representative sample of houses.

KEY WORDS: *Air Pollutants, Radioactive; Radiation Monitoring; Radon; Environmental Exposure; Air Pollution, Indoor*

INTRODUCTION

This paper was prepared by using the materials collected for the same titled lecture presented at ECE Workshop (Promotion of New Electrochemical Etching Facility and Its Applications to Natural Radiation Studies in Western Balkan Countries, Belgrade, Serbia and Montenegro, 30 June - 2 July 2003). Some problems arising in radon measurements and evaluation of exposure within the frames of epidemiological studies of effects of radon exposure are discussing in this paper.

It is commonly accepted that radon with its progeny is leading source of radiation exposure of general population. Radon as the natural radioactive gas enters all buildings and variability of indoor radon levels within each region is considerable. On the other hand the methods and techniques of indoor radon concentration measurement are well developed and allow conducting large-scale surveys including epidemiological studies. Thus the population indoor radon exposure becomes one of the most favorable subjects to investigate health effects of low-level radiation exposure. In particular, case control study is considered to be most appropriate epidemiological study design to investigate the relationship between population indoor radon exposure and risk of lung cancer. Case control study allows direct assessment of radiation risk coefficient and adjustment for nonradiation factors. An apparently important advantage of case control study is the evaluation of exposure to harmful agent and possible confounders on individual level.

A number of case control studies of lung cancer risk and indoor radon have been completed in the last 15 years and others are running now. Up to date the results of more than twenty case control studies of lung cancer and radon exposure performed in 10 different countries have been published all over the world.

One of three general indoor radon measurements techniques or its combination is used in the frames of these studies: charcoal canisters sampling, solid-state nuclear track detectors (SSNTD) and retrospective measurements with ^{210}Po surface trap. The most popular measurements method is SSNTD. The duration of SSNTD exposition was 12 months in 12 studies allowing contemporary annual radon concentration assessment although in 9 studies the duration of exposition was less than one year (6 or 3 months).

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Only 3 published studies used new so-called retrospective measurement technique. It can be easily noted that contemporary radon gas concentration measurement was overall preferred in order to assess the indoor radon exposure. By means of the results of contemporary radon gas measurements it is necessary to evaluate the exposure radon and radon progeny. Considering indoor radon and progeny some specific efforts should be undertaken to assess the exposure.

EQUILIBRIUM FACTOR

While lung exposure due to inhalation arises mainly due to radon daughters in the case of radon gas measurements application researchers have to address the disequilibrium between radon and radon progeny. It is accepted by ICRP (1) that worldwide average value of indoor equilibrium factor (F) is 0.4. Real F value depends on climatic conditions as well as house keeping characteristics and can significantly deviate from the averaged estimation. It is considered that in frowzy, dusty and aerosol rich atmosphere the F value is higher than under fresh and clean air conditions. Zhukovsky et al. (2) performed special investigation on F value based on the results of grab sampling measurements of radon progeny using elaborated approach of F value assessment. Using that approach the F values were estimated in about 800 dwellings of Middle Ural region of Russia. Distribution of estimated F values is presented on Figure 1. The average F value in this northern, relatively cold region is 0.5 and it is considerably higher than ICRP value.

Distribution of F values estimated by the same approach in Issyk-Kul area of Kirgisia is presented on the Figure 2. Kirgisian

