Canadian Individual Risks of Radon-induced Lung Cancer for Different Exposure Profiles

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ABSTRACT

Background: Indoor radon has been determined to be the second leading cause of lung cancer after tobacco smoking. There is an increasing need among radiation practitioners to have numerical values of lung cancer risks for men and women, ever-smokers and never-smokers exposed to radon in homes. This study evaluates individual risks for the Canadian population exposed to radon in homes at different radon concentrations and for different periods of their lives.

Methods: Based on the risk model developed recently by U.S. Environmental Protection Agency (EPA), individual risks of radon-induced lung cancers are calculated with Canadian age-specific rates for overall and lung cancer mortalities (1996-2000) as well as the Canadian smoking prevalence data in 2002.

Results: Convenient tables of lifetime relative risks are constructed for lifetime exposures and short exposures between any two age intervals from 0 to 110, and for various radon concentrations found in homes from 50 to 1000 Bq/m^3.

Conclusions: The risk of developing lung cancer from residential radon exposure increases with radon concentration and exposure duration. For short exposure periods, such as 10 or 20 years, risks are higher in middle age groups (30-50) compared especially to the later years. Individuals could lower their risks significantly by reducing radon levels earlier in life. The tables could help radiation protection practitioners to better communicate indoor radon risk to members of the public.

MeSH terms: Radon; lung cancer; risk assessment

La traduction du résumé se trouve à la fin de l'article.

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Radon is an inert radioactive gas produced by the decay of natural uranium in rocks and soils throughout the earth's crust. A certain fraction of the radon escapes into the air where, in the outdoors, it is quickly diluted by atmospheric mixing and is of no further concern. However, in confined spaces such as mines or homes, radon can accumulate to harmful levels. Radon is an alpha-emitter that decays with a half-life of 3.8 days into a short-lived series of progeny which become attached to aerosol particles. By inhalation, these can be deposited in the lungs and bombard sensitive lung tissue with alpha radiation. Over a period of time, this may lead to malignant transformation and the formation of lung cancer.

The most important information concerning the health risks from radon comes from epidemiological studies of underground miners. The National Research Council, Biological Effects of Ionizing Radiations (BEIR) VI committee analyzed results from 11 miner cohorts. Each of the 11 cohort studies shows a statistically significant elevation in lung cancer mortality with increasing radon exposure. In the BEIR VI report,[1] lifetime risks of radon-induced lung cancers from lifetime exposure are given for the US population.

Among radiation protection practitioners and public health workers, there is a strong interest in risk tables for the Canadian population. Exposures for shorter periods of time are of practical interest since exposure to elevated levels of radon may occur and end at any age. To meet this demand, risk tables have been generated using the most recently developed risk model and the most recent data from Statistics Canada. These lookup tables are Canadian lifetime relative risks for exposures between any two age intervals from 0 to 110 and for various radon concentrations found in homes from 50 to 1000 Bq/m^3.

METHODS

The BEIR VI report constitutes an intensive and current summary of radon risk. The BEIR VI committee analyzed results from 11 miner cohorts (4 of these 11 miner studies were Canadian) and presented two preferred risk models, the exposure-age-concentration model and the exposure-age-duration model. The two models were equally preferred by the BEIR VI commit-

tee. However, the two models result in significantly different estimates, when dealing with individual risk at residential radon levels. As stated in the BEIR VI report, the difference in estimates from the two models may be largely an artefact of the analysis, and neither estimate has more credibility than the other. For the purpose of establishing tables of individual risks, one could calculate two sets of risk tables based on the two BEIR VI preferred models, respectively. However, it will be not easy for practitioners to select which set of risk tables to use. To solve this problem, a recent publication of the U.S. Environmental Protection Agency (EPA), "EPA Assessment of Risks from Radon in Homes",[2] arrived at a single model. The EPA model is a reasonable average of the estimates from the two BEIR VI models. The EPA model is used here to calculate lifetime risks of radon-induced lung cancer. In summary, the mathematical form of the EPA model for the excess relative risk (*ERR*) is given as

$$e(a) = \beta W^* \phi_{age}(a) \qquad (1)$$

where a is age in years. The parameter β $(=0.0634)$ represents the slope of the exposure-risk relationship. For a given radon concentration, the total exposure, W^*, can be calculated as the weighted summation of three time-since-exposure windows, namely 5-14, 15-24, and 25 or more years before age a. Exposure in the last 5 years is not biologically relevant to cancer risk.

