Science of the Total Environment 596–597 (2017) 331–341

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Population attributable risk associated with lung cancer induced by residential radon in Canada: Sensitivity to relative risk model and radon probability density function choices
In memory of Professor Jan M. Zielinski

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HIGHLIGHTS

- Many cases of lung cancer in Canada and its provinces are associated with residential radon.
- Population attributable risk is sensitive to recitative risk model and probability distribution choices.
- The miner's relative risk models produce good estimates for population attributable risk for dwelling data.
- Gaussian kernel density estimator is viable for radon data.

GRAPHICAL ABSTRACT

Canadian Population Attributable Risk

Model	Gender	CA	CA(smoothed)	CA	CA(smoothed)
		Ever Smokers		Never Smokers	
BEIR VI models (Empirical Distribution)					
1) Exposure Age Concentration	male	0.160	0.174	0.318	0.340
1) Exposure Age Concentration	female	0.170	0.184	0.330	0.353
2) Exposure Age Duration	male	0.119	0.127	0.247	0.261
2) Exposure Age Duration	female	0.126	0.134	0.256	0.271
3) Scaled Concentration model					
A) Empirical Distribution	male	0.135	0.146	0.274	0.294
A) Empirical Distribution	female	0.143	0.155	0.285	0.305
B) Log-normal Distribution	male	0.144	0.156	0.294	0.314
B) Log-normal Distribution	female	0.153	0.165	0.306	0.306
4) Residential Constant Relative Risk Model					
A) Empirical Distribution					
beta=0.01	male	0.155	0.152	0.173	0.169
beta=0.01	female	0.158	0.154	0.171	0.167
B) Log-normal Distribution					
beta=0.01	male	0.165	0.162	0.187	0.183
beta=0.01	female	0.187	0.183	0.186	0.181
c) Gaussian Kernel estimation					
beta=0.01	male	0.167	0.163	0.186	0.181
beta=0.01	female	0.170	0.166	0.184	0.180

Canadian population attributable risk is sensitive to relative risk model and probability distribution choices, and smoothing of mortality rates and smoking data (Ca vs Ca smoothed). The miner's relative risk models can still be used for dwelling data. Gaussian kernel estimator is also a viable choice for radon data.

ARTICLE INFO

Article history:
Received 15 February 2017
Received in revised form 6 April 2017
Accepted 10 April 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Lung cancer
Radon gas
Residential radon
Attributable risk
Risk assessment
Sensitivity analysis
Smoothing radon probability mass function

ABSTRACT

Indoor radon has been identified as the second leading cause of lung cancer after tobacco smoking. The Population Attributable Risk (PAR) estimates the proportion of lung cancer cases associated with indoor radon exposure. Different relative risk (RR) models have been used in the literature to calculate PAR. The aim of this study is to assess how sensitive PAR is to the relative risk model and radon probability distribution functions choices.

Methods: Using Canadian observed first floor radon data collected by Health Canada during the period October 2010 to March 2011, seven common PAR radon models used for North American miners and dwelling scenarios were applied. The death rates used for this study were from the period 2006–2009. Smoking data (*Ever Smoking* ES and *Never Smoking* NS) collected in 2009 was also used in this study. The original discrete radon data for Canada overall and for each of its provinces are estimated using log-normal and Gaussian kernel density estimator distributions. PAR was then calculated for Canada and its provinces using the empirical, log-normal, and Gaussian kernel estimates distributions. Finally, cancer death cases attributable to radon are reported for the constant relative risk model for the three distributions and the reduction in the cases when the action level 200 Bq/m^3 is applied.

Results: PAR for the Canadian data is sensitive to the model choice, and it varies with a range of 10% for ES and 32% for NS, respectively. There is little difference in results between miners' models and dwelling models. PAR values for ES females are greater than those for ES males, except in Saskatchewan, Northwest Territories, Nunavut, and Yukon. The male-female range overlaps. Gaussian kernel estimator produces PAR estimates similar to the commonly used log-normal distribution.

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http://dx.doi.org/10.1016/j.scitotenv.2017.04.067

Conclusion: Many lung cancer cases could be prevented in Canada by reducing indoor radon. PAR is sensitive to the choice of RR model. Miners' models can be used for residential radon. Empirical, log-normal, and Gaussian kernel density estimation with support $[0, \infty)$ can all be applied to radon data.