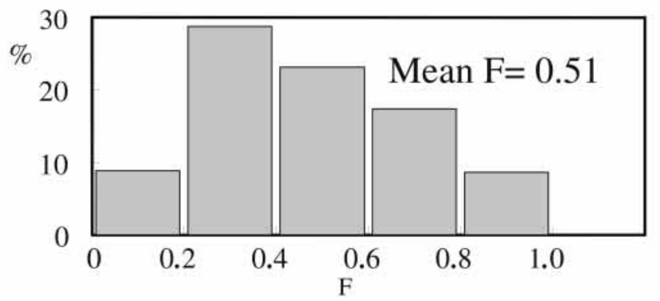

Figure 1. Equilibrium factor in northern region

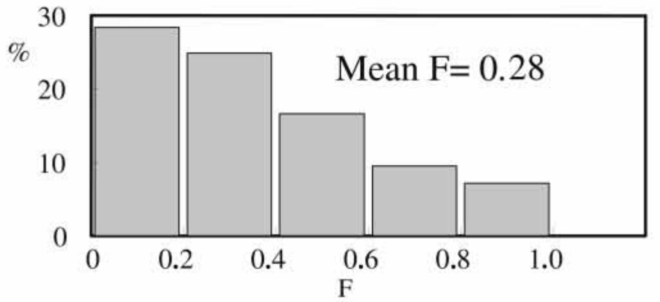

Figure 1. Equilibrium factor in southern region

Republic is situated in Middle Asia region; the climate is more soft, and average temperature considerably higher. It is necessary to note remarkable difference of lifestyle in comparison with Middle Ural region as well. The estimated average F value in Issyk-Kul area is 0.28. That value significantly lower than both ICRP and Middle Ural average values. Moreover comparing the distributions presented on Figure 1 and Figure 2 the significant difference in F distribution pattern in two regions is concluded.

Additionally, comparisons of F values in Middle Ural and Issyk-Kul regions are presented in Table 1 in dependence on type of dwelling and season.

Table 1. Mean equilibrium factor value in north and south regions

Type of dwelling	Season	Urals	Kirgisia
Rural houses	Summer	0.47	0.28
	Winter	0.53	-
Apartments	Summer	0.44	0.26
	Winter	0.44	-

INDOOR RADON TEMPORAL VARIATION

Besides disequilibrium between radon and progeny, the process that influences the exposure estimation by results of contemporary measurements is temporal variation of indoor radon level. Three types of indoor radon temporal variation are considered: diurnal, seasonal, and long-term.

Diurnal variation of indoor radon level could be easily filtered out by exposition of measuring devices, detectors, in indoor atmosphere during few days or longer time. On the one hand such approach allows average indoor radon concentration for period of exposition. However, on the other hand integral measurements of indoor radon does not allow to recognize the contribution of night-time radon concentrations (usually higher) and daytime radon concentrations (usually lower) to indoor radon exposure.

The seasonal variations of indoor radon concentration have to be considered if radon concentration measurements are conducted during the period less than all year (few months). To investigate radon season variation both modeling and experimental studies have been performed (3). The simulation of indoor radon entry has been undertaken by means of two-chamber model of the building and using three sources of radon entry: convective (advective) entry from basement space and diffusion from building materials (primary sources), as well as the infiltration of outdoor atmosphere air. The system of mathematical equations describing indoor radon entry and accumulation has been developed in that way. Performed simulation of the process allows following conclusion: The pattern of radon season variation strongly depends on the relationship between entry rates of primary radon sources. In practice, it is reasonably to consider two general cases: 1) diffusive entry rates are similar in the group of buildings and 2) linear dependence between primary radon sources' entry rates. To find appropriate parameters describing radon season variation, it is useful to investigate the groups of building with identical relation of diffusive to convective entry rates. Utilization of the developed approach consists of obtaining the representative sample of paired observations of winter and summer radon concentrations in groups of buildings supposed to be homogeneous in term of relation between convective and diffusive entry rates. Empirical dependence of summer on winter radon concentration and parameters of regression allow to estimate factors that affect radon season variation and make forecast on the pattern of the variation in similar buildings.

Such approach was used to investigate indoor radon season variation in some region of Russia, Serbia and Kirgisia. For example the observed dependence of summer on winter indoor radon concentration in the sample of buildings in Gornja Stubla region (4) is presented in Figure 3.