$$W^* = W_{5\text{-}14} + \theta_{15\text{-}24} W_{15\text{-}24} + \theta_{25+} W_{25+} \qquad (2)$$

$W_{5\text{-}14}$ is the exposure incurred between 5 and 14 yr before age a; $W_{15\text{-}24}$ the exposure incurred between 15 and 24 yr before age a; and W_{25+} the exposure incurred 25 yr or more before age a. $\theta_{15\text{-}24}(=0.78)$ and $\theta_{25+}(=0.51)$ represent the weights of the 15-24 and ≥25 time-since-exposure windows. The parameter $\phi_{age}(a)$ describes the decrease of excess relative risk with increasing age. The continuous function of $\phi_{age}(a)$ given by the EPA is used in the current calculations.

The formulae for the calculation of lifetime relative risk of lung cancer are described in the BEIR IV report.[3] In summary, the lifetime risk of lung cancer is given by the sum of the risks of lung cancer death for each year i:

$$R_e = \sum_{i=1}^{110} \frac{h_i(1+e_i)}{h^*_i + h_i e_i} \prod_{k=1}^{i-1} \exp(-(h^*_k + h_k e_k)) \left[1 - \exp(-(h^*_i + h_i e_i))\right] \qquad (3)$$

where R_e is the lifetime risk of lung cancer under a given exposure pattern; h_i and h^*_i are the lung-cancer and overall mortality rates for age i, respectively, and e_i is the excess relative risk due to exposure to radon and its progeny for age i, as given in Equation (1). A lifespan of 110 years is assumed here.

The computation of lifetime risks depends on the choice of the background age-specific lung-cancer and overall mortality rates, h_i and h^*_i. This study uses Canadian age-specific mortality rates averaged over five years from 1996 to 2000.[4]

According to the BEIR VI report, never-smokers are defined as those persons who had not yet smoked 100 cigarettes, and ever-smokers are those who had smoked at least 100 cigarettes in their lifetime. As in the BEIR VI report, it is accepted that smoking and radon exposure combine in a fashion that is submultiplicative on the relative-risk scale, i.e., less than the anticipated effect if the joint effect were the product of the risks from radon and smoking individually, but more than if the joint effect were the sum of the two individual risks. It further assumed that smoking-induced lung cancer has a 10-year latent period and the relative risks for ever-smokers compared with that for never-smokers are approximately 14 for males and 12 for females. In the adjustment of age-specific lung cancer mortality rates to reflect smoking status, a smoothed version of Canadian age-specific smoking prevalence data for males and females in 2002 is used.[5] The average age of starting to smoke is 18 among Canadians.

RESULTS AND DISCUSSION

Lifetime exposures

Lifetime relative risk (*LRR*) is defined as $LRR = R_e/R_0$, where R_0 is the baseline risk, i.e., the lifetime risk of lung cancer when exposed to background radon level, or the outdoor radon level. The *LRR* describes the proportional increment in lung-cancer risk posed by indoor radon exposure beyond the background level of exposures from outdoor air. Individual risks of radon-induced lung cancers for different exposure profiles are estimated in terms of *LRR*.

Lifetime relative risks of radon-induced lung cancer are given in Figure 1 for lifetime exposures at different radon levels for males and females, respectively. The lifetime absolute risks of lung cancer are much higher for ever-smokers than for never-

