Model of Lung Cancer Risk Due to Indoor Radon Exposure

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Abstract. Basing on the results of meta-analysis of 21 indoor radon and lung cancer case control studies the approaches to projection of radiation risk were investigated. Developed model of lung cancer risk due to indoor radon exposure utilizes the findings and considerations such as follows: linear dependence of lung cancer risk on indoor radon concentration above annual radon concentration 75 Bq/m³ and duration of exposure 29 years, relative risk of lung cancer is 1.12 (1.07-1.17) at 100 Bq/m³, findings on age dependence of lung cancer risk among uranium and other miners are applicable for indoor radon exposure conditions. Developed approach was utilized to assess the risk of lung cancer due to indoor radon exposure for population of Middle Urals region of Russia. By results of recently performed radon survey average indoor radon equilibrium equivalent concentration in the region is 27 Bq/m³ and thoron EEC is 2.4 Bq/m³. Estimated relative risk of lung cancer due to indoor radon exposure is 1.19 and attributive risk is 16%. Obtained values are 1.5-2 times lower than calculated using BEIR VI models.

1. Introduction

Up to now the models of lung cancer risk due to indoor radon exposure were developed using results of miners cohort studies. Uranium miners were exposed to high levels of radon and progeny. Extended analysis of miners and other epidemiological data were undertaken by BEIR VI Committee and presented in its Report with developed model of lung cancer risk due to radon exposure [1]. The review of cellular and molecular evidence led the Committee to the selection of a linear nonthreshold relation between lung-cancer risk and radon exposure. The use of miner-based extrapolations provides uncertain estimate of expected relative risk – 1.13 at 150 Bq/m³ with a 95% CI of 1.0-1.2 for a 30-year exposure. Uncertainty of risk estimation being high itself increases when extrapolating to the range of indoor exposure.

Considering the low value of expected relative risk a substantial number of subjects is necessary to establish the dose-effect relationship in the case of indoor radon exposure. A number of case control indoor radon and lung cancer studies have been completed around the world. Due to limited case and control groups each study along failed to yield reliable estimation of lung cancer risk due to radon exposure. Recently we have performed a meta-analysis involving published results of twenty one indoor radon and lung cancer case control studies [2]. Case and control groups of meta-analysis included 12 044 and 20 932 subjects accordingly. Using developed approach the weighted average values of odds ratio (OR) in the ranges of radon concentration were estimated. Fig. 1. shows obtained OR values.

By results of meta-analysis the total values of case and control groups allowed significant conclusions on increasing linear dose-response relationships in the range of radon concentration above 75 Bq/m³. The obtained pattern of exposure response dependence doesn’t contradict linear no-threshold theory. The slope factor of linear function representing the coefficient of relative risk is 0.0012 Bq⁻¹m³ (0.007-0.0017). We considered that the results of meta-analysis can be used to develop radiation risk assessment approach.
2. Development of model of lung cancer risk due to indoor radon exposure

To develop the model of lung cancer risk due to indoor radon exposure using the results of performed meta-analysis the following consideration were taken into account:
– linear no-threshold dependence of lung cancer risk on indoor radon exposure is accepted on;
– multiplicative dependence of absolute radiation risk on background lung cancer rate is established by results of epidemiological studies among uranium miners and plutonium workers.

General equation for estimation of excess relative risk (ERR) of lung cancer in dependence on radon exposure rate, Ė, is

\[ \text{ERR}(a,z) = \beta \cdot \phi(a) \cdot \gamma(z) \int_0^a \hat{E}(t) \cdot \theta(a-t) \, dt \]  

where
- \( a \) attained age;
- \( \beta \) coefficient of proportionality with exposure (XXX);
- \( \theta(a-t) \) modification function of time since exposure;
- \( \phi(a) \) modification function of attained age;
- \( \gamma(z) \) modification function of exposure rate.

The following characteristics of groups included to meta-analysis were taken to account to modify the Equation 1:
– weighted average coverage of exposure estimation is 29 years;
– weighted average age of case group subjects is 62 years and weighted average age of oldest subjects of case group is 81 year.