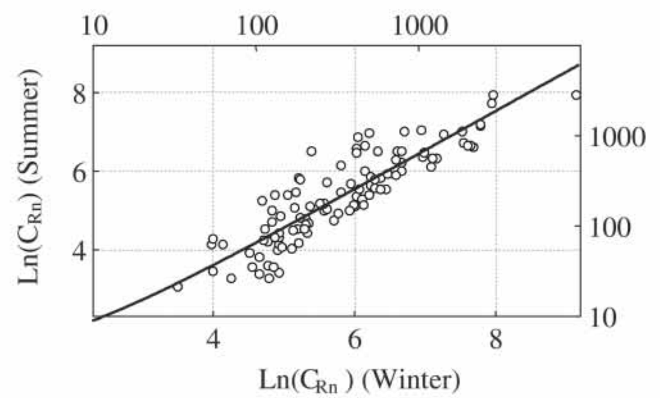

Figure 3. Dependence of summer on winter indoor radon concentration in the sample of buildings in Gornja Stubla

In this case linear equation fits well the dependence and can be utilized to predict annual indoor radon concentration by results of single season measurements.

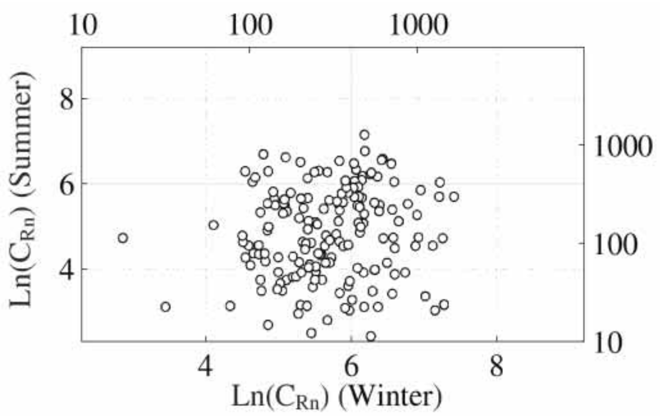

Figure 4. Dependence of summer on winter indoor radon concentration in the sample of buildings in Issyk-Kul region of Kirgisia

Under condition of independent variation of primary radon sources entry rates, a reasonable relationship between the winter and summer radon concentrations could not be found. Example of such observation is presented in Figure 4. The data used to prepare Figure 4 are collected within the frame of the radon survey performed in Issyk-Kul region of Kirgisia (5).

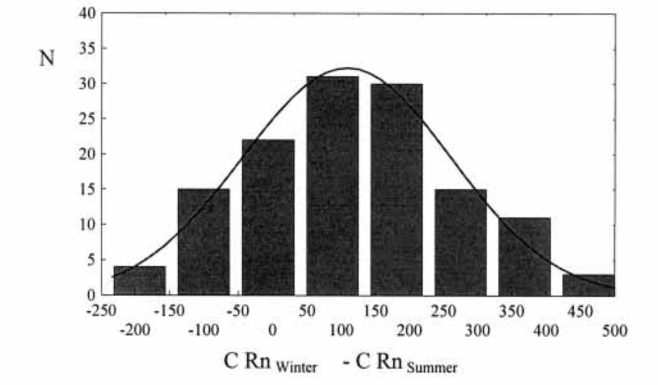

Figure 5. Distribution of difference of winter and summer indoor radon concentrations; solid line is fitted normal distribution

In this case a researcher can just assess the characteristics of winter and summer indoor radon concentrations difference as a parameter of season variation. The distribution of that parameter as observed by data from Issyk-Kul region is normal (Figure 5). The prediction that could be made basing on such observation is much poor and direct measurement during each season is necessary for exposure assessment.

The problem of long-term indoor radon variation is considered to be more important for radon epidemiology. Recently developed technique of retrospective radon measurement (6) allows direct estimation of average radon concentration within the period of interest. While that technique is relatively new the retrospective measurements were unavailable or its application were limited in most of completed radon and lung cancer case control studies. In this case the approaches to reconstruction of indoor radon concentration in the past should be developed. Investigation of indoor radon long-term variation was conducted basing both on the simulation of the process and on the results of field measurements of indoor radon concentration using retrospective and contemporary techniques performed in four regions of Russia and Serbia.

