Using Willingness to Pay to Evaluate the Implementation of Canada's Residential Radon Exposure Guideline

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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/m^3, well above Canada's guideline of 800 Bq/m^3. However, when informed of the guideline, respondents indicated they would act at exposures of 702 Bq/m^3.

Interpretation: The Canadian residential radon exposure guideline, as it has been implemented, has not effectively prompted homeowner actions to reduce exposures to radon.

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

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In 1988, a guideline for residential exposure to radon, an acknowledged lung carcinogen,[1-5] was adopted in Canada.[6] This guideline recommends that individuals act to reduce risk at a level (800 Bq/m^3) considerably higher than that recommended in the United States (150 Bq/m^3*). Its effectiveness in encouraging exposure reduction has never been evaluated. This study assesses compliance with the guideline by considering willingness to pay (WTP) for risk reduction in relation to actual exposures and responses to hypothetical scenarios.[7]

Winnipeg, Manitoba is the Canadian city with the highest proportion of homes with relatively high radon levels.[8-10] An epidemiological study conducted here between 1986 and 1991 provided a data set of 4,448 houses with exposure measurements.[11]

METHODS

Drawing from a stratified sample of 1,225 single family dwellings with known radon concentrations, residents were identified from a reverse phone directory[12] and surveyed (Figure 1). First, a mixed mode mail/telephone protocol was applied to document actions taken and expenditures made (i.e. "revealed preferences") for reducing exposure to radon and three other environmental health hazards (drinking water, ultraviolet radiation, and the threat of sewer backup in anticipation of Winnipeg's 1997 Red River flood). Other questions dealt with demographic characteristics as well as knowledge and attitudes toward risks.

A follow-up questionnaire was then mailed to all 507 respondents to obtain "expressed preference" values for reducing risk by applying a contingent valuation approach.[13,14] Respondents were given information summarizing the health risks of residential exposure to radon,[7] and then presented with various hypothetical exposure scenarios ranging from 225 Bq/m^3 to 1800 Bq/m^3. For each exposure situation, double-bounded dichotomous choice bid options were presented,[15] whereby respondents were asked if they would pay a proposed price for each action alternative, with follow-up bid options then provided that were greater or less than the amounts

* This level is roughly equal to 4 picocuries, the unit used in the United States to express its guideline.

initially presented. To examine potential influences of differences in risk communication messages,[16] the sample was randomly split into two: one group only being told of the Canadian recommended action levels, with the other group also informed of the corresponding U.S. values.

Logistic regression analysis[17] was conducted to examine influences on the decision to have spent any money or offer a positive bid to reduce risk. As the decision to reduce risk is not merely a single dichotomous choice of deciding to "mitigate" or "not mitigate", but rather represents a progression of stages,[18,19] responses were grouped as follows:

Stage 1: Obtained information.

Stage 2: Obtained exposure measurement; assessed risk reduction options.

Stage 3: Took action to reduce risk (e.g., blocking drains or sealing cracks).

Stage 4: Took action to virtually eliminate exposure (e.g., subslab depressurization).

A variable indicating attainment of each stage was included in our logistic regression analysis.

Each individual who completed the expressed preference WTP survey responded to 4 different bid options for each of 4 different radon exposure levels. As these different bids constitute 16 distinct records for regression analysis, the standard statistical assumption that all observations are independent is violated by the presence of repeated measures. Burton *et al.* have cautioned against the use of such *naïve pooling* approaches to multivariate analysis, and recommended the application of generalized estimating equations (GEE).[20,21] Accordingly, for all cases where such repeated measures were used, GEE analysis as implemented in SAS was used instead of standard logistic regression.

A full discussion of influences on risk reduction decision-making beyond the key findings can be found elsewhere.[7]

RESULTS

A response rate of 41.4% was obtained in the "revealed preference" survey. The follow-up "expressed preference" survey respondents (response rate of 53.2%) tended to be somewhat older, more likely to have been long-time residents, and more likely to expect to be staying in the same home than non-respondents. While this response rate is a potential weakness, none of these factors were found to be significant predictors of willingness to pay in the regression analyses conducted. Respondents were less likely to have acted in response to radon exposure than was the case for the other environmental health hazards considered (Figure 2). However, for those who did act, the mean amount spent tended to be higher (Table I). Assuming that the measures undertaken were effective,* respondents paid an average of $221 per 100 Bq/m^3 reduction in exposure.

