Uncertainties in Residential Radon Lung Cancer Risks

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Workshop on Guiding Public Health Policy in Areas of Scientific Uncertainty
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Collaborators

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• Bliss Tracey, Health Canada
• Michael King, McLaughlin Centre
• Kevin Brand, McLaughlin Centre
• Michael Repacholi, WHO
Outline

- What is radon?
- Historical perspectives
- Combined analysis of North American studies
- Consistency of scientific evidence
- Residential radon exposure guidelines
- Cost-effectiveness of radon mitigation
- WHO residential radon project
- Principles of risk management decision making
- Summary and conclusions
Radon-222
\(\alpha,\gamma\)

Polonium-218
\(\alpha,\gamma\)

Lead-214
\(\beta,\gamma\)

Bismuth-214
\(\beta,\gamma\)

Polonium-214
\(\alpha,\gamma\)

Lead-210
\(\beta,\gamma\)

Bismuth-210
\(\beta,\gamma\)

Polonium-210
\(\alpha,\gamma\)

Lead-206
Stable

4 day
3 min
27 min
20 min
0.2 ms
22 yrs
5 day
138 day

\(^{218}\)Po and \(^{214}\)Po deliver radiologically significant dose to the respiratory epithelium.

Long residency in glass

Decay easy to measure
## Epidemiologic Studies of Underground Miners

<table>
<thead>
<tr>
<th>Location</th>
<th>Type of Mine</th>
<th>Number of Miners</th>
<th>Period of Follow-up</th>
<th>Data Available on Smoking</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Tin</td>
<td>17,143</td>
<td>1976-87</td>
<td>Smoker: yes/no (missing on 24% of subjects, 25 (out of 907) nonsmoking lung cancer cases)</td>
</tr>
<tr>
<td>Czech.</td>
<td>Uranium</td>
<td>4,320</td>
<td>1948-90</td>
<td>Not available</td>
</tr>
<tr>
<td>Ontario</td>
<td>Uranium</td>
<td>21,346</td>
<td>1955-86</td>
<td>Not available</td>
</tr>
<tr>
<td>NFLD</td>
<td>Florspar</td>
<td>2,088</td>
<td>1950-84</td>
<td>Type of product, duration, cessation Available for 48% of subjects, incl 25 cases</td>
</tr>
<tr>
<td>Sweden</td>
<td>Iron</td>
<td>1,294</td>
<td>1951-91</td>
<td>Type of product, amount, cessation (from 35% sample of active miners in 1972, supplemented by later surveys)</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Uranium</td>
<td>3,469</td>
<td>1943-85</td>
<td>Cigarette use: duration, rate, cessation (available through time of last physical examination)</td>
</tr>
<tr>
<td>Beaverlodge</td>
<td>Uranium</td>
<td>8,486</td>
<td>1950-80</td>
<td>Not available</td>
</tr>
<tr>
<td>Port Radium</td>
<td>Uranium</td>
<td>2,103</td>
<td>1950-80</td>
<td>Not available</td>
</tr>
<tr>
<td>Radium Hill</td>
<td>Uranium</td>
<td>2,516</td>
<td>1948-87</td>
<td>Smoking status: ever, never, unknown (available for about half the subjects, 1 nonsmoking case)</td>
</tr>
<tr>
<td>France</td>
<td>Uranium</td>
<td>1,785</td>
<td>1948-86</td>
<td>Not available</td>
</tr>
</tbody>
</table>
Case-Control Study of Residential Radon and Lung Cancer in Winnipeg, Manitoba, Canada

E. G. Létourneau,¹ D. Krewski,¹,² N. W. Choi,³,⁴ M. J. Goddard,¹ R. G. McGregor,¹ J. M. Zieliński,¹ and J. Du³

A case-control study of lung cancer in relation to exposure to radon in homes in Winnipeg, Manitoba, Canada, was conducted during 1983–1990. In total, 738 individuals with histologically confirmed incident cases of lung cancer were interviewed, along with 738 controls matched on age (±5 years) and sex. Radon dosimeters were placed in all residences in which the study subjects had reported living within the Winnipeg metropolitan area for at least 1 year. Radon dosimetry was done by means of integrated alpha-track measurements over a 1-year period. In the homes monitored, the average level of radon-222 was about 120 becquerels (Bq)/m³ in the bedroom area and 200 Bq/m³ in the basement. After adjusting for cigarette smoking and education, no increase in the relative risk for any of the histologic types of lung cancer observed among the cases was detected in relation to cumulative exposure to radon. *Am J Epidemiol* 1994; 140:310–22.