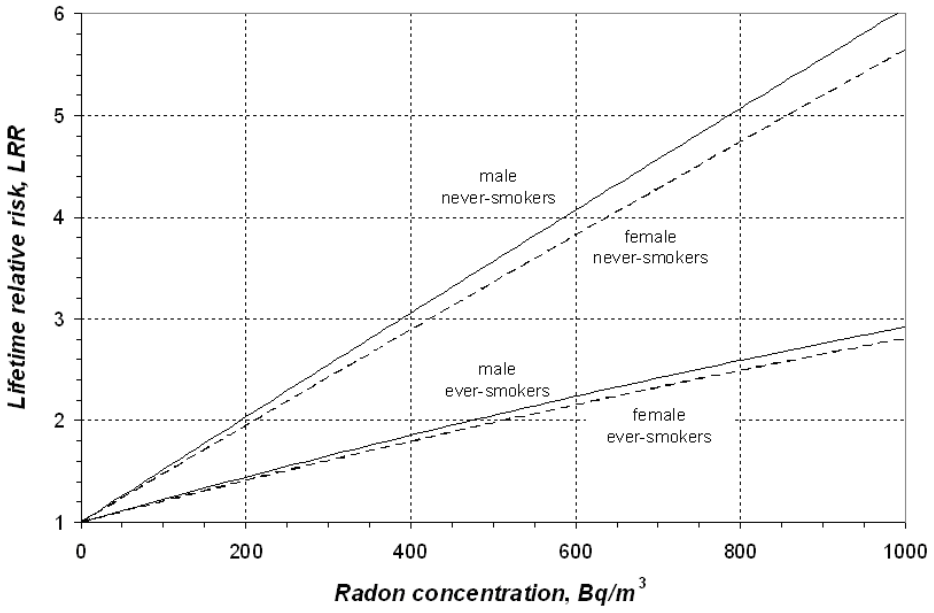

Figure 1. Lifetime relative risks (LRRs) of lung cancer for Canadian males (solid lines) and for Canadian females (broken lines) based on the EPA model and a submultiplicative interaction between smoking and exposure to radon progeny

TABLE I

Estimated Lifetime Risks (R_e) and Lifetime Relative Risks (LRR) of Lung Cancer Mortality for Lifetime Exposure at Various Radon Concentrations

Exposure*	Males				Females			
Bq/m³	Never-smokers		Ever-smokers		Never-smokers		Ever-smokers	
	R_e	*LRR*	R_e	*LRR*	R_e	*LRR*	R_e	*LRR*
0	0.0092	1.000	0.1187	1.000	0.0109	1.000	0.1214	1.000
50	0.0116	1.260	0.1322	1.114	0.0135	1.239	0.1341	1.105
100	0.0140	1.519	0.1455	1.226	0.0161	1.478	0.1467	1.209
150	0.0164	1.778	0.1586	1.336	0.0187	1.716	0.1591	1.311
200	0.0188	2.036	0.1714	1.444	0.0213	1.953	0.1712	1.411
300	0.0235	2.549	0.1963	1.654	0.0265	2.425	0.1950	1.607
400	0.0282	3.059	0.2203	1.855	0.0316	2.894	0.2179	1.796
600	0.0375	4.071	0.2655	2.237	0.0418	3.824	0.2616	2.156
800	0.0468	5.071	0.3077	2.592	0.0518	4.743	0.3025	2.493
1000	0.0559	6.060	0.3467	2.921	0.0617	5.652	0.3408	2.808

* Exposures are presented by concentrations in Bq/m³ assuming to be constant for home occupancy at the 70% level and 40% equilibrium between radon and its progeny.