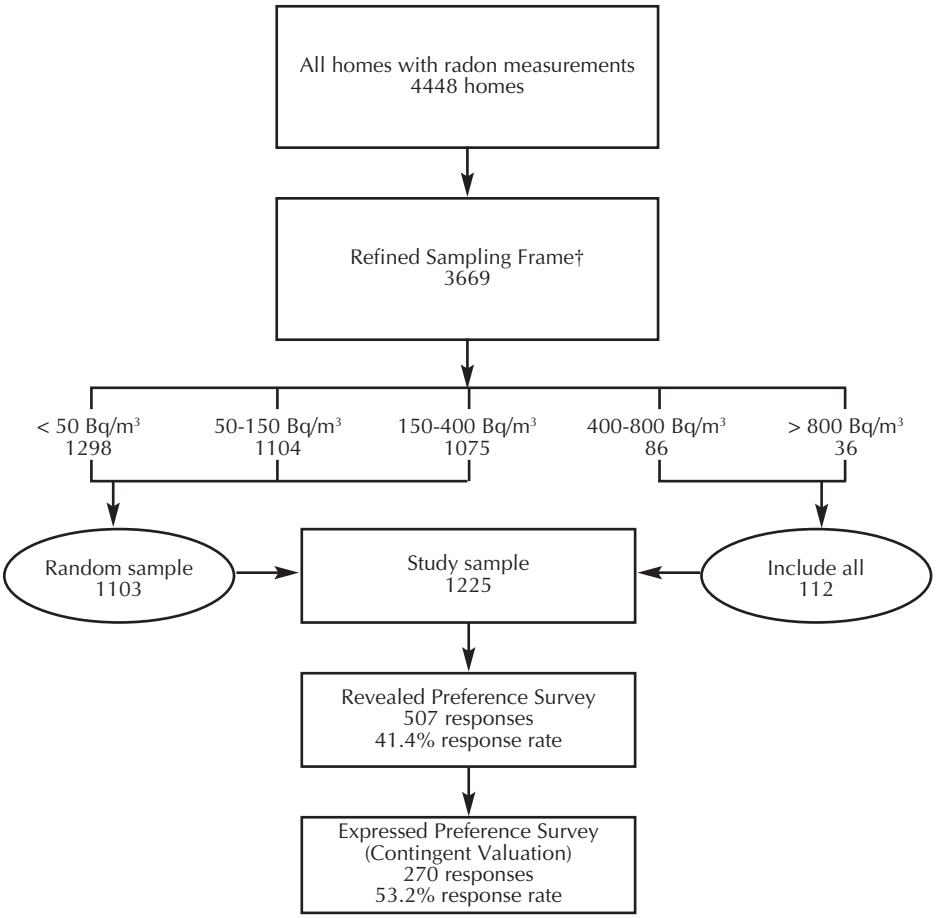

Figure 1. Sample selection protocol
† Excludes duplicates and apartments

WTP varied directly with level of radon exposure. As hypothetical exposures rose, respondents' likelihood of expressing a positive bid increased (Table II). Nevertheless, the probability of actually having spent any money at levels over twice the Canadian guideline level still remained relatively low (59%). A similar tendency was observed with respect to the likelihood of having actually spent any money to reduce actual household radon levels.

The construct of reaching a stage of risk reduction provides a more realistic representation of possible actions that might be taken in response to environmental health guidelines. For each 100 Bq/m^3 increase in radon exposure, the likelihood of advancing to the next highest protective behaviour stage rose by somewhere in the range of 20 to 44%, providing a basis for estimating the probability of individuals actually reaching a risk reduction stage at specified exposure levels. Table III provides these estimates for revealed and expressed preferences for the different hypothetical exposure scenario radon levels.

Figure 3, which shows the likelihood of having proceeded to Stage 3 (risk reduction) behaviour depending on the level of radon exposure, illustrates the point at

* Follow-up measurements were not conducted. For this calculation, it was assumed that subslab depressurization would be 99% effective and the repairing of cracks and sealing of drain openings, etc., would be 30% effective.