To simulate long-term indoor radon variation the model of the process was developed. The models are quite complicated and include as much as 30 parameters. The parameters used in the model were reviewed to identify those that might be expected to change on a long-term time scale. Only six parameters were considered to be of most importance in this context:

- Moister content in underlying soil, influencing on the soil emanation factor and the soil coefficient of diffusion,
- Factor of convective transfer between soil and basement space,
- Factor of convective transfer between basement space and living room,
- Air exchange rate in living room,

- Air exchange rate in basement,
- Coating thickness of interior wall surfaces.

Specific models of long-term change for these parameters were developed as well. The models were quite simple and just considered the chance of long-term increasing or decreasing of the parameters value in some appropriate range.

By the results of simulation (fifty years time scale) the character of the indoor radon long-term variation is close to linear and can be described as the variation of annual radon concentrations on a year-by-year basis. To describe the long-term variation by that way a coefficient of long-term variation (CLTV) was introduced, which relates the annual radon concentrations of sequential years. The simulation of long-term indoor radon variation has led to the conclusion that two main factors govern the process - long-term change of air exchange rate in indoor living spaces and relationship between contributions of convective and diffusive radon entries to indoor radon concentration. The results of the simulation are presented in Figure 6, which demonstrate the dependence of long term variation coefficient on ratio of convective to diffusive entries taking to account two variants of air exchange rate long-term change - increasing and decreasing.

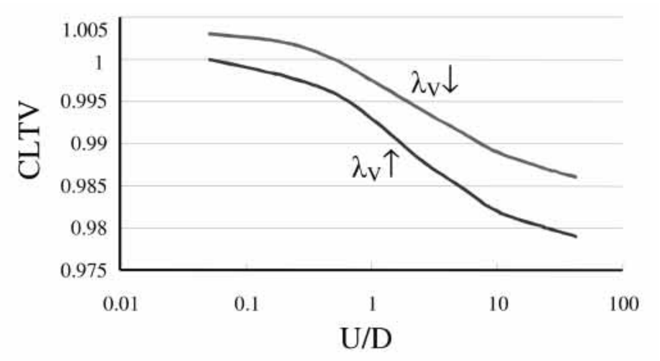

Figure 6. Results of CLTV simulation. (U - contributions of convective and D diffusive radon entries to indoor radon concentration, ↑ - case air exchange rate long-term increasing, $\lambda_V\downarrow$ - case air exchange rate long-term increasing decreasing)

Within the considered model the advective entry of radon from basement space to living room increased permanently due to formation of new entry routes (cracks, gaps, etc.) and radon diffusion from building materials decreased due to new layers of paint or wallpapers on inside walls. Important characteristic is life style of the family occupying the house. The changes in lifestyle may be considered permanent as well, for example due to growing age of dwellers. Thus the CLTV is considered as a constant characteristic of a building occupied by the family. Under constant condition the process is monotonous that is mean that indoor radon concentration either increases or decreases or stays constant. So, not long-term variation should be considered, rather it is long-term change of indoor radon variation.

The value of coefficient of long-term variation can be estimated using results of contemporary and retrospective indoor radon measurements. Experimental investigation was conducted using data of retrospective measurements (so-called 210Po surface traps) obtained in radon surveys performed in typical rural houses of three regions of Serbia and one region of the Urals in Russia. Frequency distribution of long-term variation coefficient in the combined sample is presented in Figure 7.

