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/m3.

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
The formulae for the calculation of lifetime relative 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. 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. The average age of starting to smoke is 18 among Canadians.

RESULTS AND DISCUSSION

Lifetime exposures
Lifetime relative risk (LRR) is defined as $LRR = R / R_0$, where $R_i$ 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-smokers. The average age of starting to smoke is 18 among Canadians.
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., $R_0 = R_0$ 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/m$^3$. In order to see the effect of exposure duration more clearly, some of the tabulated results are presented graphically in Figure 2 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

$$LRR_{total} = 1 + \sum_{i=1}^{n} (LRR_i - 1)$$

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 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.

* Detailed tables of $LRR$s 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

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.

‡ 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/m³ are available upon request from the corresponding author.