confounding factors (epidemiology); logistic models; lung neoplasms; radon; regression analysis; relative risk; smoking
Winnipeg Radon Case-control Study

- **1980**: Cross-Canada radon survey of 18,000 homes
  (average of 150 Bq/m3 in Winnipeg)
- **1982**: First planning meeting for Winnipeg case-control study
  (large scale, complete dosimetry)
- **1984**: Case recruitment initiated
- **1992**: Field work completed
  (750 case-control pairs, 35,000+ dosimeters)
- **1993**: Data analysis completed, manuscript written
- **1994**: Publication in *American Journal of Epidemiology*
  (Letourneau, Krewski, Zielinski et al., 140, pp. 310-322)

Overall odds ratio = 0.97 (0.81, 1.15) at 5,0000 Bq/m3-years
BEIR VI: Health Risks of Radon

- 1994: Committee convened
- 1999: Report released

“Radon responsible for 10-15% of all lung cancer deaths in the United States”
### Inventory of Case-control Studies

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of Studies</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>13</td>
<td>7,148</td>
</tr>
<tr>
<td>North America</td>
<td>7</td>
<td>3,662</td>
</tr>
<tr>
<td>China</td>
<td>2</td>
<td>1,076</td>
</tr>
</tbody>
</table>
## North American Case-control Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Case</strong></td>
</tr>
<tr>
<td>New Jersey (NY)</td>
<td>480</td>
</tr>
<tr>
<td>Winnipeg (Winn)</td>
<td>738</td>
</tr>
<tr>
<td>Missouri-I (MO-I)</td>
<td>618</td>
</tr>
<tr>
<td>Missouri-II (MO-II)</td>
<td>697</td>
</tr>
<tr>
<td>Iowa (IA)</td>
<td>413</td>
</tr>
<tr>
<td>Connecticut (CT)</td>
<td>963</td>
</tr>
<tr>
<td>Utah-South Idaho (UT)</td>
<td>511</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>4,420</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10,127</strong></td>
</tr>
</tbody>
</table>
Residential Radon and Risk of Lung Cancer
A Combined Analysis of 7 North American Case-Control Studies

Daniel Krewski,* Jay H. Lubin,† Jan M. Zielinski,++] Michael Akavanja,‡ Vanessa S. Catalan,∥
Dale P. Sandler,†† Janet B. Schoenberg,‡‡‡ Daniel J. Steck,+++ Jan A. Stolwijk,++++ Clarice Weinberg,+++†††
and Homer B. Wilcox+++†††

Background: Underground miners exposed to high levels of radon have an excess risk of lung cancer. Residential exposure to radon is at much lower levels, and the risk of lung cancer with residential exposure is less clear. We conducted a systematic analysis of pooled data from all North American residential radon studies.

Methods: The pooling project included original data from 7 North American case-control studies, all of which used long-term track detectors to measure residential radon concentrations. A total of 3662 cases and 4966 controls were retained for the analysis. We used conditional likelihood regression to estimate the excess risk of lung cancer.

(Epidemiology, 2005, Vol. 16, pp. 137-145)
Study Designs

- Smoking status: unrestricted vs current non-smokers
- Gender: both males and females vs females only
- Mobility: monitor all residences vs monitor stable population
- Radon dosimetry: one year integrated air measurements vs glass measurements
Distribution of Radon Levels

Radon Concentration (Bq/m³)

New Jersey
Winnipeg
Missouri-I
Missouri-II
Iowa
Connecticut
Utah-Idaho
Combined
### Odds Ratio (95% CI) for Lung Cancers