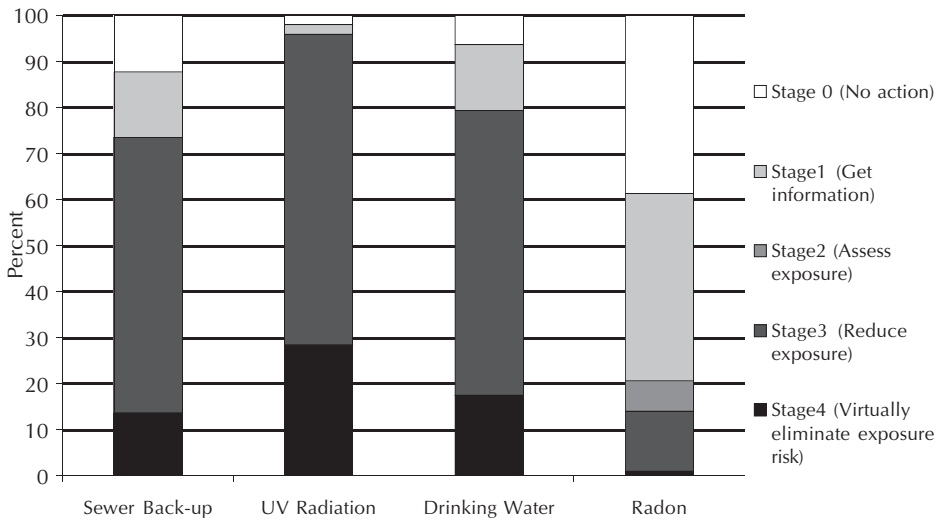

Figure 2. Distribution of willingness to pay by protective behaviour stage for different environmental health risks

TABLE I

Mean Amount Spent by Protective Behaviour Stage for Different Environmental Health Risks ± Standard Deviation

Stage	Sewer Back-up	Ultraviolet Radiation	Drinking Water	Radon
Stage 1: Obtain information	$35.69 (± 211.01)	$2.00 (± 6.32)	$1.25 (± 6.70)	$0.00 –
Stage 2: Measure	– –	– –	– –	$7.94 (±27.94)
Stage 3: Reduce exposure level*	$60.46 (± 173.73)	$48.85 (± 49.61)	$77.80 (± 165.14)	$183.82 (± 670.11)
Stage 4: Virtual risk elimination*	$383.04 (± 714.17)	$175.00 (± 535.24)	$88.93 (± 89.31)	$1,462.80 (± 2144.47)

* Examples of preventive actions for reducing the extent of exposure include the following:
Sewer back-up: Move articles from basement; install back-up valve, cut-off valve, sump pump.
UV radiation exposure: Purchase sun screen, protective clothing, alter recreational plans, additional sun protection.
Drinking water effects: Purchase bottled water, reduce water consumed; purchase/rent portable or fixed filters or distillers.
Radon exposure: Block drain / seal cracks, avoid basement, subslab depressurization.

TABLE II

Influence of Living Area Radon Level on Decision 1) to Have Spent Any Money or 2) to Express a Positive WTP Bid to Reduce Radon Exposure

Dependent Variable	Radon Exposure Level	Odds Ratio* of Spending or Bidding	Probability of Spending or Bidding
Revealed preference bids (payment actually made)	per 100 Bq/m^3	1.18**	90.4%
	Predicted at:		
	at 1800 Bq/m^3	12.75	59.0%
	at 900 Bq/m^3	2.98	25.2%
	at 450 Bq/m^3	1.44	14.0%
	at 225 Bq/m^3	reference	10.2%
Expressed preference bids (payment offered)	at 1800 Bq/m^3	5.79***	90.4%
	at 900 Bq/m^3	2.93***	82.6%
	at 450 Bq/m^3	1.52***	71.1%
	at 225 Bq/m^3	reference	61.9%

* Generalized Estimation Equation parameter estimates; Odds ratio for expressed preference presented in relation to acting at exposure of 225 Bq/m^3; Odds ratio for revealed preference presented in relation to each increase of 100 Bq/m^3
** p<0.01 *** p<0.001

which it is likely (defined as a 50% probability of taking action) that individuals would have acted to reduce exposure. This analysis suggests that individuals are only likely to have acted at a radon exposure of 1101 Bq/m^3, a level well above the Canadian guideline of 800 Bq/m^3. In contrast, however, when presented with hypothetical exposure situations and information explaining the guideline, respondents indicated that they would act at levels of 702 Bq/m^3.