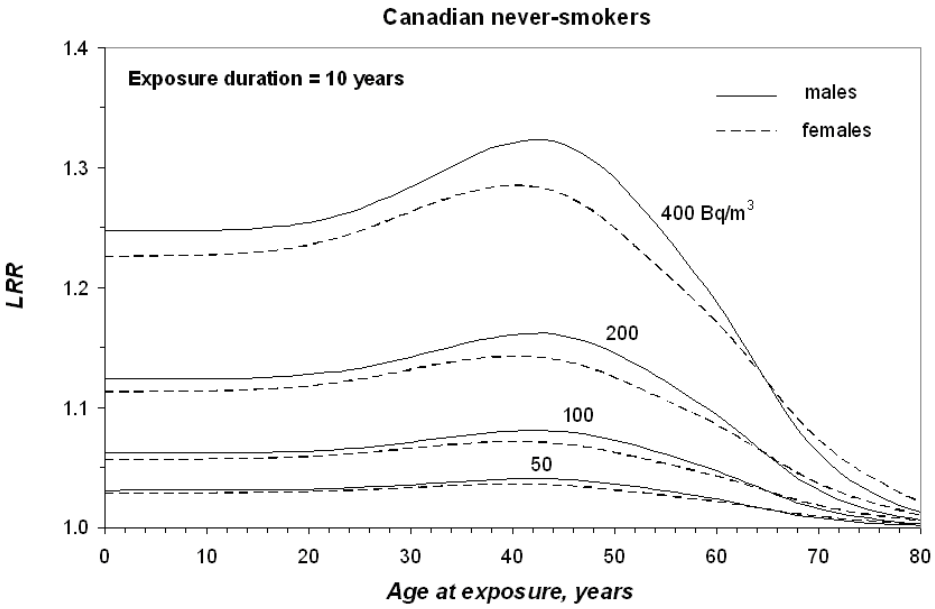

Figure 2. Lifetime relative risks as a function of age at exposure for Canadian never-smokers (solid lines for males and broken lines for females), and for an exposure duration of 10 years. Radon concentrations vary from 50 to 400 Bq/m³ found in most homes. Age at exposure indicates the age when exposure started.

smokers. Due to significantly different baseline risks, R_0, for ever-smokers and never-smokers, the lifetime relative risks are much higher for never-smokers than for ever-smokers, as demonstrated in Figure 1. Selected values of lifetime absolute risks and lifetime relative risks for lifetime exposure are given in Table I. The first row of Table I gives the baseline risks without additional indoor radon exposure, i.e., $R_e=R_0$ and $LRR=1$.

Shorter exposure periods

Most people do not live in a house for their entire life. Radon exposure levels for individuals may change when they relocate or after they take actions to mitigate their house against soil gases. Lifetime relative risks for shorter exposure periods are of practical interest.

Estimated *LRR*s for various exposure periods are tabulated* according to the age when exposure started and the age when it ended for various radon concentrations from 50 to 1000 Bq/m³. In order to see the effect of exposure duration more clearly, some of the tabulated results are presented graphically in Figure 2 for Canadian male and female never-smokers and for an exposure duration of 10 years. The estimated *LRRs* are presented as a function of ages when exposure started.

The risk of developing lung cancer increases with radon concentration and exposure duration. To view the exposure-duration effect more clearly, graphical examples are given in Figure 3 for Canadian never-smokers. Exposure to radon starts at age 0 and ends at different ages later in life. In all cases, the risks increase almost linearly up to age 60. Exposures after age 60 contribute very little to total lifetime risk resulting from lifetime exposure. After about 36 years of exposure, both Canadian males and females reach half of their total lifetime risk for a given radon concentration. This is also true for ever-smokers, even though their *LRR* estimates are different.

Varying exposure profiles

Results given in the tables and figures can be applied to situations where exposures vary with time, such as when a person lives in one house for several years and then moves to another. They are also applicable to exposures in the same house with a changing radon level. The general mathematical form for this type of application is

$$LRR_{total} = 1 + \sum_{i=1}^{n} (\mathrm{LRR}_i - 1) \qquad (4)$$

where n is the number of periods exposed to different radon concentrations. LRR_i is the lifetime relative risk for the period i at a given radon level c_i. With equation (4), one can estimate the individual risk of radon-induced lung cancer for any exposure profile.†

CONCLUSIONS

For lifetime exposures, results for Canadian individuals demonstrate the same pattern as given in the BEIR VI report for the US population. The risk of developing lung cancer from residential radon exposure increases with radon concentration and exposure duration. Because Canadian age-specific mortality rates and smoking prevalence data are used, lifetime risks of radon-induced lung cancer presented here are estimates for Canadian individ-

* Detailed tables of LRRs for Canadian males and females and for ever-smokers and never-smokers are available upon request from the corresponding author.

† Examples of how to apply the risk tables to varying exposure profiles is available with the tables upon request from the corresponding author.

uals. Results‡ are helpful for radiation practitioners to better communicate indoor radon risk to members of the public.

Risks due to radon exposure for shorter periods are of practical interest, because most people do not live in a house for their entire life. Individuals exposed for shorter periods (10-20 years) in the age range 30-50 have a higher risk than those exposed for a similar period in later years. Individuals could lower the risk significantly by reducing radon levels earlier in their life.

REFERENCES

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4. Data source: Canadian Vital Statistics - Death Database 1996-2000, Statistics Canada, Health Statistics Division.
5. The analyses were performed on Health Canada's DAIS|nesstar edition of anonymized microdata from the Canadian Tobacco Use Monitoring Survey, 2002 Annual-Persons File, which contains anonymized microdata collected by the Special Surveys Sub-division, Labour and Household Surveys Branch, Statistics Canada.