<table>
<thead>
<tr>
<th>Study</th>
<th>Radon concentration (Bq/m³)</th>
<th>( \beta \times 100 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;25</td>
<td>25-49</td>
</tr>
<tr>
<td>NJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.14</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>(0.8,1.7)</td>
<td>(0.5,2.9)</td>
</tr>
<tr>
<td>Winn</td>
<td>1</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>(0.2,1.3)</td>
<td>(0.3,1.6)</td>
</tr>
<tr>
<td>MO-I</td>
<td>1</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>(0.6,15)</td>
<td>(0.5,1.4)</td>
</tr>
<tr>
<td>MO-II</td>
<td>1</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>(0.5,1.5)</td>
<td>(0.5,1.8)</td>
</tr>
<tr>
<td>IA</td>
<td>1</td>
<td>1.56</td>
</tr>
<tr>
<td></td>
<td>(0.8,2.9)</td>
<td>(0.7,2.5)</td>
</tr>
<tr>
<td>CT</td>
<td>1</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>(0.9,1.4)</td>
<td>(0.6,1.5)</td>
</tr>
<tr>
<td>UT-ID</td>
<td>1</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>(0.7,1.8)</td>
<td>(0.7,1.9)</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>(0.9,1.3)</td>
<td>(0.9,1.3)</td>
</tr>
</tbody>
</table>

\(^a\) ORs stratified by sex, age, duration of smoking, number of cigarettes smoked per day, number of residences and years with alpha-track measurements in the exposure time window.
Restricted Data

• Completeness of Monitoring
  – Years monitored in 5 – 30 year ETW
  – Years monitored with α-track monitors in ETW

• Residential Mobility
  – Occupied only 1 or 2 residences in ETW
## Odds Ratio (95% CI) for Lung Cancers: Restricted Data

<table>
<thead>
<tr>
<th>Study</th>
<th>Radon Concentration (Bq/m³)</th>
<th>β×100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;25</td>
<td>25-49</td>
</tr>
<tr>
<td>NJ</td>
<td>1</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>(0.5,1.5)</td>
<td>(0.3,3.5)</td>
</tr>
<tr>
<td>Winn</td>
<td>1</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>(0.3,3.3)</td>
<td>(0.6,5.3)</td>
</tr>
<tr>
<td>MO-I</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>(0.6,1.7)</td>
<td>(0.6,1.7)</td>
</tr>
<tr>
<td>MO-II</td>
<td>1</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>(0.5,1.5)</td>
<td>(0.5,1.8)</td>
</tr>
<tr>
<td>IA</td>
<td>1</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>(1.1,4.1)</td>
<td>(0.8,3.4)</td>
</tr>
<tr>
<td>CT</td>
<td>1</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>(0.7,1.8)</td>
<td>(0.7,2.4)</td>
</tr>
<tr>
<td>UT-ID</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(0.5,1.8)</td>
<td>(0.8,3.2)</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>1.01</td>
</tr>
<tr>
<td></td>
<td>(0.8,1.3)</td>
<td>(1.0,1.7)</td>
</tr>
</tbody>
</table>
Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies

Relative Risk Estimates
*Cohort vs. Case Control Studies*

- Indoor studies (case-control)
- Miner studies (cohort)
- Ecologic study of Cohen

Log-linear fit to indoor data with 95% CI
Residential Radon in Canada: An Uncertainty Analysis of Population and Individual Lung Cancer Risk

Kevin P. Brand,1* Jan M. Zielinski,1,3,4 and Daniel Krewski1,3

Following a comprehensive evaluation of the health risks of radon, the U.S. National Research Council (US-NRC) concluded that the radon inside the homes of U.S. residents is an important cause of lung cancer. To assess lung cancer risks associated with radon exposure in Canadian homes, we apply the new (US-NRC) techniques, tailoring assumptions to the Canadian context. A two-dimensional uncertainty analysis is used to provide both population-based (population attributable risk, PAR; excess lifetime risk ratio, ELRR; and life-years lost, LYL) and individual-based (ELRR, and LYL) estimates. Our primary results obtained for the Canadian population reveal mean estimates for ELRR, PAR, and LYL are 0.08, 8%, and 0.10 years, respectively. Results are also available and stratified by smoking status (ever versus never). Conveniently, the three indices (ELRR, PAR, and LYL) reveal similar output uncertainty (geometric standard deviation, GSD ≈ 1.3), and in the case of ELRR and LYL comparable variability and uncertainty combined (GSD ≈ 4.2). Simplifying relationships are identified between ELRR, LYL, PAR, and the age-specific excess rate ratio (ERR), which suggest a way to scale results from one population to another. This insight is applied in scaling our baseline results to obtain gender-specific estimates, as well as in simplifying and illuminating sensitivity analysis.