Our data further suggest that the inclination to take risk reduction action is influenced by both the nature of the information provided and respondents' knowledge about radon. Respondents who were informed of the existence of the lower U.S. guideline were almost twice as likely (a statistically significant odds ratio of 1.9) to indicate they would spend money to reduce risk at an exposure level (450 Bq/m^3) midway between the U.S. and Canadian guidelines.

The probability of respondents having actually acted to reduce risk was consistently less than what they reported they would do in comparable exposure scenarios. However, when adjustment was made for the effect of having accurate knowledge of the health effects of radon, this discrepancy narrows, particularly at exposure levels in excess of the Canadian guideline (Figure 4). In this regard, it should be noted that only 21%, of those surveyed indicated they had been aware of the guideline, and only 38% could correctly identify the health concerns associated with radon exposure. While having such knowledge was itself a significant predictor of having taken risk reduction action, those aware of the Canadian guideline were in fact less prone to have acted in exposure scenarios approaching 800 Bq/m^3.

Increase in radon exposure was a statistically significant predictor of the likelihood to make a positive bid when multivariate analysis was conducted, as was individuals' expressions of anxiety that their health was being affected by environmental exposures in general. Multivariate analysis of the likelihood of actually having spent any money indicated that variables related to the level of knowledge and attitudes toward risk generally provided a better explanation of individual actions than the degree of expo-

sure. However, when the likelihood of proceeding to the stages of taking risk reduction action was used as the dependent variable, there was indeed a significant association with the actual level of radon exposure.

DISCUSSION

Agencies responsible for ensuring that the population is protected from environmental health risks can use a variety of policy instruments to achieve their objectives.[22] Interest in alternatives to "command and control" regulatory interventions has encouraged consideration of public policy interventions based on voluntary risk reduction actions.[23] It has even been suggested that it would be more appropriate to support individuals making "informed choices" rather than to regulate requirements for reducing risk.[24] Nevertheless, despite the population health implications of such interventions, few studies of their effectiveness have been undertaken, and those conducted to date have focused primarily on their impact on raising awareness rather than pursuing recommended behaviours.[25]

Contingent valuation studies, which provide a basis for estimating likely behaviour in relation to the cost of risk reduction actions and awareness of risk, are of particular relevance when considering scenarios that rely on voluntary risk mitigation actions. Consideration of stages of risk reduction action, as had been suggested for use in previous economic analyses of radon mitigation behaviour,[26] provides a particularly useful basis for analysis.

The evidence presented in this study suggests that the Canadian radon exposure guideline, as it has been implemented, has not been effective in stimulating action to reduce exposures occurring in the vicinity of the guideline. Those at risk do not appear to have been inclined to take action until exposures are substantially higher than the recommended level. This finding is of particular interest in light of the fact that the Canadian radon guideline is notably higher than similar guidelines established in other countries.

When respondents were provided with information on the health risks of radon, however, the level at which they indicated they would act was just above 700 Bq/m^3, an action level consistent with the Canadian guideline. This suggests that the likelihood of achieving the guideline's policy objective of encouraging health-protective behaviours would be increased through effective promotion of the awareness of radon risks.

When the Canadian radon exposure guideline was adopted, it was acknowledged that there was relatively little economic data to consider its policy implications. Research conducted following adoption of the guideline, however, has provided evidence that the cost-effectiveness per life year saved is attractive relative to other environmental health risks.[27-29] These results further indicate that targeting of interventions to areas of higher exposure, such as Winnipeg, provides a more cost-effective strategy for enhancing population health.

This study indicates that individuals respond rationally to radon risk, with their likelihood of acting directly associated with their level of exposure, and also influenced by other factors such as general levels of anxiety concerning environmental health risks. Accordingly, if information was bet-

TABLE III

Influence of Living Area Radon Level on Reaching Protective Behaviour Stage – Revealed and Expressed Preference