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‡ Risk tables for exposures between any two age intervals from 1 to 110 and for various radon concentrations found in most homes from 50 to 1000 Bq/m^3 are available upon request from the corresponding author.

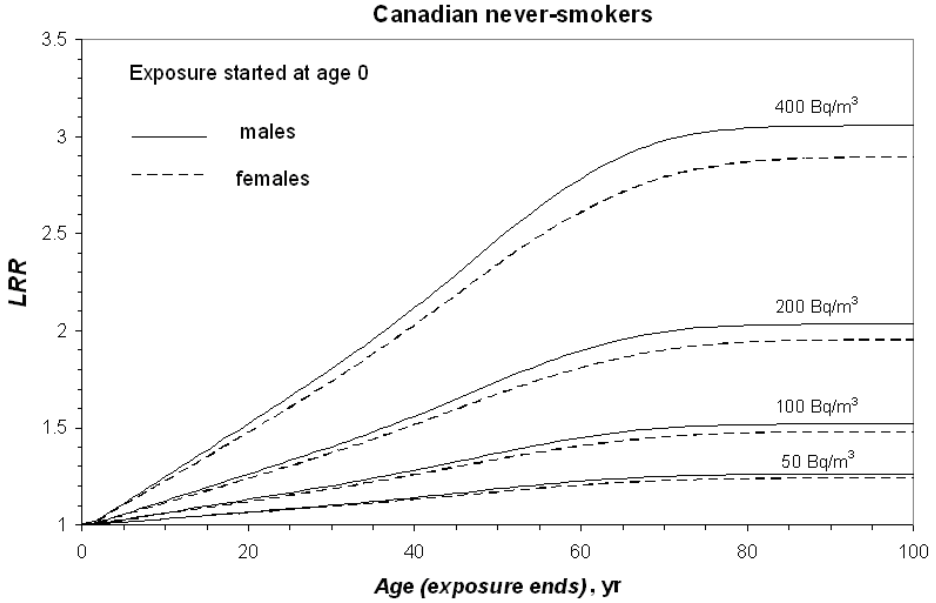

Figure 3. Lifetime relative risk as a function of age when exposure ends, for Canadian never-smokers (solid lines for males and broken lines for females) exposed to radon concentrations of 50, 100, 200, 400 Bq/m^3.

RÉSUMÉ

Contexte : L'exposition au radon en milieu résidentiel est la deuxième principale cause de cancer du poumon après le tabagisme. Les spécialistes de la radiation ont un besoin grandissant de recueillir des données numériques relatives aux risques de cancer du poumon chez les hommes et les femmes, les grands fumeurs et les personnes qui n'ont jamais fumé et qui sont exposés au radon dans un milieu résidentiel. La présente étude vise à évaluer les risques d'exposition des Canadiens au radon en milieu résidentiel, à différentes concentrations et périodes de leur vie.

Méthodes : On a calculé les risques d'exposition individuelle au radon qui entraînent un cancer du poumon à partir du modèle de détermination des risques récemment élaboré par la Environmental Protection Agency (EPA), l'agence américaine de protection de l'environnement. Ces calculs se sont fondés sur les taux, pour des groupes d'âge particuliers au Canada, de décès et de cancer du poumon (1996 à 2000) de même que les données liées à la prévalence du tabagisme au Canada en 2002.

Résultats : La création de tableaux pratiques qui permettent de déterminer l'importance des risques relatifs d'exposition permanente et pour de brèves périodes entre deux intervalles, de la naissance à 110 ans, et pour les différentes concentrations de radon relevées dans les milieux résidentiels, qui se situent entre 50 et 1 000 Bq/m^3.

Conclusions : Le risque de développer un cancer du poumon à la suite de l'exposition résidentielle au radon augmente en fonction de la concentration de radon et de la durée d'exposition. Pour de courtes périodes d'exposition, soit de 10 à 20 ans, ce sont chez les groupes d'âge intermédiaire (de 30 à 50 ans) que les risques sont les plus élevés, tout particulièrement lorsqu'on compare ce groupe au groupe d'âge plus avancé. Il est possible de réduire de façon importante les risques d'exposition au radon en réduisant le plus tôt possible les niveaux d'exposition. Les tableaux pourraient aider les praticiens en radioprotection à mieux faire connaître au grand public les risques d'exposition résidentielle au radon.