For consistency with results of meta-analysis the radon exposure is considered within two time windows: exposures received at 5-29 years and more than 29 year prior to attained age (with 5 year latency period). By results of meta-analysis the dependence of ERR on exposure rate was not significant in the range of indoor exposure and exposure rate i.e. \( \gamma(z)=1 \). Finally ERR of lung cancer due to radon exposure by developed model is calculated using the following equation:

\[ \text{ERR}(a,z) = \beta \cdot \phi(a) \cdot (P_{5-29} \cdot \theta_{5-29} + P_{29+} \cdot \theta_{29+}) \]  

where
- \( P_{5-29} \) cumulative exposure received 5-29 years prior to attained age, WLM;
- \( P_{29+} \) cumulative exposure received more than 29 year prior to attained age, WLM;
- \( \theta_{5-29} \) and \( \theta_{29+} \) relative contributions of the cumulative exposures in corresponding time period.

FIG. 1. Odds ratios obtained by results of meta-analysis of 21 case control studies of lung cancer and indoor radon exposure (OR=1 at radon concentration category 0-50 Bq/m³).
Relative contributions of exposure in dependence on time since exposure are accepted according to values of appropriate coefficients estimated by BEIR VI Committee. Coefficient $P_{0,29}$ is accepted equal to 1 then the value of $P_{29+}$ is equal to 0.39. To assess modification function $\varphi(a)$ it was accepted that ERR decreases by factor 2 every ten years of attained age and value of function at $\varphi(a)$ age 40 is equal to 1:

$$\varphi(a) = \exp(-\ln(2)/10\cdot(a-40))$$

(3)

Considering low risk of lung cancer at ages less than 40, the value of $\varphi(a)$ for $a<40$ was accepted 1. Then the value of coefficient of proportionality $\beta$ is evaluated under condition that ERR calculated using the Equation 2 is equal to ERR assessed by results of meta-analysis: $\beta=0.058 (0.034 – 0.083)$.

3. Lung cancer risk due to indoor radon exposure of Sverdlovsk oblast population

Developed model of radiation risk was utilized to assess risk of lung cancer due to radon exposure for population of Middle Urals region of Russia (Sverdlovsk oblast). The formal radon survey of Sverdlovsk oblast have been performed in 1992-1999, additionally radon measurements were conducted in some districts in of oblast in 2000-2002. During the studies indoor radon and thoron measurements have had been conducted in about 3300 dwellings which is about 0.3% of housing stock (flats and rural houses). Weighted average values of indoor radon and thoron equilibrium equivalent concentrations (EEC) and parameters of lognormal distribution obtained by results of radon survey and additional measurements are presented in the Table 1.

Table 1. Population weighted average values and parameters of lognormal distribution of indoor radon and thoron EEC in Sverdlovsk oblast.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Radon EEC</th>
<th>Thoron EEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic mean, Bq/m³</td>
<td>27</td>
<td>2.4</td>
</tr>
<tr>
<td>Geometric mean, Bq/m³</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Geometric standard deviation, Bq/m³</td>
<td>3.2</td>
<td>3.9</td>
</tr>
</tbody>
</table>

To assess the parameters of radon induced lung cancer we used sex specific distribution of Sverdlovsk oblast population by ages and age and sex specific lung cancer mortality rate in oblast. Assessed parameters of lung cancer risk for population of Sverdlovsk oblast due to radon exposure with 95% confidence interval are as follows:

- excess absolute risk (EAR) $5.9 \times 10^{-3} (3.5 \times 10^{-3} – 8.4 \times 10^{-3})$,
- relative risk $1.19 (1.11 – 1.27)$,
- attributive risk 16% (10–21%).

The dependence of age specific excess absolute risk of lung cancer due to indoor radon exposure on attained age for average person from Middle Ural population is presented on the Fig. 2. The assessed dependence is monotonous which is general distinct from BEIR risk assessment approach.

Using population characteristics of Sverdlovsk oblast we estimated dependence of lifetime excess absolute risk of radon induced lung cancer on EEC of radon. Results of estimation are presented on the Fig. 3. The estimation is conducted to assess the supportability of Russian Radiation Safety Standards in the field of indoor radon exposure limitation by comparison of risk attributable to radon with reference levels. Using model calculations the reference indoor values included into Russian Radiation Safety Standards (EEC 100 Bq/m³ for new buildings and 200 Bq/m³ for old buildings) were tested and it is obtained that exposure at such levels results in decreasing of lung cancer rate in 1.5 and 1.9 times accordingly.
FIG. 2. Dependence of EAR of lung cancer due to indoor radon exposure on attained age for average person from Middle Ural population.

FIG. 3. Dependence of lifetime EAR of radon induced lung cancer on EEC of radon.

REFERENCES