Dependent Variable	Stage 1 (Obtain Information) or more	Stage 2 (Measure) or more	Stage 3 (Reduce exposure) or more	Stage 4 (Virtual elimination)
Revealed Preference				
Odds ratio*	1.28	1.20	1.23	1.44
Probability of reaching stage				
@ 1800 Bq/m^3	98.9%	83.4%	80.7%	67.7%
@ 900 Bq/m^3	90.7%	48.7%	38.9%	7.1%
@ 450 Bq/m^3	76.0%	29.3%	20.9%	1.5%
@ 225 Bq/m^3	64.4%	21.4%	14.3%	0.7%
Expressed Preference				
Odds ratio **				
@ 1800 Bq/m^3	5.8	7.9	5.4	2.6
@ 900 Bq/m^3	2.9	3.7	3.4	1.7
@ 450 Bq/m^3	1.5	1.6	1.5	1.1 (ns)
Probability of reaching stage				
@ 1800 Bq/m^3	90.4%	84.4%	69.3%	38.9%
@ 900 Bq/m^3	82.6%	71.9%	58.5%	25.9%
@ 450 Bq/m^3	71.1%	53.0%	39.2%	15.9%
@ 225 Bq/m^3	61.8%	40.7%	29.5%	11.9% (ns)

* Odds ratio expresses increased likelihood of reaching a stage for each 100 Bq /m^3 increase in radon exposure; Generalized Estimation Equation parameter estimates; All odds ratios p<0.0001

** Odds ratio expresses the increased likelihood compared to that at 225 Bq/m^3; Generalized Estimation Equation parameter estimates; All odds ratios p<0.0001 except where noted by (ns)

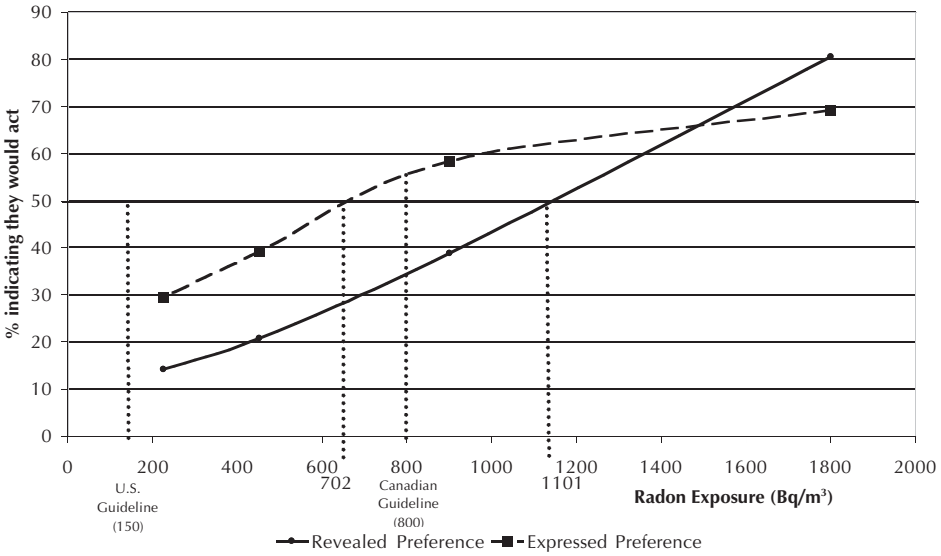

Figure 3. Probability of reducing radon risk (Stage 3) – expressed vs revealed preference

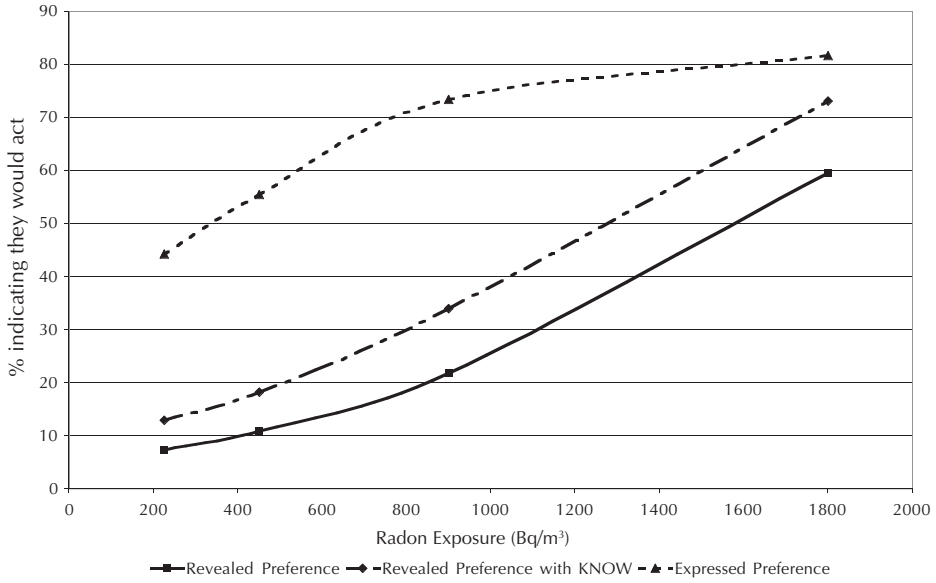

Figure 4. Influence of being informed on the probability of reducing risk (Stage 3).

ter communicated, it could be presumed that it could effectively be applied voluntarily. Similarly, the use of incentives could be considered as a further way to influence voluntary actions.