KEY WORDS: Lifetime relative risk; life-years lost; lung cancer; population attributable risk; radon; uncertainty analysis; variability
# Residential Radon Risks in Canada

*Brand, Zielinski & Krewski (2005)*

<table>
<thead>
<tr>
<th>Index of Lifetime Detriment</th>
<th>Overall Population</th>
<th>Ever-Smokers</th>
<th>Never-Smokers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime Relative Risk (LRR)</td>
<td>1.137</td>
<td>1.099</td>
<td>1.195</td>
</tr>
<tr>
<td>(1.003, 1.778)</td>
<td>(1.002, 1.541)</td>
<td>(1.004, 2.069)</td>
<td></td>
</tr>
<tr>
<td>Population attributable Risk (PAR)</td>
<td>0.098</td>
<td>0.073</td>
<td>0.135</td>
</tr>
<tr>
<td>(0.061, 0.155)</td>
<td>(0.038, 0.125)</td>
<td>(0.067, 0.240)</td>
<td></td>
</tr>
</tbody>
</table>
ASSESSMENT AND MANAGEMENT OF RESIDENTIAL RADON HEALTH RISKS: A REPORT FROM THE HEALTH CANADA RADON WORKSHOP

Bliss L. Tracy
Radiation Protection Bureau, Health Canada
Ottawa, Ontario, Canada

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University of Ottawa, Ottawa, Ontario and McLaughlin Centre for Population Health Risk Assessment, University of Ottawa, Ottawa, Ontario, Canada

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Kevin P. Brand
McLaughlin Centre for Population Health Risk Assessment
University of Ottawa, Ottawa, Ontario, Canada

Dorothy Meyerhof
Radiation Protection Bureau, Health Canada
Ottawa, Ontario, Canada
COST EFFECTIVENESS OF RADON MITIGATION IN CANADA

Environmental Health Directorate
Department of National Health and Welfare
775 Brookfield Road, Ottawa, Ont. K1A 1C1, Canada

Abstract — This paper examines the cost effectiveness of comprehensive strategies for reducing exposure to radon gas in indoor air in Canadian homes. The analysis is conducted within the context of a general framework for risk management programme evaluation which includes well-known evaluation techniques such as cost effectiveness and cost–benefit analyses as special cases. Based on this analysis, it is clear that any comprehensive programme to reduce exposure to environmental radon will be extremely expensive, and may not be justifiable in terms of health impact, particularly when considered in relation to other public health programmes. None the less, testing of homes at the point of sale and installing sub-slab suction equipment to reduce exposure to indoor radon where necessary appears to be a relatively cost-effective radon mitigation strategy. Because of regional differences in radon levels in Canada, radon mitigation will be more cost effective in some areas than others. In general, radon mitigation was found to be most cost effective in cities with relatively high levels of radon.
Mitigation Strategies

Screening (5 Options)
1. Screen all current dwellings
2. Screen all newly-constructed dwellings
3. 1+2
4. Screen all homes when they are sold
5. 2+4

Mitigation (3 Options)
Reduce concentrations that exceed some ‘action level’.

- e.g. 800 Bqm$^{-3}$
- 400 Bqm$^{-3}$
- 200 Bqm$^{-3}$
Referent Case:

- Homeowner compliance: 50%
- Reduction in radon concentrations: 90%
- Annual discount rate: 5%
# Incremental Cost-Effectiveness

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Action Level (Bqm⁻³)</th>
<th>Cost (Millions)</th>
<th>QALYs Gained</th>
<th>Incremental Cost ($/QALY Gained)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Screen All Current Homes</td>
<td>200</td>
<td>$661</td>
<td>10,546</td>
<td>$62,636</td>
</tr>
<tr>
<td>3. All Current &amp; New Homes</td>
<td>200</td>
<td>$801</td>
<td>12,379</td>
<td>$76,615</td>
</tr>
</tbody>
</table>

† Discounted at 5% per annum
Using Willingness to Pay to Evaluate the Implementation of Canada’s Residential Radon Exposure Guideline

Jerry M. Spiegel, PhD, MA, MSc
Daniel Krewski, PhD, MHA

ABSTRACT

Background: The objective of this investigation was to determine the effectiveness of Canada’s residential radon exposure guideline in influencing individuals’ health protection decisions.