1. Introduction

Radon is a radioactive gas that is found naturally in decayed uranium found in rocks and soil. Since it is a gas, it can escape into the air or seep into homes. In the outdoor air, radon does not pose a health risk. However, radon that accumulates in high levels in homes or buildings increases the risk of occupants lung cancer (Health Canada, 2017). The first associations between radon and lung cancer were found from studies of uranium miners exposed to high radon levels in their workplaces. However, recent studies in Europe, North America and Asia have provided strong evidence relating indoor radon and development of lung cancer (World Health Organization (WHO), 2009). Currently, radon is considered to be the second leading cause of lung cancer in the general population after tobacco smoking (World Health Organization (WHO), 2009).

In 1998, Health Canada first established a radon guideline with an action level of 800 Bq/m^3. This guideline was based on data from studies of uranium miners, which was the best information at that time (Chen et al., 2012; Lubin and Boice, 1989). In June 2007, this guideline reduced the action level from 800 Bq/m^3 to 200 Bq/m^3. To continue updating the Canadian guideline, the Cross-Canada of radon concentrations survey project in homes was established in 2009 involving 18,000 participants over two years.

The proportion of lung cancer cases related to indoor radon is assessed by population attributable risk (PAR), which is theoretically the proportion of lung cancer cases prevented by reducing indoor radon concentration Lubin and Boice (1989). Several occupational and residential models derived from epidemiological studies to estimate PAR (Prüss-Üstün et al., 2003). PAR for European populations calculated using various radon concentrations and various risk models can be found in Hunter et al. (2015). Unfortunately, most researchers still use miners' models for residential data. In addition, most ignore the sources of uncertainty and variability in estimating PAR (Krewski et al., 1999). For the most recent Canadian provincial data (2010/2011), no complete study has been done to estimate PAR for Canada and its provinces using the resident model, and none has been done to catch variability due to using various models.

In this work we will ask the following questions:

1. What proportion of lung cancer cases in Canada and each of its provinces could be prevented if indoor radon levels greater than 200 Bq/m^3 are reduced to the outside radon level 15 Bq/m^3?
2. Are there significant differences in PAR estimations if miners' models are used for indoor data?
3. How sensitive is PAR to the relative risk model and radon distribution choices? How big is the range of variability in PAR results?
4. Is log-normal probability density distribution the only distribution that can be used to approximate and smooth radon concentration probability mass distribution? Can Gaussian kernel estimator with support $[0, \infty)$ or any other viable distributions be used in this context?

Note that up to our knowledge this is the first work that uses Gaussian kernel density estimator to produce results for PAR similar to log-normal distribution.

We used indoor radon concentration data during October 2010 to March 2011, smoking data, all cases and lung cancer death rates to calculate PAR. In Section 2, we introduced the sources of our data. In Section 3, the models used in calculations and parameter values are presented. Section 4 discusses the method used to approximate the radon concentration data distribution, and in Section 5, we present the results and conclusion.

2. Data sources for this study

First floor indoor provincial radon data during the period October 2010-March 2011 is provided by Health Canada, details about sampling are given (Health Canada, 2017). The summary of this data is given in Table 1. In the data radon levels $\leq$ 15 Bq/m^3 were hard to measure and given the estimated value 8 Bq/m^3. We replaced all 8 Bq/m^3 values in this radon data by randomly generated values between 0 and 15. We assumed that 2% of the radon provincial data are outlier data, so we ignored 1% from both the lower and the upper bounds of ordered radon data. Note that dropping 1% from the lower bound may solve a big part of the problem coming from measuring radon levels less than or equal to 15 Bq/m^3. Mortality rates data for 2006–2009 by age group and sex are derived from data in Statistics Canada (2017) and Statistics Canada (2017). Provincial smoking data for 2009 by age group and sex are taken from Statistics Canada (Statistics Canada, 2017). Mortality and smoking tables are piecewise constant function, which means average value per interval. In some parts of our work, we smoothed these step functions to be piecewise linear continuous functions achieved by the sequential lines connecting the startings of any two sequential line segments.

3. Methods: life table analysis

3.1. Attribute risk (AR)

The attributable risk is the fraction of lung cancer deaths due to radon.

$$AR = \frac{\int_0^\infty R(\omega)p_m(\omega)d\omega - R(0)}{\int_0^\infty R(\omega)p_m(\omega)d\omega} \tag{1}$$

or

$$AR = \frac{\int_0^\infty (RR(\omega)-1)p_m(\omega)d\omega}{\int_0^\infty RR(\omega)p_m(w)dw}.$$

Here, $p_m(\omega)$ is the probability density function of radon concentration. $R(\omega)$ is the life time risk of the lung cancer for a life time exposure to radon exposure at a yearly rate ω.

$$RR(\omega) = \frac{R(\omega)}{R(0)}, \tag{2}$$

is the lifetime relative risk.

Since lifetime relative risk $RR(\omega)$ depends on age specific risk factors, we define some additional age specific parameters. Let $\mu(i)$ and