Since the introduction of the Canadian residential radon exposure guideline in 1988, scientific data on radon and lung cancer has continued to accumulate. A review of the health effects of exposure to radon recently conducted by the U.S. National Research Council concluded that radon in U.S. homes is responsible for some 10-15% of all lung cancer cases in that country.[1] This estimate is based on a combined analysis of lung cancer rates in over 60,000 underground miners from eleven different epidemiologic studies conducted around the world, including uranium miners in northern Ontario and fluorospar miners in Newfoundland.[3] Extrapolation of the miner data to the lower exposure levels of exposure encountered in residential settings in fact produces risk estimates that are compatible with those based on a meta-analysis of eight large scale case-control studies of residential radon exposure and lung cancer.[2]

CONCLUSIONS

In light of the recent BEIR VI review of the health effects of radon confirming earlier evidence of lung cancer risks associated with exposure, it may be opportune to reconsider the Canadian residential exposure guideline, which remains one of the highest of any country maintaining such a guideline. However, if such a re-examination is undertaken, attention should not be restricted to reviewing the guideline's numerical value. Given our current understanding of public attitudes towards radon risks, consideration should be given to implementation of a broader risk management strategy for residential radon risks that could promote action to reduce risk through more effective risk communication, particularly in areas of high exposure. Guidelines, after all, are not ends in and of themselves, but rather a means of promoting risk reduction and enhancing population health.

REFERENCES

1. National Research Council. *Health Effects of Exposure to Radon: BEIR VI*. Washington, DC: National Academy Press, 1999.
2. Lubin JH, Boice JD, Jr. Lung cancer risk from residential radon: Meta-analysis of eight epidemiologic studies. *J Natl Cancer Inst* 1997;89:49-57.
3. Lubin JH, Boice JD, Jr, Edling C, et al. Lung cancer in radon-exposed miners and estimation of risk from indoor exposure. *J Natl Cancer Inst* 1995;87:817-27.
4. IARC. *Man-Made Fibres and Radon. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans,* Vol. 43. Lyon: International Agency for Research on Cancer, 1988.
5. Krewski D, Rai SN, Zielinski JM, et al. Characterization of uncertainty and variability in residential radon cancer risks. *Ann NY Academ Sci* 1999;895:245-72.
6. Canada Mortgage and Housing Corporation (CMHC). *Radon - A Guide for Canadian Homeowners.* Ottawa: CMHC and Health Canada Report C97-090282-2, 1997.
7. Spiegel JM. *A Comparison of Economic Valuation Methods for Environmental Health Risk Reduction: Assessing Residential Radon Mitigation in Manitoba [dissertation].* Winnipeg, MB: University of Manitoba, 2000.
8. Letourneau EG, et al. A Radon Standard for Canada. In: Walkinshaw DS (Ed.). *Transactions of Indoor Air Quality in Cold Climates: Hazards and Abatement Measures.* Air Pollution Control Association, 1985.
9. Yuill GK. *A Survey of Radon Concentrations in Manitoba Outside Winnipeg.* Report prepared for Manitoba Environment. Winnipeg, 1992.
10. Health Canada Medical Services Branch. *Radon Study of Manitoba Reserves*, 1992.
11. Letourneau EG, Krewski D, Choi NW, et al. Case-control study of residential radon and lung cancer in Winnipeg, Manitoba, Canada. *Am J Epidemiol* 1994;140:310-22.
12. MTS Advanced Inc. *Who Called Me? Directory*. Winnipeg, July 1998.
13. Mitchell RC, Carson RT. *Using Surveys to Value Public Goods: An Assessment of the Contingent Valuation Method.* Washington, DC: Resources for the Future, 1989.
14. Tolley G, Fabian R. Future directions for health value research. In: Tolley G, Kenkel D, Fabian R (Eds.). *Valuing Health for Policy*. Chicago: University of Chicago Press, 1988;300-18.
15. Hannemann M, Loomis J, Kanninen B. Statistical efficiency of double-bounded dichotomous choice contingent valuation. *Am J Agr Econ* 1991;73(November):1255-63.
16. Bennett P, Calman C (Eds.). *Risk Communication and Public Health*. Oxford: Oxford University Press, 1999.
17. Menard S. *Applied Logistic Regression Analysis*. Sage University Papers # 07-106. London: Sage Publications, 1995.