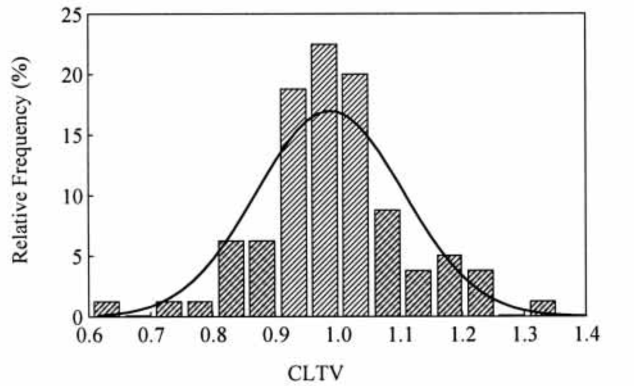

Figure 7. Frequency distribution of CLTV values. Solid line is fitted normal distribution

Observed values follow the normal distribution considering the sample as whole and close to normal in each region.

Average results of the estimation of long-term variation coefficient by regions are presented in Table 2. Mean retrospective, CR, and contemporary, CC, indoor radon concentration are presented in the Table 2 as well. The difference between average values of long-term variation coefficients was tested.

Table 2. Average values of CLTV estimated for houses in four regions

Region	Mean C_R, Bq/m^3	Mean C_C, Bq/m^3	Mean CLTV
Gornja Stubla	328	756	0.87
Kalna	128	194	0.96
Uzice	139	131	1.03
Sysert	161	88	1.06

Figure 8 represents the Box-and-Whisker plot demonstrating the difference of regional mean CLTV, which are plotted versus regional mean values of contemporary indoor radon concentration with standard error of estimation and 95% confidence interval. It can be seen that the difference of regional mean long-term

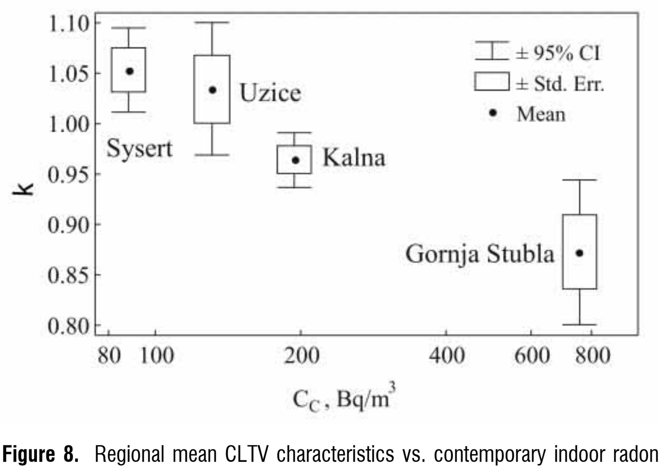

Figure 8. Regional mean CLTV characteristics vs. contemporary indoor radon concentration

variation coefficients is significant. It can also be seen the correlation of mean coefficient values with mean indoor radon level in the regions.

In this regard it is interesting to compare Figure 6, which demonstrates the results of simulation of dependence of long-term variation coefficients on ratio of convective to diffusive entries contribution to radon concentration, and Figure 8, which illustrates the dependence of regional mean coefficient on regional mean indoor radon concentrations. It is obvious that the pattern of relationship is similar. It can be assumed that increasing levels of indoor radon concentration appear due to increasing contribution of convective radon entry. So it is valid to suppose that there is a correlation between the indoor radon concentration and the ratio of contributions of convective and diffusive radon entries.

Recognized characteristic of long-term indoor variation can be used for reconstruction of house specific indoor radon history. The estimation of the CLTV allows not only the integral characteristic of indoor radon exposure within the specific time period but also a year-by-year assessment of annual indoor radon concentration both for years within that period and earlier years as well.

CONCLUSION

Contemporary indoor radon gas measurement results have become a surrogate of indoor radon progeny exposure in epidemiological studies of radon and lung cancer. Such a simplification has resulted in errors in exposure assessment, and increased the uncertainty of radiation risk estimates. More precise exposure assessment could be performed by using special investigation of equilibrium factor and temporal variations of indoor radon concentration in representative sample of the buildings.

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