Method: Homeowners with known exposure levels in a high residential radon area (Winnipeg, Manitoba) were surveyed to document what they had done and spent to reduce their exposure to radon. The 507 respondents were then re-surveyed to elucidate their response to hypothetical scenarios. Logistic regression was used to model risk reduction decisions as a function of exposure and other explanatory variables.

Results: Homeowners were only likely to have taken action to reduce exposure at levels exceeding 1,100 Bq/m³, well above Canada’s guideline of 800 Bq/m³. However, when informed of the guideline, respondents indicated they would act at exposures of 702 Bq/m³.

Interpretation: The Canadian residential radon exposure guideline, as it has been implemented, has not effectively prompted homeowner actions to reduce exposures to radon.
WORLD HEALTH ORGANIZATION'S INTERNATIONAL RADON PROJECT

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Zhanat Carr
Radiation and Environmental Health Programme
World Health Organization

Daniel Krewski
Department of Epidemiology and Community Medicine, Faculty of Medicine, University of Ottawa, Ottawa, Ontario and McLaughlin Centre for Population Health Risk Assessment, University of Ottawa, Ottawa, Ontario, Canada

Michael Repacholi
Radiation and Environmental Health Programme
World Health Organization
WHO Residential Radon Program 2005-2008

- Worldwide database on residential radon levels, radon action levels, regulations, and research institutions and authorities
- Public health guidance for awareness-raising and mitigation
- Global burden of disease associated with residential radon exposure
RISK MANAGEMENT FRAMEWORKS FOR HUMAN HEALTH AND ENVIRONMENTAL RISKS

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John H. Shortreed, Lorraine Craig
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McLaughlin Centre for Population Health Risk Assessment, University of Ottawa, Ottawa, Ontario, Canada

Chris Furgal
Public Health Research Unit, Université Laval, Beauport, Quebec, Canada

Stephen McColl
Department of Health Studies and Gerontology, University of Waterloo, Waterloo, Ontario, Canada

A comprehensive analytical review of the risk assessment, risk management, and risk communication approaches currently being undertaken by key national, provincial/state, territorial, and international agencies was conducted. The information acquired in this review was used to identify the differences, commonalities, strengths, and weaknesses amongst the various approaches, and to identify elements that should be included in an effective, current, and comprehensive approach applicable to environmental, human health and occupational health risks.
Principles of Risk Management Decision Making

- Do more good than harm
- Fair process of decision making
- Ensure an equitable distribution of risk
- Seek optimal use of limited risk management resources
- Promise no more risk management than can be delivered
- Impose no more risk than you would tolerate yourself
- Be cautious in the face of uncertainty
- Foster informed decision making for all stakeholders
- Risk management processes must be flexible and evolutionary
- The complete elimination of risk is not possible
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- Risk management processes must be flexible and evolutionary
- The complete elimination of risk is not possible
Precautionary Principle

- ‘Better safe than sorry’ principle
- A tool to aid decision-making under conditions of uncertainty
- Fast becoming a fundamental principle of international environmental law
  - Present in over 20 international laws, treaties, protocols and declarations
- Application to health risk management?
  - Currently unclear
  - Widespread debate regarding the definition, scope and implementation of the principle
  - As many as 14 different interpretations currently in use
Precautionary Principle

“En route to Paris, smoke was detected in the cockpit, and as a precautionary measure, flight AC 882 made an unscheduled landing in Goose Bay to investigate further.”

Air Canada, July 5, 2005
Applicable Issues

Scientific Uncertainty

- Climate Change
- Biodiversity Loss
- Particular Matter
- Ozone Depletion
- BSE & vCJD
- GMOs

Harm

- less serious reversible
- serious irreversible
Risk Based Decision Making

“The best use of resources will have proportionality - the effort/action should be proportional to or bear a reasonable relation to the level of risk.”

Jardine et al. (2003)
Radon: Summary and Conclusions

• Studies of underground miners have implicated radon as a known cause of lung cancer in humans

• Recent studies of residential radon have provided direct evidence of increased lung cancer risks due to radon in homes

• These residential data are consistent with predictions based on extrapolation of the miner data

• Collectively, these data suggest that radon may play a role in about 10% of all lung cancer deaths
Radon: Remaining Uncertainties

- Global indoor radon concentrations
- Global burden of disease
- Establishment of cost-effective radon guidelines
- Communication of residential radon risks