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RÉSUMÉ

Contexte : Cette enquête avait pour but de déterminer l'efficacité des directives d'exposition concernant le radon dans l'air intérieur des maisons au Canada dans les décisions individuelles en matière de protection de la santé.
Méthode : Les propriétaires de maisons situées dans une région à haute teneur de radon dans l'air des résidences (Winnipeg, au Manitoba) ont fait l'objet d'un sondage au sujet des mesures qu'ils ont prises pour réduire les niveaux d'exposition au radon et des montants dépensés à cet effet. Les 507 répondants ont été interrogés une deuxième fois pour expliquer leurs réponses à des scénarios hypothétiques. La régression logistique a été utilisée pour modéliser les décisions liées à la réduction du risque en fonction de l'exposition et d'autres variables explicatives.
Résultats : Les propriétaires de maisons les plus susceptibles d'avoir agi étaient ceux dont les teneurs en radon étaient supérieures à 1 100 Bq/m^3, soit bien au delà de la directive canadienne de 800 Bq/m^3. Cependant, après s'être familiarizés avec cette dernière, les répondants ont indiqué qu'ils agiraient désormais lorsque les teneurs atteindraient 700 Bq/m^3.
Interprétation : Nos résultats laissent entendre que les directives d'exposition concernant le radon dans l'air intérieur des maisons au Canada, dans leur application actuelle, ne semblent pas inciter les propriétaires de maisons à réduire les teneurs en radon.

18. Weinstein ND, Rothman AJ, Sutton SR. Stages theories of health behaviour: Conceptual and methodological issues. *Health Psychology* 1998;17(3):290-99.
19. Weinstein ND, Sandman PM. Experimental evidence for stages of health behaviour change: The precaution adoption process model applied to home radon testing. *Health Psychology* 1998;17(5):445-53.
20. Burton P, Gurrin L, Sly P. Extending the simple linear regression model to account for correlated responses: An introduction to generalized estimating equations and multi-level mixed modeling. *Statistics in Medicine* 1998;17:351-63.
21. Williamson DS, Bangdiwala SI, Marshall SW, et al. Repeated measures analysis of binary outcomes: Applications to injury research. *Accid Anal and Prev* 1996;28(5):571-79.
22. Krewski D, Oxman D, Torrance GW. A decision-oriented framework for evaluating environmental risk management strategies: A case study of lead in gasoline. In: Paustenbach DJ (Ed.), *The Risk Assessment of Human Health Hazards: A Textbook of Case Studies.* New York: John Wiley and Sons, 1986.
23. Adler RS, Pittle RD. Cajolery or command: Are education campaigns an adequate substitute for regulation? *Yale J Regulation* 1984;1:159-93.
24. Johnson FR. Risk communication and regulatory culture clash. In: Garrick BJ, Gekler WC(Eds.), *The Analysis, Communication and Perception of Risk.* New York: Plenum Press, 1991;441-50.
25. Stieb DM, Paola J, Neuman K. Do smog advisories work? Results of an evaluation of the Canadian Smog Advisory Program. *Can J Public Health* 1996;87(3):166-69.
26. Akerman J, Johnson FR, Bergman L. Paying for safety: Voluntary reduction of residential radon risks. *Land Economics* 1991;67(4):435-46.
27. Tengs TO, Adams ME, Pliskin JS, et al. Five hundred life-saving interventions and their cost-effectiveness. *Risk Analysis* 1995;15:369-90.
28. Letourneau EG, Krewski D, Zielinski JM, McGregor RG. Cost-effectiveness of radon mitigation in Canada. *Radiation Protection Dosimetry* 1992;45:593-98.
29. Ford ES, Kelly AE, Teutsch SM, et al. Radon and lung cancer: A cost-effectiveness analysis. *Am J Public Health* 1999;89(3):351-57.

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